ASSESSING THE VULNERABILITY OF THE ARAFURA AND TIMOR SEAS MARINE REGION TO CLIMATE CHANGE

This report is prepared by Dr Johanna Johnson and David J. Welch with contributions from Dr Ruben van Hooidonk & Dieter Tracey for The Arafura and Timor Seas Ecosystem Action Phase 2 (ATSEA-2) Project.
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Authors:
Johanna Johnson[1,2], David J. Welch[2,3], Ruben van Hooidonk[4,5], & Dieter Tracey[6]

[1]C2O Pacific, Cairns, Australia and Vanuatu
[2]College of Science & Engineering, James Cook University, Australia
[3]C2O Fisheries, Cairns, Australia
[4]Cooperative Institute for Marine and Atmospheric Studies, Rosenstiel School of Marine and Atmospheric Science, University of Miami, Miami, FL 33149
[5]Atlantic Oceanographic and Meteorological Laboratory, National Oceanic and Atmospheric Administration (NOAA), Miami, FL 33149
[6]Science Graphics, Cairns, Australia

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NON-TECHNICAL SUMMARY

The Arafura and Timor Seas (ATS) region is shared by Indonesia, Timor-Leste, Australia and Papua New Guinea. The ATS region is at the intersection of two major Large Marine Ecosystems (LMEs), the Northern Australian Shelf, and the Indonesian Sea. High coastal population densities, degraded habitats, overexploited fisheries, low profile coasts, shallow continental shelves and macro-tidal conditions mean that the coastal and marine environments of the ATS region are under pressure, making them more vulnerable to the impacts of climate change.

A number of projects in the ATS region have provided foundational baseline information on ecosystems in the region and the communities that depend on them, as well as potential climate change impacts. Projects include the Arafura and Timor Seas Ecosystem Action program (ATSEA-1) and this study which is part of the follow-up Phase 2 of the Arafura and Timor Seas Ecosystem Action program (ATSEA-2). Other relevant studies include rapid local community vulnerability assessments in Timor-Leste, a vulnerability assessment for Southeast Sulawesi, community action planning in Timor-Leste and a transboundary diagnostic analysis in the ATS region. Where relevant, these studies were drawn on during the climate change vulnerability assessment presented in this report. This report also provides a review of available climate data and projections for the ATS region, and a selection of data for inputting to the vulnerability assessment.

Global climate models (GCM) are the most common tool for climate change projections, however, their coarse spatial resolution (in the hundreds of km) mean GCM outputs are inadequate for sub-national or local assessments. Therefore, downscaling techniques are needed to provide more regional and local information. The latest downscaled climate model outputs for 2070 in the ATS region are available through different sources depending on the climate variable. Projections of rainfall and air temperature are available at 20 km resolution (BMKG Indonesia), sea surface temperature and ocean chemistry (pH) at 5 km resolution (NOAA), sea-level rise, ENSO, winds and waves, storms and cyclones at a regional scale (CSIRO Australia), and for solar radiation at a global scale (IPCC). The accuracy of these projections also varies among the different climate variables.

Climate change is expected to have profound effects on the status and distribution of coastal and pelagic habitats, the fish and invertebrates they support and, as a result, the communities and industries that depend on them. To prepare for and respond to these impacts it is necessary to understand the sources of vulnerability and identify effective and targeted adaptation actions.

Regional results of the vulnerability assessment were spatially variable and identified coral reefs (shallow) as highly vulnerable to climate change, particularly in the Timor-Leste and Indonesia-Arafura sub-regions, with hotspots around Manatuto and Barique Municipality, Timor-Leste and Tual in the Arafura Sea. Drivers of this vulnerability are poor habitat condition, non-climate pressures, particularly land-based pollution that impacts water quality, and lack of management. Seagrass meadows were most vulnerable in the Gulf of Carpentaria due to a hotspot of sea surface temperature increase, Indonesia-Arafura due to low connectivity and other non-climate pressures, and Timor-Leste due to increases in sea temperatures, sea level rise and lack of formal management. Mangroves and estuarine habitats were most vulnerable in Timor-Leste and western PNG, with sea level rise, rainfall declines, poor current condition, low species diversity, low connectivity and lack of management key drivers of this vulnerability.

Species vulnerability was also spatially variable, with highly vulnerable and high priority species identified for each sub-region. A key driver of species vulnerability was their stock status, with many species in Timor-Leste, western Papua New Guinea and Indonesia, and several in northern Australia, either overfished or potentially overfished due to a lack of information. Lack of management in the northern sub-regions of the ATS, as well as other pressures such habitat loss, poor water quality and illegal, unregulated and unreported fishing were other key drivers. Species of conservation concern also tended to be assessed as highly vulnerable to climate change impacts, driven by their already threatened status and that they tend to be low productivity species that take many years to recover from impacts.

This report provides recommendations for addressing the main drivers of vulnerability for habitats and species, and opportunities for improving the assessment outputs if further data become available. While the assessment is focused on the ATS marine ecosystem and the scale of results are at the regional and sub-regional level, they can be used to inform local climate change assessments through application of local processes, outlined in the supplementary Guide for Decision-Maker.

RINGKASAN NONTEKNIS

Wilayah Laut Arafura dan Laut Timor (*Arafura and Timor Seas* – ATS) terbagi ke dalam negara Indonesia, Timor-Leste, Australia dan Papua Nugini. Wilayah ATS berada di persimpangan dua *Large Marine Ecosystems* (LMEs) atau ekosistem laut besar dan utama dunia, yaitu Landas Kontinen Australia bagian Utara dan Perairan Samudra Indonesia. Berbagai kondisi seperti kepadatan populasi di wilayah pesisir; kualitas habitat yang terdegradasi; pemanfaatan perikanan secara berlebihan; topografi pantai yang rendah; landas kontinen yang dangkal; serta kondisi pasang surut yang tinggi, membuat lingkungan pesisir dan laut di wilayah ATS berada di bawah tekanan, dan rentan terhadap perubahan iklim.

Sejumlah proyek di wilayah ATS telah memberikan informasi dasar yang sangat penting tentang kondisi ekosistem di wilayah tersebut, termasuk kondisi masyarakat yang bergantung pada dampak perubahan iklim. Kajian ini merupakan bagian dari program Arafura and Timor Seas Ecosystem Action Tahap 2 (ATSEA-2). Kajian lain yang relevan terkait kondisi ekosistem di wilayah ATS yaitu, penilaian cepat terkait kerentanan masyarakat lokal yang tinggal di Timor-Leste, penilaian kerentanan untuk Sulawesi Tenggara, perencanaan aksi masyarakat di Timor-Leste, dan analisis diagnostik lintas batas di wilayah ATS. Hasil kajian yang relevan akan dimanfaatkan sebagai panduan untuk menyusun penilaian kerentanan perubahan iklim dalam laporan ini. Lebih jauh, laporan ini juga memberikan tinjauan data dan proyeksi iklim yang tersedia untuk wilayah ATS. Selain itu, laporan ini juga memberikan pilihan data yang akan dimasukkan ke dalam kajian penilaian kerentanan.

Model iklim global (MIG) adalah alat atau pendekatan yang paling umum untuk memproyeksikan perubahan iklim, tetapi, resolusi spasial kasar yang dihasilkannya (dalam ratusan kilometer) menunjukkan bahwa keluaran dari model ini tidak memadai untuk penilaian sub-nasional atau lokal. Oleh karena itu, diperlukan teknik downscaling atau mengurangi skala resolusi untuk memberikan informasi yang lebih akurat di tingkat regional dan lokal. Keluaran dari model iklim terbaru yang menggunakan teknik *downscaling* untuk tahun 2070 di wilayah ATS tersedia dari beberapa sumber, tergantung pada variabel iklim yang digunakan. Proyeksi curah hujan dan suhu udara tersedia pada resolusi 20 km (BMKG Indonesia), suhu permukaan dan tingkat keasaman laut (pH) tersedia pada resolusi 5 km (NOAA), kenaikan muka air laut, ENSO, angin dan gelombang, badai dan siklon tersedia pada skala regional (CSIRO Australia), dan untuk radiasi matahari tersedia pada skala global (IPCC). Keakuratan proyeksi ini juga berbeda-beda di antara variabel iklim yang bermacam-macam.

Perubahan iklim diperkirakan akan berdampak besar pada status dan distribusi habitat pesisir dan pelagis, terutama ikan dan invertebrata. Sebagai akibatnya, masyarakat dan industri yang bergantung pada habitat tersebut juga mengalami dampak yang besar dari perubahan iklim. Untuk mempersiapkan dan menghadapi dampak-dampak ini, diperlukan sebuah kajian untuk memahami sumber kerentanan dan mengidentifikasi tindakan adaptasi yang efektif dan terarah.

Hasil kajian kerentanan di wilayah regional menunjukkan bahwa, secara spasial atau tata ruang, wilayah ATS sangat bervariasi tingkat kerentanannya. Selain itu, kajian ini juga menemukan bahwa terumbu karang di wilayah dangkal sangat rentan terhadap perubahan iklim, khususnya di sub-wilayah Timor-Leste dan Indonesia-Arafura, terutama di sekitar Kota Manatuto dan Barique, Timor-Leste dan Tual di Laut Arafura. Pemicu kerentanan ini adalah kondisi habitat yang buruk, tekanan noniklim, terutama pencemaran berbasis lahan yang berdampak pada kualitas air, serta kurangnya manajemen pengelolaan. Kondisi ekosistem padang lamun yang sangat rentan terdapat di Teluk Carpentaria. Kerentanan di Teluk Carpentaria diakibatkan karena wilayah tersebut merupakan daerah rawan atau hotspot peningkatan suhu permukaan laut. Tidak hanya itu, wilayah Laut Arafura di Indonesia juga mengalami peningkatan suhu permukaan laut karena konektivitas ekosistem padang lamun yang rendah dan tekanan noniklim lainnya. Sementara itu, kondisi ekosistem padang lamun di Timor-Leste mengalami peningkatan suhu permukaan laut, kenaikan permukaan air laut, dan kurangnya pengelolaan wilayah secara formal. Habitat hutan bakau dan habitat di muara, merupakan habitat yang paling rentan di Timor-Leste dan Papua Nugini bagian barat. Kenaikan permukaan air laut dan penurunan curah hujan, membuat kondisi habitat semakin memburuk. Tak hanya itu, keanekaragaman spesies yang semakin rendah, konektivitas yang rendah dan kurangnya pengelolaan juga menjadi pendorong utama kondisi kerentanan di wilayah ini.

Kerentanan spesies juga bervariasi secara spasial, terutama pada spesies sangat rentan dan spesies prioritas tinggi (utama) yang teridentifikasi di setiap sub-wilayah. Faktor utama kerentanan spesies adalah status stok spesies tersebut. Terdapat banyak spesies yang rentan berada di Timor-Leste, Papua Nugini bagian barat, dan Indonesia, serta beberapa di Australia utara, kerentanan disebabkan karena spesies tersebut ditangkap secara berlebihan atau berpotensi ditangkap secara berlebihan akibat dari kurangnya informasi di masyarakat. Kurang efektifnya pengelolaan di sub-wilayah ATS bagian utara, serta tekanan lain seperti hilangnya habitat, kualitas air yang buruk, dan kegiatan penangkapan ikan tidak sah (ilegal), tidak dilaporkan, dan tidak diatur adalah faktor pendorong lain bagi kerentanan spesies. Selain itu, spesies yang menjadi perhatian konservasi juga cenderung sangat rentan terhadap dampak perubahan iklim. Hal ini disebabkan oleh status spesies tersebut yang sudah terancam dan cenderung berproduktivitas rendah, sehingga membutuhkan waktu bertahun-tahun untuk pulih dari dampak perubahan iklim.

Laporan ini memberikan rekomendasi untuk merespons penyebab utama kerentanan habitat dan spesies, serta peluang untuk meningkatkan hasil kajian kerentanan, setelah data lebih lanjut sudah tersedia. Kajian ini difokuskan pada ekosistem laut ATS dengan skala hasil berada di tingkat regional dan sub-regional. Selain itu, kajian ini dapat digunakan untuk memberikan informasi bagi kajian perubahan iklim lokal melalui penerapan proses di tingkat lokal, yang diuraikan dalam dokumen tambahan yaitu Panduan untuk Pengambil Keputusan.

SUMÁRIU LA'ÓS-TÉKNIKU

Rejiaun Arafura no Tasi Timor (ATT) hafahe-uza hosi Indonézia, Timor-Leste, Australia no Papua Nova Guiné. Rejiaun ATT nu'udár interseksaun ba Ekosistema Marina Boot (EMB) rua, Plataforma Norte Australianu no Tasi Indonézia. Densidade populasaun kosteira nian ne'ebé aas, degradasaun ba abitasaun, peska ezesívu, kosteira ho perfíl badak, plataforma kontinente ne'ebé la-kle'an no kondisaun mákro-meti-maran hatudu katak ambiénte kosteira no marina rejiaun ATT nian iha presaun laran, halo nia sai vulnerável liu hasoru impaktu alterasaun klimátika.

Númeru projetu balun iha rejiaun ATT fornese ona informasaun baze fundamentál kona-ba ekosistema iha rejiaun no komunidade sira ne'ebé depende ba nia, nune'e mós impaktu potensiál alterasaun klimátika nian. Projetu sira ne'e inklui Programa Asaun Ekosistema Arafura no Tasi Timor (AEATT-1) no estudu ne'e nu'udár parte kontinuidade Faze 2 ba Programa Asaun Ekosistema Arafura no Tasi Timor (AEATT-2). Estudu relevante siraseluk inklui avaliasaun vulnerabilidade rápida ba komunidade lokál iha Timor-Leste, avaliasaun vulnerabilidade ba Sulawesi Sudéste, planu asaun komunitáriu iha Timor-Leste no análize diagnótiku trans-fronteirisa iha rejiaun ATT. Karik relevante, estudu sira ne'e elabora durante avaliasaun kona-ba vulnerabilidade alterasaun klimátika ne'ebé aprezenta iha relatóriu ida ne'e. Relatóriu ne'e mós fornese revizaun data klimátika no projesaun ne'ebé iha ba rejiaun ATT, no selesaun ba data hodi integra iha avaliasaun ba vulnerabilidade.

Modelu Klimátika Globál (MKG) nu'udár intrumentu komún liu ba projesaun alterasaun klimátika, bi'ár nune'e, nia rezolusaun espasiál krukut (iha kilometru atus ba atus) signifika rezultadu MKG ne'e inadekuadu ba avaliasaun sub-nasionál no lokál. Nune'e, presiza tékniku hamenuz eskalaun atu fornese liutan informasaun rejionál no lokál. Rezultadu modelu hamenuz eskalaun klimátika ikusliu ba tinan 2070 ba rejiaun ATT disponível ona liuhosi fonte oioin depende ba variável klimátika. Projesaun ba udan-been no temperatura ár disponível iha rezolusaun 20 km (BMKG Indonézia), superfíse tasi no kímika oseánia (pH) iha rezolusaun 5 km (NOAA), nível-tasi sa'e, ENSO, anin no laloran, anin-fuik no siklóne iha eskalaun rejionál (CSIRO Australia), no ba radiasaun solár iha eskalaun globál (IPCC). Presizaun ba projesaun sira ne'e mós la hanesan entre variável sira klimátika nian.

Iha espetativa katak alterasaun klimátika sei fó efeitu makaas ba estatutu no distribuisaun abitasaun kosteira no oseániku, ikan no invertebrata ne'ebé sira tulun no, hanesan rezultadu, komunidade no indústria mós depende ba sira. Atu prepara no hatan ba impaktu hirak ne'e nesesáriu duni atu kumpriénde fonte vulnerabilidade no identifika asaun adaptasaun ne'ebé efetivu no ho alvu loloos.

Rezultadu rejionál ba avaliasaun vulnerabilidade ne'e espasialmente iha variedade no identifika ahu-ruin (la-kle'an) sai vulnerável liu ba alterasaun klimátika, partikularmente iha Timor-Leste no sub-rejiaun Indonézia-Arafura nian, ho fatin sira hanesan iha munisípiu Manatuto no Barique, Timor-Leste, no Tual iha Tasi Arafura. Fatór ba vulnerabilidade hirak ne'e maka kondisaun abitasaun ne'ebé mukit, presaun la'ós-klimátiku, partikularmente poluisaun mai hosi rai ne'ebé fó impaktu ba kualidade bee no falta jestaun. Du'ut-tasi rai-hae sai mós vulnerável iha Abízmu Carpentaria kauza hosi fatin ba temperatura superfíse tasi sa'e, Indonézia-Arafura nian kauza hosi konetividade kiik no presaun la'ós-klimátika siraseluk, no Timor-Leste kauza hosi temperatura tasi ne'ebé sa'e, nível tasi sa'e no falta jestaun formál sira. Ai-parapa no abitasaun estuarinu maka vulnerável liu iha Timor-Leste no PNG oéste, ho nível tasi sa'e, deminuisaun udan-been, kondisaun ezistente ne'ebé mukit, diversidade espésie ne'ebé kiik, konetividade kiik no falta jestaun ba fatór xave sira iha vulnerabilidade ida ne'e.

Vulnerabilidade espésie mós espasialmente iha variedade, ho espésie ne'ebé vulnerável liu no ho prioridade aas ne'ebé identifika tiha ona ba sub-rejiaun idaidak. Fatór xave ba vulnerabilidade espésie maka nia estatutu disponibiliade, ho espésie ne'ebé barak iha Timor-Leste, PNG oéste no Indonézia, no balun iha Australia norte, ne'ebé hetan peska ezesivu ka potensialmente ezesivu tanba falta informasaun. Falta jestaun iha ATT sub-rejiaun norte nian, nune'e mós presaun siraseluk hanesan abitasaun ne'ebé lakon, kualidade bee ne'ebé mukit no peska ilegál, la regula no la iha relatóriu maka sai mós hanesan fatór xave entre siraseluk. Espésie ba kestaun konservasaun mós iha tendensia hetan avaliasaun basá iha vulnerabilidade aas ba impaktu alterasaun klimátika, basá nia estatutu ameadu no iha tendensia ba produtividade espésie ne'ebé kiik ne'ebé presiza tempu naruk atu rekupera híkas hosi impaktu sira ne'e.

Relatóriu ida ne'e fornese rekomendasaun atu hatan ba fatór prinsipál ba vulnerabilidade ba iha abitasaun no espésie sira, no oportunidade atu hadi'ak rezultadu avaliasaun bainhira iha data seluk ne'ebé disponível. Maske avaliasaun ne'e foka ba ekosistema marina ATT nian no eskala rezultadu ne'ebé iha nível rejionál no sub-rejionál, bele utiliza sira hodi informa avaliasaun alterasaun klimátika lokál liuhosi aplikasaun ba prosesu lokál, ne'ebé deskreve kle'an iha Matadalan komplementár ba Makfoti-Desizaun sira.

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CHAPTER 1. INTRODUCTION

The Arafura and Timor Seas (ATS) region is located at the intersection of two major Large Marine Ecosystems (LMEs), the Northern Australian Shelf to the south, and the Indonesian Sea to the north. The ATS region is shared by Indonesia, Timor-Leste, Australia and Papua New Guinea (PNG). It is a tropical sea connecting the Pacific and Indian Oceans and extending from the Timor Sea to the Torres Strait, including the Arafura Sea and Gulf of Carpentaria (Figure 1). The region has high human coastal population density, particularly in Indonesia, and is adjacent to the Coral Triangle, which has the world's highest marine biodiversity and contains some of the most pristine as well as highly threatened coastal and marine ecosystems. At a regional scale, the ecosystems are rich in marine biodiversity, fisheries, oil and gas and play important economic, cultural, social and ecological roles for all nations bordering the Arafura and Timor Seas.

Figure 1. *Map of ATS region, showing four spatial sub-units to be used for vulnerability assessment*

The Arafura and Timor Seas Ecosystem Action program (ATSEA-2) is the second phase of the GEF-financed, UNDP-supported ATSEA program, building upon the foundational results realized in the first phase, covering Indonesia, Timor-Leste, Papua New Guinea, and Australia. ATSEA-2 is designed to enhance regional collaboration and coordination in the ATS region and will specifically focus on supporting the implementation of the endorsed Strategic Action Program (SAP), a 10-year vision for the Arafura-Timor Seas with the long-term objective "*to promote sustainable development of the*

Arafura-Timor Seas region to improve the quality of life of its inhabitants through restoration, conservation and sustainable management of marine-coastal ecosystems".

The 5-year ATSEA-2 project will support implementation of the following governance and environmental objectives of the ATS regional SAP: (i) Strengthening of ATS regional governance; (ii) Recovering and sustaining fisheries; (iii) Restoring degraded habitats for sustainable provision of ecosystem services; (iv) Reducing land-based and marine sources of pollution; (v) Protecting key marine species; and (vi) Adaptation to the impacts of climate change.

One of the ATSEA-2 project objectives is to improve understanding of climate change impacts on marine and coastal ecosystems, especially the impacts on fisheries that are critical to sustaining socio-economic development in the ATS region. As climate change impacts are expected to increase, affecting more and more people and disrupting ecosystems and infrastructure, it is imperative to educate national and local government planners and other decision makers, as well as the general public, about the need to implement resilient strategies and to allocate sufficient resources for climate change adaptation and mitigation measures.

This report provides a synthesis of a review of studies in large marine ecosystems (LMEs), global climate models and a regional analysis of current climate change models and strategies within the ATS region. The report also summarises the outputs of scale-appropriate climate models for the ATS region (where available) using predicted climate variables that are expected to impact the region over the next 50 years (to 2070). Included is an overview of how coastal and ocean habitats are predicted to be influenced by climate change. The climate change projection data were used for the ATSEA-2 climate change vulnerability assessment, as a primary input for the 'exposure' component for assessing important fisheries and supporting habitats in the ATS region. The vulnerability assessment was conducted for five spatial sub-units in the ATS region – Indonesia-Arafura, Timor-Leste, western PNG, Gulf of Carpentaria and northwest Australia (see Figure 1) – to deliver results relevant to the habitats, species and fisheries in those sub-units. An overview of the methodology for the vulnerability assessment is provided in Section 4, climate change projections are provided in Section 5, results of the vulnerability assessment are provided in Sections 6 and 7, the discussion of results in Section 8, and recommendations in Section 9.

CHAPTER 2. ARAFURA & TIMOR SEAS REGIONAL CONTEXT

Large Marine Ecosystems (LMEs) are ocean areas of approximately 200,000 km² or more, adjacent to continents in coastal waters where primary productivity is generally higher than in the open oceans. Globally, LMEs produce about 80% of the annual world's marine fisheries catch. They are also centers of coastal ocean pollution, nutrient enrichment, habitat degradation, overfishing, biodiversity loss, and climate change effects. The US$12.6 trillion in goods and services contributed annually by LMEs to the world's economy is at risk from unsustainable practices (UNDP & GEF 2013)[1].

The ATS region is within two LMEs; the Indonesian Sea (#38) and the North Australian Shelf (#39) and is situated at the convergence of the Pacific and Indian Oceans, bordered by Indonesia, Timor-Leste, Australia and PNG. The Indonesian Sea LME covers an area of 2.3 million km², with 1.49% protected, and contains 10% and 0.75% of the world's coral reefs and sea mounts, respectively (Sea Around Us 2007). Indonesia is one the world's largest archipelago nations, with a coastline around 84,000 km in length. The warm ocean acts as a 'heat engine' of global atmospheric circulation, with complex ocean-atmospheric dynamics, including the El Nino Southern Oscillation (ENSO). The convergence of three tectonic plates – the Eurasian, the Indo-Australian and the Pacific – makes the region geologically and topographically diverse. Seasonal monsoons, during which ocean currents reverse directions, exert a significant influence on the LME. The seas around Indonesia have complex and rapid currents due to high-energy tides over rough topography and also owing to the Indonesian Throughflow, a warm-water current flowing between the Pacific and Indian Oceans (see Figure 2; Pitcher et al. 2007, UNEP 2005). Surface waters in the Timor and Arafura Seas are generally lower in salinity than adjacent oceanic waters due to higher precipitation. High salinities can occur in many coastal areas due to enhanced evaporation, particularly at the end of the dry season.

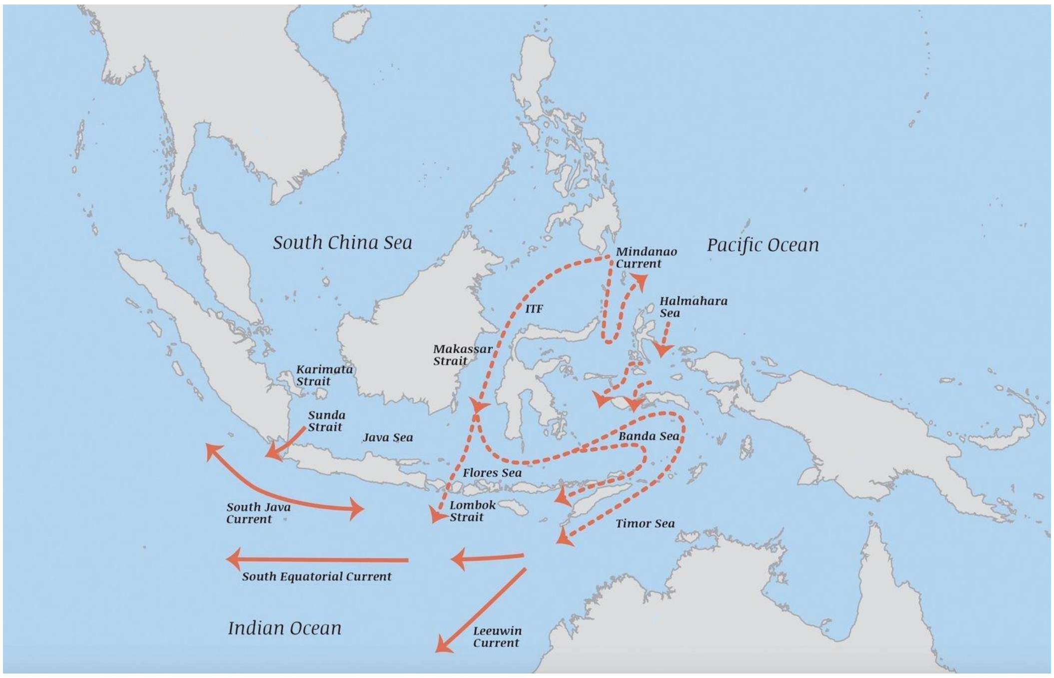

Figure 2. *Map showing the Indonesian Throughflow, northwest monsoon and circulation patterns in the ATS region (Blue Corner Marine Research)*

[1] http://lme.edc.uri.edu/index.php/lme-introduction

The Indonesian Sea LME is considered a Class I ecosystem with high productivity (>300 gCm-2yr-1). The Banda Sea and the Aru Basin in particular, are areas of extensive seasonal upwelling and downwelling related to the monsoon system, a dominant large-scale seasonal feature (Wijffels et al. 2018). During upwelling periods, species biomass and productivity at all levels in the food chain are greatly enhanced. Stocks of small pelagic fish are also considerably higher during upwelling. The changing oceanographic conditions in this LME also influence phytoplankton and zooplankton species composition.

The North Australian Shelf LME lies on the north coast of Australia from the Timor Sea to the Torres Strait and includes the Gulf of Carpentaria and Joseph Bonaparte Gulf and is 772,214 km^2 in area. This LME is a Class I ecosystem with high productivity (average of 475 gCm-2yr-1) although offshore areas are more oligotrophic. Approximately 0.65% of this LME is covered by mangroves (US Geological Survey 2011) and 0.24% by coral reefs, representing about 0.7% of global reef area (Global Distribution of Coral Reefs 2010). It has a high area under management, with the LME having an increase in MPA coverage from 531 km^2 prior to 1983 to 153,288 km^2 by 2014. This represents a significant increase and about 20% of the total LME area, placing it in the 'high' category of MPA change.

The Indonesian Throughflow, crosses the north-western part of this LME and plays a vital role in driving the world's climate system, carrying up to 10,000,000 m^3 per second from the Pacific Ocean into the Indian Ocean. The Throughflow is of particular importance to Australia since it warms the sea surface of the Indian Ocean and is a major driver of climate in northern Australia. The region has a monsoon climate and tropical cyclones are common seasonal events. Based on a combined measure of the Human Development Index (HDI) and indicators for current condition and pressures (e.g. fish & fisheries, pollution & ecosystem health), the overall risk factor in this LME is considered very low (IOC-UNESCO & UNEP 2016)[2].

The ATS region is located in the Indo-West Pacific centre of biodiversity, supporting very high diversity (Roberts et al. 2002). More than 600 species of reef-building corals, 2,500 species of marine fish, 47 species of mangroves and 13 species of seagrass are found in the region (Tomascik et al. 1997, Veron 2000, Spalding et al. 2010). Pelagic ocean habitats are important and support high biodiversity of both large and small migratory marine species, including cetaceans, such as the blue fin and humpback whales, and other species that frequently migrate through the region (Kahn and Pet 2003).

A number of climate change studies have been conducted in other LMEs, including vulnerability assessments for target sectors. For example, in the North Brazil Shelf LME and Caribbean Sea LME is engaging with seven countries under the Climate Change Adaptation in the Eastern Caribbean Fisheries Sector project funded by GEF-FAO. The project is focussing on fisheries, as the sector is expected to be severely impacted by climate variability and change through slow-onset changes as well as extreme events. The project objective is to increase resilience and reduce vulnerability to climate change impacts in the Eastern Caribbean fisheries sector, through the introduction of adaptation measures in fisheries management and capacity building for fisherfolk and aquaculturists (FAO 2018). Similarly, a project in the Humboldt Current LME is strengthening the adaptive capacity to climate change in the fisheries and aquaculture sector to reduce vulnerability.

[2] http://onesharedocean.org/LME_39_North_Australian_Shelf

A global comparative assessment of LMEs provided a snapshot of LME condition with respect to a number of priority issues, including unsustainable fishing, pollution, habitat destruction and climate change. The patterns of risk among LMEs highlighted that, in general, LMEs in developing tropical regions are at highest potential risk, and that climate change (ocean warming and acidification) impacts are already evident in many LMEs and are projected to play an increasing role in determining LME condition into the future. Across all LMEs, the individual stressors relating to climate change are the largest contributors to cumulative impact scores. Importantly, the global assessment of LMEs could not examine cause and effect, which is likely to vary among and within LMEs, and recommended detailed sub-LME assessments to make causal links for specific issues and obtain integrated results that can inform management. This study is one such sub-LME assessment that will use downscaled climate data to assess vulnerability of habitats and fisheries to climate change and provide targets for adaptation action (IOC-UNESCO & UNEP 2016).

CHAPTER 3. ARAFURA & TIMOR SEAS ECOSYSTEM ACTION PROJECT

The ATS region covers more than 170 million ha and contains important coastal ecosystem such as coral reefs (shallow and deep), seagrass and mangroves. Shallow coral reefs and seagrass are widely distributed in clearer waters, while mangroves are mostly distributed from the coast of Papua and PNG to the north coast of Australia (Figure 3). Deep reefs are generally associated with sea mounts and are another important habitat, along with pelagic or open ocean habitats. The marine environment in the ATS region is in significant decline, primarily as a result of overharvesting and other direct and indirect impacts of anthropogenic stresses including climate change. The Reefs at Risk project identified Indonesian reefs as having the largest area of threatened coral reefs in the ATS region, with overfishing and destructive fishing pressures driving much of the threat, followed by watershed-based pollution and coastal development (Burke et al. 2011). A global study of primary productivity and fisheries in LMEs under future climate change projected the greatest declines in potential fish production in the Indo-Pacific, which includes the ATS region (Blanchard et al. 2012).

The first phase of the ATSEA program conducted a series of consultations and identified five key environmental issues that require urgent action to address:

1. Unsustainable fisheries,
2. Habitat degradation,
3. Marine and land-based pollution,
4. Loss of biodiversity, and
5. Impacts of climate change.

The bathymetry and oceanography of the region – shallow continental shelves and semi-enclosed gulfs – have resulted in strong connectivity in oceanographic and ecological processes, such as the movements of larvae, pelagic and migratory species. This means that species and fish stocks are shared between jurisdictions, e.g., offshore demersal snapper fisheries for *Lutjanus malabaricus*, *L.erythropterus* and *L. argentimaculatus* (Blaber et al. 2005; Salini et al. 2006), and globally significant populations of migratory protected species (turtles, dugongs, cetaceans, sawfishes, elasmobranchs) are found throughout the ATS region (Alongi et al. 2011). For migratory species such as sea turtle, the Arafura Sea plays role as feeding and nursery ground after they were nesting in Palau (Klain et al. 2007) and the Papua Birds head (Doi et al. 2019).

Fisheries in the ATS region are a particularly complex and productive socio-economic sector, with multiple actors, target species and technology used. The main characteristics of depletion of shared ATS transboundary stocks by fishery were assessed as part of the ATS transboundary diagnostic analysis in 2012 (ATSEA 2012). The analysis under ATSEA-1 found that the combined pressures of climate change, unsustainable harvesting, destructive fishing practices, illegal unreported unregulated (IUU) fishing, and bycatch are having significant impacts on marine species in the ATS region. Particularly on globally threatened coastal marine megafauna including migratory, rare, and threatened species of turtles, dugongs, seabirds/shorebirds, sea snakes, cetaceans, sharks and rays. Fisheries in the Indonesian Sea LME are 88% fully exploited and 12% overexploited, while in the Northern Australian LME, 78% of fisheries are considered fully exploited and 18% overexploited (Sherman 2014). Marine pollution is also a threat to ecosystems in the region, with sources of marine pollution in the region including marine debris, marine-based pollution from oil and gas activities, land-based runoff from coastal development (Brodie et al. 2019), and waste from fishing and shipping vessels.

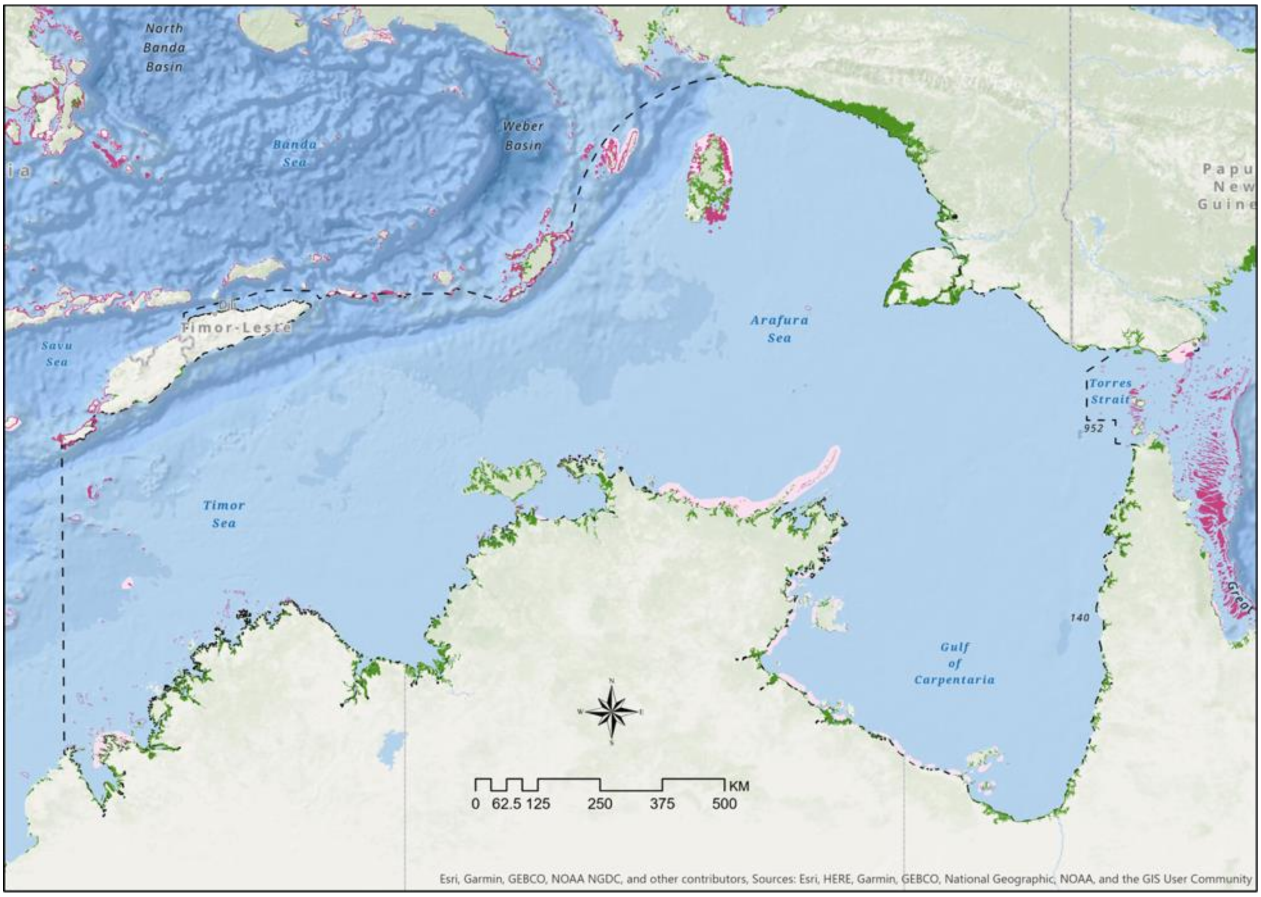

Figure 3. *Important coastal ecosystems of the ATS region; dark pink=coral reefs, light pink=seagrass, green=mangroves.*

The ATS region is also characterized by strong land-sea connectivity, with high standing islands in Timor and Papua New Guinea and large catchment areas in northern Australia, result in high river discharge of freshwater and sediments to coastal waters. Such discharges can have significant impacts on coastal and offshore ecosystems. These rivers transport a disproportionately large amount of sediment to the ocean because of their generally small drainage basin areas, high topographic relief, relatively young and erodible strata (often impacted by human activities such as deforestation and agriculture) and seasonally heavy rainfall (Milliman et al.1999, Milliman and Farnsworth 2011). Rivers on the islands of Sumatra, Java, Borneo, Sulawesi, Timor and New Guinea are estimated to discharge about 4.2x109 t/year of sediment. This strong coupling of land-sea processes underscores the critical need to address integrated catchment management in managing the ATS region (Alongi et al. 2011).

Timor-Leste has been classified as extremely vulnerable to climate change impacts such as increased climate variability and increased frequency of climate-related natural hazards such as flooding and droughts (Weaver 2008). A rapid vulnerability assessment of six communities in Timor-Leste used a Participatory Assessment of Vulnerability and Adaptation (PACE-SD) Rapid Assessment method (Limalevu and McNamara 2012). The study found variability between communities in their vulnerability to climate change but generally the main areas were: Health and Sanitation, Water Resources, Agriculture and Food Security, and vulnerability to floods, inundation, cyclones and storm surges (USP-EU GCCA 2013).

A participatory community vulnerability assessment in Timor-Leste in four inland municipalities applied the same framework with the components of exposure, sensitivity and adaptive capacity. The study identified strong wind, landslide, drought, flood and fire as the most common and concerning climate impacts in the 24 communities (sucos) assessed (noting that landslide and fire are secondary impacts; UNDP 2018). All 24 sucos were assessed as having high vulnerability and inadequate adaptive capacity, with variability between sucos. Cross-cutting issues that influence vulnerability across most sucos included: insecure land tenure, limited financial and human resources, poor infrastructure, lack of enabling policies, and weak coordination of planning and implementation (UNDP 2018).

Outside the ATS region to the north, climate change vulnerability assessments in North and South Sulawesi assessed marine habitats and fisheries (Retnowati, et al. 2019, RARE Indonesia 2020). The South Sulawesi assessment found some notable drivers of vulnerability: bleaching potential, changing fish catches, economic dependence on fisheries, low hard coral cover, low fish biomass, no marine management/ reserves, lack of social trust, unresponsive governance, poor community empowerment and low education levels (RARE Indonesia 2020). The North Sulawesi assessment was conducted in three villages on Lembeh Island and found that decline of the fisheries resources and lack of knowledge and information were the main drivers of vulnerability. While alternative livelihood options were the main source of community resilience to climate variability and change (Retnowati, et al. 2019).

CHAPTER 4. METHODS

4.1 Geographic Scope

The vulnerability assessment focused on marine and coastal habitats and species in the ATS region important to communities, industries and governments of coastal nations in the region. There are four government jurisdictions in the ATS project region, and goal of the ATSEA-2 project is to deliver activities to those requiring regional support, namely Indonesia, Timor-Leste and PNG. While the ATS region is characterised by high ecological connectivity (i.e., shared fish stocks and biodiversity, land-sea interactions, migratory species), the vulnerability assessment focused primarily on sub-regions where governance and decision-making are likely to be supported by ATSEA-2 – Indonesia/Arafura, Timor-Leste and western PNG. However, recognising the connectivity of habitats and species, assessments were also conducted for the northwest Australia and the Gulf of Carpentaria sub-regions (Figure 1). Noting that recommendations relating to resources managed by the Australian government and supporting activities are not likely to be progressed by the ATSEA-2 project.

Timor-Leste Sub-region

The Timor-Leste sub-region includes waters of Timor-Leste to the south and east and the shallow continental Timor Sea (50–120 m depth). The shelf on the southern coast is wide and relatively shallow, with gentler slopes than the northern coast. The southern coastal plains are wide, and as a result, support many deltas, floodplains, lagoons and mangrove forests. Long stretches of sandy beach with strong waves and surf are common on the southern coast, and as a result, the nearshore waters there are turbid most of the time. Located in the western part of the ATS, this offshore sub-region is characterised by deeper waters, containing slope, rise and abyssal habitats, and several geomorphic features, including the submarine valleys of the Timor Trough. The trough is an 850 km long valley (2–15 km wide, maximum depth 3,200 m) that extends between the island of Timor and the Sahul Shelf (Alongi 2011).

Indonesia/Arafura Sea sub-region

The Indonesian sub-region includes the shallow semi-enclosed Arafura Sea (~30–90 m depth). Located in the northern part of the ATS, this sub-region is characterised by archipelagic islands and deeper waters, containing slope, rise and abyssal habitats, and major geomorphic features, including the submarine valleys of the Arafura Depression and the submarine terraces (120-250 m deep) (Alongi 2011).

Western PNG Sub-region

Located in the most eastern side of the ATS region, the western PNG sub-region is a small coastal strip between the northern Torres Strait islands and the PNG mainland. The continuous continental shelf between Australia and PNG means that waters are very shallow with muddy substrate. Despite high local currents, there is very little net exchange of water between the Pacific and Indian Oceans through the shallow Torres Strait (<15 m at its shallowest). This sub-region is exposed to land-derived flood plumes from the Fly River to the east, and as a consequence, experiences high sediment loads and turbidity.

Northwest Australian Sub-region

The northwest Australian sub-region is dominated nearshore by shallow (<200 m) shelf waters and semi-enclosed gulfs (Dieman's Gulf, Joseph Bonaparte Gulf), with water depths rarely exceeding 70m across most of continental margin. The western part of this sub-region is characterised by deeper waters, containing slope, rise and abyssal habitats, and major geomorphic features, including the submarine terraces (120-250 m deep) and complex algal banks on the Sahul Shelf (Alongi 2011).

Gulf of Carpentaria sub-region

The Gulf of Carpentaria (GoC) sub-region is dominated by shallow (<200 m) shelf waters, with water depths rarely exceeding 70m across most of continental margin. Within the GoC, there is some exchange of water and nutrients with the Arafura and Coral Seas but flushing of the basin is considered to be slow and limited (Alongi 2011).

4.2 Habitats and Species of Interest

The habitats selected for assessment in this project were on the basis of their ecological, social and economic importance, including their role as critical habitats for species and the goods and services they provide. The process was participatory with local experts and stakeholders and identified five marine habitats for assessment – coral reefs (shallow areas <40 m), seagrass meadows, mangroves, deep reefs (>40 m) and pelagic open ocean.

The species chosen for inclusion in the vulnerability assessment were on the basis of their fishery importance and/or the level of conservation concern in each sub-region. Selection of species to assess for the Timor-Leste and Indonesia/Arafura sub-regions were based initially on a comprehensive list compiled from the published literature and refined based on local knowledge and stakeholder consultations. For western PNG, species were selected based on recent published literature and expert knowledge by the assessment specialists. For the two Australian sub-regions, the species selected were predominantly those previously assessed in a complementary project which also conducted a vulnerability assessment of species of conservation interest and fisheries to climate change, and which went through a rigorous stakeholder consultation and expert-based process to determine the key species (see Welch et al. 2014a). To ensure these assessment lists remained relevant for the current assessment, consultations were made with fishery management staff at the Northern Territory Department of Primary Industries and Resources.

4.3 Assessment Data

The vulnerability assessment approach draws on and collates existing empirical data, including climatologies, climate projections, species and habitat thresholds and response, status and trends, demographics, available modelling and expert knowledge. Three sources of data were used for the assessment: (1) existing published data, (2) expert judgment, and (3) critical data collection to filling knowledge gaps. Structured expert elicitation provided a semi-quantitative way to estimate exposure, sensitivity and adaptive capacity (Martin et al. 2012), particularly when limited empirical data exists. Expert judgement was used for a number of assessment indicators where there were limited data. The level of confidence in the analysis is determined by the quality and quantity of data inputs.

In some cases, it may be necessary to collect or re-analyse specific data that are essential for completing an assessment. For example, some of the downscaled climate change projections were new model runs for the emissions scenario and timeframe of interest for the project (i.e., SSP5-8.5 for 2070).

Habitat Data and Species Profiles

We conducted a literature review to summarise information on documented habitat types and extent in the ATS region, and known sensitivities of these habitats to climate drivers, including results from related and regional projects (Fajariyanto et al. 2019, UNDP 2018, Welch et al. 2014a). The habitats selected for assessment in this project – coral reefs, seagrass meadows, mangroves, deep reefs (>40 m) and pelagic open ocean – have been assessed in adjacent regions using the same structured vulnerability assessment framework (Bell et al. 2011, Welch et al. 2014b, Johnson and Welch 2016). Therefore, this project reviewed the published literature and the results from compatible habitat vulnerability assessments to collect the necessary input data for the tailored habitat vulnerability assessment for the ATS region.

The species to assess were selected based on their economic, social and ecological importance, and ensuring a good representation of different life history characteristics. For example, red snapper is an important fishery for the Timor and Arafura Seas areas and up to 20 different species are caught by the fishery. The selection of species to assess was based on those that represent the greatest volume or numbers in the catch, as well as species that have different life histories. That allows for assessment results that can inform current management of important species from a fisheries or conservation perspective, as well as results that are indicative of a range of similar species, which may emerge as important in the future. Allowing the transferability of climate change vulnerability results across a wider range of species.

Reviews for each of the species selected focused on input data required for the vulnerability assessment analysis, particularly sensitivity to climate drivers and adaptive capacity. The reviews synthesised existing literature and unpublished work to develop a species profile that was comprised of three sections: (i) fishery characteristics (if applicable), (ii) species life cycle characteristics, and (iii) known or inferred sensitivity of the species to environmental drivers. Information about the fishery characteristics were only compiled for exploited species and not species of conservation interest (e.g., dugong), and included aspects such as status of stocks, current operational characteristics, historic harvest levels, and the nature of existing management. Information about the species life cycle included aspects such as the productivity of the species, critical life history stages, level of plasticity in biological characteristics (e.g., spawning times, maturity, growth), habitat use and movement capabilities. The profile about the sensitivity of species to environmental changes (e.g., sea temperature, pH, sea level, rainfall/river flow, currents and wind) included information on whether species are likely to respond to changes in particular environmental variables and the nature of that change, critical life history stages most sensitive to changes, and their potential capacity to cope with changes.

4.4 Climate Change Projections

The climate change projections were collated through a comprehensive review that included a literature search for relevant publications, technical reports and project reports on similar studies in LMEs and the ATS region, as well as global and regional climate change projections. The review has been conducted collaboratively with regional and national professionals and practitioners in the ATS region, and includes the compilation of global climate models (sourced from the IPCC), regional downscaled climate models (sourced from the BMKG – Indonesian meteorological service, NOAA/ University of Miami, Australian Bureau of Meteorology [BOM] and CSIRO), relevant primary publications on climate studies, grey literature, project and policy documents. The information collated will support decisions about key indicators and criteria incorporated into the vulnerability assessment framework.

4.5 Assessing Climate Change Vulnerability

The vulnerability assessment applied available data to conduct a desktop analysis of habitats and species in the five ATS sub-regions. We applied a structured semi-quantitative approach for the vulnerability assessment based on a widely-adopted framework that includes the elements of Exposure, Sensitivity and Adaptive Capacity proposed by the IPCC and United Nations Framework Convention on Climate Change (UNFCCC) (adapted from Schroter et al. 2004; Figure 4). The components of the analysis and general approach is consistent with other vulnerability assessment methods applied in the broader region (e.g., Retnowati, et al. 2019, CTI Vulnerability Assessment Tools for Coastal Ecosystems, MERF 2013). For example, the South Sulawesi climate change vulnerability assessment applied the same basic framework with the components of exposure, sensitivity and adaptive capacity but used disaggregated ecological and social components of vulnerability by capturing the exposure of the physical changes, the ecological sensitivity to those changes, the ecological adaptive capacity, the social sensitivity, and the social capacity separately. The results were quantified rankings of vulnerability across the area with higher scores indicating higher vulnerability, similar to the outputs that this method will deliver for the ATS region (RARE Indonesia 2020).

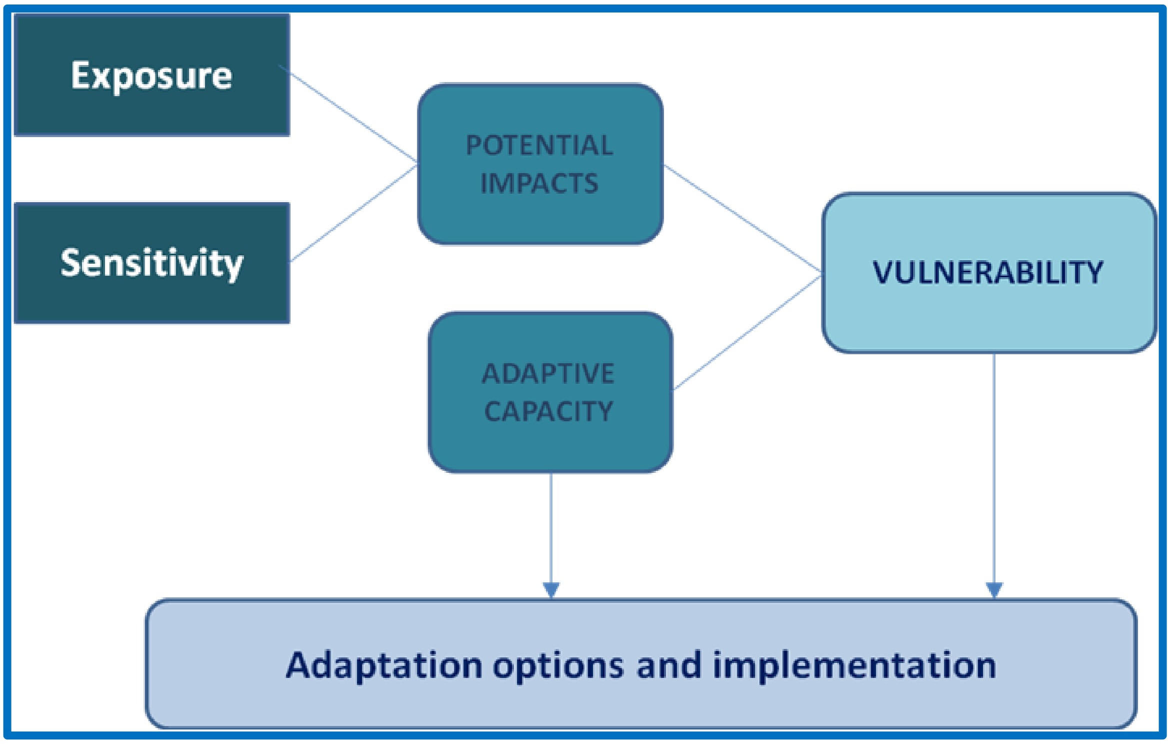

Figure 4. *Vulnerability assessment framework adopted by the Intergovernmental Panel for Climate Change (adapted from Schroter et al. 2004).*

The framework provides a structured approach for determining the potential impacts of climate change on habitats and species, their relative level of vulnerability and drivers of vulnerability. The assessment focused on the five spatial sub-units in the ATS region (see Figure 1) to deliver locally relevant results. The framework also provides transparency to stakeholders by incorporating socio-economic survey data and adaptive capacity, allowing for potential adaptation responses for relevant fisheries stakeholder groups.

The assessment used known biology, ecology and responses to climate variation to develop a series of indicators for: (i) exposure, (ii) sensitivity and (iii) adaptive capacity for each habitat and for species. Indicators for exposure are based on climate projections. Criteria were also adapted for analysing each indicator taking a risk-based approach using ecologically relevant triggers and relationships. Detailed methods are available in Johnson et al. 2016 and Johnson and Welch 2016. The full list of indicators and criteria used for the vulnerability assessment for habitats and species are provided in Appendix A. Notably, lack of data presented challenges in analysing all fields and therefore the results are considered preliminary and can be updated if further data become available.

For coral reefs, the suite of indicators used are consistent with many reef resilience assessments (e.g., Maynard et al. 2016) however some key data were unavailable (coral cover, replenishment potential, connectivity, macroalgae cover, recruitment, herbivore biomass), and their inclusion would improve the accuracy of the assessment.

A vulnerability metric was used to quantify results so that components were systematically ranked based on their relative vulnerability to climate change. Scores are assigned for each indicator using a 3-point scale based on specific criteria, whereby low scores represent low vulnerability. The analysis followed the method outlined in Johnson et al. (2016) to calculate a vulnerability index using the metric: *V = (PI x AC index) + 1*[3]. The components are then ranked from highest to lowest relative vulnerability.

4.6 Prioritising Species for Future Action

The vulnerability assessment provides an objective basis for identifying species of highest concern and therefore priority species and fisheries for future action and/or further investigation, particularly for climate change adaptation. Relative vulnerability however should not be the only consideration for prioritisation of species. The relative local 'importance' of individual species should also be taken into account to ensure local resources are focused and efficiently utilised.

To determine the relative local 'importance' of each species we prioritised species lists for each region using a separate semi-quantitative framework that incorporated: (1) Cultural importance, (2) Subsistence importance, (3) Economic importance, and (4) Conservation importance, depending on the sub-region (Table 1). Scores were decided based on the average from expert elicitation for Timor-Leste and Indonesia/Arafura, and from expert elicitation, published information and previous research (Welch and Johnson, 2013; Welch et al., 2014b) for the Australian sub-regions. Scoring for 'conservation importance' was based on IUCN Red List classifications (www.iucnredlist.org). Local importance was determined for the Australian sub-regions using criterion 1, 3 and 4, while all four criteria were used in other sub-regions. Scores were assigned for each species and summed across each category. For example, the local importance score for a particular species in the Gulf of Carpentaria was determined by:

Local importance (species X) = cultural importance score + economic importance score + conservation importance score

Table 1. *Criteria used for scoring local importance ranking for each species in each sub-region. Scoring for 'conservation concern' is based on IUCN Red List classifications (www.iucnredlist.org).*

Criterion	Guiding definition	Scoring			
		0	1	2	3
1. Cultural importance	Species has significance for cultural practices	Not important	Low importance	Some significance	Highly significant
2. Subsistence importance	Species is an important target species for home consumption	Not consumed at home	Low volumes caught mainly for home consumption	Some importance for subsistence but not high	Highly important as a species for subsistence
3. Economic importance	Species has economical value and is primarily sold	No value	Low value species	Moderate value species	High value species
4. Conservation importance	Species is of conservation concern	No concern or not assessed	Data deficient or Least Concern	Vulnerable or Near Threatened	Endangered or Critically Endangered

[3] Where V=vulnerability, PI=potential impacts (exposure x sensitivity), AC Index=adaptive capacity inverse

To assist managers, scientists and other fishery end-users in prioritising species for future action, we incorporated the local importance ‘scores’ of each species with relative vulnerability. That is, species with higher vulnerability scores and higher fishery importance scores get higher priority for management. Since the axes used for each measure have different scales, a standard mathematical approach is used called Euclidean distances to determine which species are closest to the upper right corner of the plot. Those closest to this corner are presented as the 20th percentile group, being the top 20% of species, and therefore the highest priority for management action. The 40th percentile group (the top 20-40% of species) are the next highest priority group of species, and so on.

CHAPTER 5. CLIMATE CHANGE PROJECTIONS

5.1 Climate Data

The data collated for ocean and surface climate for variables that marine habitats and tropical fisheries are most likely to be sensitive to is based on known responses and thresholds of habitats and selected species (see Bell et al. 2011, Pecl et al. 2014, Welch et al. 2014a, Welch and Johnson 2013, Booth et al. 2017). The climate information was drawn from a range of sources, particularly newly generated climate modelling for the ATS region for sea surface temperature and ocean pH (NOAA & University of Miami, van Hooidonk), the Indonesian BMKG (Meteorological Services) for rainfall and air temperature, the Australian Climate Change Science Program for sea-level rise and tropical storms (BoM and CSIRO), and global projections where no downscaled data were available (e.g., ENSO, ocean circulation). The summary of climate data accessed, and the data sources used for the vulnerability assessment is in Table 2.

Table 2. *Variables selected for climate change projections and data sources.*

Variable	Data source
Sea surface temperature	NOAA; van Hooidonk et al.
Ocean chemistry (pH)	NOAA; van Hooidonk et al.
Rainfall	Indonesian BMKG; Australian CSIRO & BOM
Air temperature	Indonesian BMKG; Australian CSIRO & BOM
Storms and cyclones	Knutson et al. 2010, Lough et al. 2011
Sea level & tides	Dewi et al. 2018; Australian CSIRO & BOM
El Niño Southern Oscillation (ENSO) & upwelling	Dewi et al. 2018; BOM and CSIRO 2014, Dwi et al. 2001
Ocean circulation	BOM and CSIRO 2014
Ocean salinity	BoM and CSIRO 2014
Solar radiation	Suppiah et al. 2011
Wind and waves	Lemos et al. 2019; Dewa 2016

5.2 Projected Climate Change

The climate projections for this project are based on the outputs of global climate models. A climate model is a numerical description that represents our understanding of the physics, and in some cases chemistry and biology, of the ocean, atmosphere, land surface and ice regions. All models are 'coupled' models, meaning that ocean, atmosphere, land and ice models are coupled together, with information continuously being exchanged between these components to produce an estimate of global climate. These climate models are run for hundreds of simulation-years subject to constant, pre-industrial (1870) forcing, i.e., constant solar energy and appropriate greenhouse gas levels to develop a baseline. The 20th century simulations incorporate increasing greenhouse gases in the atmosphere in line with historic emissions and using observed natural forcing (e.g., changes in solar radiation, volcanic eruptions). At the end of the 20th century, projection simulations are carried out based on predefined 'plausible' future emission trajectories.

The models then consider a range of possible futures, known as emissions scenarios, that are based on different possible futures of what society will do to curtail greenhouse gas emissions (IPCC 2014) to run simulations of future climate. While many climate models run projections for a range of future emissions scenarios, the current global trajectory most closely matches RCP8.5 (or the new SSP5-8.5). Therefore, this review focuses mainly on a moderate warming scenario RCP4.5 and the high-emissions scenario RCP8.5. This high-emissions scenario is often referred to as "business as usual", suggesting that is the likely outcome if society does not make concerted efforts to cut greenhouse gas emissions and continues on the current trajectory.

Climate change projections in Indonesia use the Regional Climate Model (RCM), which is derived from the Global Climate Model (GCM). GCM depicts climate with a three-dimensional grid on a globe, specifically with a large spatial resolution of between 250–600 km. GCM resolution is crude relative to the exposure unit scale required for most vulnerability assessments. The GCM model has become the most common approach to climate change projections, however, in many applications, especially for sub-national or local scales, the information provided by GCM is insufficient, so downscaling techniques are needed to provide more regional information.

5.3 Air Temperatures & Rainfall

The Indonesian BMKG processes output data from RCM as part of the international consortium CORDEX-SEA, increasing the spatial resolution of projections to 20 km x 20 km. The simulation is carried out using a statistical approach to project the future climate in Indonesia against a baseline climate for the 1981–2010 period, and a climate scenario 2011–2100. Data obtained from the output of CORDEX-SEA modelling activities consist of an ensemble of the results of the downscaling process of six types of global climate models (GCM) in two future representative concentration pathway (RCP) scenarios. The data are presented as the normal mean/composite mean of the two periods being compared for rainfall and air temperature. The period being compared is a historical baseline simulation (1976-2005) with a future projection period (2041-2070) under a high greenhouse gas emission scenario RCP8.5 (business-as-usual) for rainfall (Figures 5 and 6) and air temperature (Figure 7).

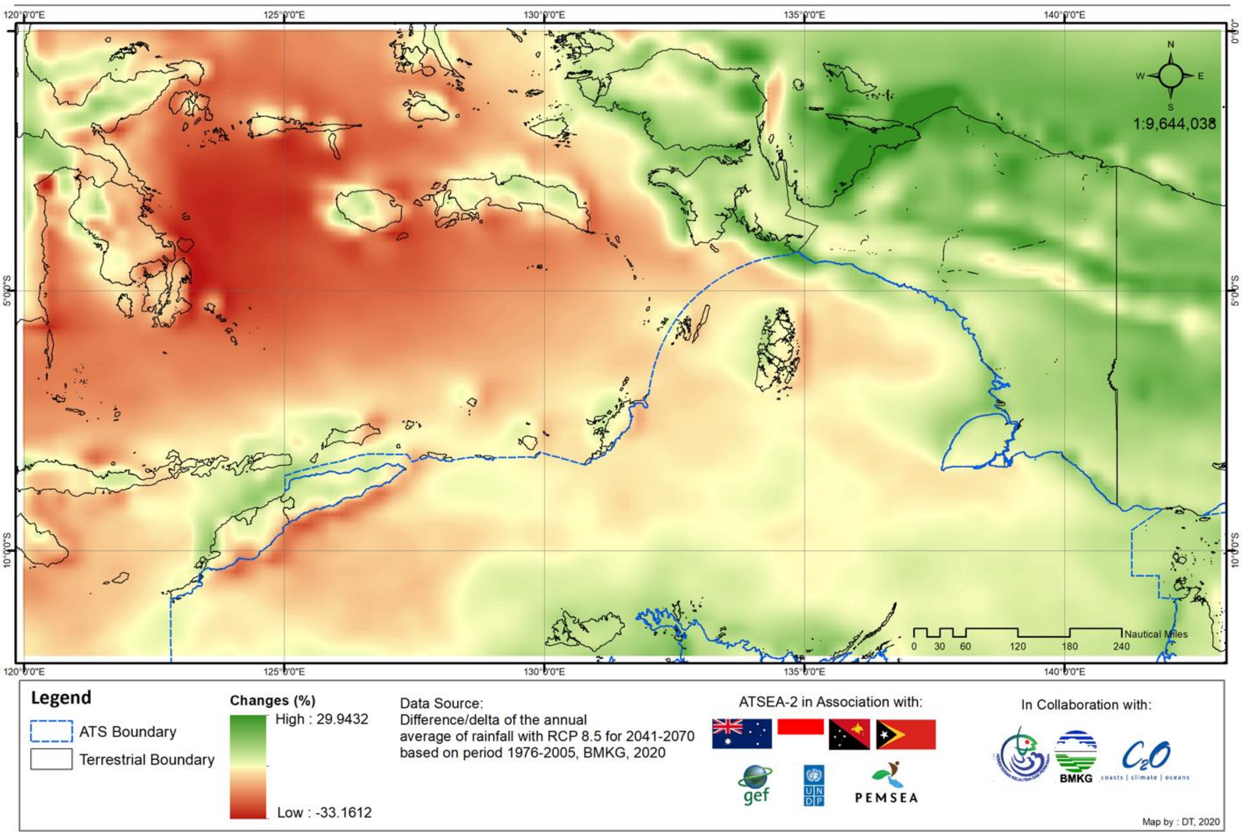

Figure 5. *Projection of percentage (%) change in annual average rainfall for 2041-2070 period relative to 1976-2005 baseline data under emissions scenario RCP8.5 (Source: BMKG)*

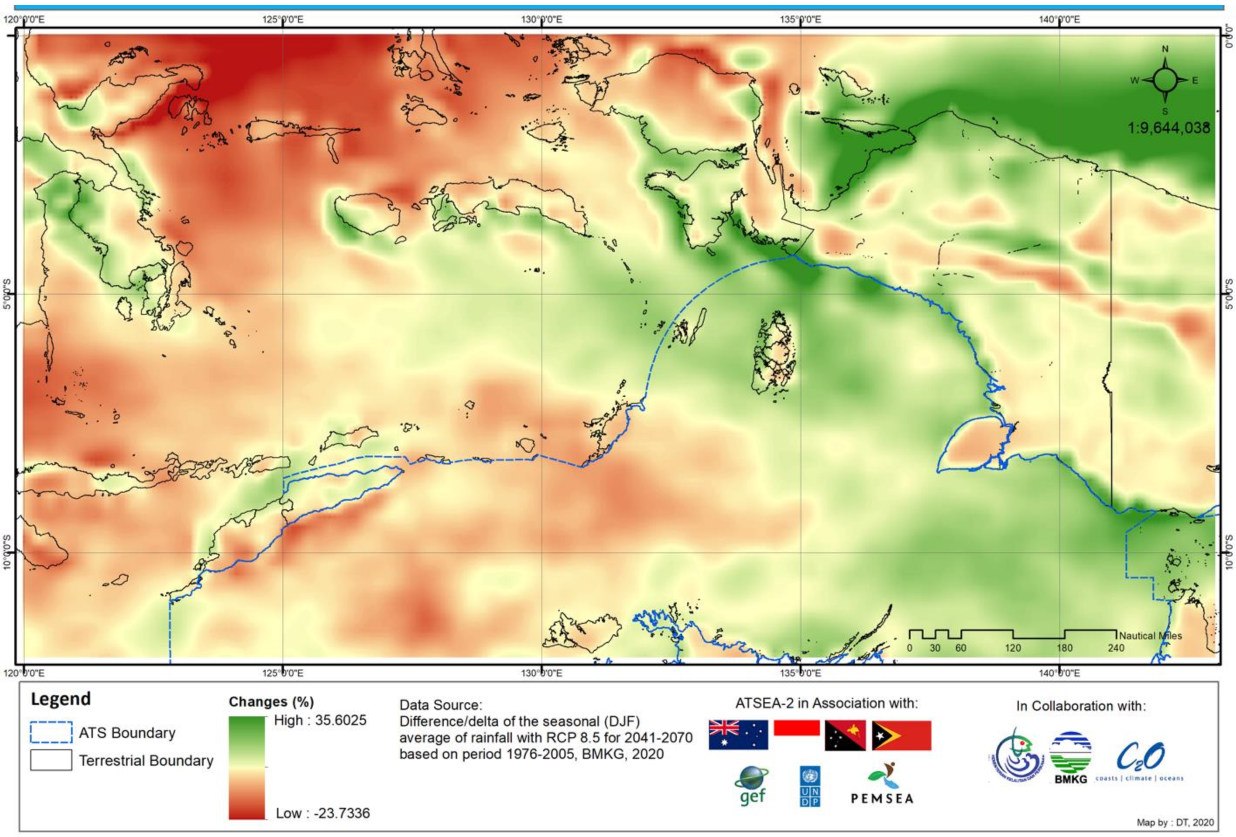

Figure 6. *Projection of percentage (%) change in seasonal average rainfall for 2041-2070 period relative to 1976-2005 baseline data for monsoon season (DJF) under emissions scenario RCP8.5 (Source: BMKG)*

The projected changes in rainfall for Indonesia and Timor-Leste show an increase in annual average rainfall by 2070 on most archipelagic islands and West Papua in the north-eastern ATS region of up to 1180 mm or +20 to +30% and a slight decrease around southern Timor-Leste (Figure 5). This pattern is accentuated during the monsoon season (December to February) with an increase in rainfall also projected for the Gulf of Carpentaria (Figure 6). The annual and seasonal rainfall projections show a neutral trend for open ocean areas with rainfall changes mainly near coasts and over land areas. The implications of these rainfall changes in terms of terrestrial runoff into marine ecosystems will be most pronounced around West Papua, that has the larger land mass and more rivers, with potentially more land runoff, while Timor-Leste coastal habitats may experience less terrestrial runoff, particularly to the south.

The projected changes in annual average air temperature for Indonesia and Timor-Leste show an increase of up to 3.6–3.8 °C by 2070 for most archipelagic islands in the ATS region, and a greater increase of more than 4 °C by 2070 for West Papua (Figure 7). There are also changes projected for annual average maximum and minimum air temperatures, with the most change projected for annual average minimum temperatures for most archipelagic islands in the ATS region, and a greater increase for West Papua.

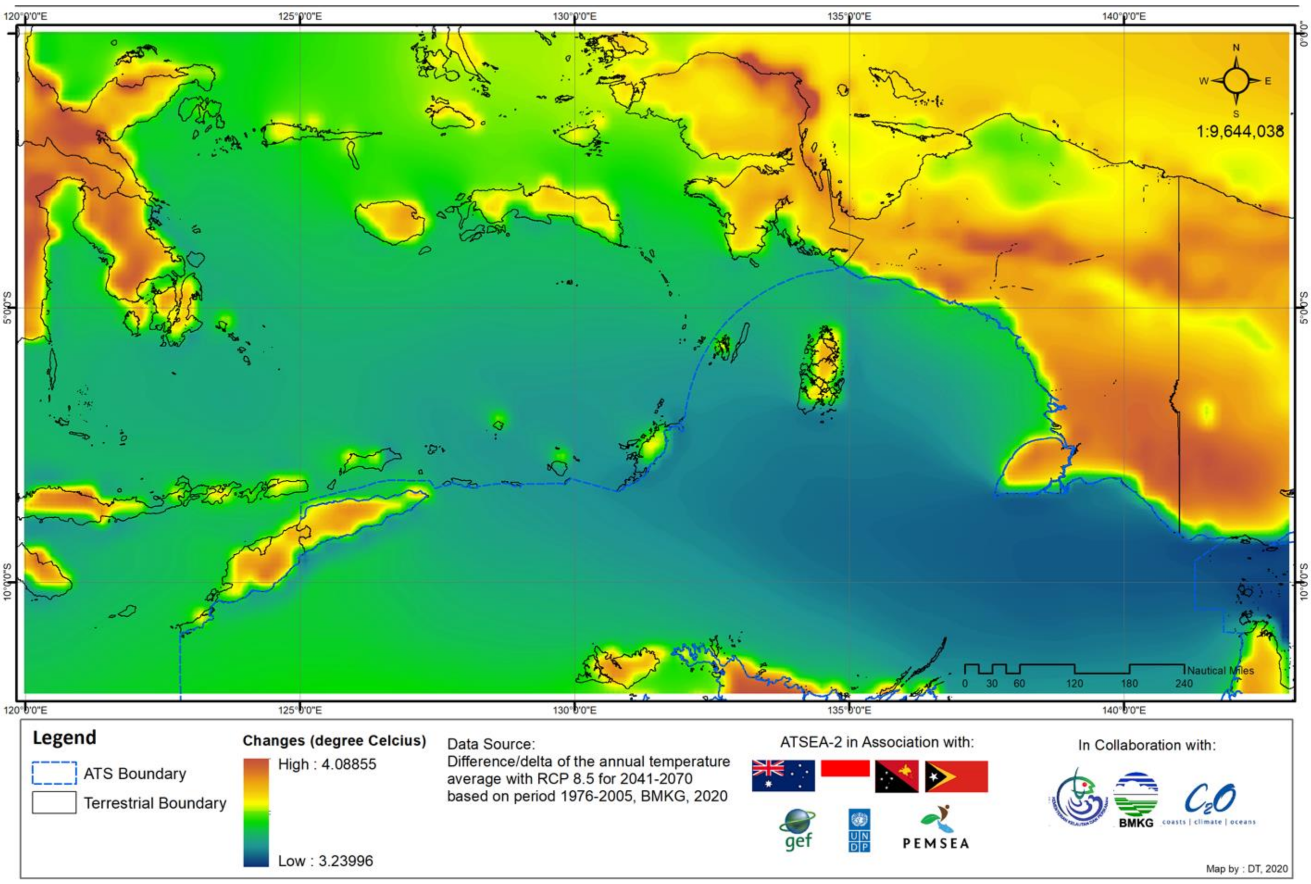

Figure 7. *Projection of change (°C) in annual average temperature for 2041-2070 period relative to 1976-2005 baseline data under emissions scenario RCP8.5 (Source: BMKG)*

Projections of changes in rainfall and air temperature for northern Australia will also influence the conditions in the ATS region, through land-based runoff of freshwater and associated sediment and nutrients, and changing conditions on coasts that can impact species, for example turtle nesting beaches. The latest projections for northern Australia indicated that by late in the century, potential summer and autumn rainfall changes are approximately -20 to +10% under RCP4.5 and -30 to +25% under RCP8.5. While the trends for annual rainfall are uncertain, projections of increased intensity of extreme rainfall events have higher confidence and therefore the risk of both a drier and wetter climate as well a more extreme rainfall need to be considered. The projections have a higher level of certainty for air temperature, with annual average warming of 0.5–1.3 °C by 2030 (for all emissions scenarios) and 2.7–4.9 °C by 2090 under RCP8.5. Under RCP4.5 the projected warming is 1.3 to 2.6 °C[4]. The warming trends projected are consistent with those for Indonesia and Timor-Leste.

5.4 Sea Surface Temperature & Ocean Acidification

Ocean circulation in the ATS region plays an important role influencing sea surface temperature (SST) patterns. In the Timor Sea, SST patterns suggest cool advection through the Torres Strait, corresponding with modelled circulation on the eastern Gulf of Carpentaria (Condie 2011). In the northern Arafura Sea, isolated cold patches are found that seasonally shift, particularly around the Aru Islands (Wijffels et al. 2018). SST varies seasonally in the ATS region, with the highest variation in the waters of the Java, Timor, Arafura and Banda Seas (based on 1986 to 2015 data), which is postulated to be due to upwelling process. Interannual variability in SST is also notable, with a negative anomaly dominant from 1986 to 2000, and a positive anomaly dominant from 2001 to 2015. The Indian Ocean Dipole has a greater influence on SST fluctuations than ENSO. Over the past 30 years, SST in Indonesian waters show an overall increasing trend, with the greatest rise (0.66 °C) occurring in the Halmahera Sea (north of the ATS region) and the smallest rise in the Timor Sea (0.36 °C) (Martono 2016).

Downscaled projections for sea surface temperature (SST) are available using Coupled Model Intercomparison Project phase 6 (CMIP-6) under the new Shared Socioeconomic Pathways (SSP) scenarios SSP5-8.5 (high emissions) and SSP2-4.5 (moderate emissions). Values for the variable (sea surface temperature and pH) were downloaded at native grid resolution, for all available models in SSP5-8.5 and SSP2-4.5 (see van Hooidonk 2020 for each scenario). Data were concentrated where needed to create complete time series. Where multiple runs were present, they were averaged using equal weighting. Missing data was filled in the zonal direction using NCL's poisson function. All SST model runs were adjusted to the mean of a NOAA Coral Reef Watch coraltemp_v3.1 2005-2019 climatology by subtracting the mean of the first 5 years of the model run from the entire period and then adding the mean of the *CoralTemp* climatology.

SST data were downscaled using a method similar to van Hooidonk et al. (2016), the ensembles were re-gridded to 5 km resolution, and the annual cycle was replaced with that of the *CoralTemp* 1985-2012 climatology[5]. The model delivers data at 5 km resolution up to 2070 in monthly data bins to provide output maps for absolute SST (Figure 8) and changes in SST between 2015 and 2070 (Figure 8) using homogenised spatial data for the entire ATS region.

[4] www.climatechangeinaustralia.gov.au

[5] https://coralreefwatch.noaa.gov/product/5km/description_climatology.php

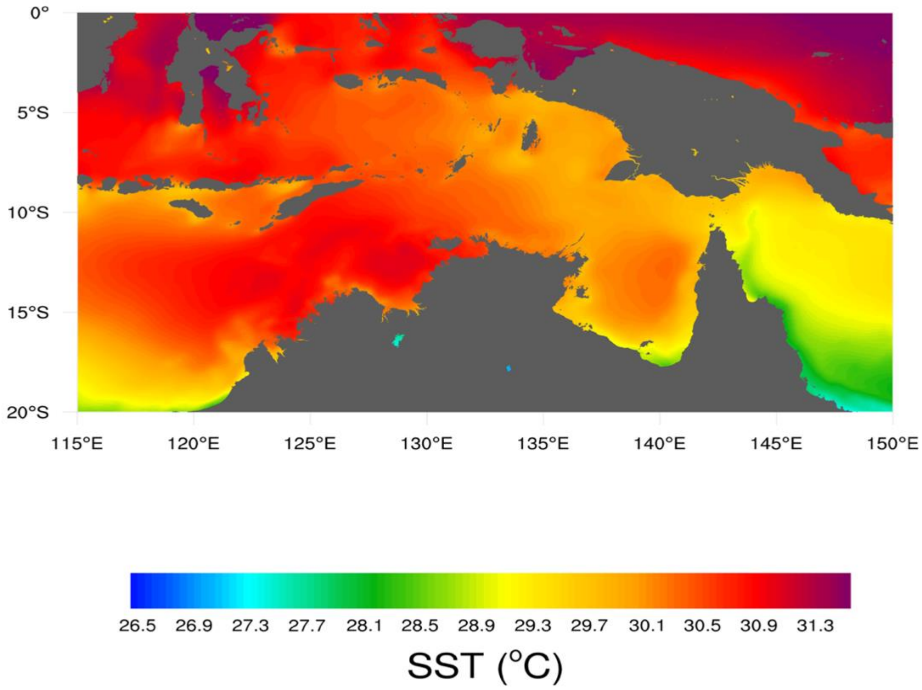

Figure 8. *Downscaled SST projections for 2070 under SSP5-8.5 (high emissions) scenario using statistical downscaling and validated against observed ocean data (Source: van Hooidonk, NOAA & University of Miami)*

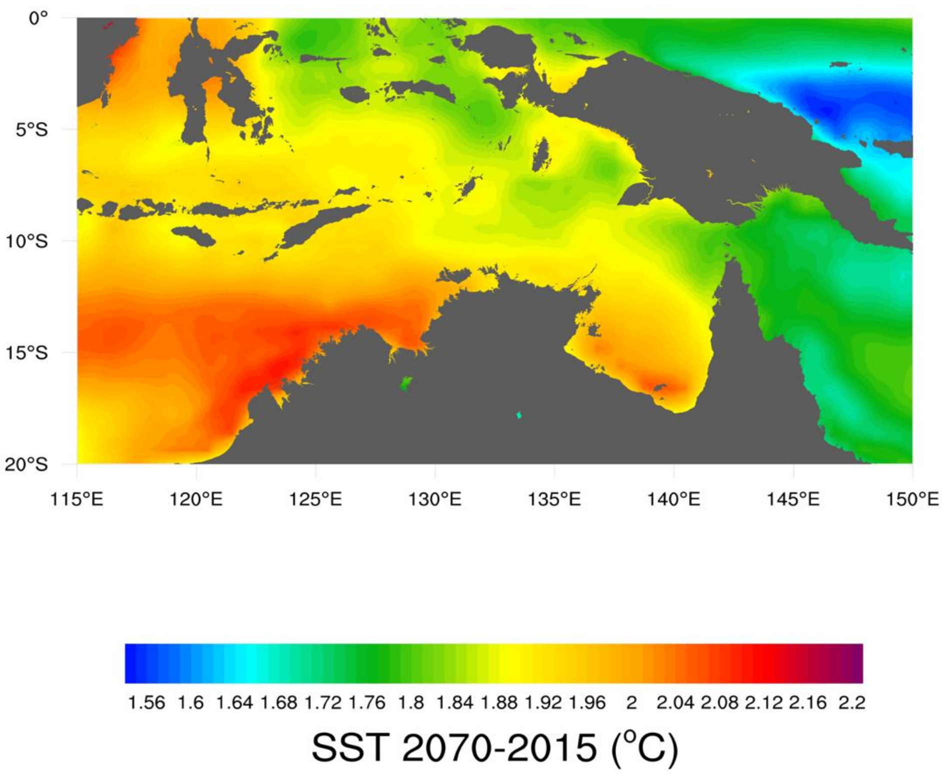

Figure 9. *Downscaled SST differences between 2015 to 2070 under SSP5-8.5 (high emissions) scenario using statistical downscaling and validated against observed ocean data (Source: van Hooidonk, NOAA & University of Miami)*

The spatial patterns are particularly interesting, with the absolute SST projections showing similar temperatures in 2070 in northwest Australia and the northern Timor Sea into the Banda Sea of 30.9 to 31.3 °C (Figure 8), the warming rate is greatest in northern Australia, where there is a 2.12 °C increased between 2015 and 2070, while northern Timor Sea is warming by about 1.88 °C during the same period (Figure 9).

Under all emissions scenarios, a net SST increase in the ATS region is projected, with the magnitude and rate of this warming proportional to the emissions scenario, i.e., the largest changes in SST are under the highest future atmospheric CO_2 concentrations (SSP5-8.5). By 2070, under SSP5-8.5, a (spatially averaged) warming of 1.72 °C is expected relative to 2015, and absolute SST will be above 29.5 °C for most of the region (as an annual average). While under SSP2-4.5, a (spatially averaged) warming of 1.13 °C is expected relative to 2015, and absolute SST will be above 28.9 °C for most of the region (Figure 10).

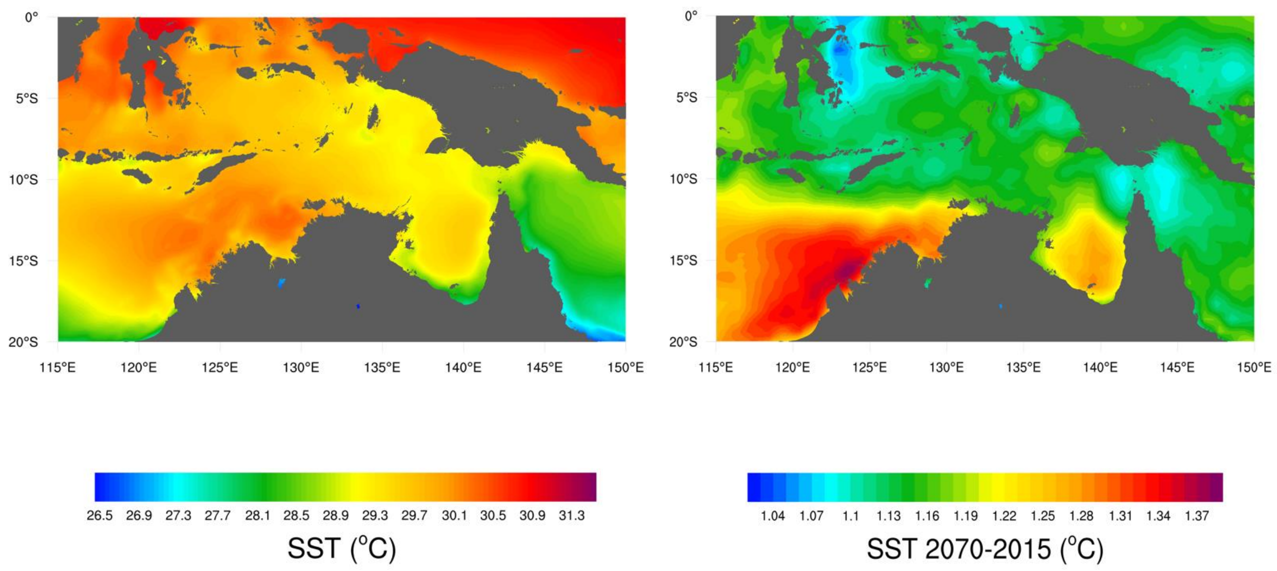

Figure 10. *Downscaled SST projections for 2070 (left) and SST differences between 2015 to 2070 (right) under SSP2-4.5 (moderate emissions) scenario using statistical downscaling and validated against observed ocean data (Source: van Hooidonk, NOAA & University of Miami)*

All emission scenarios show a net decrease in pH in the ATS region, with the magnitude and rate of change proportional to the atmospheric CO_2 concentrations. Under a high emissions scenario (SSP5-8.5) there is a (spatially averaged) decrease of 0.227–0.212 units by 2070, relative to the 2015 observations, and an absolute pH value of around 7.8 with the effects most pronounced to the west near West Papua and the Gulf of Carpentaria (Figure 11)

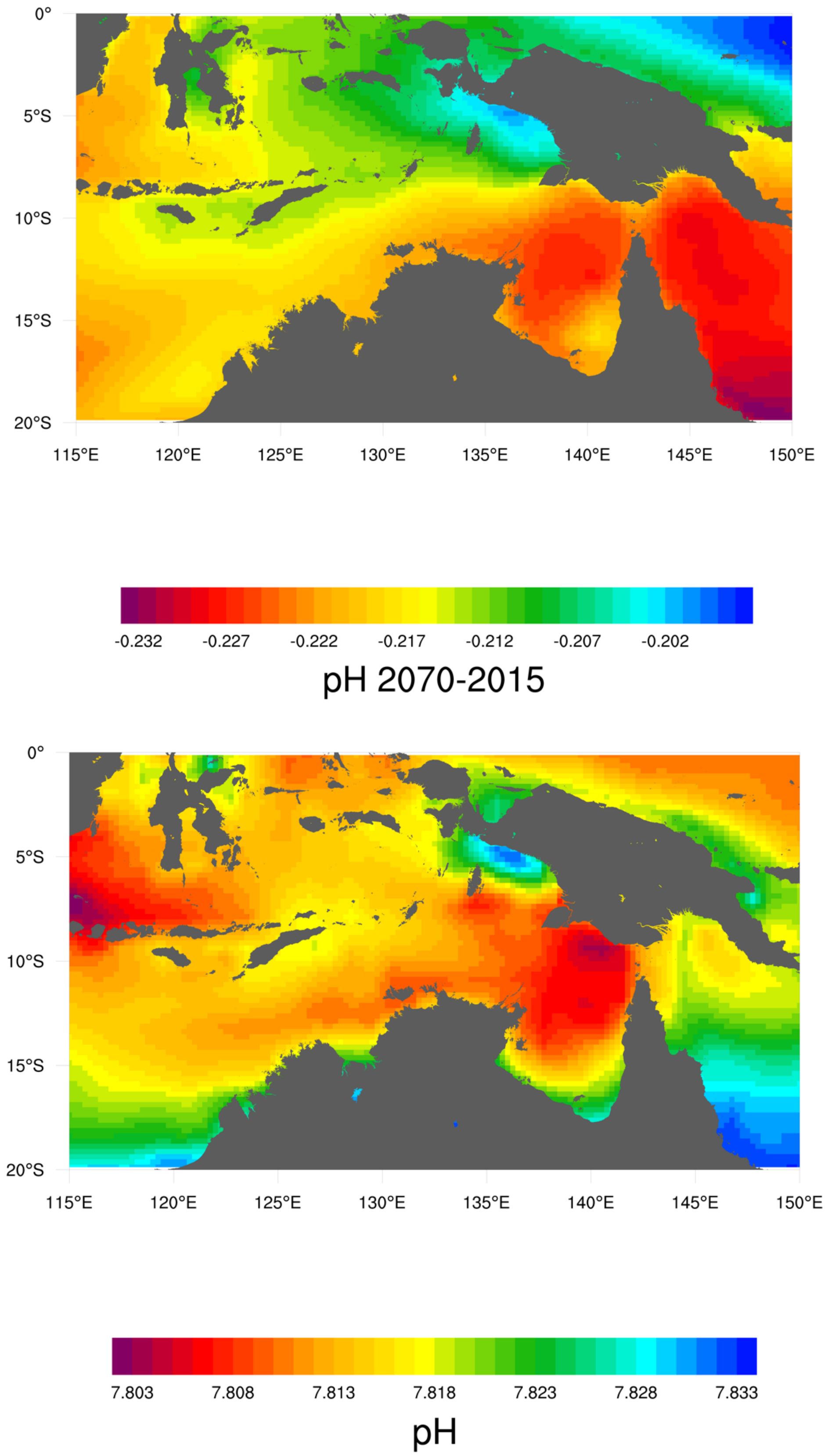

Figure 11. *Downscaled pH projections showing change between 2015 and 2070 (top panel) and absolute pH in 2070 (bottom panel) under SSP5-5.5 (high emissions) scenario using statistical downscaling and validated against observed ocean data (Source: van Hooidonk, NOAA & University of Miami)*

Under a moderate emissions scenario (SSP2-4.5) there is a (spatially averaged) decrease of 0.126–0.116 units by 2070, relative to the 2015 observations, and an absolute pH value of around 7.9 with the effects most pronounced to the west near West Papua and the Gulf of Carpentaria.

A comparison of these latest SST and pH projections using the most contemporary global climate models (CMIP-6) and IPCC scenarios (SSP) with earlier Australian projections using an ensemble of the CMIP-5 models and IPCC RCP scenarios confirms consistency in results but with higher resolution and confidence in outputs. Under the CMIP-5 models and RCP4.5 and RCP8.5 emissions scenarios, the ATS oceans exhibit warming and continued acidification with similar spatial patterns and variability. An assessment of where the Earth System Models show good agreement by calculating the ensemble range for SST and pH (Figure 12) provides insight into where the models show good (low values) and poor (high values) agreement. Figure 12 shows that in terms of SST, earlier models show reasonable agreement across north Australia and into the Arafura and Timor Seas (Lenton et al. 2015).

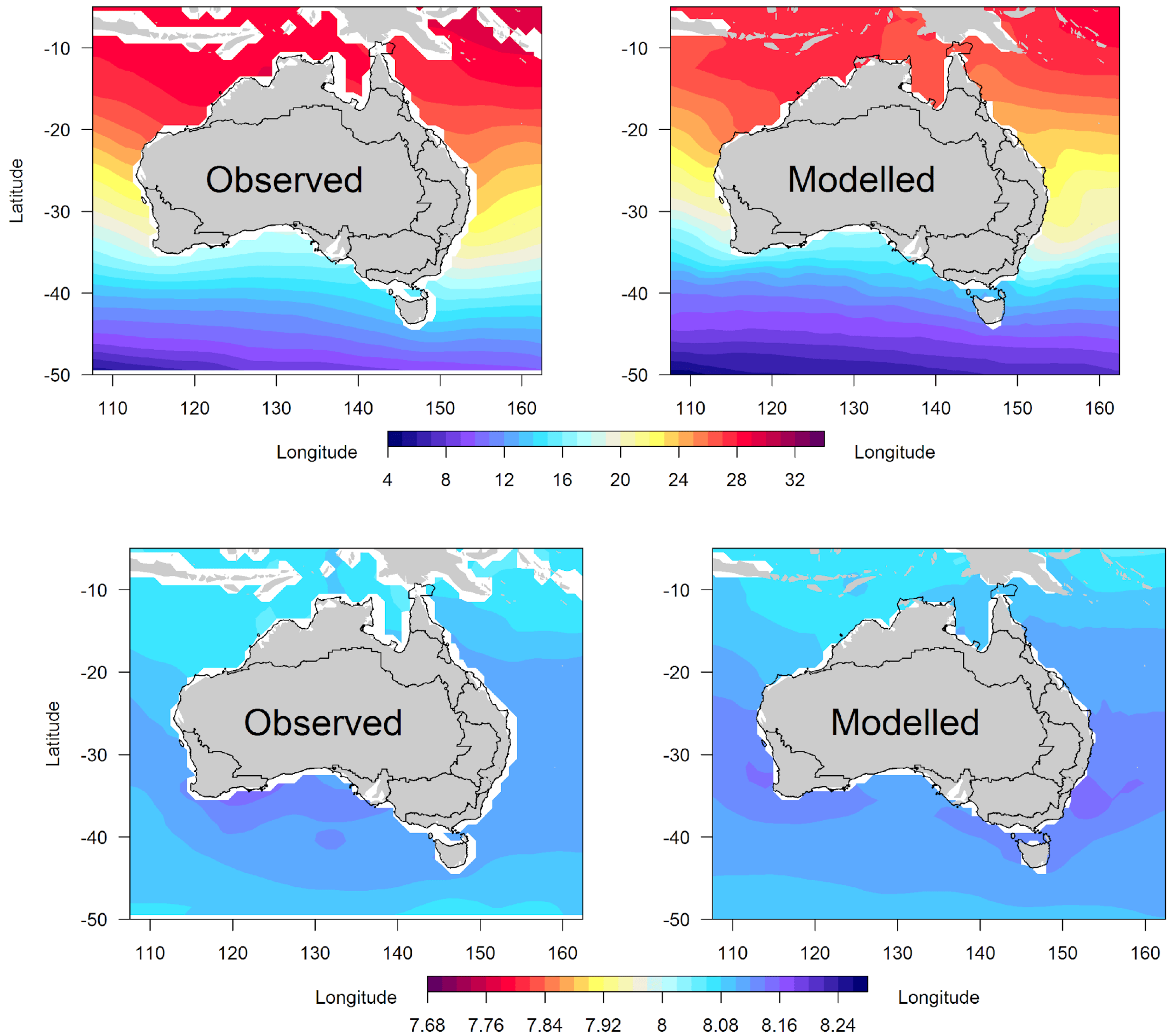

Figure 12. *Validation of CMIP5 against observed SST (top panels) and observed ocean pH (bottom panels) demonstrating good agreement and therefore confidence in the ATS region for climate change projections (Source: CSIRO).*

5.5 Sea-level

While downscaled sea-level projections aren't available for the ATS region specifically, projections by CSIRO in Australia cover the project area and provide current data relevant to northern Australian as well as the Arafura and Timor seas. Observational data (after accounting for the influence of ENSO and natural climate variability) show that sea levels have risen in the area of interest at an average rate of 2.1 mm/year over 1966–2009 and 3.1 mm/year over 1993–2009. These observed rates of rise are consistent with global average values.

The latest sea-level rise projections for the ATS region use 40 model ensembles of CMIP5 under low, medium and high emissions scenarios (RCPs 2.6, 4.5 and 8.5 respectively) and available for 2050, 2070 and 2100[6] and Figure 12 shows the RCP8.5 (high emissions scenario) projections for 2070. The rate of sea-level rise is not projected to be homogenous across the entire ATS region, with the Gulf of Carpentaria and West Papua coast expected to experience the least increase of about 0.4 m, while the Indonesian archipelagic islands and Timor-Leste will experience increases of 0.5–0.6 m by 2070 (Figure 13).

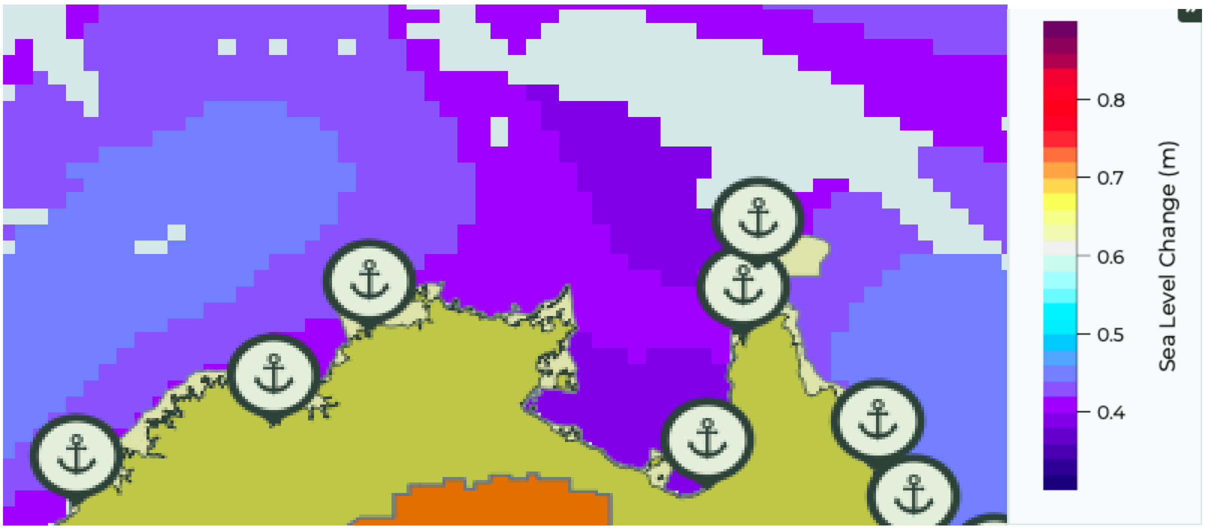

Figure 13. *Map of projected sea-level rise (mm/year) under RCP8.5 by 2070. Detailed site projections are available for locations indicated by anchors (Source: Climate Change in Australia)*

With these sea level rise projections by the end of the century, understanding how tidal ranges will also be influenced is crucial for determining the potential implications for coastal ecosystems and low-lying communities. Using an established tidal model (validated for present day conditions), the effect of large levels of sea-level rise (SLR) on tidal characteristics around Australasia found that future projections of SLR will generate new tidal nodes within the Gulf of Carpentaria and large-amplitude tidal changes in the Arafura Sea and embayments on Australia's northwest coast (Harker et al. 2019).

6 www.climatechangeinaustralia.gov.au

5.6 Storms and Cyclones

Tropical storms and cyclones are more frequent in the northern parts of the ATS region, they can influence the condition of coastal and marine habitats. There is large uncertainty about how tropical cyclones will change under a warmer climate. However, a review of modelled tropical cyclone characteristics predicts a likely increase in the maximum intensity of tropical cyclones as the mean global temperature rises, of between +3% to +21% by 2100, or between +2% and +11% if expressed as maximum wind speed (Knutson et al. 2010). The consensus from many advanced modelling studies is that the frequency of tropical storms and cyclones will either stay the same or decrease, ranging from -6% to -34% globally by 2100 (Knutson et al. 2010). Ultimately, tropical cyclone numbers are projected to decline in the future but those that do occur are likely to be more intense (Lough et al. 2011).

5.7 El Niño Southern Oscillation (ENSO)

The El Niño Southern Oscillation (ENSO) is a major source of inter-annual climate variability in the Arafura and Timor Seas with more flooding over the wet season, during El Niño phases (e.g., in Timor-Leste in 1982, 1986, 1992, 2005, 2006), as well as very severe flood events at the height of the wet season during even weak La Niña phases (e.g., in Timor-Leste in 1999, 2012, 2013; Barnett and Campbell 2010). During typical La Niña events, the summer monsoon circulation is stronger than normal with more cloud cover and rainfall all higher than average. ENSO drives the strength of the Australian-Indonesian Monsoon circulation, and therefore influences rainfall, sea level and the risk of tropical cyclones (BOM and CSIRO 2014).

ENSO also influences the variability of marine productivity in the ATS region (Ahmad et al. 2016), via interactions with chlorophyll-a concentrations due to changes in SST and upwelling associated with different ENSO phases. During El Niño phases, the Java-Sumatra upwelling extends spatially and temporally (Dwi et al. 2001) causing a decrease in sea level and enhanced upwelling. These conditions are reversed during La Niña (Dewi et al. 2018).

The current generation of global climate models are not good at representing the variability associated with ENSO and show little consensus on the simulation of likely changes in the frequency, intensity and patterns of future El Niño and La Niña events (BOM and CSIRO 2014). Therefore, all that can be said about ENSO in the future is that it will continue to be a source of inter-decadal variability in the region (Lough and Hobday 2011).

5.8 Other Climate Variables

Projected alterations in the speed and direction of some major ocean currents will have potential implications for currents, stratification and productivity in the ATS region. Any changes in the highly variable and complex tidal regime in ATS will have implications for species life cycles, and larval and nutrient exchange in the region. The projected increased stratification of the upper layers of the ocean is a major factor influencing the supply of nutrients from the deep ocean to the surface zone and will impact on primary productivity and ultimately fisheries in the region.

Other ocean climate variables that are expected to influence marine ecosystems in the ATS region are ocean salinity and solar radiation. Salinity can have direct effects on fish species and life cycle stages, while solar radiation is important for the growth and maintenance of seagrass meadows, a critical habitat for many species in the region.

Ocean salinity in coastal waters will be affected by changes to rainfall and evaporation. Changes in salinity can affect stratification and mixing, and potentially nutrient supply. A net reduction in the salinity of Australian coastal waters is projected, but this projection is of low confidence (BoM and CSIRO 2014).

Projected changes in regional solar radiation are for decreases, with the projected annual change for 2030 being -0.31% under a moderate emissions scenario and -0.43% under a high emissions scenario. Larger decreases are projected for 2070, of -0.79% for the moderate emissions scenario and -1.10% for the high emissions scenario. Seasonal changes are also dominated by decreases (Suppiah et al. 2011).

Global projections of changes to wind and wave climate under RCP8.5 show statistically significant increases in the global mean wind speed, wave height, wave period and wave energy flux by 2050, most evident in mid-to-high latitudes of the Southern Hemisphere (Lemos et al. 2019). However, in the equatorial ATS region, decreases in wave heights, periods and energy fluxes are projected, especially during the Austral winter (Lemos et al. 2019). This will influence wind and wave conditions that currently vary between monsoon and non-monsoon periods. Currently during the southeast monsoon, south-easterly winds from Australia (Dewa 2016) generate upwelling in the Arafura, Banda and Timor Seas with wind speed ranging from 13 to 20 knots (Dewi et al. 2018). During the northwest monsoon, north-westerly winds from Asia blow over the Arafura Sea with relatively low speeds ranging from 5 to 8 knots (Dewa 2016).

Examination of the global projections for waves show that winter *mean significant wave heights* are expected to decrease by 7% in the Arafura Sea by 2050, and *wave energy flux* is projected to decrease during winter by 20% in the Arafura Sea. However, as the mean wave energy flux is relatively low for this area (below 40 kW/m), the absolute difference rarely surpasses –3 kW/m between the historic simulation and the 2050 wave climate projections (Lemos et al. 2019).

A summary of the future projections for the different climate variables is provided in Table 3.

Table 3. *Arafura & Timor Seas climate change projections by sub-region under high emissions scenario (RCP8.5 or SSP5-8.5) to 2070*

Variable	Arafura Sea (Indonesia)	Timor Sea	PNG (Western Province)	Northwest Australia	Gulf of Carpentaria
Sea surface temperature[1]	29.4 to 29.8 °C (+1.8 °C)	30.9 to 31.3 °C (+1.88 °C)	29.4 to 29.8 °C (+1.76 °C)	30.9 to 31.3 °C (+2.12 °C)	29.7 to 30.1 °C (+2.04 °C)
Ocean chemistry (pH)	−0.212 to −0.20	−0.217 to −0.212	−0.227 to −0.222	−0.222 to −0.217	−0.227 to −0.222
Rainfall change	+20 to +30% (coastal); 0 to −5% (open ocean)	−25 to −33% (coastal); 0 to −5% (open ocean)	+15 to +20%	−30 to +25%	−30 to +25%
Air temperature	+3.6 to +3.8 °C (land)	+3.6 to +3.8 °C (land)	+3.8 to +4 °C (land)	+2.7 to +4.9 °C (2090)	+2.7 to +4.9 °C (2090)
Storms and cyclones[2]	+3 to +21% maximum intensity; −6 to −34% frequency				
Sea level rise	+0.5 to +0.6 m	+0.5 to +0.6 m	+0.4 m	+0.45 m	+0.4 m
El Niño Southern Oscillation (ENSO)	Continued source of inter-decadal variability in the region				
Solar radiation	−1.10%				
Wind and waves[3]	Mean wave height −7%; wave energy flux −20%				

1. Increase relative to 2015 baseline
2. Global projections for 2100
3. Regional projections for 2050

CHAPTER 6. RESULTS: VULNERABILITY OF HABITATS

The ecosystems in the ATS region have evolved to operate within a specific range of prevailing local climatic conditions – the coping range (e.g., Jones and Mearns 2005, Hoegh-Guldberg et al. 2007). Any changes in these specific climate conditions will influence coastal and oceanic habitats and the species, populations and communities they support. Therefore, understanding how climate change is likely to influence key habitats – coral reefs (shallow and deep), seagrass meadows, mangroves and estuaries, pelagic ocean – is important when seeking to assess how these resources are likely to respond under future climate change. The information presented in this section draws on assessments of vulnerability in other tropical habitats (Bell et al. 2011) and some spatial sub-units of the ATS region (Welch et al. 2014b, Welch and Johnson 2013) to climate change, and their known sensitivities to climate drivers.

Marine and coastal habitats will be exposed to a range of changing climate variables and combined with their known sensitivities will provide insights into the potential impacts on these habitats and the species they support.

6.1 Coastal Wetlands and Estuaries

Coastal wetlands and mangrove forests provide nursery areas for many species, including harvested fish and invertebrates, and feeding grounds for many species of adult demersal fish and invertebrates (e.g., shrimp, mud crab, emperors and snappers) (Waycott et al. 2011). Mangroves on small islands are also particularly important for coastal protection and preventing sea water intrusion into ground-water.

The ATS region has few estuaries on the archipelago islands that have only small rivers flowing into the ocean, with the West Papua and northern Australian coasts representing the major estuaries in the region. Estuaries form a transition zone between land and ocean environments and are subject to both marine influences, such as tides, waves, and the influx of salt water; and riverine influences, such as flows of fresh water and sediment. These two influences provide high levels of nutrients in the water column and sediment, making estuaries among the most dynamic and productive natural habitats in the world. Because coastal wetland and mangrove habitats provide critical habitat for different life history stages of many important estuarine and reef species, any changes in habitat condition or area will have implications for the species they support. There are documented effects of the changes in rainfall and riverflow on species in these habitats, particularly on recruitment success, growth and catchability.

Mangroves of Timor-Leste

Coastal ecosystems such as mangrove forests have patchy geographic distribution in Timor-Leste and are considered to be in poor condition. Mangrove forest degradation is due to sedimentation and human activity (e.g., clearing). Sucos in Timor-Leste with documented mangrove forests are Beco in Covalima; Duyung (Sereia) and Sabuli in Dili; Clacuc in Manufahi; and Uaitame in Viqueque (UNDP 2018). The extent of mangroves in Timor-Leste is unknown but estimated to occupy a few thousand hectares of shoreline (Boggs et al. 2009).

Mangroves of Indonesia

The coastal regions of Indonesia support high mangrove diversity with 45 species recorded (Spalding et al. 2010), and extensive mangrove systems located on the southern coast of Papua, in the Wasur National Park, Papua (listed as Wetlands of International Importance; Wirasantosa et al. 2011) and Merauke. The largest continuous area of mangrove forest in the ATS region is along the southwest coast of Papua. The coastal zone of Indonesia supports approximately 60% of the 238 million population (BPS 2010) and thousands of Indonesian coastal villages are located adjacent to mangrove forests, that are often cleared for development or expanding villages, and exploited for firewood, building materials, food and medicines. These anthropogenic activities have impacted mangroves, with canopy cover declining from 1996 to 2016 in all locations surveyed (ATS Atlas 2020).

Mangroves of western PNG

Well-developed mangrove forests and estuaries exist along much of the western PNG coast, which is characterised by fine sediment and low relief (ATSEA 2012). The condition of these mangrove habitats is largely undocumented, but delivery of sediment is known to originate from the Fly River catchment and the river plumes have a large and year-round influence on western PNG habitats, including mangrove systems (Waterhouse et al. 2018).

Mangroves of northwest Australia & Gulf of Carpentaria

Coastal mangrove forests are found throughout northern Australia, including the Gulf of Carpentaria and northwest Australian sub-regions, particularly where rivers and estuaries meet the coast. These two sub-regions contain some of the largest, pristine catchments, tidal estuaries, coastal wetlands, coastal savannahs, tropical rivers and mangrove forests still relatively intact. The high coastal biodiversity of northern Australia is of major cultural, social and economic significance for Aboriginal people inhabiting these remote regions (ATSEA 2012).

Vulnerability of Mangroves to Climate Change

Coastal wetlands and estuaries may become warmer and more eutrophic in the future, offering less suitable habitat for vegetation such as mangroves and fisheries species. In some locations where mangroves are the main components, there may be a reduced area of available habitat. Mangrove habitats will be vulnerable to more intense storms and cyclones, decreasing rainfall and riverflow, and sea-level rise with high sediment accumulation rates allowing some adaptation to rising sea levels via migration (Waycott et al. 2011).

Their location on the coastal fringe of low-lying alluvial islands makes them highly vulnerable to sea-level rise that will exacerbate extreme high tide flooding, storm surge and shoreline erosion, as well as more intense storms and cyclones (Duke et al. 2012). This will be further exacerbated by sea-level rise, as will storm surge associated with increasing storm severity. More intense storms will further impact mangrove forests through the physical processes of erosion, burial, wind throw and lightning strikes. Projected changes in rainfall, particularly the amplification of the seasonal cycle has implications for mangrove growth depending on whether the rainfall changes coincide with the peak mangrove growing season (Duke et al. 2012).

The location of mangroves will determine their exposure to projected future climate change, particularly changing rainfall quantities and seasons, sea-level rise, and more intense storms and cyclones. Although the entire ATS region is projected to experience these changes, there is spatial variation in the magnitude of change under all emissions scenarios. Therefore, the vulnerability of mangroves varies across the sub-regions due to different drivers (Table 4).

Table 4. *Relative vulnerability of mangroves in the ATS region and drivers of vulnerability*

Sub-region	Drivers of vulnerability	Expected impact
Western PNG	Poor current condition; low species diversity; lack of management	Decline in condition and area
Timor-Leste	Rainfall declines; sea-level rise; low connectivity; limited formal management	Decline in condition and area
Indonesia/Arafura	Sea-level rise; poor current condition	Decline in condition and area
Northwest Australia & GoC	Sea-level rise	Stable

The results of the vulnerability assessment indicate that mangroves in the western PNG and Timor-Leste sub-regions are most vulnerable to future climate change. Particularly, sea-level rise, rainfall changes, and more intense storms and cyclones. This vulnerability is driven by their poor current condition, low species diversity and lack of management in western PNG, and low connectivity and limited formal management in Timor-Leste. Mangrove forests in the Indonesia/Arafura sub-region are also vulnerable to climate change, with sea-level rise and poor current conditions the main drivers of this vulnerability. In Indonesia and Timor-Leste where coastal development and infrastructure are extensive, there will be physical barriers to mangrove inland migration as sea level rises, further exacerbating vulnerability.

Ultimately, these climate-driven changes are expected to impact the condition and area of mangrove forests in these sub-regions, and adaptations should focus on addressing the source of vulnerability. Specifically:

- Establish local MPAs to protect mangrove forests as part of a connected coastal mosaic of habitats.
- Implement management to promote recovery and improve condition of mangrove forests (e.g., replanting) and reduce non-climate pressures on mangroves (e.g., clearing and development).

Mangroves have the ability to adapt to projected sea-level rise, if sediment accretion is fast enough and landward barriers, such as roads and buildings, don't constrain migration. Higher atmospheric carbon dioxide (CO_2) concentrations and greater rainfall in some sub-regions could enhance this potential to expand landward by increasing mangrove productivity (Steffen et al. 2009, Waycott et al. 2011). Ultimately, the pace of sea-level rise under high emissions is expected to be greater than the ability of mangroves to migrate (Lovelock et al. 2015), and if their landward migration is further inhibited by structures, the area of mangroves will decline (Johnson et al. 2020). Therefore, another important adaptation is the relocation or removal of barriers to landward migration (e.g., weirs and roads), and future urban planning that considers areas that mangroves may expand into.

6.2 Seagrass Meadows

Seagrasses provide nursery areas for many species of fish and invertebrates (e.g., shrimp, sea cucumbers, mud crab and emperors), and feeding grounds for many species of adult demersal fish targeted by fisheries (e.g., *Lutjanidae*, *Lethrinidae* and *Serranidae*; CTI-TLS 2012) as well as green turtles and dugong. Seagrasses (and intertidal flats) are also permanent habitats for a wide range of invertebrates, such as sea cucumbers (Waycott et al. 2011). In some regions, local communities engage in gleaning of nearshore seagrass meadows during low tide targeting juvenile fishes, crabs, molluscs, and sea urchins. Apart from fisheries production, seagrasses provide a range of goods and services including attenuating wave energy thus reducing coastal erosion/sedimentation and cultural importance.

The ATS region has diverse seagrass meadows that are dense and important habitats in some locations (e.g., near western PNG and off Nhulunbuy in northwest Australia). The species reported from the region are generally found along the coast of most countries in the Arafura, Timor, Flores, Savu and Banda Seas, including Timor-Leste, northern Australia, Papua New Guinea, and the Indonesian provinces of East Nusa Tenggara, Maluku, and Papua.

Seagrass of Timor-Leste

Limited information is available on seagrass habitats in Timor-Leste with no comprehensive mapping surveys, meaning area estimates are based on broad-scale, mostly remote assessments. Surveys of the northern coast documented 5 species, and an estimated area of 2,200 ha of seagrass (Boggs et al. 2009, Edyvane et al. 2009). The results of all broadscale mapping combined (2007 and 2012; Boggs et al. 2009, Edyvane et al. 2009) estimates the total area of seagrass habitat in Timor-Leste to be approximately 4,266 ha and confirmed a total of eight seagrass species in the waters of Timor-Leste (SeagrassWatch[7]).

Seagrass of Indonesia

Indonesian seagrasses often form extensive mixed or monospecific meadows. Mixed seagrass communities composed of 8-9 species are common in many coastal areas in Indonesia. Along coastlines dominated by mangrove forests, seagrass communities often provide a functional link and a buffer between the seaward coral reefs and the inshore mangroves. Seagrass are also an integral component of Indonesian reefs, found in shallow-water back reefs and lagoons. Eight genera and 13 species of seagrass have been documented in Indonesian coastal waters. These include: *Cymodocea serrulata*, *Cymodocea rotundata*, *Enhalus acoroides*, *Syringodium isoetifolium*, *Halodule pinifolia*, *Halodule uninervis*, *Halophila spinulosa*, *Halophila decipiens*, *Halophila ovalis*, *Thalassia hemprichii*, *Halophila minor*, *Thalassodendron ciliatum* and *Ruppia maritima*. Seagrass diversity in Indonesia is moderate and it has also been suggested that this may be partly a consequence of the oceanic currents that effectively form geographic harriers to seagrass dispersal resulting in longitudinal differences[8].

[7] https://www.seagrasswatch.org/timor-leste/#footnote
[8] https://www.seagrasswatch.org/?s=indonesia

Seagrass of Western PNG

The western PNG sub-region covers a small coastal strip adjacent to the Torres Strait Islands of Australia. While not well documented, shallow soft sediments are covered with either sparsely distributed Halophila or mixed species communities (Halodule, Thalassia and Syringodium) of seagrasses. The area of seagrass meadows in this sub-region is relatively small.

Seagrass of Northwest Australia & Gulf of Carpentaria

The northwest Australian sub-region has 15 species of seagrass and due to large tidal variation (1–11 m) that causes strong tidal flows, seagrass meadows are mostly found in sheltered intertidal bays along the southern coast of the Kimberley region, with low to moderate abundance. Seagrasses are also interspersed in coral reef environments in northwest Australia, but the high-energy environments of the northern Kimberley mean seagrass are largely absent on that part of the coast. On the Sahul Shelf, surveys of Ashmore Reef recorded 5 species of seagrass and the highest average seagrass cover of the reefs of the Sahul Shelf, with 22.13 km^2 of seagrass beds (>10% cover; Brown and Skewes 2005). In the Gulf of Carpentaria, the generally shallow and soft sediment environment supports extensive areas of seagrass in coastal and estuarine locations, however recent mapping observed low diversity and biomass.

Vulnerability of Seagrass Meadows to Climate Change

Seagrasses face a range of pressures as human populations increase and the potential effects of climate change, such as increased storm activity, come into play (Waycott and McKenzie 2010, Grech and Coles 2010). Seagrass habitats are susceptible to degradation through a number of anthropogenic impacts, including sedimentation, destructive aquaculture practises (e.g., intensive seaweed farming), overfishing, coastal mining (e.g., sand extraction), coastal development and land-based pollution. Unsustainable agricultural practices (e.g., traditional slash and burn) and poor land management (e.g., deforestation, domestic livestock grazing) combined with steep terrain and short, intense rainfall periods can result in high soil erosion which causes sedimentation and elevated turbidity that impact seagrass meadows in nearshore waters. Population growth (increasing urbanisation), coastal development and inadequate wastewater disposal all contribute to an increase in nutrients and other pollutants entering the coastal environment and impacting seagrass.

Changes in nutrient dynamics and light penetration in coastal waters due to flood events have been shown to impact on seagrass growth and reproduction (McKenzie et al. 2006, Orth et al. 2006). Chronic elevated nutrients have been reported to lower the availability of light to seagrasses due to increased growth of algae and epiphytes on the plants (Burkholder et al. 2007). Chronic and pulsed increases in suspended sediments that increase turbidity can also reduce light and result in reduced productivity and seagrass loss (Waycott and McKenzie 2010).

The dynamics of tropical seagrasses are heavily influenced by weather patterns, including flood and cyclone events that have the potential to physically damage seagrass meadows, particularly in shallow area (Waycott et al. 2011, Johnson et al. 2020). Collectively, the impacts from climate change are projected to reduce seagrass condition and area, resulting in less suitable habitat for species, as well as reduced food resources for dugong and green turtles (Sobtzick et al. 2012, Johnson et al. 2020).

The location of seagrass meadows will determine their exposure to projected future climate change; particularly increasing sea surface temperature (SST), changing rainfall and terrestrial runoff, sea-level rise, more intense storms and cyclones, and decreasing solar radiation. Although the entire ATS region is projected to experience increases in SST, sea-level rise and changing rainfall, there is spatial variation in the magnitude of change under all emissions scenarios. Therefore, the vulnerability of seagrass meadows varies across the sub-regions due to different drivers (Figure 14) but ultimately seagrass meadows are expected to decline in condition and area (Table 5).

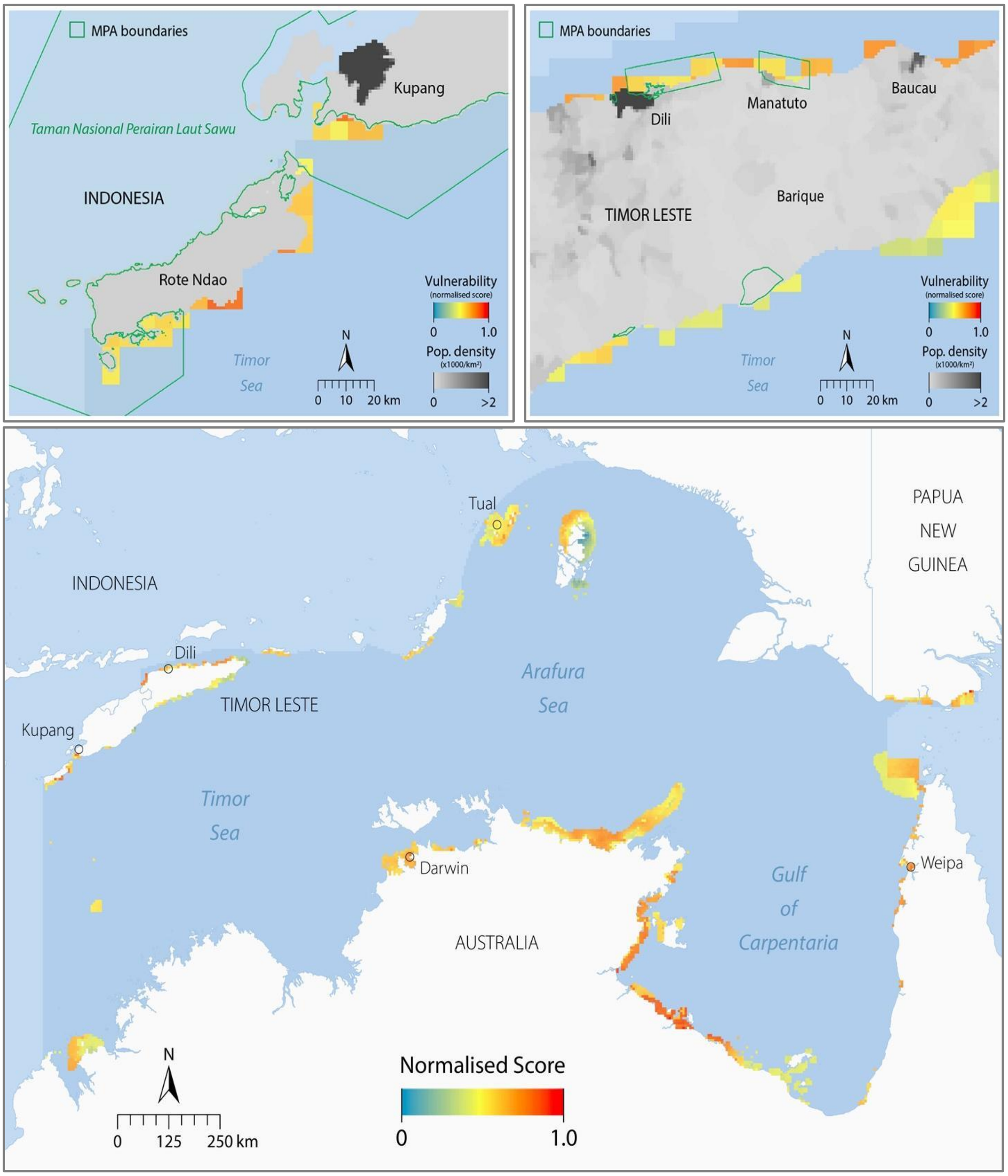

Figure 14. *Regional relative vulnerability of seagrass meadows in the ATS region, with vulnerability calculated as V=PI x (1-AC), where PI=potential impacts (a function of exposure and sensitivity), AC=adaptive capacity, and 1-AC is scaled from 0.5 to 1. Colour represents normalised scores from 0 (white; not vulnerable) to 1.0 (dark red; very high vulnerability). Insert A=detailed vulnerability results for seagrass around Rote Ndao, Indonesia; Insert B=detailed vulnerability results for seagrass around Barique Municipality, Timor-Leste, showing current MPA boundaries.*

Table 5. *Vulnerability of seagrass meadows in the ATS region and drivers of vulnerability*

Sub-region	Drivers of vulnerability	Expected impact
GoC	SST+; historic SST+ exposure; rainfall changes; low species diversity	Decline in condition and area
Indonesia/Arafura	Rainfall increase/coastal runoff; sea-level rise; low connectivity; non-climate pressures	Decline in condition and area
Timor-Leste	SST+; sea-level rise; limited formal management	Decline in area
Western PNG	Historic SST+ exposure; rainfall increase/coastal runoff; low diversity; no management	Decline in condition and area
Northwest Australia	SST+; historic SST+ exposure	Stable

The results of the vulnerability assessment indicate that seagrasses in the Gulf of Carpentaria and Indonesia/Arafura sub-regions are most vulnerable to future climate change. Particularly, increasing SST, rainfall changes that will drive more land-based sediment and nutrient runoff to coastal areas, and sea-level rise. This vulnerability is driven by low seagrass species diversity and hotspot increases in SST in the Gulf of Carpentaria, and low connectivity and other non-climate pressures on seagrasses in Indonesia/Arafura. Timor-Leste is also vulnerable to climate change, with increasing SST, sea-level rise and limited formal management the main drivers of this vulnerability. In western PNG, vulnerability is driven by low seagrass species diversity and lack of management, and the influence of rainfall may be slightly underestimated as this sub-region has higher baseline rainfall and more intense rainfall events may increase impacts from land-based runoff. Ultimately, these climate-driven changes are expected to impact the condition and area of seagrass meadows in these sub-regions, and adaptations should focus on addressing the source of vulnerability, particularly focussed in areas important for fisheries or listed species (e.g., dugong and green turtles). Specifically:

- Reduce land-based inputs to nearshore seagrass habitats through integrated catchment management of deforestation, agriculture and coastal development in Indonesia/Arafura and western PNG.
- Establish local MPAs to protect seagrass habitats in western PNG.
- Implement management of non-climate pressures on seagrass meadows (e.g., intensive seaweed farming, overfishing, coastal mining and sand extraction) in Indonesia/Arafura.

6.3 Coral Reefs

Coral reefs are an important habitat in the ATS region, with shallow fringing reefs occurring mainly around the islands of Indonesia and Timor-Leste, and deep reefs (below the photic zone > 40 m depth) found on seamounts and abyssal hills. Coral reefs support hundreds of fish and invertebrate species, as well as important fisheries for demersal fish (e.g., coral trout and emperors), near-shore pelagic fish (e.g., Spanish mackerel), and invertebrates targeted for livelihoods and food (e.g., tropical rock lobster and pearl shell). Maintaining the structural complexity of reef frameworks is vitally important to the continuation of these fisheries.

Coral Reefs of Timor-Leste

Coral reefs (including coastal fringing and long patch reefs) cover 146 km^2 of the Timor-Leste's nearshore area. In Timor-Leste, most of the reefs are on the north coast, which is characterized by karst geology and uplifted ancient coral reefs, which results in reefs with a narrow reef flat (20-100 m) and a steep drop-off (40-60 m depth). In 2012, a marine rapid assessment of coral reefs at 22 sites, including 14 sites within Nino Konis Santana National Park, 4 sites on the northern mainland coast and 4 sites on Pulau Atauro Island found extremely high hard coral cover at Atauro Island compared to the mainland. This was postulated to be due to high land erosion and sedimentation in the north and the absence of major rivers and therefore sedimentation on Atauro Island.

Coral Reefs of Indonesia

The Arafura Sea sub-region includes coral reefs in the Coral Triangle and comprises some of the world's most diverse tropical marine ecosystems (Burke et al. 2012, Veron et al. 2015). These reefs provide critical habitat for many species, including rare, threatened and protected species (e.g., marine turtles, cetaceans, manta rays, sharks; Mangubhai et al. 2012), and important food and livelihoods for coastal communities (Mangubhai et al. 2012, ADB 2014). Unfortunately, coral reefs in this sub-region and the ecosystem services they provide are threatened by a range of local anthropogenic impacts (including habitat loss, overharvesting, destructive fishing, coastal development, mass tourism, mineral, oil and gas exploration and mining) and global changes in climate and ocean chemistry (Burke et al. 2012, Mangubhai et al. 2012, ADB 2014).

Coral Reefs of Western PNG

The western PNG sub-region has poorly developed coral reefs along the southern coast due to high river flow and resulting turbidity (ATSEA 2012). Limited data exist on their condition, diversity or trends.

Coral Reefs of Northwest Australia & Gulf of Carpentaria

The northwest Australian sub-region has coastal coral reefs mainly on the edge of the continental margin of the northern Australian Shelf, the Sahul Banks (Heyward et al. 1997, Wells and Allen 2005) between latitudes 20° and 24 °S, and a concentration of offshore reefs centred around 17 °S (Rowley Shoals). The shelf edge is characterised by an almost continuous chain of submerged carbonate banks that rise from water depths of 150 m to 300 m, resulting in differences between the reef fauna of these reefs and reefs present on continental coasts (Wells and Allen 2005). North of Ashmore Reef (Sahul Shelf), the reefs are made mostly of the coralline algae *Halimeda,* as well as foraminifer and mollusc skeletons (ATSEA 2012). Coral development in the Gulf of Carpentaria is limited (Weipa, Wellesley Islands, Groote Eylandt, and Cape Wilberforce). However, a 2003 survey documented large table-top reef structures 40-50 m deep in the southern part of the Gulf, including Big Reef that is 100 km^2 in area, which has thriving coral growth. Similar deep-water reefs may occur elsewhere in the Gulf (Harris et al. 2008), including fringing reefs in the Kimberly region that are undocumented (ATSEA 2012).

Vulnerability of Coral Reefs to Climate Change

Coral reefs found in waters less than 40 m are most vulnerable to increasing SST and ocean acidification, due to their exposure to these changes in surface waters and the sensitivity of corals. Corals are particularly sensitivity to thermal stress, with thermal bleaching impacts documented for reefs around the world as a result of extended periods of above average SST (Wilkinson et al. 2008). In Indonesia, bleaching occurred during the 2016 summer in 21 of 22 reef monitoring sites covering all the major islands (Kimura et al. 2018). The projected increase in SST in the ATS region will result in further bleaching events that can undermine the structure and function of coral reef habitats.

An assessment of when thermal bleaching is expected to become an annual event on reefs in Indonesia under a high emissions scenario predicts that by 2044 (on average), Indonesian reefs will be exposed to SST above the threshold for coral bleaching annually (Figure 15). Notably, the range spans 65 years with less than 1% of reef area predicted to experience annual severe bleaching annually by 2030, and 10% of reef area after 2055 (UNEP 2017).

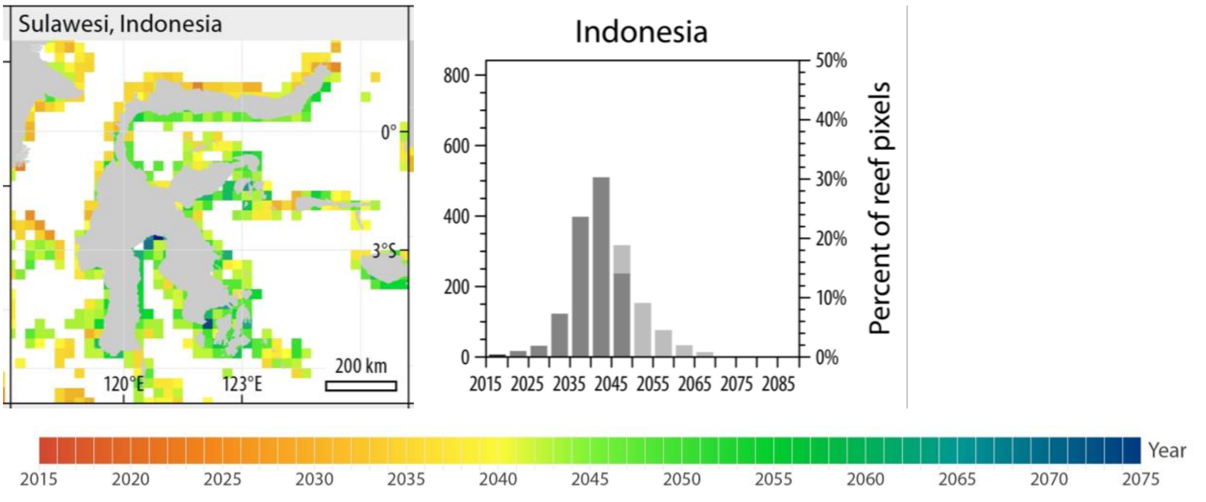

Figure 15. *Map showing year of onset of annual severe coral bleaching in Indonesia (left) and range of years for the onset of annual severe bleaching (right) (UNEP 2020).*

In Timor-Leste, thermal bleaching is expected to become an annual event on reefs under a high emissions scenario by 2040 (on average). Notably, the range spans only 20 years with some reefs experiencing annual severe bleaching as early as 2030 and others in 2050 (UNEP 2017).

Ocean acidification is expected to increasingly slow the rate of reef accretion and enhance erosion over the coming decades (Silverman et al. 2009). Reductions in calcification rates at lower ocean pH suggests that corals, and the reefs they build, are highly vulnerable to ocean acidification, and that increases in atmospheric CO_2 above 450 ppm are likely to result in net erosion of coral reefs throughout the tropics (Bell et al. 2013, Johnson et al. 2020). Studies in shallow CO_2 seeps in PNG (Fabricius et al. 2011) have observed reductions in coral diversity, recruitment and abundance of framework building corals, and shifts in competitive interactions between taxa as pH declines from 8.1 to 7.8 (the change expected if atmospheric CO_2 concentrations increase from 390 to 750 ppm by

2100). However, coral cover remained constant between pH 8.1 and ~7.8, as massive Porites corals dominated, despite low rates of calcification, and reef development ceased below pH 7.7.

Coral reefs in ATS are also expected to be moderately vulnerable to increases in storm and cyclone intensity, and changes in rainfall and terrestrial inputs from more intense floods from coastal rivers. An assessment of the implications of sea-level rise for coral reefs using historic reef records found that reef development was inhibited on the reef crest (+3 m) with a 2–3 m sea-level rise during the last interglacial period (Blanchon et al. 2009), which is a threshold that may be exceeded if the Antarctic and Greenland ice sheets melt rapidly.

The location of coral reefs in the ATS region will have a strong influence on their exposure and therefore vulnerability to changes in ocean temperature, circulation, rainfall and productivity; as some will receive fewer nutrients and recruits, whereas others will receive more. Isolated reefs with limited connectivity to receive larvae are more likely to be vulnerable to climate change. Their ecological characteristics will also influence how they respond to climate drivers and therefore how resilient they are to future change. For example, a resilience assessment conducted on reefs around the Forgotten Islands of Indonesia (north of the ATSEA-2 project site), found that factors such as coral diversity, macroalgae cover, bleaching resistance, recruitment, temperature variability, herbivore biomass, fishing access, and nutrient and sediment exposure influence resilience (Figure 16; Maynard et al. 2017).

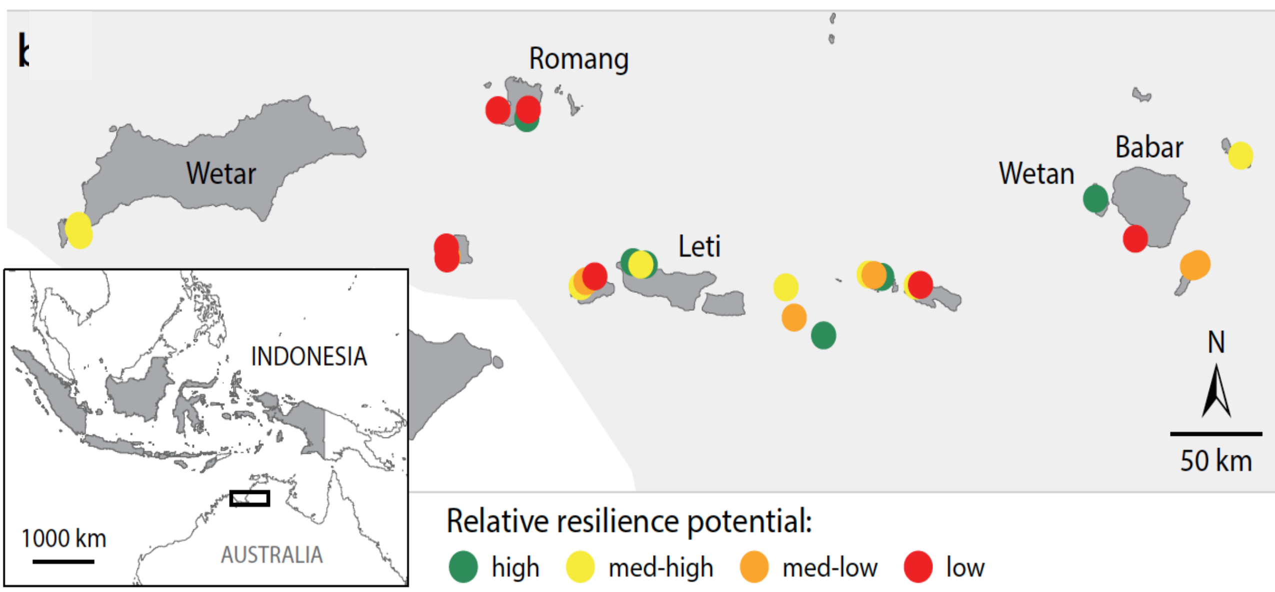

Figure 16. *Map outputs showing relative resilience for fringing reef sites in the Forgotten Islands, Indonesia using data compiled from long-term monitoring (Maynard et al. 2017).*

The location of coral reefs will determine their exposure to projected future climate change; particularly increasing sea surface temperature (SST), changing rainfall and terrestrial runoff, ocean acidification, more intense storms and cyclones, and changing currents. While the entire ATS region is projected to experience increases in SST, ocean acidification, more intense storms and changing rainfall, there is spatial variation in the magnitude of change under all emissions scenarios. Therefore, the vulnerability of reefs varies across the sub-regions due to different drivers with hotspots of vulnerability around Manatuto and Barique Municipality, Timor-Leste and Tual in the Arafura Sea (Figure 17) and ultimately most reefs are expected to decline in condition and area (Table 6).

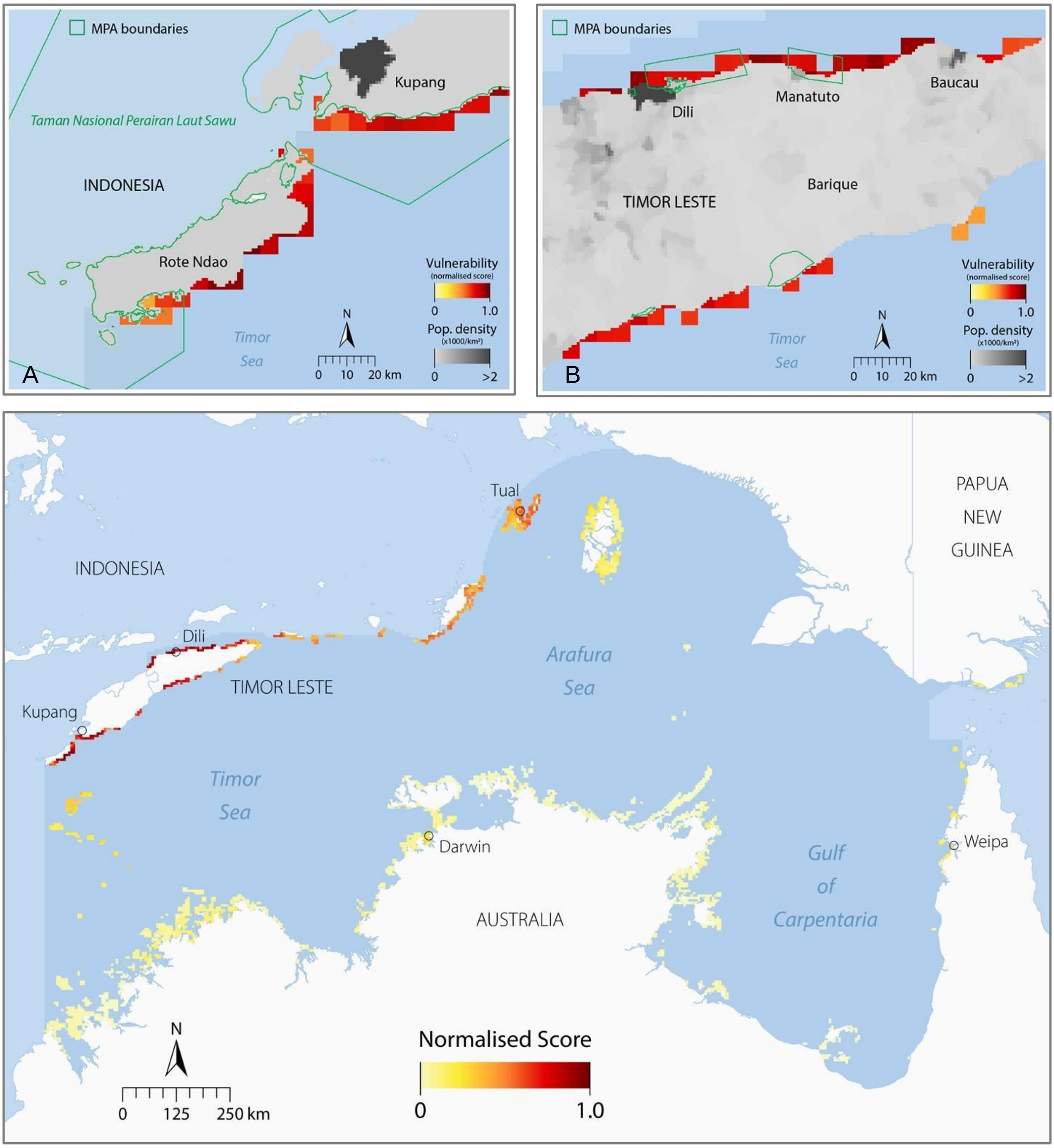

Figure 17. *Regional relative vulnerability of shallow coral reefs (< 40m) in the ATS region, with vulnerability calculated as V=PI x (1-AC), where PI=potential impacts (a function of exposure and sensitivity), AC=adaptive capacity, and 1-AC is scaled from 0.5 to 1. Colour represents normalised scores from 0 (white; not vulnerable) to 1.0 (dark red; very high vulnerability). Insert A=detailed vulnerability results for coral reefs around Rote Ndao, Indonesia; Insert B=detailed vulnerability results for coral reefs around Barique Municipality, Timor-Leste, showing current MPA boundaries.*

Table 6. *Relative vulnerability of shallow coral reefs in the ATS region and drivers of vulnerability*

Sub-region	Drivers of vulnerability	Expected impact
Timor-Leste	Projected SST+; poor current condition; limited formal management	Declining condition, diversity and area
Indonesia/Arafura	Poor current condition; non-climate pressures, particularly pollution	Decline in condition, diversity and area
Western PNG	Low diversity; lack of management	Decline in condition and area
Northwest Australia	Projected SST+	Stable to declining

The results of the vulnerability assessment indicate that coral reefs in the Timor-Leste and Indonesia/Arafura sub-regions are most vulnerable to future climate change, with western PNG also vulnerable to climate change. The range of potential impacts resulting from future climate change means that shallow coral reef habitats are predicted to change, with coral cover expected to decline and macroalgae (fleshy and turf algae) projected to become more dominant (Hoegh-Guldberg et al. 2011, Johnson et al. 2020). Similarly, coral diversity is projected to decline with ocean acidification and increasing SST (Fabricius et al. 2011), resulting in simpler reef habitats. This will have implications for reef-dependent species, such as finfish and some invertebrates, as long-term studies have detected declines in reef fishery catches consistent with lagged impacts of habitat disturbance (Pistorius and Taylor 2009).

While local and regional management cannot influence the exposure of coral reefs to projected climate changes, adaptations can build resilience and minimise impacts. Therefore, adaptations that focus on addressing the source of vulnerability are most likely to be effective. Specifically:

- Establish local MPAs to protect coral reefs habitats and promote recovery and improved condition.
- Implement management of non-climate pressures on coral reefs (e.g., overfishing, destructive fishing, poor water quality and land-based pollution).
- Reduce land-based inputs to nearshore reefs through integrated catchment management of deforestation, agriculture and coastal development.
- Consider reef restoration activities in locations that have been severely degraded and are not showing signs of recovery.

The implications of climate change for *deep reefs* are not well understood and are expected to be driven by changes to ocean chemistry (acidification), stratification that will influence temperatures and oxygen levels in deeper waters and changing ocean circulation. Similar to shallow coral reefs, the current condition and diversity of deep reefs and other non-climate pressures will be important determinants of climate change vulnerability.

6.4 Pelagic Habitats

The projected changes in ocean circulation are expected to alter the timing, location, and extent of the upwelling processes on which most oceanic primary productivity depends. Changes in the vertical structure of the water masses and in the depth and strength of the thermocline can also impact the availability of nutrients. The production of phytoplankton at the base of oceanic food webs is primarily constrained by the availability of nutrients (e.g., nitrogen), and/or micro-nutrients (e.g., iron). In turn, production of organisms at higher trophic levels in the food web (e.g., zooplankton, micronekton, mid-level and top predators) are constrained by variations in phytoplankton production, size-structure and composition (Woodworth-Jefcoats et al. 2013), and directly by environmental factors such as temperature and ocean acidification.

A range of studies point to reduced phytoplankton production as the ocean warms in relation to nutrient supply, with subsequent decreases in zooplankton. At the global level, a 2–20% decrease in mean primary productivity is projected by 2100 under a high emissions scenario, including in the tropics (Henson et al. 2013, Steinacher et al. 2010).

A range of climate change implications have been identified for the ATS region, including, declines in coral reef habitats and associated coastal fisheries productivity, impacts of more intense storms on shallow coastal habitats, compromised growth of corals and species with calcareous shells, and loss of seagrass and mangrove habitats.

The implications of the projected changes in ocean climate for marine capture fisheries have been modelled using an ecosystem approach that predicts declines in maximum catch potential in the ATS region under RCP8.5 of 25-50% by 2050 and 50-75% by 2095 (Cheung et al. 2018). This considers all marine capture fisheries collectively and doesn't allow for species-specific characteristics or local interventions. However, it points to a concerning future for habitats and species in the ATS region, and the need for downscaled vulnerability assessments, such as this one, to better understand which habitats and species are most vulnerable, and the source of this vulnerability as targets for management action.

CHAPTER 7. RESULTS: VULNERABILITY OF SPECIES

7.1 Species Selection

A total of 23 species/species groups were identified for Timor-Leste, 26 for the Indonesia/Arafura sub-region, 7 for the western PNG sub-region, 18 species for the Gulf of Carpentaria sub-region 19 species for the northwest Australia sub-region (Tables 7–11). Individual species were included for assessment, however in some instances, groupings of species were included based on expert feedback. Given the overlap in species across sub-regions these lists represented a total of 51 species/species groups for the entire ATSEA region. The identification of species was not intended to provide definitive species list for each sub-region, rather it was intended to be representative of locally important fishery and conservation species, and provide a range of climate change vulnerability assessment results that guide climate relevant action for these species.

Table 7. *Species selected for the vulnerability assessment for Timor-Leste based on expert knowledge.*

Family name	Common name	Scientific name
Scombridae	Short-bodied mackerel	*Rastrelliger brachysoma*
Clupeidae	Spotted sardinella	*Amblygaster sirm*
Caesionidae	Fusiliers	*Pterocaesio tile/Caesio teres/C. luris/Paracaesio xanthura*
Lutjanidae	Ruby snapper/Crimson snapper/Rusty jobfish	*Etelis carbunculus/Pristipomoides filamentosus/Aphareus rutilans*
Mobulidae	Reef Manta ray	*Mobula alfredi*
Scombridae	Frigate tuna	*Auxis thazard*
Scombridae	Narrow-barred Spanish mackerel	*Scomberomorus commerson*
Dugongidae	Dugong	*Dugong dugon*
Cheloniidae	Green turtle	*Chelonia mydas*
Carcharhinidae	Whitetip reef shark	*Triaenodon obesus*
Carangidae	Bluefin trevally	*Caranx melampygus*
Lutjanidae	Midnight snapper/Black & white snapper	*Macolor macularis/M. niger*
Serranidae	Flowery cod	*Epinephelus fuscoguttatus*
Siganidae	Forktail rabbitfish/Orange-spotted spinefoot	*Siganus argenteus/S. guttatus*
Serranidae	Black-tipped rockcod	*Epinephelus fasciatus*
Scombridae	Yellowfin tuna	*Thunnus albacares*
Order Octopoda	Octopus	*Octopus*
Lethrinidae	Ornate emperor	*Lethrinus ornatus*
Lutjanidae	Yellow lined snapper	*Lutjanus rufolineatus*
Lutjanidae	Mangrove red snapper	*Lutjanus argentimaculatus*
Acanthuridae	Striated surgeonfish	*Ctenochaetus striatus*
Menidae	Moonfish	*Mene maculata*
Lutjanidae	Blubberlip snapper/Maori snapper	*Lutjanus rivulatus*

Table 8. *Species selected for the vulnerability assessment for Indonesia/Arafura based on expert knowledge.*

Family name	Common name	Scientific name
Holothuriidae	Black teatfish	*Holothuria whitmaei*
Rhinidae	Wedgefish	*Rhynchobatus australiae*
Lutjanidae	Red emperor	*Lutjanus sebae*
Lutjanidae	Mangrove red snapper	*Lutjanus argentimaculatus*
Cheloniidae	Hawksbill turtle	*Eretmochelys imbricata*
Serranidae	Coral trout - passionfruit	*Plectropomus areolatus*
Lutjanidae	Ruby snapper	*Etelis carbunculus*
Serranidae	Yellowspotted rockcod	*Epinephelus areolatus*
Palinuridae	Scalloped spiny lobster	*Panulirus homarus*
Cheloniidae	Green turtle	*Chelonia mydas*
Lutjanidae	Saddletail snapper	*Lutjanus malabaricus*
Lutjanidae	Crimson snapper	*Lutjanus erythropterus*
Penaeidae	Green (Grooved) tiger prawn	*Penaeus semisulcatus*
Serranidae	Coral trout - common	*Plectropomus leopardus*
Carcharhinidae	Whitetip reef shark	*Triaenodon obesus*
Carcharhinidae	Common blacktip shark	*Carcharhinus limbatus*
Tegulidae	Trochus	*Trochus niloticus*
Penaeidae	White banana prawn	*Fenneropenaeus merguiensis*
Haemulidae	Painted sweetlip	*Diagramma labiosum*
Lethrinidae	Blue-lined emperor	*Lethrinus laticaudis*
Latidae	Barramundi	*Lates calcarifer*
Carangidae	Mackerel scads	*Decapterus spp.*
Carcharhinidae	Silky shark	*Carcharhinus falciformis*
Dugongidae	Dugong	*Dugong dugon*
Portunidae	Mud crab	*Scylla serrata*
Loliginidae	Indian Ocean squid	*Uroteuthis duvaucelii*

Table 9. *Species selected for the vulnerability assessment for western PNG based on literature and expert knowledge.*

Family name	Common name	Scientific name
Cheloniidae	Green turtle	*Chelonia mydas*
Latidae	Barramundi	*Lates calcarifer*
Sciaenidae	Black jewfish	*Protonibea diacanthus*
Dugongidae	Dugong	*Dugong dugon*
Portunidae	Mud crab	*Scylla serrata*
Carcharhinidae	Whitetip reef shark	*Triaenodon obesus*
Holothuriidae	Black teatfish	*Holothuria whitmaei*

Table 10. *Species selected for the vulnerability assessment for the Gulf of Carpentaria based on previous research and expert elicitation.*

Family name	Common name	Scientific name
Latidae	Barramundi	*Lates calcarifer*
Penaeidae	White banana prawn	*Fenneropenaeus merguiensis*
Penaeidae	Brown tiger prawn	*Penaeus esculentus*
Penaeidae	Green (Grooved) tiger prawn	*Penaeus semisulcatus*
Portunidae	Mud crab	*Scylla serrata*
Scombridae	Grey mackerel	*Scomberomorus semifasciatus*
Polynemidae	King threadfin	*Polydactylus macrochir*
Polynemidae	Blue threadfin	*Eleutheronema tetradactylum*
Dugongidae	Dugong	*Dugong dugon*
Cheloniidae	Green turtle	*Chelonia mydas*
Carcharhinidae	Blacktip sharks	*Carcharhinus limbatus/C. tilstoni*
Scombridae	Narrow-barred Spanish mackerel	*Scomberomorus commerson*
Lutjanidae	Mangrove red snapper	*Lutjanus argentimaculatus*
Lutjanidae	Saddletail snapper	*Lutjanus malabaricus*
Lutjanidae	Crimson snapper	*Lutjanus erythropterus*
Lutjanidae	Red emperor	*Lutjanus sebae*
Lutjanidae	Golden snapper	*Lutjanus johnii*
Sphyrnidae	Scalloped hammerhead	*Spyhrna lewini*

Table 11. *Species selected for the vulnerability assessment for NW Australia based on previous research and expert elicitation.*

Family name	Common name	Scientific name
Latidae	Barramundi	*Lates calcarifer*
Penaeidae	White banana prawn	*Fenneropenaeus merguiensis*
Penaeidae	Brown tiger prawn	*Penaeus esculentus*
Penaeidae	Green (Grooved) tiger prawn	*Penaeus semisulcatus*
Portunidae	Mud crab	*Scylla serrata*
Scombridae	Grey mackerel	*Scomberomorus semifasciatus*
Polynemidae	King threadfin	*Polydactylus macrochir*
Dugongidae	Dugong	*Dugong dugon*
Cheloniidae	Green turtle	*Chelonia mydas*
Carcharhinidae	Blacktip sharks	*Carcharhinus limbatus/C. tilstoni*
Scombridae	Narrow-barred Spanish mackerel	*Scomberomorus commerson*
Lutjanidae	Mangrove red snapper	*Lutjanus argentimaculatus*
Lutjanidae	Saddletail snapper	*Lutjanus malabaricus*
Lutjanidae	Crimson snapper	*Lutjanus erythropterus*
Lutjanidae	Red emperor	*Lutjanus sebae*
Lutjanidae	Golden snapper	*Lutjanus johnii*
Sphyrnidae	Scalloped hammerhead	*Spyhrna lewini*
Sciaenidae	Black jewfish	*Protonibea diacanthus*
Lutjanidae	Goldband snapper	*Pristipomoides multidens*

7.2 Indonesia/Arafura Sub-region

There were 26 species included in the vulnerability assessment for the Indonesia/Arafura sub-region. The most vulnerable species was black teatfish (*Holothuria whitmaei*). Other species with high relative vulnerability were barramundi, green and hawksbill turtles, mangrove red snapper (mangrove jack), wedgefish and mud crab (Figure 18). The least vulnerable species were mackerel scads, Indian Ocean squid, several shark species and reef and/or shoal finfish species.

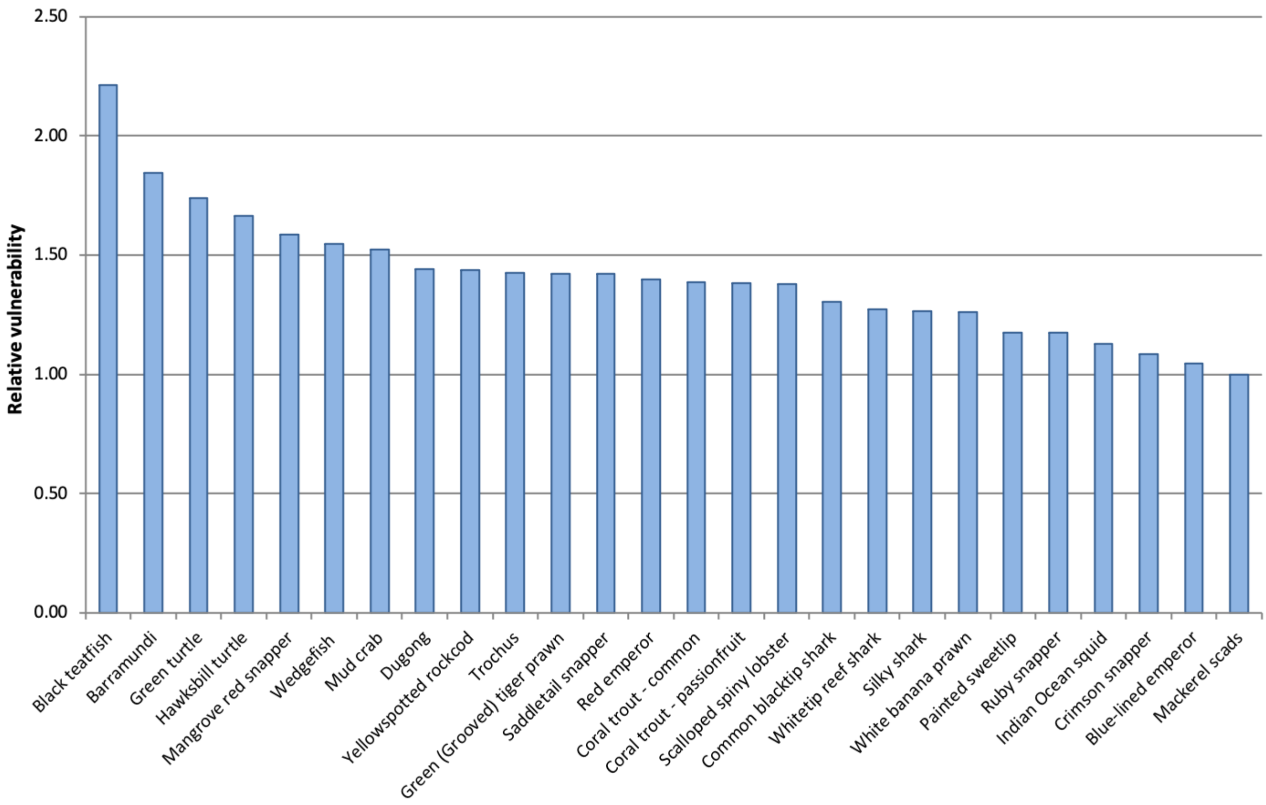

Figure 18. *Relative vulnerability of key species from the Indonesia/Arafura sub-region.*

A key driver of exposure of Indonesia/Arafura species was that many species are shallow water or spend a part of their life history in shallow water, particularly estuarine habitats. For example, the species that had the highest exposure were mud crab, white banana prawn and barramundi). Another main driver was that a large number of species are dependent on key habitats for at least some of their life cycle. These factors make these species more highly exposed to projected increases in SST, rainfall and changes to habitat condition or area.

A key driver of sensitivity overall was the short larval duration of many species or being live young bearers. Accordingly, the species that had the highest sensitivity scores were green and hawksbill turtles, dugong, mud crab and several elasmobranch species. The key drivers of sensitivity for these species are that they tended to have relatively low fecundity and a high average age at maturity. That is, they tended to be species with a lower reproductive potential for replenishing their populations after impacts. Further, gender of turtle hatchlings from eggs laid in beach sand is strongly linked to air temperature which further increases their sensitivity. Mud crab was an exception being a relatively productive species, however, has been shown to be highly sensitive to changes in SST and in particular rainfall and river flow with effects on survival, growth and recruitment.

No species were assessed as likely to benefit overall from predicted climate change. The summary of potential impacts and factors that may result in an overall benefit for these species are given in Table 12.

The overall drivers that influenced low adaptive capacity were: many species are currently assessed as, or are likely to be, overfished; the cumulative impact of other anthropogenic pressures on the species; a high dependence as food for home consumption; and a general lack of awareness of climate change among fishers. Although the first two of these are environmental drivers, both are driven by human factors and they represented the lowest adaptive capacity scores across all species. The species that had the lowest adaptive capacity were black teatfish and two of the deep-water snapper fishery species, red emperor and saddletail snapper. Mangrove red snapper also had a very low adaptive capacity and as adults can be considered as a deep-water snapper. The drivers of low adaptive capacity of black teatfish were a combination of being overfished, having low population replenishment potential, low availability of their preferred coral reef habitat in the sub-region coupled with the projected climate-related impacts on coral reefs, a winter spawning season with SST projected to increase, and their low mobility. The drivers of low adaptive capacity for the deep-water snapper species were being overfished or likely to be approaching this, having a low to moderate replenishment potential, a preference to live on coral reef habitats, and exposure to multiple other anthropogenic pressures. The species with the highest adaptive capacity were those classified as sustainably fished (with the exception of Indian Ocean squid), with moderate to high replenishment potential and generally a high availability of their preferred habitat outside the sub-region (e.g., inter-reefal habitat and pelagic habitat).

Under the adaptive capacity component, scores for '*Governance*' from expert elicitation were relatively high suggesting that fisheries management in Indonesia tends to be flexible and adaptive, and therefore generally effective. Despite this, the literature reports a significant number of overfished stocks, which is also reflected in the assessment scoring, and a recent review of fisheries in Indonesia stated that: "*…Indonesia's existing fisheries management regime has so far shown only limited success in halting destructive fishing practices (including trawling) and limiting fishing effort…*" (California Environmental Associates 2018). Although the assessment framework is intended to provide relative measures, it is likely that the scoring for governance does not accurately represent the reality in Indonesia.

Priority Species for Management Focus

For the Indonesia/Arafura sub-region, expert elicitation for the four criteria that determined local importance are given in Appendix B. The prioritisation of species is shown in Figure 19 which shows vulnerability against the local importance. Prioritisation of species uses Euclidean distance calculations based on the two axes, with distances colour coded by their 20 percentile groupings, with those in the lowest percentile grouping being the highest priority (Figure 19). This highlighted five species as highest priority for the Indonesia/Arafura sub-region: black teatfish, wedgefish, hawksbill turtle, mangrove red snapper (mangrove jack) and red emperor (Figure 19). Although the prioritisation of species identifies a ranking for each species, the process is intended as a guide for local stakeholders and uses a logical framework with an easy to interpret visualisation of these rankings. This therefore allows flexibility for local stakeholders to customise their priority species for action in an informed approach. For example, barramundi was given a moderate ranking despite having a relatively high vulnerability overall. This was because of their relatively low score in terms of 'local importance'. The results allow users to readily identify this species as a possible species for action depending on local priorities, and the assessment framework provides the basis for determining why they are vulnerable thereby informing potential responses.

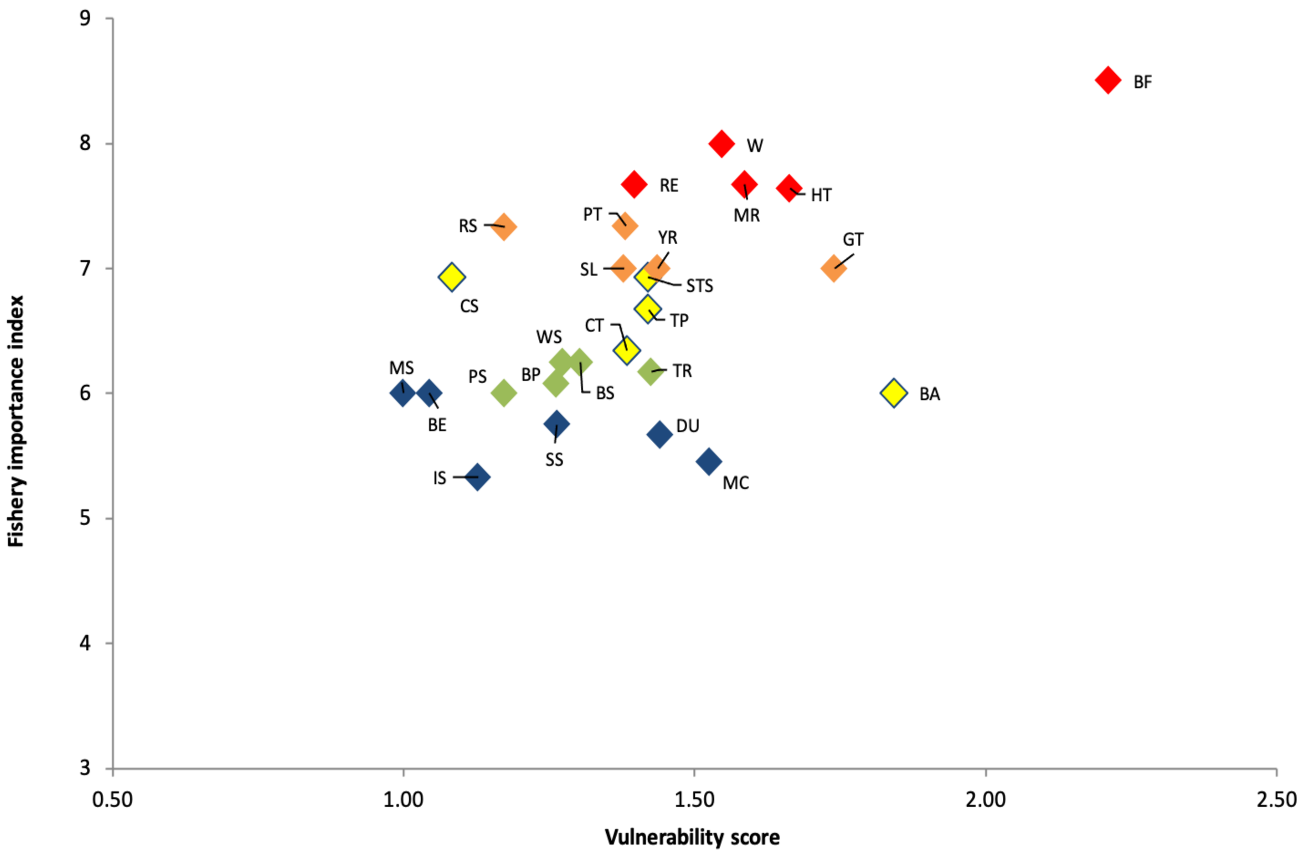

Figure 19. *Prioritisation plot showing the 26 species assessed for the Indonesia/Arafura sub-region and their relative vulnerability against an index of local importance to prioritise species for further research and/or action. To highlight priority species, we calculated Euclidean distances for each data point from the uppermost top right corner of the two axes, and colour coded them based on their percentile group: < 20th percentile - ◆; 20th percentile - ◆; 40th percentile - ◇; 60th percentile - ◆; 80th percentile -◆. Species are indicated by letter codes as: BF – black teatfish, GT – green turtle, HT – hawksbill turtle, DU – dugong, TR – trochus, TP – green (grooved) tiger prawn, SL – scalloped spiny lobster, CT – common coral trout, MC – mud crab, MS –mackerel scads, BA – barramundi, MR – mangrove red snapper, STS – saddletail snapper, RE – red emperor, W – wedgefish, YR – yellowspotted rockcod, BS – common blacktip shark, WS – whitetip reef shark, SS – silky shark, CS – crimson snapper, RS – ruby snapper, BP – white banana prawn, PS – painted sweetlip, IS – Indian Ocean squid, BE – blue-lined emperor and PT – passionfruit coral trout.*

Projected Impacts on Priority Species

This section provides an overview of the key observations and likely impacts for the highest priority and most vulnerable species, based on the vulnerability assessment and published literature. There are some general observations also provided that apply to most or all of the species assessed in this sub-region.

No species were assessed as benefiting from projected future climate changes. Several species may experience conditions that will likely benefit their populations (e.g., barramundi, mangrove red snapper and mud crab) however current local factors were considered significant enough to mitigate these benefits. The primary factors that influenced this was that these species were likely to be overfished currently and are also exposed to multiple non-climate stressors, such as pollution and coastal development impacts on habitats.

The high level of non-climate pressures was reflected in the low adaptive capacity scores provided by expert elicitation and is also well-documented in the literature as a serious issue locally (and globally). These pressures are likely to negatively impact all marine and estuarine species in this sub-region and include:

- *Illegal, unreported and unregulated (IUU) fishing* – illegal and unreported catches in Indonesia have long been documented as a "massive" issue (Buchary et al. 2008, California Environmental Associates 2018) and in reference to the introduction of new laws and policies over time it has been stated that there is *"...little evidence of the implementation of policies that could ensure the sustainability of seafood and fishing livelihoods. Today, despite new fishery laws, ... most Indonesian marine ecosystems exhibit such severe symptoms of over-fishing that the prognosis is very poor for seafood security"* (Buchary et al. 2008).
- *Excessive coastal development* – the human population density throughout the region, and particularly in coastal areas that support 70% of the population, has significant implications for the effect of projected sea level rise and increased rainfall. For many species that rely on estuarine habitats for critical parts of their life cycle, and in particular mangroves, the above changes can result in positive effects by connecting key habitats (e.g., floodplains) and increasing potential habitat area (Waycott et al. 2011). However, where coastal development is widespread, the effect is likely to be the opposite with less available area inland for migration of habitats due to infrastructure acting as barriers. Further, it is likely to lead to flooding of human settlements.
- *Pollution* – water quality is key to healthy and productive ecosystems and is affected in this sub-region by multiple sources including plastics, agricultural runoff, discharge of nutrients, pesticides, and untreated sewage. Indonesia is reported to be the world's second biggest marine polluter, discarding 3.22 million tons of waste annually, accounting for 10% of the world's marine pollution (Tibbetts 2015).

Further details on the assessment outcomes for the highest priority species are provided below. The potential impacts for these and other key species are summarised further in Table 12.

Black teatfish, *Holothuria whitmaei*

Black teatfish was assessed as the most vulnerable species to climate change due to high exposure to climate change and, although only moderately sensitive, the species has the lowest adaptive capacity. This was due to multiple factors including: current overfished status, low reproductive potential (Uthicke et al. 2004), winter spawning preference (Shiell and Uthicke 2006) with increased sea temperatures likely to restrict or prevent spawning as they are close to the northern edge of their range, and very low adult mobility, which limits their capacity to relocate if environmental conditions become unfavourable. Although ocean acidification could be a significant factor affecting spicule development in the longer term, especially in juvenile sea cucumbers, this remains a significant knowledge gap (Byrne 2011).

Wedgefish, *Rhynchobatus australiae*

Although assessed as having a low exposure to climate change, their low productivity means they have relatively high sensitivity and low adaptive capacity, resulting in a high relative vulnerability.

Further, other key indicators include their current overfished status due partly to their high value for fins, and the high incidence of IUU fishing in the region (Buchary et al. 2008, California Environmental Associates 2018, Kyne et al. 2019). Further, wedgefish were recently assessed as the *"most imperilled marine fish families globally, with all but one of the 16 species facing an extremely high risk of extinction"* (Kyne et al. 2019). Their conservation status also contributed to their high local importance score giving them an overall high priority status. The potential impacts of climate change on wedgefish are uncertain, however their current status and existing pressures, likely to be exacerbated by future climate change, highlight an urgent need for management action now.

Hawksbill and Green Turtles

Although turtles received a relatively low 'local importance' score, they were assessed as having a high relative vulnerability to future climate change mainly due to their very high sensitivity. This sensitivity has already been observed through direct effects on turtles as well as indirect effects on nesting success (Fuentes et al. 2010). There is high confidence in the projection of future impacts on marine turtles. These impacts include stranding due to storms (Meager and Limpus 2012), seawater inundation of nesting beaches (Pike and Stiner 2007), the influence of temperature on hatchling gender (Hawkes et al. 2009), and the potential loss of important food resources associated with predicted declines in seagrass meadows (Marsh and Kwan 2008).

Mangrove red snapper (mangrove jack), *Lutjanus argentimaculatus*

As a species that relies on estuarine and nearshore shallow waters for their early and pre-adult life history stages, which can be up to 10 years or more, mangrove red snapper will be highly exposed to projected climate change. Despite this, their overall sensitivity to these changes was assessed as moderate. However, with a very low adaptive capacity score, mangrove red snapper was assessed as having a high relative vulnerability. The key factors which influenced their low adaptive capacity were their currently overfished status, low biological replenishment potential, high level of non-climate (non-fishing) pressures, and the relatively high local dependence on them as household food.

The key potential impacts of climate change on mangrove red snapper are summarised in Table 12. Although these changes are most likely to have a positive impact on mangrove red snappers, these are likely to be mitigated and probably negated by local factors, including the range of non-climate pressures (e.g., pollution) and widespread coastal development. This species is a relatively resilient species to different environmental conditions, since they occupy many different habitat types across a wide range of latitudes and are reported to have population mixing over very large spatial scales (Ovenden and Street 2003). Therefore, they are more resilient to localised changes. Despite their overall resilience, climate change is not likely to benefit mangrove red snapper populations due to existing local anthropogenic factors, most critically, that local populations are currently overfished which compromises their resilience to future climate-induced impacts.

Red emperor, *Lutjanus sebae*

Although red emperor was assessed as having low exposure and moderate sensitivity, their adaptive capacity was very low relative to the other species in the sub-region resulting in a high-moderate vulnerability ranking. Their low adaptive capacity was primarily due to very low reproductive potential to replenish populations when they are depleted, the high level of non-climate pressures, and a high dependence as a local food source.

Knowledge of physiological tolerance limits and responses to changes in environmental conditions is poorly known for red emperor. Therefore, the potential impacts of climate change are uncertain. However, given their relatively low exposure it is expected that the greatest threats are less likely to be climate-related and more likely to be from fishing activities.

Table 12. *Potential impacts and factors that influence impacts for key species in the Indonesia/Arafura sub-region based on climate change projections for 2070 under the RCP8.5 ('business as usual') climate scenario. These factors were considered in determining if there was likely to be an overall impact or benefit from climate change for any species.*

Species	Key factors that influence likely overall effects of climate change (by 2070)
Mangrove red snapper	● Increased rainfall will likely promote higher recruitment success and growth in early life history stages, as demonstrated for other species with similar life histories and use of estuarine environments, suggesting the potential for higher population abundance (Balston, 2009a,b; Halliday et al. 2011, 2012; Meynecke et al. 2006; Robins et al. 2006; Staunton-Smith et al. 2004). ● Increasing SST may result in higher abundance due to lower winter temperatures which will likely provide favourable over-wintering conditions for juvenile fish thereby enhancing recruitment (Tolan and Fisher, 2009). ● Sea-level rise may increase abundance through increased availability of juvenile habitat in coastal wetlands, however, in the Indonesia/Arafura sub-region this may be limited to small localised areas due to the existence of extensive coastal infrastructure and development which act as local barriers to mangrove replenishment and migration (ref). ● Potential benefits are likely to be moderated by their likely current overexploited status (Konservasi and Nusantara, 2020), a high level of non-fishing pressures (e.g., IUU, pollution) (e.g., Buchary et al., 2008; Tibbetts, 2015) and predicted declines in mangrove condition and area (this report).
Green (Grooved) tiger prawn	● Increased rainfall may increase the catchability of tiger prawns but may also contribute to lower abundance since low salinity waters from flooding has been shown to increase mortality (Xu et al., 1995). ● Predicted negative impacts on seagrass beds is likely to reduce abundance due to decreased juvenile growth and survival (this report; Young and Carpenter, 1977; Coles and Lee Long, 1985; Staples et al. 1985; Coles et al. 1987; Loneragan et al. 1994).
Black teatfish	● Increasing SST may compromise reproductive success since they spawn during winter in low latitudes resulting in range contraction poleward (Shiell and Uthicke, 2006). ● Predicted declines in area and condition of coral reefs is likely to reduce their populations die to reduced habitat (this report). ● Their stock status is unknown however is likely to be overexploited due to experiences elsewhere with sea cucumber fisheries, the local widespread IUU (Buchary et al., 2008; California Environmental Associates, 2018) and their exposure to other non-fishing pressures (e.g., Tibbetts, 2015).
Wedgefish	● Climate-related impacts are highly uncertain, however their current seriously depleted status puts them at heightened risk from any impact.
Trochus	● Are highly exposed to predicted declines in coral reef habitats, their preferred habitat for food and shelter, which will likely result in population declines. ● Low mobility and very short larval duration (Bertram, 1998) collectively limit their avoidance and dispersal capabilities. ● Overall impacts are largely unknown.
Scalloped spiny lobster	● Appear to be sensitive to SST with a relatively narrow preferred range reported. Other similar species (*P. ornatus*) show similar sensitivities and have been shown to move to deeper water during recent SST warming in Torres Strait, Australia (Johnson and Welch, 2016). Accessibility to fishers in the future may decrease if they move deeper. ● Changes in ocean circulation patterns in the future may strongly influence local recruitment due to their long pelagic larval duration (Farhadi et al., 2013).

	● It is likely that they are currently overfished in Indonesia with population impacts already evident (Damora et al., 2019) and as a nearshore species are highly exposed to multiple non-fishing impacts (Tibbetts, 2015).
Yellowspotted rockcod	● Impacts largely unknown. Research on the conspecific *Plectropomus leopardus* suggests changes in ocean pH and SST may alter early growth and survival as well as their predator avoidance behaviour (Munday et al., 2012; Pratchett et al, 2013). ● Predicted declines in coral reef habitats may result in lower abundance (Pratchett et al., 2011).
White banana prawn	● Increased rainfall is likely to increase the catchability of banana prawns as the flows assist pre-adult prawns recruiting to nearshore fishing grounds. ● Banana prawns are highly reliant on mangrove-lined mud banks in estuarine areas for post-larval growth and survival and predicted declines in mangrove condition and area (this report) indicate that decreased banana prawn abundance is likely.
Barramundi	● Increased rainfall will likely promote higher recruitment success and growth in early life history stages suggesting the potential for higher population abundance (Balston, 2009a,b; Halliday et al., 2011, 2012; Meynecke et al., 2006; Robins et al., 2006; Staunton-Smith et al., 2004). ● Sea-level rise may increase abundance through increased availability of post-larvae and juvenile habitat in coastal wetlands, however, in the Indonesia/Arafura sub-region this may be limited to small localised areas due to the existence of extensive coastal infrastructure and development which act as local barriers to mangrove replenishment and migration (ref). ● Potential benefits are likely to be moderated by their likely overexploited status (Pierre, 20134), a high level of non-fishing pressures (e.g., IUU, pollution) (e.g., Buchary et al., 2008; Tibbetts, 2015) and predicted declines in mangrove condition and area (this report).
Green and Hawksbill turtles	● Increasing air temperatures are likely to result in strongly female biased populations due to thermal influence on gender during incubation (Hawkes et al., 2009). ● Sea level rise, more intense storms and extremes in rainfall are likely to result in increased stranding, decrease available nesting sites and disrupt successful nesting through inundation (Meager and Limpus, 2012; Pike and Stiner, 2007). ● Predicted declines in sea grass condition and area (this report) may reduce on turtle growth, survival and condition (Marsh and Kwan, 2008). ● Stock status in Indonesian waters is unknown however Hawksbill turtles are globally listed as 'Critically Endangered', while Green turtles are listed as 'Endangered' with populations of each decreasing (https://www.iucnredlist.org/search?query=turtles&searchType=species).
Passionfruit and Common coral trout	● Projected SST increases for Indonesia/Arafura (above 28 °C) are likely to reduce fertilisation rates, hatching rates, larval feeding and development rates, and ultimately will reduce larval survival (Pratchett et al. 2013). ● Coral trout populations will need to spawn earlier in the season to correspond with SST regimes that are suitable for successful larval survival or there will be much lower population sizes in this sub-region. Adults may also move poleward or to deeper water. ● Ocean acidification may compromise juvenile survival and compromise their predator avoidance behaviour (Munday et al. 2012). ● Predicted declines in coral reef habitat area and condition will also have negative consequences for post-settlement coral trout (this report).

Indonesia/Arafura Sub-region Recommendations

For the Indonesia/Arafura sub-region, there are some significant overarching issues that affect all marine species and their resilience to future shocks from climate change. In particular, these are the high number of stocks that are currently overfished or likely to be approaching this status, and their high exposure to current non-targeted fishing pressures such as IUU (Buchary et al. 2008, California Environmental Associates 2018), pollution and poor water quality (Tibbetts 2015). Effectively this means that many of the impacts projected for marine species due to climate change, are already being experienced by species in the Indonesia/Arafura sub-region.

Therefore, for key local species to be resilient to future climate change and continue to fulfil important ecological roles and support fisheries in the region, the following local actions are strongly recommended:

1. For stocks assessed as at risk from overfishing, management actions that effectively and appropriately control harvest to sustainable levels and allow stocks to rebuild are urgently required. This may require more conservative measures for species with low replenishment potential.
2. The need to effectively mitigate and address the multiple chronic cumulative pressures that further compromise fishery populations, especially IUU fishing and pollution that drives poor water quality.
3. Measures that restore, conserve and protect estuarine and wetland areas used by multiple species during their life cycles need to be implemented (Bell et al. 2011).
4. Identification of alternative species as a preferred local food source to reduce community reliance, thereby increasing resilience to possible future impacts on stocks. These should be species that are currently underutilised and have high replenishment potential.
5. Species of conservation interest require special attention and should be protected where appropriate. However, multiple actions will be required to minimise the potential impacts that climate change will have. These actions include: habitat restoration and/or protection, improvement of local water quality, and measures to mitigate their capture, both targeted and incidental.

7.3 Western PNG Sub-region

There were 7 species included in the vulnerability assessment for the western PNG sub-region. The most vulnerable species were mud crab and dugong. Green turtle, barramundi and black jewfish all had moderate vulnerability while whitetip reef sharks were least vulnerable (Figure 20).

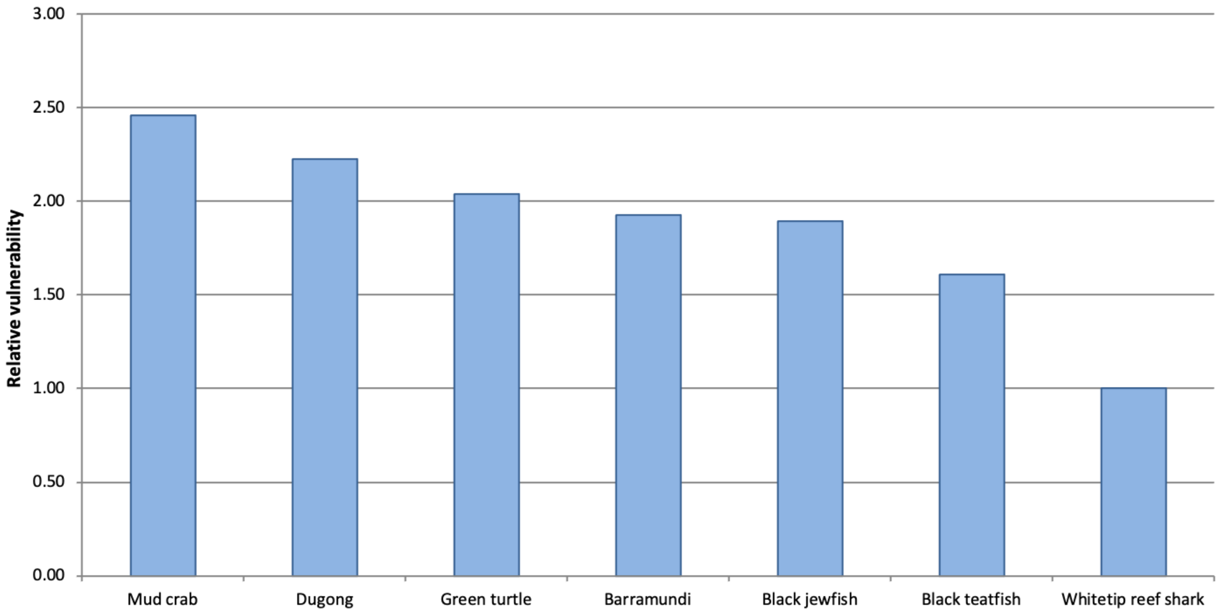

Figure 20. Relative vulnerability scores for key species from the western PNG sub-region.

Priority Species for Management Focus

For the western PNG sub-region, expert elicitation data for the four local importance criteria are given in Appendix B. The prioritisation of species is shown in Figure 21, which shows vulnerability against the local importance. Prioritisation highlighted two species as highest priority for the western PNG sub-region: Green turtle and dugong (Figure 21). However, given the small number of species assessed, other factors need to be considered in determining required actions and species (discussed below).

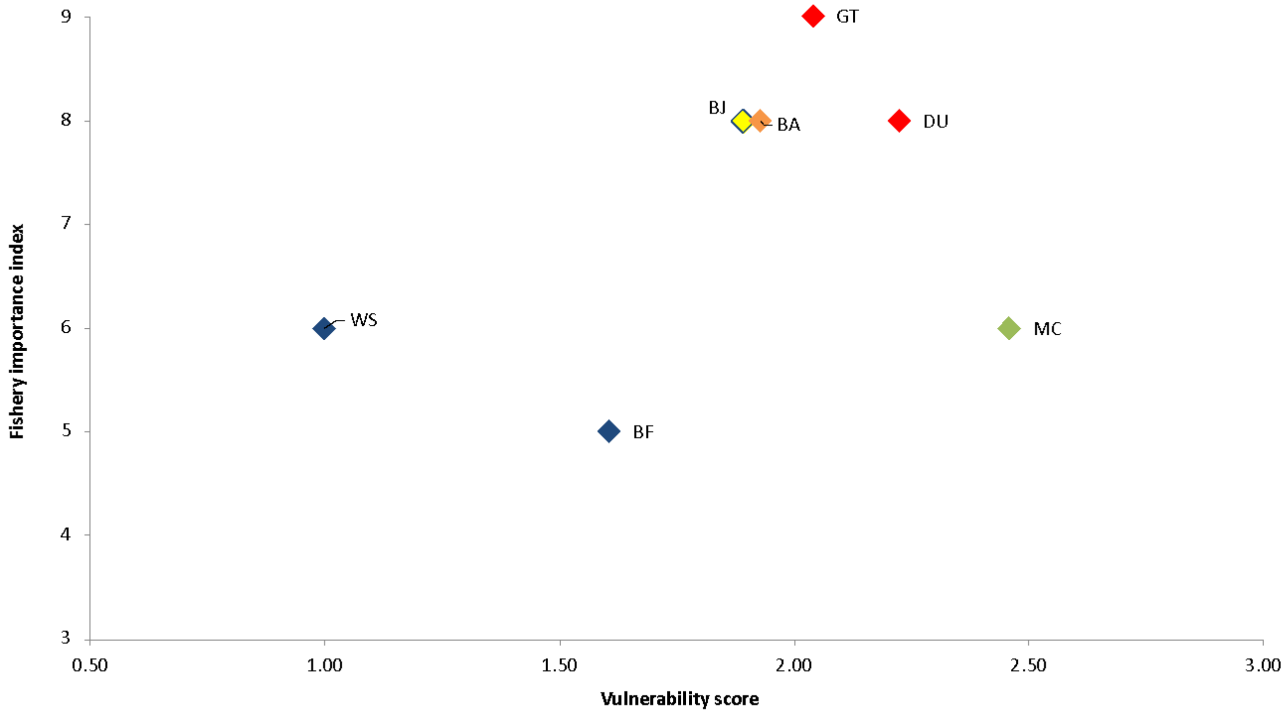

Figure 21. Prioritisation plot showing the 7 species assessed for the western PNG sub-region and their relative vulnerability against an index of local importance to prioritise species for further research and/or action. To highlight priority species, we calculated Euclidean distances for each data point from the uppermost top right corner of the two axes, and colour coded them based on their percentile group: < 20th percentile - red; 20th percentile - orange; 40th percentile - yellow; 60th percentile - green; 80th percentile - blue. Species are indicated by letter codes as: BF – black teatfish, GT – green turtle, DU – dugong, MC – mud crab, BA – barramundi, BJ – black jewfish and WS – whitetip reef shark.

Projected Impacts on Priority Species

No species were assessed as benefiting from projected climate change with potential impacts varied (Table 13). Several species may experience conditions that will likely benefit their populations (e.g., barramundi and mud crab), however current local factors were considered significant enough to mitigate these benefits. The primary factors that influenced this was the current overfished status of species and exposure to multiple non-climate stressors such as poor water quality and it's impacts on species and habitats. In western PNG, coastal water quality is very poor with untreated sewage entering local waterways daily and the chronic influence of the Fly River plume. Further, IUU fishing is widespread in the region (Busilacchi et al. 2014).

The prioritisation process identified the highest priority species as green turtle given their very high local importance as well as their relatively high vulnerability. This vulnerability is due largely to very low reproductive potential but especially their sensitivity. This is because they are highly dependent on seagrass as their primary food source, which is projected to decline by 2070, and rising air temperatures are likely to result in strongly female biased populations due to thermal influence on gender during incubation in nesting beaches (Hawkes et al. 2009).

Overall, the seven species assessed in western PNG generally had high exposure to climate change given their preference for shallow nearshore and/or estuarine waters, which are dominant in the sub-region. Notably, there were three overall indicators that were key drivers of species vulnerability in the region: (i) stock status – four of the seven species were assessed as overfished while the others were 'undefined'; (ii) non-climate pressures on stocks were very high, namely poor water quality and IUU fishing; and (iii) poor governance, which is also linked to the previous indicators. The assessment clearly identified green turtle, barramundi, black jewfish, mud crab and dugong as the priority species for action, and also identified key areas of concern that will inform what actions are appropriate.

Table 13. *Potential impacts and factors that influence impacts for key species in the western PNG sub-region based on climate change projections for 2070 under the RCP8.5 ('business as usual') climate scenario. These factors were considered in determining if there was likely to be an overall impact or benefit from climate change for any species.*

Species	Key factors that influence likely overall effects of climate change (by 2070)
Green turtle	● Increasing air temperatures are likely to result in strongly female biased populations (Hawkes et al. 2009). ● Sea level rise, more intense storms and extremes in rainfall are likely to result in increased stranding, decrease available nesting sites and disrupt successful nesting through inundation (Meager and Limpus 2012; Pike and Stiner 2007). ● Predicted declines in seagrass condition and area (this report) may reduce turtle growth, survival and condition (Marsh and Kwan 2008). ● Animals present in western PNG are part of stocks from a much larger area and they are globally listed as 'Endangered' with populations reported to be decreasing (https://www.iucnredlist.org/search?query=turtles&searchType=species). ● Green turtles are harvested locally, possibly extensively, for subsistence and livelihoods with no management controls. ● Very low productivity means they have a low capacity to recover from impacts.
Dugong	● Projected declines in sea grass will likely negatively impact dugong populations due to their strong association with sea grass beds as their preferred habitat and their primary food source (Bell and Ariel, 2011; Gales et al., 2004; Marsh and Kwan, 2008). ● More intense storms may also directly increase dugong mortality through strandings (Limpus and Reed, 1985). ● Dugong are harvested locally, possibly extensively, for subsistence and livelihoods with no management controls. ● Very low productivity means they have a low capacity to recover from impacts.
Barramundi	● Increased rainfall likely promotes higher recruitment success and growth in early life history stages suggesting potential for higher population abundance (Balston 2009a,b; Halliday et al., 2011,2012; Meynecke et al. 2006; Robins et al. 2006; Staunton-Smith et al. 2004). ● Barramundi extensively harvested locally for subsistence and livelihoods with effectively no management (Busilacchi et al. 2014). ● Predicted declines in mangrove condition and area are likely to reduce recruitment success and growth, resulting in lower abundance. ● Potential benefits are likely to be further negated by their overexploited status (Busilacchi et al., 2014) and very poor local water quality influenced by the Ok Tedi mine in the adjacent Fly River, and local untreated sewage outfall from local villages.
Black jewfish	● Increased rainfall may promote higher recruitment success and growth in early life history stages suggesting the potential for higher population abundance, since their life cycle is similar to Barramundi, although post-larval/juvenile habitat is likely to be include nearshore habitats, however this is poorly understood for this species ● Black jewfish are extensively and increasingly harvested locally for subsistence and livelihoods, and for their highly valued swim bladders, with effectively no management controls. ● Any potential benefits are likely to be negated by their overexploited status (Busilacchi et al., 2014) and very poor local water quality influenced by the Ok Tedi mine in the adjacent Fly River, and local untreated sewage outfall from local villages.
Black teatfish	● Increasing SST may compromise reproductive success since they spawn during winter in low latitudes (Shiell and Uthicke, 2006). ● Predicted declines in area and condition of coral reefs is likely to reduce their populations die to reduced habitat (this report).
Mud crab	● Increased rainfall will likely promote higher recruitment success and growth in early life history stages suggesting the potential for higher population abundance (Loneragan and Bunn, 1999; Halliday and Robins, 2007; Meynecke and Lee, 2011). ● Mud crab extensively harvested locally for subsistence and livelihoods with effectively no management controls (Busilacchi et al. 2014). ● Predicted declines in mangrove condition and area are likely to reduce recruitment success and growth, resulting in lower abundance. ● Potential benefits are likely to be further negated by their overexploited status (Busilacchi et al. 2014) and very poor local water quality influenced by the Ok Tedi mine in the adjacent Fly River, and local untreated sewage outfall from local villages.

Western PNG Species Recommendations

For the western PNG sub-region, there are some universal issues that affect all marine species and their resilience to future shocks from climate change. Several species are currently overfished or likely to be approaching this status and have high exposure to non-targeted fishing pressures such as IUU (Busilacchi et al. 2014), as well as pollution and poor water quality. Effectively this means that many of the impacts projected for marine species due to climate change are already being experienced by species in the western PNG sub-region.

Therefore, for key local species to be resilient to future climate change and continue to support fisheries for the western PNG communities that rely on them for food and livelihoods, the following local actions are strongly recommended:

1. For the species assessed as overfished, management actions that effectively and appropriately reduce and control harvest to sustainable levels and allow stocks to rebuild are urgently required. This may require more conservative measures for species with low replenishment potential and will need strong government and community engagement and education.
2. Effective and locally appropriate mitigation actions that address the multiple chronic cumulative pressures that further compromise fishery populations, especially IUU fishing and poor local water quality, are urgently required.
3. Measures are needed that restore, conserve and protect estuarine and wetland areas used my multiple species during their life cycles (Bell et al 2011).
4. Identification of alternative species as a preferred local food source will reduce community reliance on species currently under pressure, thereby increasing resilience to possible future impacts on stocks. These should be species that are currently underutilised and have high replenishment potential (e.g., local invasive species such as tilapia and climbing perch), and should be complemented by terrestrial animals (e.g., goats).
5. Species of conservation interest require special attention and should be protected where appropriate, but multiple actions will be required to minimise the impacts climate change will have. These actions may include: habitat restoration and/or protection, improvement of local water quality, measures to mitigate their capture, and shading for turtle nests.

7.4 Timor-Leste Sub-region

Currently, only a small proportion of the population in Timor-Leste is engaged in fisheries and aquaculture. The 2015 census reports that 10,000 households (5% of total households) are involved in small-scale fisheries to some degree and that there are approximately 5,000 fishers across Timor-Leste, with around 2,000 on the island of Atauro (GOTL, 2015). Today, fish accounts for 31% of animal-sourced protein in the Timorese diet (https://www.worldfishcenter.org/country-pages/timor-leste).

The latest 'State of the Coral Triangle' report for Timor-Leste noted that: "*Timor-Leste has a narrow continental shelf, with few reefs and seagrass beds. These mainly occur where fishing already takes place. Also, earlier reports have noted the small size of fish and degraded condition of* *reefs, indicators that the main fishing areas are overexploited already. Thus, the country's fisheries potential cannot be high*." (Asian Development Bank, 2014).

Data for Timor-Leste fisheries, their management and status are generally lacking. For the purposes of this assessment expert opinion was elicited from stakeholders, however there were few responses and the high variability among responses may be a reflection of the lack of local information. Where possible, scoring for the assessment was further inferred from published data, which was also used to augment the stakeholder responses, particularly for estimating dependence of fishers on certain species for food and/or income (see López-Angarita et al., 2019). Generally, there isn't a high dependence on any one species due to the multi-species nature of coastal fishing in Timor-Leste: "*Small-scale fishers in Timor-Leste catch a diverse range of fish. Most fishers report that they do not target a particular species but use a variety of gear throughout the year to catch multiple species*." (López-Angarita et al., 2019).

Apart from general statements like that quoted from the 'State of the Coral Triangle' report (above), the status of fishery stocks in Timor-Leste are largely unknown due to a lack of data and assessments. Therefore, the stock status of the key species for assessment purposes was largely inferred based on several factors:

- the reported level of local fishing pressure;
- the biology of each particular species;
- the species stock structure and likelihood they are shared with adjacent jurisdictions; and
- if shared, the stock status and/or level of fishing pressure in adjacent jurisdictions.

There were 23 species included in the vulnerability assessment for the Timor-Leste sub-region, as identified by local stakeholders. It is worth noting that this species list did not correspond well to published data which ranks the relative importance of local catches for food and income (see López-Angarita et al., 2019). Notable species that were not identified for assessment but were identified as important by López-Angarita et al. (2019), were: garfish, *Hemiramphus* spp. (income); fying fish, *Cypselurus* sp. (income and subsistence); long tom, *Tylosurus crocodilus* (income and subsistence); and, to a lesser extent, black triggerfish, *Melichthys niger*. Several individual snapper (Lutjanidae) species were also identified however it is likely that catch levels among snapper species is highly variable in Timor-Leste, although mangrove red snapper (*Lutjanus argentimaculatus*) was identified as a key species for subsistence and is assumed to be a key snapper species overall (López-Angarita et al., 2019).

The assessment results indicated that the species most vulnerable to the effects of climate change in Timor-Leste were green turtle, flowery cod, mangrove red snapper (Mangrove jack), and octopus (Figure 22). The least vulnerable species were rabbitfish species, bluefin trevally, Spanish mackerel and fusiliers (Family Caesionidae).

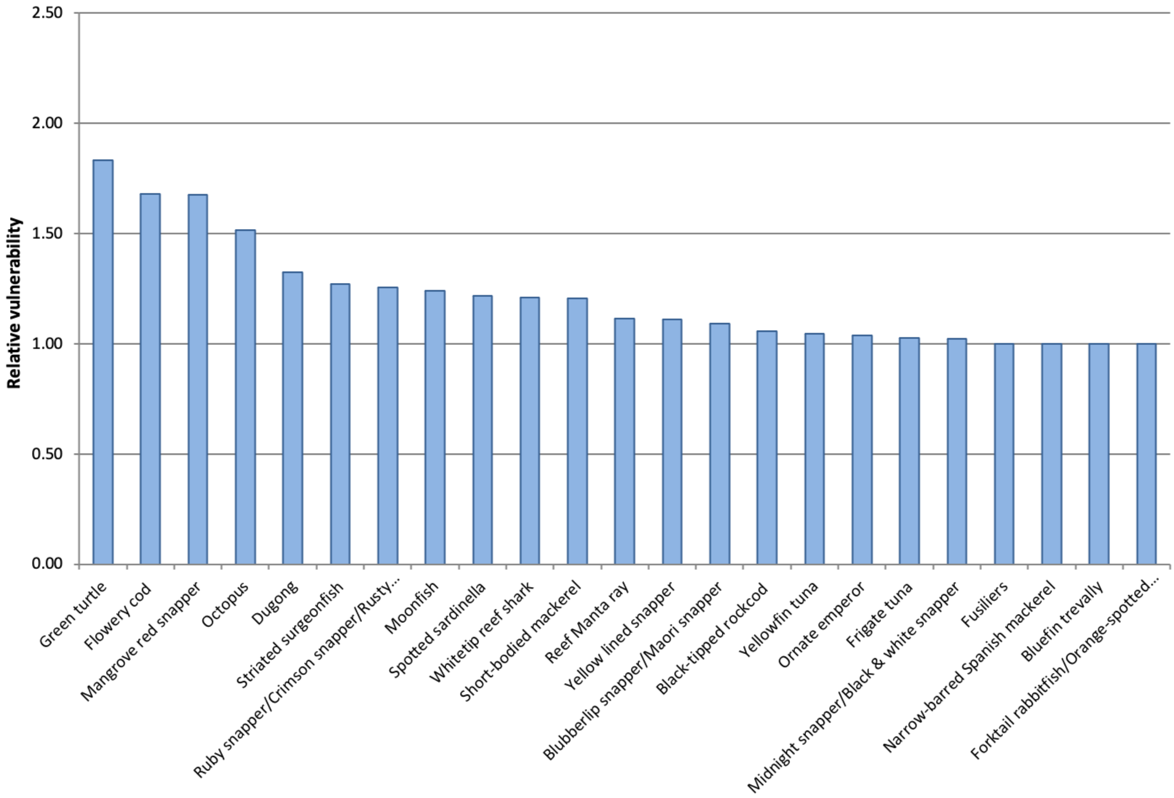

Figure 22. *Relative vulnerability of key species from the Timor-Leste sub-region.*

A key driver of exposure of Timor-Leste species was that many spend a large part of their life history in shallow water, where they are likely to be more exposed to changes in SST. Another key driver was that many species were reliant on coral reef habitats for all or some of their life history. There is relatively high confidence that these habitats will decline in area and condition due to the effects of climate change. For example, the majority of species that had high-moderate exposure were octopus, snappers, surgeon fish, cods, emperors and fusiliers; all coral-reef associated species. Another main driver was that a large number of species are dependent on key habitats for at least some of their life cycle.

A key driver of sensitivity overall was that many species were either live young bearers or they have a relatively short larval duration. Accordingly, the species that had the highest sensitivity scores were green turtles, dugong, reef manta ray and whitetip reef sharks. The key drivers of sensitivity for these species are that they tended to have relatively low fecundity and a high average age at maturity. That is, they tended to be species with a lower reproductive potential for replenishing their populations. Further, gender of turtle hatchlings from eggs laid in beach sand is strongly linked to air temperature which further increases their sensitivity.

Despite most of Timor-Leste fisheries being multi-species, it was perceived by stakeholders that there is a relatively low capacity for fishers to adapt by changing their targeting practices. This may be somewhat surprising given that local fishing practices generally use simple and low-cost gears (Tilley et al., 2019). However, overwhelmingly the adaptive capacity was limited most by the fact that the stock status of all species was scored as overfished or that overfishing is occurring, or their status was undefined due to data deficiencies. Stakeholder survey data indicated that cumulative pressures other than targeted fishing is low, resource dependence for food and income is only moderate, and that fisheries management is relatively flexible and adaptive. Although the framework provides for a relative assessment, relevant literature suggests that fisheries management in Timor-Leste is lacking (Asian Development Bank, 2014). Therefore, as with the Indonesia sub-region, it is likely that the scoring for governance does not accurately represent the reality in Timor-Leste.

The species that had the lowest adaptive capacity included mangrove red snapper, flowery cod, green turtle and octopus. The drivers for the low adaptive capacity for mangrove red snapper and flowery cod were that both were assessed as overfished and both have very low replenishment potential being relatively long-lived, late maturing and slow growing. Further, there was a relatively high reliance on these species for local income. Green turtles also have a low replenishment potential as egg layers. Despite being a highly productive species with a rapid life cycle, octopus in Timor-Leste were perceived to be highly relied on for local subsistence food and to a lesser extent for income. They are an important species especially targeted by women and children gleaning on the reef at low tide (López-Angarita et al., 2019), however they were also assessed as overfished. The summary of potential impacts and influencing factors for Timor-Leste species are given in Table 14.

Priority Species for Management Focus

For the Timor-Leste sub-region, scoring of the criteria to provide a 'local importance' ranking of each species are provided in Appendix B. The prioritisation of species (Figure 23) plots each species' vulnerability against their level of local importance. The five species identified as highest priority for the Timor-Leste sub-region were: green turtle, dugong, flowery cod, octopus and yellowfin tuna (20th percentile group) followed by whitetip reef shark, reef manta ray, Spanish mackerel and short-bodied mackerel (Figure 23). As mentioned, it is acknowledged that local importance of individual species in Timor-Leste is likely to vary among different local areas. For example, the largest coral reef area in Timor-Leste is on the northern coastline (Asian Development Bank, 2014; Figure 3) and therefore reef fish species are likely to be more important for communities along the north coast than for communities on the south coast.

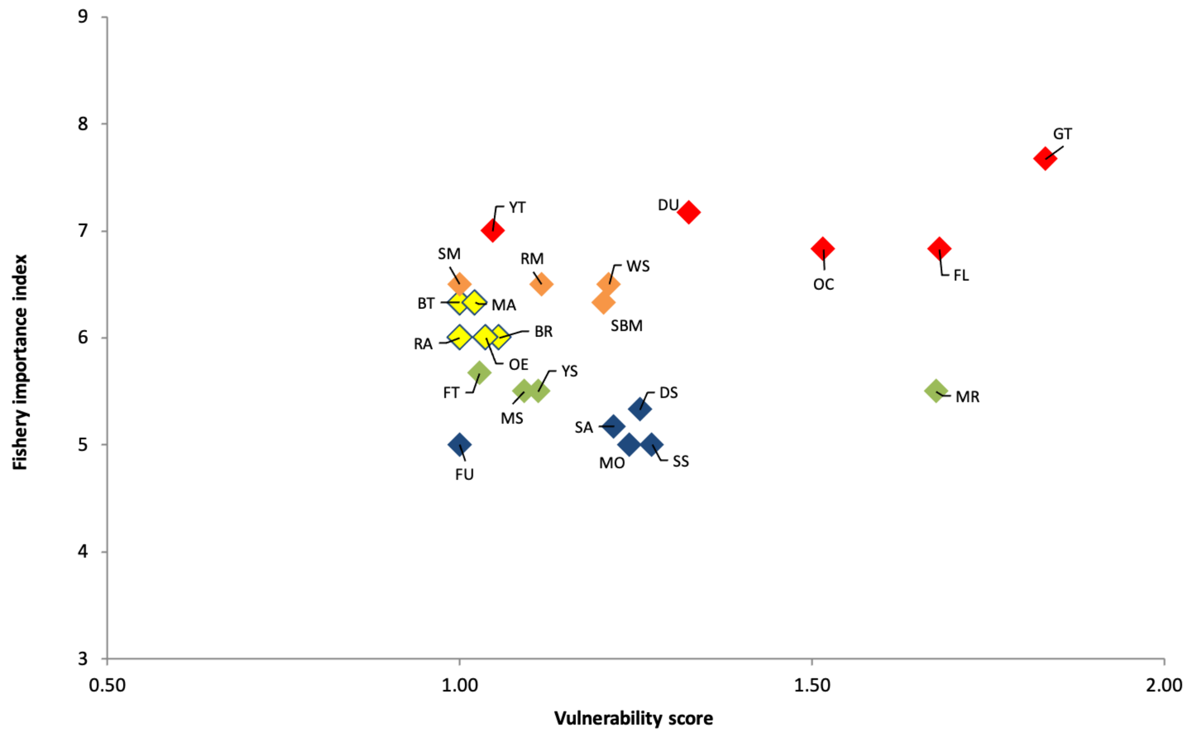

Figure 23. *Prioritisation plot showing the 23 species assessed for the Timor-Leste sub-region and their relative vulnerability against an index of local importance to prioritise species for further research and/or action. To highlight priority species, we calculated Euclidean distances for each data point from the uppermost top right corner of the two axes, and colour coded them based on their percentile group: < 20th percentile - red; 20th percentile - orange; 40th percentile - yellow; 60th percentile - green; 80th percentile - blue. Species are indicated by letter codes as: GT - green turtle, DU - dugong, FL - flowery cod, OC - octopus, YT - yellowfin tuna, WS - whitetip reef shark, RM - reef manta ray, SM - Spanish mackerel, SBM - short-bodied mackerel, MA - midnight/black & white snapper, BT - bluefin trevally, BR - black-tipped rock cod, OE – ornate emperor, RA – rabbitfish, MR - mangrove red snapper, FT – frigate tuna, YS – yellow lined snapper, MS – maori snapper, DS – deep water snappers, SA – spotted sardinella, SS – striated surgeonfish, MO - moonfish, and FU - fusiliers.*

Projected Impacts on Priority Species

No species were assessed as likely to benefit overall from predicted climate change (Table 14). For the few species that use or rely on seagrass and/or mangrove areas during part of their life cycle, they are likely to experience lower recruitment and/or growth over time as rainfall decreases significantly by 2070 and these habitats decline in area and condition. The species most likely to be impacted by these factors include dugong and green turtle (feeding); rabbitfish (nursery and feeding); mangrove red snapper, Spanish mackerel and ornate emperor (nursery). Further, some of the most highly targeted species include sardines, scads and mackerels which tend to be seasonal and are fished around highly productive river plume zones on the southern coast where the oceanography and topography provides a productive pelagic and benthic environment (Alongi et al., 2009; López-Angarita et al., 2019; Tilley et al., 2019). Much lower projected rainfall for Timor-Leste will likely reduce the incidence and extent of coastal productivity which will potentially reduce the abundance and availability of these species.

Most of the species assessed for Timor-Leste are coral reef associated species and Timor-Leste coral reefs are projected to decline in area and condition due primarily to increasing SST but also their current condition is already degraded and management is lacking (Asian Development

Bank, 2014). Very little is research has been carried out on the environmental sensitivities and thresholds for the species assessed in the Timor-Leste sub-region, however it is likely that habitat impacts will indirectly impact on the survival and growth of coral reef-associated species. But, the current status of most of these species is either overfished or undefined (and therefore may be overfished) meaning they are already experiencing the impacts that climate change is expected to bring. Therefore, effective primary fisheries management in Timor-Leste represents a current adaptation priority that will be critical to maximise the ability of target species to cope with future climate-related shocks (Bahri et al., 2021).

Based on the stakeholder surveys, non-targeted fishing pressure on marine resources was perceived to be relatively low for all species. Although data and information are lacking, runoff and flood events have been documented as key vulnerability factors for Timor-Leste habitats and species on the south coast in particular where high seasonal river discharges are reported (Alongi et al. 2009). Extensive mangrove clearing has also been reported to occur. Further, several species are likely to be part of larger stocks shared with adjacent jurisdictions where overfishing and illegal, unregulated and unreported fishing are prevalent (e.g., Buchary et al. 2008; California Environmental Associates 2018).

Table 14. *Potential impacts and factors that influence impacts for key species in the Timor-Leste sub-region based on climate change projections for 2070 under the RCP8.5 ('business as usual') climate scenario. These factors were considered in determining if there was likely to be an overall impact or benefit from climate change for any species.*

Species	Key factors that influence likely overall effects of climate change (by 2070)
Green turtles	● Increasing air temperatures are likely to result in strongly female biased populations due to thermal influence on gender during incubation (Hawkes et al., 2009; Fuentes et al., 2010). ● Sea level rise, more intense storms and extremes in rainfall are likely to result in increased stranding, decreases in available nesting sites and disruptions to successful nesting through inundation (Meager and Limpus, 2012; Pike and Stiner, 2007; Pike et al., 2015). ● Predicted declines in sea grass condition and area (this report) may reduce turtle growth, survival and condition (Marsh and Kwan, 2008). ● Stock status in Timor-Leste waters is unknown, however, green turtles are listed globally as 'Endangered' with populations reported to be decreasing (https://www.iucnredlist.org/search?query=turtles&searchType=species). They appear to be harvested, although to what extent is unknown, since stakeholder surveys gave a relatively high value for income.
Dugong	● Projected declines in sea grass will likely negatively impact dugong populations due to their strong association with sea grass beds as their preferred habitat and their primary food source (Bell and Ariel, 2011; Gales et al., 2004; Marsh and Kwan, 2008). ● More intense storms may also directly increase dugong mortality through strandings (Limpus and Reed, 1985). ● Dugong appear to be harvested locally, although to what extent is unknown, since stakeholder surveys gave a relatively high value for income. There appears to be no management controls on harvest. ● Their very low productivity means they have a low capacity to cope with and/or recover from impacts.
Flowery cod	● Impacts are largely unknown. Research on another serranid, the leopard coral grouper *Plectropomus leopardus,* suggests changes in ocean pH and SST may alter early growth and survival as well as their predator avoidance behaviour, which may further compromise survival (Munday et al., 2012; Pratchett et al, 2013). ● Predicted declines in their preferred habitat, coral reefs, may result in lower abundance (Pratchett et al., 2011). ● Their likely overfished status (Asian Development Bank, 2014) (due to high value and low productivity) reduces their resilience climate-related impacts and currently there does not appear to be any management controls on harvest.
Octopus	● Impacts are largely unknown. Their very high relative level of exposure given their shallow coastal habitat preference, and the low adaptive capacity of the fishery, make them highly vulnerable to climate change impacts. ● Their likely overfished status (Crespo, 2015; Asian Development Bank, 2014), due to their high value and high importance for subsistence fishing, reduces their resilience to climate-related impacts. Management controls on harvest are apparently lacking.
Yellowfin tuna	● Their overfished status[1] (due to high value) reduces their resilience to climate-related impacts. ● Climate-related impacts on ocean currents and productivity are highly uncertain but could change the distribution and abundance of tuna potentially making them less available to Timor-Leste fishers.
Whitetip reef shark	● Impacts largely unknown. It is uncertain what impact a decline in the condition and area of coral reefs will have on their populations.

Reef manta ray	• Stakeholder surveys gave a relatively high value for income suggesting that they are harvested in Timor-Leste, although to what extent is unknown. Assessed as overfished which reduces their resilience to climate-related impacts. • Their large-scale movements mean it is almost certain that Timor-Leste animals are part of a shared stock with adjacent jurisdictions (Jaine et al., 2014), particularly with Indonesia, where historically they have been harvested heavily (although their capture has been banned in adjacent Indonesian waters since 2014[2]). • Changes in local upwelling and current dynamics due to climate change are highly uncertain. Any changes may alter the distribution and abundance of this species in Timor-Leste due to their planktonic diet (Beale et al., 2019; Rohner et al., 2013).
Short-bodied mackerel	• Their fully exploited status (Zamroni and Ernawati, 2019) reduces their resilience to climate-related impacts. Also, they are likely to be part of a stock shared with adjacent jurisdictions (see Akib et al., 2015) and so fishing levels outside Timor-Leste also impact their populations. • Management in Timor-Leste appears to be lacking and in adjacent jurisdictions is either lacking or ineffective (California Environmental Associates 2018). • Their ability to cope with climate-related impacts are likely to be helped by their apparent tolerance to temperature and salinity changes and their very high replenishment capacity (Collette and Nauen, 1983). • Changes in local upwelling and current dynamics due to climate change are highly uncertain, and may alter the productivity of pelagic systems for which their populations are highly dependent (e.g., Sojisuporn et al., 2010). Declines in oceanic productivity would reduce *Rastrelliger* spp. population abundance.

[1] https://wwfint.awsassets.panda.org/downloads/factsheet_tuna_blueprint_hires.pdf

[2] https://blog.nationalgeographic.org/2018/07/26/reducing-manta-ray-mortality-in-the-worlds-largest-targeted-manta-fishery/

Timor-Leste Sub-region Recommendations

For the Timor-Leste sub-region, there are some significant overarching issues that affect all marine species and their resilience to future shocks from climate change. In particular, data and information on the species identified for assessment in Timor-Leste are scarce. Therefore, much of the information used in each species assessment is inferred based on similar species or fishing in adjacent areas. For example, several of the species assessed are likely to be part of a shared stock with adjacent jurisdictions (e.g., deep water snappers, spotted sardinella, short-bodied mackerel, reef manta ray, Spanish mackerel, green turtle and dugong). This resulted in all species being assessed as either overfished or likely to be approaching this status, or undefined, meaning they may well be overfished, a finding supported by a 2014 State of the Coral Triangle report for Timor-Leste (Asian Development Bank, 2014), as well as community perceptions (Tilley et al., 2019). Effectively this means that many of the impacts projected for marine species due to climate change, are already being experienced by species in the Timor-Leste sub-region.

Further, information limitations also mean that identifying and assessing the level of impact that other factors may have on adaptive capacity of Timor-Leste species is highly uncertain. For example, the extent that cumulative pressures such as IUU fishing, coastal development and water quality are affecting Timor-Leste waters are poorly documented. Finally, although governance of fisheries in Timor-Leste was perceived to be at a relatively high standard during stakeholder surveys, published information suggests that limited fisheries management is poorly implemented likely rendering it ineffective (López-Angarita et al., 2019; Tilley et al., 2019).

Therefore, for key local species to be resilient to future climate change and continue to fulfil important ecological roles and support fisheries in the region, the following local actions are strongly recommended:

1. For stocks assessed as at risk from overfishing, management actions that effectively and appropriately control harvest to sustainable levels and allow stocks to rebuild are urgently required. The ongoing but delayed process of decentralisation of fisheries management in Timor-Leste, coupled with inadequate resourcing (Tilley et al., 2019), are two key areas for priority action if effective management is to be achieved.
2. To reduce the current uncertainty inherent in this assessment, a review and assessment of available information on Timor-Leste fisheries is needed. This should include an assessment of habitat status to enable prioritisation of restoration and conservation efforts.
3. For relevant key target species likely to be part of stocks shared with adjacent jurisdictions, in particular Indonesia, complementary co-management arrangements should be discussed.
4. For prioritisation of species for action, a localised approach should be undertaken in Timor-Leste due to the regional differences in habitats, target species and fisher participation levels.
5. Species of conservation interest require special attention and should be protected where appropriate, including limiting harvest and habitat restoration and/or protection.
6. An assessment of the possible effects of climate change on agriculture production should be conducted, given the projections of significantly lower rainfall. This should assess the

likelihood that future effort may be transferred into fishing activities if crop productivity is reduced.

7.5 Gulf of Carpentaria and North-western Australia Sub-regions

Given the high level of overlap in the species assessed in the two northern Australian sub-regions, the assessment results are presented here together. There were 18 species included in the vulnerability assessment for the Gulf of Carpentaria sub-region, and 19 species for north-western Australia. In the Gulf of Carpentaria, the most vulnerable species was king threadfin. Other species with high relative vulnerability were green turtle, dugong, barramundi, golden snapper and mud crab (Figure 24). The least vulnerable species were blacktip sharks and white banana prawns.

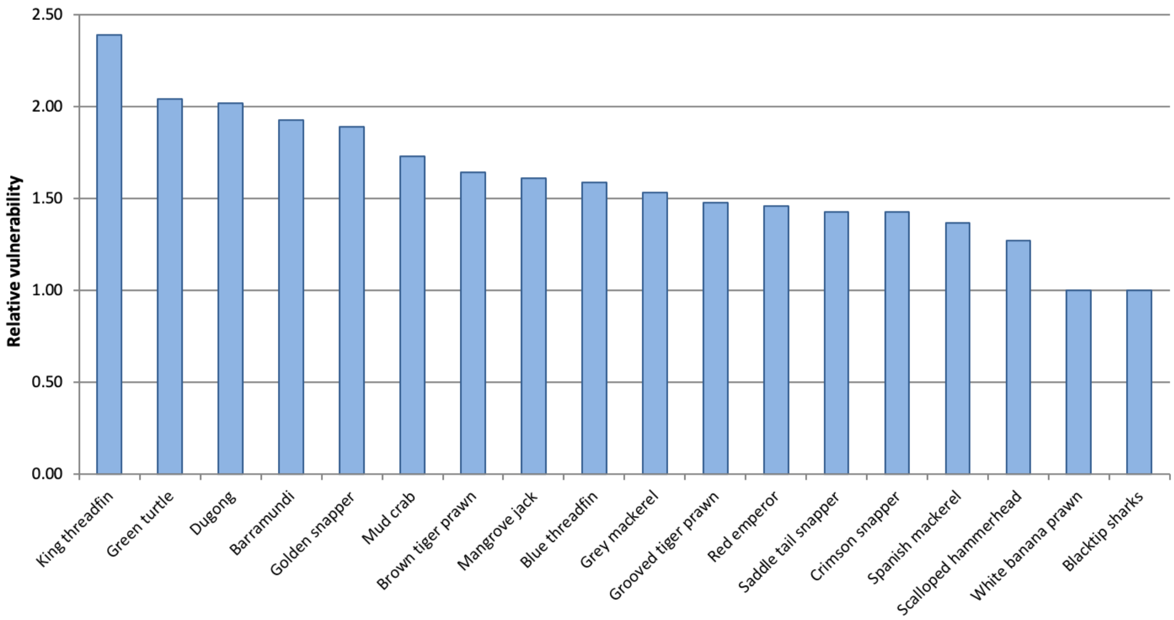

Figure 24. *Relative vulnerability of key species from the Gulf of Carpentaria sub-region.*

In north-western Australia the most vulnerable species was golden snapper. Other species with high relative vulnerability were green turtle, black jewfish, dugong and king threadfin (Figure 25). The least vulnerable species were deep water snapper species, the three shark species assessed and white banana prawn.

For both sub-regions, a key driver for species that had a high exposure to changes in climate variables was that they tended to have shallow water and/or nearshore distribution (e.g., golden snapper, mud crab, king threadfin, barramundi), low mobility (e.g., prawn species), and a dependency of estuarine habitats for critical parts of their life cycle (e.g., brown tiger prawns, white banana prawn, mud crab, king threadfin, barramundi, golden snapper, blue threadfin).

A key driver of sensitivity overall was a low capacity for larval dispersal for many species, with either a relatively short larval duration or none at all (live/egg bearers). For example, the most sensitive species across both sub-regions were green turtle, dugong, scalloped hammerhead and the two blacktip shark species; all are either egg layers or live young bearers. Another key driver was that the most sensitive species were often late maturing (e.g., turtle, dugong, shark species, king threadfin). A third key driver of sensitivity was the influence of environmental drivers for recruitment, survival and growth for some species. These species tended to be those whose populations are known to be strongly influenced by changes in rainfall and riverflow, even though rainfall projections are highly uncertain for this region. This included king threadfin, barramundi and mud crab. Deep water snapper species were assessed as having the lowest relative sensitivity.

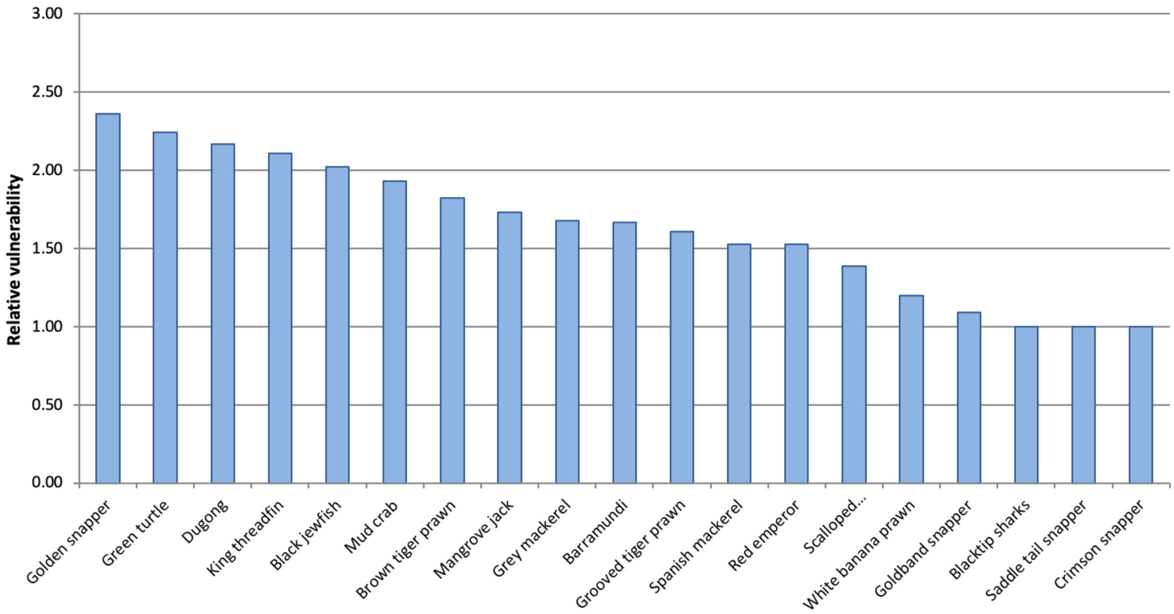

Figure 25. *Relative vulnerability of key species from the north-western Australia sub-region.*

The species that had the lowest adaptive capacity across both sub-regions included king threadfin, dugong, golden snapper, black jewfish, red emperor and mangrove jack. Key drivers for low adaptive capacity tended to be a low population replenishment potential (e.g., dugong, green turtle, golden snapper, red emperor, mangrove jack and sharks) and a stock status assessed as depleted or overfished (e.g., Gulf: king threadfin and barramundi; NW Aust.: golden snapper). Non-fishing pressures were assessed as another driver of low adaptive capacity, especially plans for increasing water diversion in gulf rivers further reducing riverflow under a possible reduced rainfall future (https://www.etheridge.qld.gov.au/downloads/file/346/http-1-pdf). Also, governance was assessed as relatively inflexible and non-adaptive. Assessment scores for non-fishing pressures and governance were based on stakeholder surveys conducted during an earlier assessment (Welch et al., 2014b). Currently plans for dams in the Gulf region are continuing, however fishery management reforms are currently underway for the region which should make management more responsive and robust to the effects of climate change (https://www.daf.qld.gov.au/business-priorities/fisheries/sustainable/sustainable-fisheries-strategy-overview).

Priority Species for Management Focus

For the Gulf of Carpentaria and north-western Australia sub-regions, scoring of the criteria to provide a 'local importance' ranking of each species are provided in Appendix B. The prioritisation of species for the Gulf of Carpentaria is shown in Figure 26 with the species identified as highest priority for the sub-region as: barramundi, mud crab, green turtle, Spanish mackerel (20th percentile group), followed by king threadfin, dugong and scalloped hammerhead (20-40th percentile group) (Figure 26).

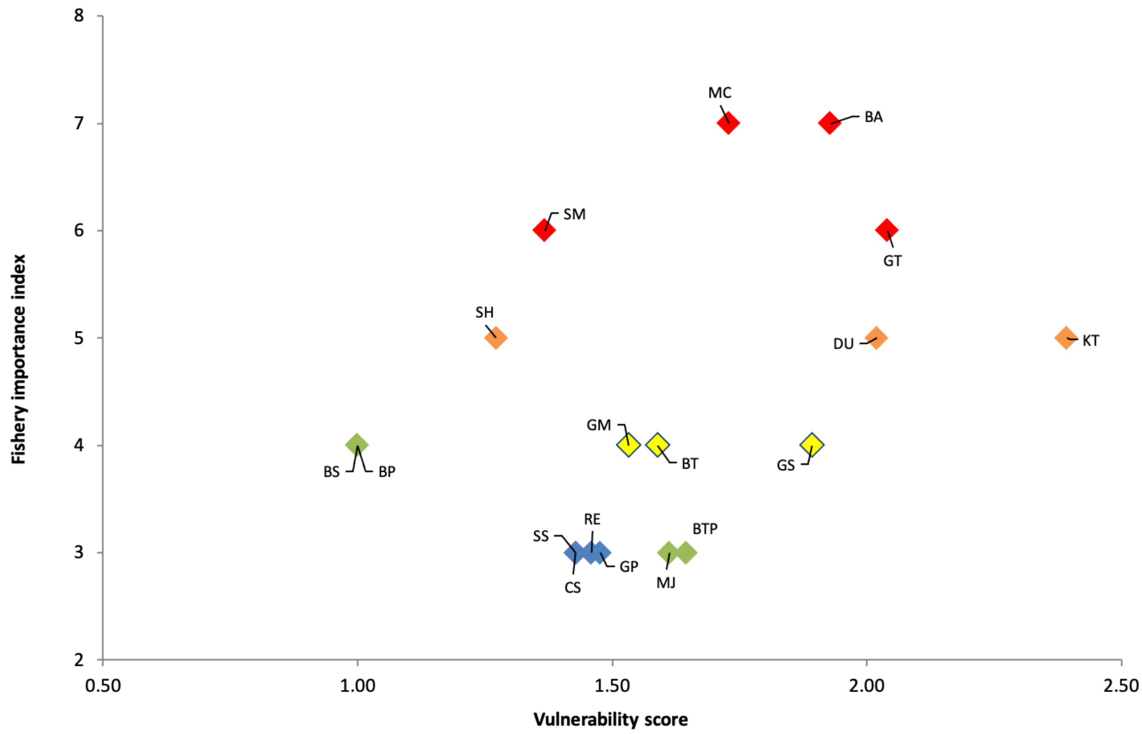

Figure 26. *Prioritisation plot showing the 18 species assessed for the Gulf of Carpentaria sub-region and their relative vulnerability against an index of local importance to prioritise species for further research and/or action. To highlight species in order of priority we calculated Euclidean distances for each data point from the uppermost top right corner of the two axes, and colour coded them based on their percentile group: < 20th percentile - red; 20th percentile - orange; 40th percentile - yellow; 60th percentile - green; 80th percentile - blue. Species are indicated by letter codes as: BA – barramundi, MC – mud crab, GT – green turtle, SM – Spanish mackerel, KT – king threadfin, DU – dugong, SH – scalloped hammerhead, GS – golden snapper, BT – blue threadfin, GM – grey mackerel, BS –blacktip sharks, BP – white banana prawn, BTP – brown tiger prawn, MJ – mangrove jack, GP – grooved tiger prawn, RE – red emperor, CS – crimson snapper and STS – saddletail snapper.*

The prioritisation of species for north-western Australia is shown in Figure 27 with the species identified as highest priority for the sub-region as: black jewfish, mud crab, Spanish mackerel and barramundi (20th percentile group), followed by green turtle, grey mackerel, golden snapper and dugong (20-40th percentile group) (Figure 27).

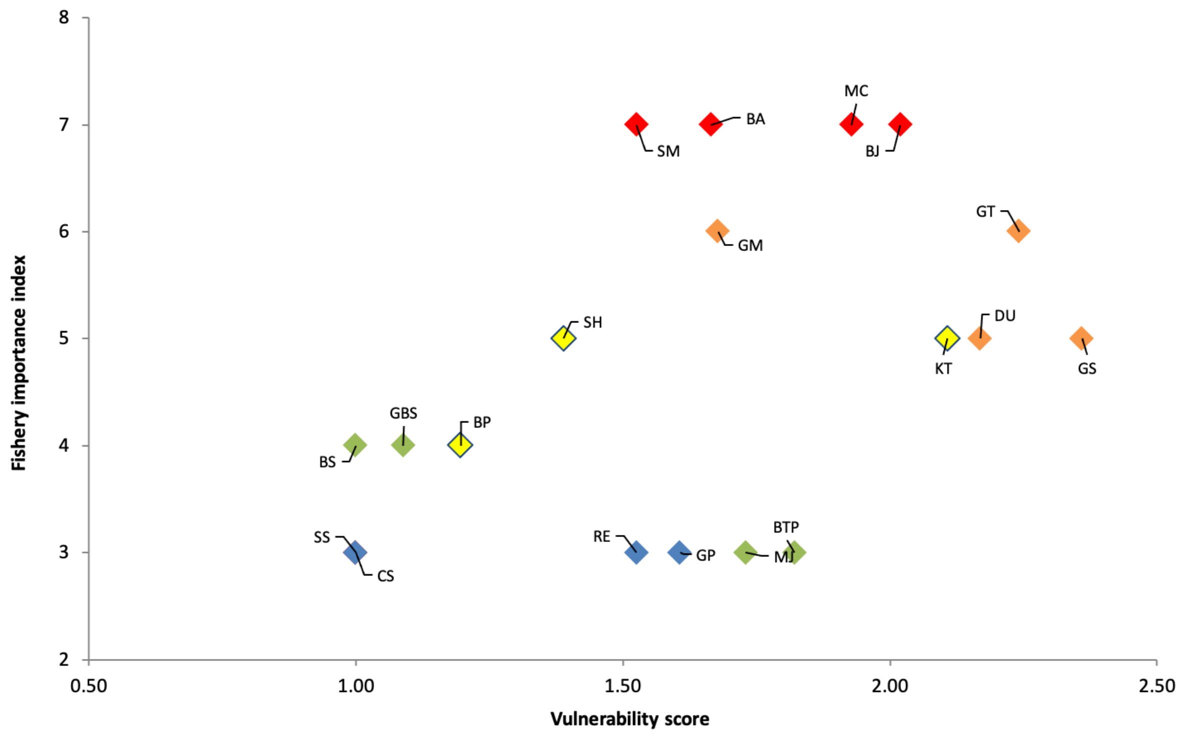

Figure 27. *Prioritisation plot showing the 19 species assessed for the North-western Australia sub-region and their relative vulnerability against an index of local importance to prioritise species for further research and/or action. To highlight priority species, we calculated Euclidean distances for each data point from the uppermost top right corner of the two axes, and colour coded them based on their percentile group: < 20th percentile - red; 20th percentile - orange; 40th percentile - yellow; 60th percentile - green; 80th percentile - blue. Species are indicated by letter codes as: BJ – black jewfish, MC – mud crab, SM – Spanish mackerel, BA – barramundi, GT – green turtle, GM – grey mackerel, GS – golden snapper, DU – dugong, KT – king threadfin, SH – scalloped hammerhead, BP – white banana prawn, GBS – goldband snapper, BS – blacktip sharks, MJ – mangrove jack, BTP – brown tiger prawn, GP – grooved tiger prawn, RE – red emperor, CS – crimson snapper and STS – saddletail snapper.*

Projected Impacts on Priority Species

No species from either of the northern Australian sub-regions were assessed as benefiting from projected future climate changes; however, it is possible that positive impacts from climate changes will result for some species. The strong positive relationship between rainfall/riverflow and recruitment, growth and catchability for several estuarine-linked species (i.e., mud crab, king threadfin, barramundi, white banana prawn), provide the possibility that populations for these and other species that rely on estuarine habitats will become more productive with increased rainfall in the future. However, climate model projections for rainfall are highly uncertain for the northern Australian sub-regions with estimates by 2070 ranging from a 30% decrease to a 25% increase for both the Gulf of Carpentaria and north-western Australia (this report).

Of the sub-regions assessed, the northern Australian region is projected to experience the highest warming of SST with an average increase of more than 2 °C by 2070, relative to the baseline year of 2015 (this report). Air temperature is also forecast to rise by as much as 4.9 °C. Temperature tolerance limits have been studied for some species, but remain largely unknown, especially for the sensitive early life history stages of most species. Despite this, most of the species assessed appear to be relatively resilient to changing conditions as they are shallow-water and/or estuarine species. However, increases in SST may have unforeseen consequences, such as food web or habitat impacts, that indirectly affect fishery target species (Fulton et al., 2018, in press). However, it is likely that air temperature increases will have potentially major consequences on turtle populations, with altered gender ratios (Fuentes et al., 2010), and on dieback of mangrove habitats (see Accad et al., 2019, and mud crab below).

Further details on the assessment outcomes for the highest priority species are provided below, and potential impacts for these and other key species are summarised further in Table 15.

King threadfin

King threadfin were assessed as having the highest vulnerability for the Gulf of Carpentaria sub-region and was also moderate-high for the north-western Australia sub-region. They have relatively high exposure due to their nearshore preference and strong association with estuarine habitats; a relatively high sensitivity primarily due to their known reliance on riverflow as a driver of recruitment (Halliday et al., 2008, 2012); and a relatively low adaptive capacity largely due to their moderately low replenishment potential (Moore et al., 2011). In the Gulf of Carpentaria their relative vulnerability was higher because they are classified as depleted/overfished in this sub-region (Moore et al., 2017; Whybird et al., 2018). Their resilience to future climate impacts in this sub-region will be increased with management actions that effectively reduce harvest rates to sustainable levels.

Barramundi

Barramundi were assessed as having moderate relative vulnerability in north-western Australia and high in the Gulf of Carpentaria. The difference was due to one of the two barramundi stocks in the Gulf assessed as depleted in the most recent national assessment process (Saunders et al., 2018). Overall, barramundi are likely to be highly exposed due to their nearshore and estuarine habitat preference, particularly given their close association with river systems at all life history stages (Russell and Garrett, 1985); are sensitive to rainfall changes as they have a known strong reliance on rainfall (and associated linkages: riverflow, flood plain inundation, higher nutrient levels/food availability) as an indicator of recruitment and a trigger for spawning but also for downstream movement of adults and upstream movement of juveniles into floodplain areas (Staunton-Smith et al., 2004; Halliday et al., 2012; Russell and Garrett, 1985; Grey 1987). Riverflow also influences growth rates and fishery catch rates (Robins *et al.* 2005, 2006; Meynecke *et al.* 2006; Balston 2009a, b). Barramundi ecological adaptive capacity is generally high, and they tend to be adaptable to changes and have been shown to have a wide thermal tolerance (Jerry et al. 2013). However, they are one of the most iconic recreational, commercial and Indigenous target species across northern Australia, suggesting a high fishery dependence on this species.

Golden snapper

Golden snapper has the highest relative vulnerability for the north-western Australia sub-region, and one of the highest vulnerability scores for the Gulf of Carpentaria sub-region. The difference was due to stocks in the Darwin region, where most of the effort towards golden snapper occurs, to be in a depleted state (Penny et al., 2018a). In this region they are particularly important as a recreational target species. They have high vulnerability to projected climate change because they will be highly exposed due to their nearshore shallow habitat preference, and particularly the preference for juveniles (and possibly larvae) to occupy estuaries (Saunders et al., 2016). A key driver of their sensitivity is that they are relatively late maturing (Hay *et al.* 2005), and although not proven, given their juvenile estuarine phase, it is highly possible that rainfall/riverflow is a significant driver of population productivity as with other species with similar life histories (e.g., king threadfin). They also have very low adaptive capacity because of their relatively low replenishment capacity, and may be subject to non-fishing pressures given their estuarine/nearshore habitat preference. Their overfished status in the north-western Australia sub-region also reduces their resilience to climate change.

Green turtle

Although turtles received a relatively low 'local importance' score overall (high cultural value), they were assessed as having a high relative vulnerability to future climate change mainly due to their very high sensitivity. This sensitivity has already been observed through direct effects on turtles as well as indirect effects on nesting success (Fuentes et al. 2010). These impacts include stranding due to storms (Meager and Limpus 2012), seawater inundation of nesting beaches (Pike and Stiner 2007), the influence of temperature on hatchling gender (Hawkes et al. 2009), and the potential loss of important food resources associated with possible declines in seagrass meadows (Marsh and Kwan 2008). There is high confidence in the projection of future impacts on marine turtles. Their global 'Endangered' status and their low replenishment potential limit their adaptive capacity. Therefore, effective conservation at a global level will be important for green turtles to cope with future climate-related impacts.

Dugong

Another species that had a high relative sensitivity was dugong, which not only are live bearers but their rate of pregnancy is very low with females giving birth every 3–7 years (Marsh et al. 1984). Also, although seagrass habitat is projected to remain stable in the Gulf of Carpentaria (this report), dugong is highly dependent on seagrass meadows and are therefore very sensitive to any changes (Marsh and Kwan, 2008). Further, their adaptive capacity is one of the lowest relative to all other species due to their very low replenishment potential and their global listing as 'Vulnerable' and an overall declining population trend, although they are thought to be stable in north-western Australia sub-region waters (https://www.iucnredlist.org/species/6909/160756767).

Mud crab

Mud crabs are a highly popular target species for commercial, recreational and cultural purposes in both the Gulf of Carpentaria and north-western Australia sub-regions. Although they had a high-moderate vulnerability score for both sub-regions, their widespread popularity and importance put them in the top 20 % of priority species (Figures 26 & 27). Their relatively high vulnerability was due to: their high exposure as a shallow nearshore species that relies on estuarine areas and mangroves as a critical part of their life cycle (Hill et al., 1982); and moderate-high sensitivity due largely to their known influence that rainfall (and riverflow) has on recruitment success and growth in early life history stages (Loneragan and Bunn, 1999;

Meynecke and Lee, 2011). Their adaptive capacity was assessed as moderate, due to their rapid life cycle and high replenishment potential, but also moderated by their low mobility to move if conditions become extreme, and the high fishery dependence. Further, although mangrove forests are predicted to remain stable across both the northern Australian sub-regions, a recent dieback of coastal mangroves in the Gulf of Carpentaria covered an area of 2,774 hectares. This unexpected event is thought to be most likely due to a prolonged water balance stress derived from a number of coinciding climatic factors including record evaporation levels and near record vapour pressure, minimum temperature and radiation levels (Accad et al., 2019). If similar events were to persist in these regions, then it could have significant and detrimental effects on mud crab populations.

Black jewfish

Black jewfish were only assessed in the north-western Australia sub-region, where they are particularly popular, however they are also relatively popular in the Gulf of Carpentaria. They have relatively high exposure because they occupy nearshore and estuarine habitats throughout their life. Their sensitivity was assessed as moderate however this is largely due to the fact that there is a very poor understanding of the influence of environmental variability on black jewfish population dynamics. Given that they occupy nearshore areas and juveniles live in estuaries, rainfall and riverflow are likely to be important drivers. Also, given their fine-scale stock structure (Saunders et al, 2016), impacts may be positive or negative and at localised scales, depending on rainfall levels across the northern Australian region. Black jewfish also have relatively low adaptive capacity, being prone to overfishing (Phelan, 2008), and were most recently assessed as a ‘recovering’ stock in the Northern Territory (Penny et al., 2018b), suggesting prudent fisheries management is needed to ensure they are resilient to future potential climate-induced impacts. Their low adaptive capacity is also influenced by the heavy dependence on them as a local target species, particularly by the recreational fishing sector. Future research should focus on the importance of environmental variability on the life history stages of black jewfish.

Table 15. *Potential impacts and factors that influence impacts for key species in the Gulf of Carpentaria sub-region based on climate change projections for 2070 under the RCP8.5 ('business as usual') climate scenario. These factors were considered in determining if there was likely to be an overall impact or benefit from climate change for any species.*

Species	Key factors that influence likely overall effects of climate change (by 2070)
Barramundi	● Altered rainfall (and riverflow) will likely affect recruitment success and growth in early life history stages (Balston, 2009a,b; Halliday et al., 2011, 2012; Meynecke et al., 2006; Robins et al., 2006; Staunton-Smith et al., 2004), however this remains uncertain in both northern Australian sub-regions due to highly uncertain rainfall projections (this report). Proposed damming of local rivers will potentially negatively affect abundance depending on water management (Halliday et al., 2012). ● Sea-level rise may increase abundance through increased availability of post-larvae and juvenile habitat in coastal wetlands (Russell and Garrett, 1985), although projections on mangrove area and condition in both northern Australian sub-regions are that they will be stable (this report). ● The current 'depleting' stock status for the southern GoC stock will compromise their resilience to future changes unless recovery is facilitated (Saunders et al., 2018).
Mud crab	● Altered rainfall (and riverflow) will likely affect recruitment success and growth in early life history stages (Loneragan and Bunn, 1999; Meynecke and Lee, 2011), however this remains uncertain in both northern Australian sub-regions due to highly uncertain rainfall projections (this report). Proposed damming of local rivers will potentially negatively affect abundance depending on water management (Halliday et al., 2012). ● Critical mangrove and seagrass habitats are projected to remain stable in the northern Australia (this report), however recent events such as the extensive and unforeseen mangrove dieback in the Gulf of Carpentaria that occurred during 2015-16 (see Accad et al., 2019), may cause significant declines in mud crab populations. Assessment of the impacts of the dieback, which has yet to recover, may give a better indication of future likely impacts on northern Australia mud crab populations. ● Recent modelling predicts that by 2050 catches of mud crab in the Gulf of Carpentaria will decline by 10 % (high confidence), although it may be localised and there is uncertainty depending on rainfall, any changes in mangrove habitat and dammed river flow (Fulton et al., 2018, in press).
Green turtle	● Increasing air temperatures are likely to result in strongly female biased populations due to thermal influence on gender during incubation (Hawkes et al., 2009). ● Sea level rise, more intense storms and extremes in rainfall are likely to result in increased strandings, a decrease in available nesting sites and disruption of successful nesting through inundation (Meager and Limpus, 2012; Pike and Stiner, 2007). ● Stock status is unknown however they are listed globally as 'Endangered' with populations decreasing (https://www.iucnredlist.org/search?query=turtles&searchType=species). ● Recent modelling predicts that by 2050 turtle populations will decline in both sub-regions of northern Australia by 10-30 % (medium confidence), with a key risk being inundation of nests (Fulton et al., 2018, in press).
King threadfin	● Altered rainfall (and riverflow) will likely affect the recruitment and abundance of king threadfin (Halliday et al., 2008, 2012), although this remains uncertain in both northern Australian sub-regions due to highly uncertain rainfall projections (this report). Proposed damming of local rivers will potentially negatively affect abundance depending on water management (Halliday et al., 2012).

	• Resilience to future changes may be poor due to their large size, older age at sex change (to female) and their depleting/overfished stock status in the Gulf of Carpentaria (Welch et al., 2010; Moore et al., 2011, 2017; Whybird et al., 2018). • Localised population impacts may be evident due to their fine scale stock structure (Welch et al., 2010; Moore et al., 2012), resulting in higher inter-annual variability in catches.
Dugong	• Sea grass area and condition is predicted to remain stable in both northern Australian sub-regions, however any unforeseen changes will likely affect dugong populations due to their strong association with sea grass beds as their preferred habitat and their primary food source (Bell and Ariel, 2011; Gales et al., 2004; Marsh and Kwan, 2008). • More intense storms may also directly increase dugong mortality through strandings (Limpus and Reed, 1985). • Very low productivity means they have a low capacity to recover from impacts. • Recent modelling predicts that by 2050 dugong populations in the Gulf of Carpentaria sub-region will decline by 15 % (medium confidence) (Fulton et al., 2018, in press), despite stable seagrass habitat predictions (this report).
Golden snapper	• Relationships with climate variables are poorly understood however their resilience to future changes may be poor due to their late maturity and their susceptibility to localised depletion (Hay et al., 2005; Saunders et al., 2016; Penny et al., 2018a). The lack of knowledge increases the uncertainty in their assessment. • Their current depleted status in the north-western sub-region increases their vulnerability unless their status can be improved. • Maintenance of healthy nearshore/estuarine habitats is also likely to be critical for golden snapper and similar other key fishery species.
Black jewfish	• Altered rainfall may affect the juvenile survival and therefore population abundance, however this is poorly understood for this species • Their current 'recovering' status in the north-western Australia sub-region (and their status is 'undefined' in the Gulf of Carpentaria sub-region) reduces their resilience to cope with potential negative impacts of climate change (Penny et al., 2018b). • Future observed impacts will most likely be at localised scales given their fine-scale stock structure (Saunders et al., 2016), unless key environmental changes are widespread and uniform.
Brown and grooved tiger prawn	• Seagrass habitat area and condition is predicted to remain stable to 2070 in both northern Australia sub-regions (this report), however if this changes it will likely affect juvenile growth and survival (Young and Carpenter, 1977; Coles and Lee Long, 1985; Coles et al. 1987; Loneragan et al. 1994). • Projected increases in SST to 2070 (this report) may compromise growth and survival of brown tiger prawn as they are near their optimal limit (O'Brien, 1994), although being a short-lived species may provide an ability to adapt faster. • Recent modelling predicts that by 2050 that catches of tiger prawns in the Northern Prawn Fishery (covering both sub-regions) will decline by 10-20 % (high confidence), depending on food web interactions, changes in seagrass and the combination of rainfall/riverflow and damming flows (Fulton et al., 2018, in press). • Increases in SST in the Gulf of Carpentaria (and north-western Australia) may result in a change in the timing of spawning (Fulton et al., 2018, in press). • Increases in more extreme rainfall events that are predicted (Fulton et al., 2018, in press) may increase the catchability of tiger prawns but may also contribute to lower abundance of Grooved tiger prawn since low salinity waters from flooding has been shown to increase mortality in this species (Xu et al., 1995).

White banana prawn	● Although rainfall projections for northern Australia is highly uncertain (this report), a scenario of increased rainfall is likely to increase the catchability of banana prawns as the flows assist pre-adult prawns recruiting to nearshore fishing grounds (Vance et al. 1985; Vance et al. 2003). ● Banana prawns are highly reliant on mangrove-lined mud banks in estuarine areas for post-larval growth and survival and, although projections on mangrove area and condition in both northern Australia sub-regions are that they will be stable (this report), any change to this will likely affect banana prawn populations. If the recent mangrove dieback event in the Gulf of Carpentaria (Accad et al., 2019) becomes more common, greater variability in catches and an overall population decline is likely. Assessment of the impacts of the dieback, which has yet to recover, may give a better indication of future likely impacts on northern Australia banana prawn populations. ● Recent modelling predicts that by 2050 that catches of banana prawns in the Northern Prawn Fishery (GoC and NW Australia) will decline by 10 % (high confidence), and that this decline will be higher with more variable rainfall (predicted), any mangrove loss and dammed river flows (Fulton et al., 2018, in press).
Spanish mackerel	● Increasing SST could alter the timing and/or location of spawning. ● Recent modelling predicts that by 2050 catches of Spanish mackerel in northern Australia will decline by 10 % (low-medium confidence) (Fulton et al., 2018, in press).
Scalloped hammerhead	● Potential likely impacts due to climate change are largely unknown. ● Scalloped hammerhead and blacktip sharks also had a high relative sensitivity primarily due to their low productivity, including live young and late maturity (Harry et al., 2012; Rigby et al., 2019).
Deep water snappers (*L. sebae, L. malabaricus, L. erythropterus*)	● Assessed as having the lowest sensitivity to projected climate changes, and low-moderate overall vulnerability, however knowledge of climate-related effects on these species is poor. ● Recent modelling for 'Snapper' in the adjacent NW trawl fishery area (western part of north-western Australia sub-region) and the similar species Mangrove jack in the Gulf of Carpentaria, suggest declines of 10-20 % (low-medium confidence) (Fulton et al., 2018, in press).

Gulf of Carpentaria and North-western Australia Sub-Region Recommendations

For both the Gulf of Carpentaria and north-western sub-regions, the vast majority of species assessed can be characterised as shallow nearshore and estuarine species. Further, many of these species have been the subject of research that has demonstrated strong relationships between rainfall and river flows with their recruitment, growth and catchability. Projections for rainfall to 2070 across the region are highly uncertain, making projections about likely impacts also uncertain, and depending on rainfall levels the resultant impacts could be strongly positive or negative. Until a more certain picture of future rainfall patterns in northern Australia can be established, fishery stakeholders should be prepared for the potential for less productive target fishery stocks.

Most of these nearshore/estuarine species, as well as important species of conservation interest, also have a high reliance on mangroves and/or seagrass during their life cycles. Therefore, any impacts on these habitats have the potential to indirectly impact fishery and conservation species. Although it is predicted that these habitats will remain stable across the two sub-regions, the recent significant mangrove dieback due to climatic factors in the Gulf of Carpentaria, highlights the uncertainty associated with predicting future scenarios and the potential for unforeseen events like this to occur. The impacts on mangrove-dependent species in the region of the dieback is yet to be determined, however it is likely that many species would be negatively impacted. Measures to protect and conserve these critical habitats should be maintained to enhance their resilience to cope with future climate-related impacts.

Although fishery stocks in northern Australia have historically been generally assessed as in a healthy state, the latest biennial assessment concluded that some stocks of several species were subject to overfishing and in decline or were recovering from an overfished state (barramundi, golden snapper, black jewfish). Measures are in place for these fisheries to return stocks to sustainable levels, including broader fishery reforms, and maintaining these will be important to ensure populations are as resilient as possible to the potential impacts of climate change. This will include the need for flexible and adaptive management that can respond to increased variability in catches and unforeseen events that impact stocks.

Therefore, for key local species to be resilient to future climate change and continue to support fisheries in the region, the following local actions are strongly recommended:

1. For stocks, such as king threadfin, black jewfish, golden snapper and barramundi, currently assessed as at risk from overfishing in some areas of the two sub-regions, management actions that effectively and appropriately control harvest to sustainable levels and allow stocks to rebuild are needed.
2. Protection of key habitats, especially mangroves and seagrass, will be important as a mechanism to increase their ability to cope with future climate-related impacts.
3. The planned damming of several rivers throughout the area of the two northern Australia sub-regions should consider the need for adequate flows to the sea, and flow timing, to avoid the potential to negatively impact species that rely on the water cycle as part of their life cycle.
4. Current (and future) fishery reforms in the sub-regions are urged to consider and incorporate where possible, the projected longer-term climate effects. A key element to any revised management framework should include flexibility to allow responsiveness to projected

increased variability in target species abundance and catchability, as well as the potential for unforeseen events that may also affect populations.

5. Revised assessments should be conducted in the future for the region as projected environmental changes become more certain. In particular, downscaled and less uncertain rainfall projections will enable determination of the likelihood of positive or negative impacts on estuarine-linked species.

CHAPTER 8. DISCUSSION AND CONCLUSIONS

8.1 Key Findings

Due to anthropogenic greenhouse gas emissions, the ocean is getting warmer, more acidic, and oxygen content is declining. These changes are driving large-scale effects on marine biodiversity (Portner et al. 2014) and are expected to continue to alter patterns of global marine primary productivity (Bopp et al. 2013) and biodiversity (Jones and Cheung 2015). This will have consequences for marine habitats, species and fisheries catches in many parts of the world, including the ATS region, impacting food security and livelihoods (Cheung et al. 2016, Golden et al. 2016, Lam et al. 2016). This report documents current and spatially relevant climate change projections for the ATS region, particularly for ocean ecosystems, to understand the potential impacts on marine and coastal habitats and the species they support, in particular species of conservation interest and fisheries species. The available data varies greatly among climate variables, with SST and ocean chemistry having the highest spatial resolution using the latest global climate models and scenarios, while air temperature and rainfall are locally downscaled by the Indonesian BMKG. Other variables such as sea-level, oxygen levels and ocean circulation are only available at larger regional scales.

The available data for habitats and species in the ATS region used for this study come from a range of sources, including published reports, grey literature, downscaled climate models and expert elicitation. The results of the vulnerability assessment were spatially variable and identified highly vulnerable habitats and species in each sub-region, the drivers of vulnerability, as well as those components that are vulnerable across multiple sub-regions (Table 16). Coral reefs were most vulnerable in Timor-Leste and Indonesia-Arafura, with hotspots around Manatuto and Barique Municipality, Timor-Leste and Tual in the Arafura Sea. Poor current condition and non-climate pressures, particularly land-based pollution and lack of management, were key drivers of this vulnerability. Seagrass meadows were most vulnerable in the Gulf of Carpentaria due to a hotspot of sea surface temperature increase, Indonesia-Arafura due to low connectivity and other non-climate pressures, and Timor-Leste due to increases in sea temperatures, sea level rise and lack of formal management. Mangroves and estuarine habitats were most vulnerable in Timor-Leste and western PNG, with sea level rise, rainfall declines, poor current condition, low species diversity, low connectivity and lack of management key drivers of this vulnerability (Table 16). Vulnerable of marine and coastal habitats that are connected by currents as well as the people and industries that access their resources, would benefit from consistent and complementary approaches to management that aim to minimise the drivers of vulnerability across all countries.

The identification of the most vulnerable species in each sub-region informs target species for action and management. The prioritisation of species in this study takes into account local importance, and the results can be used directly at the national/sub-regional level. Alternatively, where appropriate, using only the species vulnerability rankings will inform species for action at smaller local scales. Where species identified for action are likely to be part of a stock shared by adjacent jurisdictions, cooperative inter-jurisdictional management should be explored (see supplementary Guide for Decision-Makers). For example, two species that are highly vulnerable in all five sub-regions, green turtle and dugong, are likely to be part of inter-connecting populations shared across large areas of the ATS region. In addressing these species' vulnerability to climate change, the individual sub-regional assessment results can be used to identify the drivers of vulnerability, and therefore inform the most effective management actions at sub-regional and regional scales. Similarly, for other species, a consistent driver of vulnerability across sub-regions was their status as overfished or undefined, meaning they may also be overfished, and vulnerability results can be used to inform the most effective management actions at sub-regional and regional scales. Some of the species that were consistently assessed across multiple sub-regions as being highly or moderately vulnerable to climate change are shown in Table 16.

Table 16. *Synthesis of relative vulnerability of marine habitats and most vulnerable species common across multiple sub-regions. Data are based on vulnerability results and do not include prioritisation for importance/value. Red=high vulnerability; orange=moderate vulnerability; yellow=low vulnerability. n/a indicates species not assessed. A species name is in* ***bold*** *where they are likely to have population structures that overlap one or more jurisdictions.*

VULNERABILITY	Indonesia-Arafura	Timor-Leste	Western PNG	Gulf of Carpentaria	Northwest Australia
Coral reefs (shallow)				n/a	
Seagrass meadows					
Mangroves					
Green turtle					
Dugong					
Barramundi		n/a			
Mangrove red snapper (mangrove jack)			n/a		
Mud crab		n/a			
Black jewfish	n/a	n/a		n/a	
King threadfin	n/a	n/a	n/a		
Golden snapper	n/a	n/a	n/a		
Black teatfish		n/a		n/a	n/a

8.2 Interpreting Vulnerability and Species Prioritisation Results

While the synthesis in Table 16 presents relative vulnerability levels of habitats and species, incorporating a local importance score by sub-region to assist jurisdictions target species for action, resulted in some highly vulnerable species given a lower priority. Therefore, because the prioritisation process incorporates importance, the list of species is not identical to the list of species that have the highest vulnerability to climate change. This means the results for the species vulnerability assessment are presented in two ways for each sub-region: (1) as relative ranked vulnerability to climate change from highest to lowest, and (2) as priorities for management action based on the combination of their vulnerability and local importance/value.

Therefore, the assessment outputs can be used differently depending on sub-regional and local circumstances. It is likely that for some species in some sub-regions, the relative level of local importance will be similar and therefore a logical approach for action would be to focus on using the prioritised list of species that incorporates both vulnerability and local importance, thereby taking a sub-regional approach. However, often there will be large enough differences in levels of use and even value for a particular species at different local scales, such that the sub-regional level derived local importance scores become irrelevant. In this case, the ranked relative vulnerability species list should be used to guide priority species for action (see supplementary Guide for Decision-Makers). For example, in Timor-Leste the northern coastlines have far more coral reefs than the southern coastline meaning that the numerous coral reef-associated species assessed for Timor-Leste may have far greater local importance in the northern fishing communities than other species.

Whether species vulnerability rankings or prioritisation results are used, the detailed assessment results should be examined to provide insight into to the key drivers of vulnerability, which will guide selection of adaptation options that are appropriate either at a local, sub-regional/national or regional scale.

Importantly, many habitats and species that are highly vulnerable have compromised condition and resilience due to existing pressures, such as overfishing and land-based pollution. A notable example is wedgefish that, although only assessed in the Indonesia-Arafura sub-region, was assessed as high vulnerability, and due to its extreme risk of extinction globally affirmative action is needed to address threats to this species as a priority, and in all sub-regions. Therefore, many species and habitats are likely to be already experiencing impacts that climate change is expected to exacerbate (e.g., reduced productivity and distribution), and are less able to cope with the increased stress of climate change compared to habitats and species that are in good condition and with high resilience. Immediate action is essential if these species and habitats are to withstand future projected climate impacts.

8.3 Data Availability and Quality

Data availability was highly variable, and some assessment criteria could not be applied because the requisite information was not available (particularly regarding habitat diversity, recovery potential, connectivity, and downscaled projections for salinity and currents). Where possible, proxy data were used; for example, a proxy was used for 'coral condition' for the reef habitat assessment, however better information on condition as well as local-scale diversity would greatly improve understanding of sensitivity and hence vulnerability to climate change.

Data availability was also highly variable and often lacking for the species assessments in the Timor-Leste sub-region especially, and also the Indonesia Arafura sub-region. In particular, data on fishing levels and the status of species was lacking for these sub-regions. Key data gaps for most sub-regions were:

- Larval capability in terms of the extent that winds and currents influenced exposure.
- Larval duration.
- Physiological tolerances.
- Environmental drivers.
- Stock status.
- Availability of alternative areas with suitable habitat.

Also, stakeholder survey responses from the Timor-Leste and Indonesia Arafura sub-regions were sometimes conflicting, suggested different levels of understanding or knowledge, and therefore some responses could not be for the assessment. Therefore, a high level of uncertainty exits in the scoring for the socio-economic indicators for these two regions.

As additional data become available to fill data gaps, particularly through implementation of new activities under the ATSEA-2 program, the analysis can be updated and re-run based on the results of:

- Detailed surveys of coastal habitats (i.e., coral reefs, mangrove forests and seagrass meadows) to document current condition, diversity and recovery potential and using this as additional analysis input data.
- Identifying and documenting herbivore fish biomass as an important indicator of coral reef adaptive capacity.
- Fishery characteristics and species stock status.
- Relationships between environmental drivers and species life histories.
- Physiological tolerances of key species.
- Studies of larval capacity and duration for key species.
- Modelling or mapping availability of alternative suitable habitat and connectivity between sub-regions.
- Understanding the potential effects of changes in climate and ocean chemistry on pelagic ocean habitats and the associated changes in plankton communities, ecosystem function and dynamics.
- Improved understanding of the implications of changes in food web interactions.

CHAPTER 9. RECOMMENDATIONS

The vulnerability assessment process identified highly vulnerable habitats and species in the ATS region and five sub-regions, as well as key drivers of vulnerability. Addressing these drivers (or sources) is important for minimising vulnerability and maximising resilience of habitats and species to future climate change. Most of the habitats and species that are highly vulnerable have compromised condition and resilience due to existing pressures, such as overfishing and land-based pollution. Therefore, they are expected to experience climate change impacts sooner than habitats and species that are in good condition and with high resilience, thus making immediate action essential. Targeted recommendations for habitats and species for each sub-region were provided in earlier sections (Sections 6 and 7, respectively). The recommendations below are applicable to all habitats or species across all sub-regions in the ATS project area (summarised in Table 18) and are aimed at addressing common drivers of climate change vulnerability, that is, current pressures that undermine condition and/or resilience. Stakeholders should also refer to their respective individual sub-region recommendations.

9.1 Universal Recommendations

1. Effective mitigation to address multiple chronic cumulative pressures that further compromise habitat condition and fishery populations, especially land-based pollution that drives poor water quality and unsustainable fishing, including IUU.
2. Complementary and co-ordinated management of vulnerable species that are part of shared stocks with adjacent jurisdictions, in particular between Indonesia and Timor-Leste.
3. Protection of species of conservation interest (SOCI) requires special attention since some species of marine turtle, e.g., green turtle, and dugong, were assessed as highly vulnerable in all sub-region (see Table 15). With large connected ranges and wide distributions, these vulnerable species should be protected through actions that include: restoration and/or protection of nesting and feeding habitats, improvement of local water quality, and measures to mitigate their capture (targeted and incidental).
4. Primary fisheries management (using an ecosystem-based approach to fisheries management) for stocks assessed as at risk from overfishing, that effectively and appropriately control harvest to sustainable levels and allow stocks to rebuild are urgently required. This may require more conservative measures for species with low replenishment potential, greater community awareness and education, or governance mechanisms that suit the local context, such as decentralization of fisheries management in Timor-Leste.
5. Measures that restore, conserve and protect critical habitats, including coral reefs, estuarine and wetland areas (e.g., mangroves and seagrass), that are used by multiple species during their life cycles. Such measures may include: establishing MPAs particularly in climate vulnerability hotspots, restoration of damaged habitats, prohibiting damaging practices and minimising upstream pressures, e.g., land-based pollution and clearing.
6. Identification of alternative species as a local food source to reduce community dependence on vulnerable species, thereby increasing resilience to possible future impacts on stocks.

These alternative species should be acceptable to communities, currently underutilised and have high replenishment potential.

7. Assessing potential land-use change implications on downstream marine environments is important to avoid future impacts and has been particularly highlighted in some sub-regions. Activities in catchments or watersheds also drive impacts on coastal and marine environments, through direct impacts of land-based pollutants, such as sediment and nutrients, as well as through land-use changes that can transfer livelihood pressure to marine resources or change the connectivity between land and sea, e.g., dams.

Table 17. *Summary of recommendations applicable across the ATS project area and their specific focus for each sub-region.*

RECOMMENDED ACTIONS	Indonesia-Arafura	Timor-Leste	Western PNG	Gulf of Carpentaria & northwest Australia
Address cumulative pressures	land-based pollution; IUU	land-based pollution; IUU	land-based pollution; IUU	
Co-ordinated management of shared stocks	fisheries; SOCI	fisheries; SOCI	fisheries; SOCI	fisheries; SOCI
Protection of species of conservation interest (SOCI)	limit harvest; habitat restoration; improve local water quality; shading turtle nests	limit harvest; habitat restoration; shading turtle nests	limit harvest; improve local water quality; shading turtle nests	limit harvest; shading turtle nests
Primary fisheries management for overfished stocks	All species	All species	All species	
Conserve and protect critical habitats	establish MPA; restoration; prohibit damaging practices; minimise upstream pressures	establish MPA; restoration; prohibit damaging practices; minimise upstream pressures	prohibit damaging practices; minimise upstream pressures	minimise upstream pressures, e.g., from catchments
Identify alternative food species	x	x	x	
Assess land-use change implications		Agriculture transfer to marine resources		New dams changing river flows and coastal productivity

9.2 Strategic Regional Recommendations

In addition, there are drivers of vulnerability that require longer-term cooperation between jurisdictions and further information to implement. These strategic recommendations are applicable at a regional scale, and will require coordination and support through the ATSEA-2 program.

- Current (and future) national fishery reforms to consider and incorporate where possible, the projected longer-term climate effects. A key element to any revised management framework should include flexibility to allow responsiveness to projected increased variability in target species abundance and catchability, as well as the potential for unforeseen events that may also affect populations.
- Establish cost-effective, standardised and routine monitoring in the ATS region that collects information on habitat condition, diversity and recovery potential, fish stock status and other core indicators that can be used to inform management actions and assess their effectiveness.
- Revised assessments should be conducted in the future for the region as additional data become available and projected environmental changes become more certain. In particular, downscaled and more certain rainfall projections will enable determination of the likelihood of positive or negative impacts on estuarine-dependent species.

The above recommendations provide targets for management to address the main drivers of vulnerability for habitats and species, identify where cross-jurisdictional management is needed, and opportunities for improving the assessment outputs if further data become available. While the assessment is focused on the ATS marine ecosystem and the scale of results are at the regional and sub-regional level, they can be used to inform local climate change assessments through application of local processes, outlined in the supplementary Guide for Decision-Makers.

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APPENDIX A: INDICATORS AND CRITERIA FOR ASSESSING MARINE HABITAT VULNERABILITY TO CLIMATE CHANGE

Table A1. *Indicators and criteria for* ***coral reefs (shallow and deep)*** *with those highlighted in green having available data and non-highlighted indicators not being applied due to lack of data.*

		Low=1	**Medium=2**	**High=3**
Exposure	SST+ projected (°C)	< 1.5	1.5 - 2.0	> 2.0
	SST+ historic exposure	last 10 years (SST+ inducing bleaching)	last 5 years (SST+ inducing bleaching)	last 1 year (SST+) or multiple exposures in last 5 years
	aragonite saturation zone	4+ (optimal for calcification)	3.5 (sub-optimal for calcification)	3 (marginal for calcification)
	Salinity decline	0	0.01-0.05 psu	> 0.05 psu
	Altered large-scale currents: micro-currents & productivity	no change	small to medium change in current direction or magnitude	large change in current direction or magnitude
	Intense cyclones/storms	no change	more intense but no change or decline in frequency	more intense and more frequent
	Nutrient and sediment exposure	more than every 5-year delivery of land-based pollutants (flood plumes)	once every 5-year delivery of land-based pollutants (flood plumes)	annual delivery of land-based pollutants (flood plumes)
Sensitivity	coral cover	High (> 30%)	Medium (10-30%)	Low (< 10%)
	bleaching resistance (impact history)	no exposure to thermal stress in past 10 years and/or no bleaching impacts	low bleaching impacts in past 10 years if exposed to thermal stress	high bleaching impacts in past 10 years if exposed to thermal stress
	current condition (health)	Healthy	moderate condition or status unknown	Poor condition
	Coral diversity	high species diversity	moderate species diversity	low species diversity

	rugosity	high	moderate.	low
		Low=1	**Medium=2**	**High=3**
Adaptive Capacity	Replenishment potential - coral growth & recruitment	slow growth rate (e.g., Porites dominated)/ >10 years	moderate growth rate/3-10 years	fast growth rate (e.g., Acropora dominated)/ ≤ 2 years
	connectivity	>1,000 km between reefs	10-1,000 km between reefs	<10 km between reefs
	macroalgae cover	High (> 30%)	Medium (10-30%)	Low (< 10%)
	non-climate pressures (e.g., poor WQ)	chronic pressures (e.g., poor water quality, disease, incidental catch)	some acute pressures (e.g., cyclones, storms, floods)	no or minimal other pressures
	herbivore fish biomass (g/m2)	< x kg/ha	x - y kg/ha	> y kg/ha
	unoccupied habitat/substrate	none available or suitable	limited available or moderately suitable to meet species requirements (not both)	readily available and suitable to meet species requirements
	management regime/governance	no formal management (not within an existing MPA)	within existing MPA but without enforcement or compliance	within existing MPA with effective enforcement and compliance

Table A2. *Indicators and criteria for* ***seagrass meadows*** *with those highlighted in green having available data and non-highlighted indicators not being applied due to lack of data.*

		Low=1	Medium=2	High=3
Exposure	SST+ projections (°C)	< 1.5	1.5 - 2.0	> 2.0
	SST+ historic exposure	last 10 years (SST+)	last 5 years (SST+)	last 1 year (SST+) or multiple exposures in last 5 years
	Rainfall and turbidity increase	Decreasing rainfall to <5% increase	5-10% increase	>10% increase
	Sea level rise	< 0.4 m	0.4 to 0.5 m	>0.5 m
	Altered large-scale currents: micro-currents & productivity	no change	small to medium change in current direction or magnitude	large change in current direction or magnitude
	More intense cyclones/storms	no change	more intense but no change or decline in frequency	more intense and more frequent
	Solar radiation decrease	no change	<5%	>5%
	Nutrient and sediment exposure	more than every 5-year delivery of land-based pollutants (flood plumes)	once every 5-year delivery of land-based pollutants (flood plumes)	annual delivery of land-based pollutants (flood plumes)
Sensitivity	seagrass cover (density)	High (> 60%)	Medium (30-60%)	Low (< 30%)
	thermal resistance (impact history)	no exposure to thermal stress in past 10 years and/or no impacts	low to moderate thermal impacts in past 10 years if exposed	high thermal impacts in past 10 years if exposed
	current condition (health)	Healthy	moderate condition or status unknown	Poor condition
	Seagrass diversity	high species diversity	moderate species diversity	low species diversity
		Low=1	Medium=2	High=3
Adaptive Capacity	Replenishment potential - growth & recruitment	slow growth rate (e.g., XX dominated)/> 10 years	moderate growth rate/3-10 years	fast growth rate (e.g., XX dominated)/≤ 2 years
	connectivity	isolated seagrass meadows	patchy network of seagrass meadows (5-20 km between)	network of seagrass meadows (<5 km between)

	epiphyte cover	High (> 30%)	Medium (10-30%)	Low (< 10%)
	non-climate pressures (e.g., poor WQ)	chronic pressures (e.g., poor water quality, disease, incidental catch)	some acute pressures (e.g., cyclones, storms, floods)	no or minimal other pressures
	herbivore biomass (g/m2)	< x kg/ha	x - y kg/ha	> y kg/ha
	unoccupied habitat/substrate	none available or suitable	limited available or moderately suitable to meet species requirements (not both)	readily available and suitable to meet species requirements
	management regime/governance	no formal management (not within an existing MPA)	within existing MPA but without enforcement or compliance	within existing MPA with effective enforcement and compliance

Table A3. *Indicators and criteria for* ***mangrove forests*** *with those highlighted in green having available data and non-highlighted indicators not being applied due to lack of data.*

		Low=1	Medium=2	High=3
Exposure	Air temp projection (°C)	< 3.0	3.0 to 4.0	> 4.0
	Rainfall	Increasing rainfall to <5% decrease	5-10% decrease	>10% decrease
	Sea level rise	< 0.4 m	0.4 to 0.5 m	>0.5 m
	Altered large-scale currents: micro-currents & productivity	no change	small to medium change in current direction or magnitude	large change in current direction or magnitude
	More intense cyclones/storms	no change	more intense but no change or decline in frequency	more intense and more frequent
	Altered riverflow/nutrient supply			
Sensitivity	mangrove canopy cover	Continuous canopy (90-100% cover)	Gaps in canopy (30-90% cover)	Broken canopy (<30% cover)
	current condition (health)	Healthy	moderate condition or status unknown	Poor condition
	Mangrove diversity	high species diversity	moderate species diversity	low species diversity
		Low=1	Medium=2	High=3
Adaptive Capacity	Replenishment potential - growth & recruitment	slow growth rate (e.g., XX dominated)/> 10 years	moderate growth rate/3-10 years	fast growth rate (e.g., XX dominated)/≤ 2 years
	connectivity	isolated mangrove forests	patchy network of mangroves (5-20 km between)	network of mangroves (<5 km between)
	non-climate pressures (e.g., poor WQ)	chronic pressures (e.g., poor water quality, disease, incidental catch)	some acute pressures (e.g., cyclones, storms, floods)	no or minimal other pressures
	unoccupied land inland to migrate	none available or suitable	limited available or moderately suitable to meet species requirements (not both)	readily available and suitable to meet species requirements
	management regime/governance	no formal management (not within an existing MPA)	within existing MPA but without enforcement or compliance	within existing MPA with effective enforcement and compliance

Table A4. *Species exposure indicators and criteria.*

	Environmental factor	Low = 1	Medium = 2	High = 3
Exposure	**SST increase**	Adult spends <50% of time in surface (<25 m) waters	Adult spends 50-80% of time in surface (<25 m) waters	Adult spends 80-100% of time in surface (<25 m) waters
	Changes in rainfall	Spends no time in estuarine or freshwater habitats during any life history phase	Spends <50% of time in estuarine or freshwater habitats; no critical (larvae, juvenile, spawning) life history phase in these habitats	Spends >50% of time or has critical (larvae, juvenile, spawning) part of life cycle in estuarine or freshwater habitats
	pH decline	Open ocean or deep-water species	Continental shelf species	Inshore or estuarine species
	Salinity decline	Open ocean or deep-water species	Continental shelf species	Inshore or estuarine species
	Habitat changes (loss of productivity, structure or function) (nb. this incorporates sea level rise)	Species with wide habitat preferences	Species dependent on pelagic or mangrove/estuarine habitats	Species dependent on seagrass or coral reef habitats
	Altered large-scale currents	Live young/egg bearers or no dependence on large-scale wind/current for larval dispersal/settlement	Proximate dispersal/settlement of young not entirely dependent on large-scale wind/current dispersal	Dispersal/settlement of young 100% dependent on large-scale wind/currents
	More intense cyclones/storms	Deep water or highly mobile species	Shallow water (< 25 m) and moderately mobile species	Shallow water (< 25 m) or low mobility species
	Altered riverflow/nutrient supply	Spends no time in estuarine or freshwater habitats during any life history phase	Spends <50% of time in estuarine or freshwater habitats; no critical (larvae, juvenile, spawning) life history phase in these habitats	Spends >50% of time or has critical (larvae, juvenile, spawning) part of life cycle in estuarine or freshwater habitats

Table A5. *Species sensitivity indicators and criteria.*

			Low = 1	Medium = 2	High = 3
Sensitivity	Abundance	**Fecundity – egg production**	>20,000 eggs/year	100-20,000 eggs/year	<100 eggs/year or live young
		Average age at maturity (females)	≤2 years	3-10 years	>10 years
		Generalist v. specialist (food & habitat)	Reliance on *neither* habitat or prey for any life history stage	Reliance on *either* habitat or prey for any life history stage	Reliance on *both* habitat and prey for any life history stage
	Distribution	**Capacity for larval dispersal or larval duration – hatching to settlement (benthic species), hatching to yolk sac re-adsorption (pelagic species).**	>8 weeks	2-8 weeks	<2 weeks or no larval stage
		Physiological tolerance - latitudinal coverage of adult species as a proxy of environmental tolerance.	Threshold unlikely to be exceeded for any climate variable; > 20° latitude	Physiological thresholds may be exceeded; 10-20° latitude	Threshold likely to be exceeded for one or more climate variable; < 10° latitude
	Phenology	**Environmental driver as a phenological cue (for spawning, breeding or settlement)**	No apparent correlation to environmental variable	Weak correlation to environmental variable	Strong correlation to environmental variable
		Potential for timing mismatch of life cycle events (duration of spawning, moulting or breeding season)	Continuous duration; >4 months	Moderate duration; 2-4 months	Brief duration; <2 months

Table A6. *Species adaptive capacity indicators and criteria.*

			Low = 1	Medium = 2	High = 3
Adaptive Capacity	Ecological	**Stock status**	Overfished or on the verge of overfishing	Undefined	Sustainably fished
		Replenishment potential	Late maturing (>6 years), slow growth or few young	Matures at 3-6 years, moderate growth or moderate numbers of young	Early maturing, fast growth or many young
		Suitable alternate habitat availability	Low availability of habitat outside range *or* currently near northern edge of range	Some availability of habitat outside range *or* currently near middle of range	High availability of habitat outside range *and* currently near middle of range
		Species mobility	Low mobility; can travel <2 km/day	Moderately mobile; can travel 2-10 km/day	Highly mobile; can travel >10 km/day
		Non-fishing pressures on stock	Multiple chronic pressures (e.g., poor water quality, disease, incidental catch)	Some acute pressures (e.g., cyclones, storms, floods)	No or minimal other pressures
	Socio-economic	**Resource dependence (food)**	No alternate species and/or significant gear/practice modifications required to target other species	Some alternate species that could be targeted with minor gear/practice modifications	Multiple alternate target species that could be targeted without any gear/practice modifications
		Resource dependence (livelihoods)	No alternate livelihood options and/or significant costs/technical (training, equipment, infrastructure) needs required to develop new livelihoods	Some alternate livelihood options that could be developed with moderate costs/technical (training, equipment, infrastructure) needs	Alternate livelihood options that could be developed with minimal costs/technical (training, equipment, infrastructure) needs
		Ability to change fishing practices	Not able to change	Able to change with support	Able to change without support
		Climate change awareness	Unaware	Aware and no planning steps taken	Aware and has taken preparatory action
		Governance	Inflexible or non-existent	Flexible *or* adaptive (not both)	Flexible *and* adaptive

APPENDIX B: PRIORITISATION RESULTS FOR SPECIES

Table B1. *Indonesia/Arafura sub-region local importance analysis for prioritisation of species.*

Species name	Cultural importance	Subsistence importance	Economic importance	Conservation importance	Index
Holothuria whitmaei	2	1.5	2	3	8.5
Rhynchobatus australiae	1.33	1.33	2.33	3	7.99
Lutjanus sebae	2	2	2.67	1	7.67
Lutjanus argentimaculatus	2	2	2.67	1	7.67
Eretmochelys imbricata	1.67	1.17	1.8	3	7.64
Plectropomus areolatus	1.67	1.67	2	2	7.34
Etelis carbunculus	2	2	2.33	1	7.33
Epinephelus areolatus	2	2	2	1	7
Panulirus homarus	2	1.33	2.67	1	7
Chelonia mydas	1.43	1	1.57	3	7
Lutjanus malabaricus	1.33	2	2.6	1	6.93
Lutjanus erythropterus	1.33	2	2.6	1	6.93
P. semisulcatus	2	2	2.67	0	6.67
Plectropomus leopardus	1.67	1.67	2	1	6.34
Triaenodon obesus	1.25	0.75	2.25	2	6.25
Carcharhinus limbatus	1.25	0.75	2.25	2	6.25
Trochus niloticus	2	1.67	2.5	0	6.17
Fenneropenaeus merguiensis	1.33	2	2.75	0	6.08
Diagramma labiosum	2	1.5	1.5	1	6
Lethrinus laticaudis	2	1.5	1.5	1	6
Lates calcarifer	1	1.5	2.5	1	6
Decapterus spp.	1.33	1.67	2	1	6
Carcharhinus falciformis	1	1	1.75	2	5.75
Dugong dugon	2.33	0.67	0.67	2	5.67
Scylla serrata	1.75	1.5	2.2	0	5.45
Uroteuthis duvaucelii	1.33	1.67	2.33	0	5.33

Table B2. *Western PNG sub-region local importance analysis for prioritisation of species.*

Species name	Cultural importance	Subsistence importance	Economic importance	Conservation importance	Index
Chelonia mydas	2	1	3	3	9
Lates calcarifer	1	3	3	1	8
Protonibea diacanthus	1	2	3	2	8
Dugong dugon	3	1	2	2	8
Scylla serrata	1	3	2	0	6
Triaenodon obesus	2	1	1	2	6
Holothuria whitmaei	0	0	2	3	5

Table B3. *Timor Sea sub-region local importance analysis for prioritisation of species.*

Species name	Cultural importance	Subsistence importance	Economic importance	Conservation importance	Index
Rastrelliger brachysoma	1	2	2.33	1	6.33
Amblygaster sirm	1	1.5	1.67	1	5.17
Pterocaesio tile/Caesio teres/C. luris/Paracaesio xanthura	1	1	2	1	5
Etelis carbunculus/Pristipomoides filamentosus/Aphareus rutilans	1	1	2.33	1	5.33
Mobula alfredi	1	1	2.5	2	6.5
Auxis thazard	1	1	2.67	1	5.67
Scomberomorus commerson	1	1.5	2	2	6.5
Dugong dugon	1.67	1	2.5	2	7.17
Chelonia mydas	1	1	2.67	3	7.67
Triaenodon obesus	1.5	1	2	2	6.5
Caranx melampygus	1.5	1.5	2.33	1	6.33
Macolor macularis/Macolor niger	1.5	1.5	2.33	1	6.33
Epinephelus fuscoguttatus	1	1.5	2.33	2	6.83
Siganus argenteus/S. guttatus	1	1	3	1	6
Epinephelus fasciatus	1	1	3	1	6
Thunnus albacares	1	1	3	2	7
Octopus	1.33	2	2.5	1	6.83
Lethrinus ornatus	1	1	3	1	6
Lutjanus rufolineatus	1	1	2.5	1	5.5
Lutjanus argentimaculatus	1	1	2.5	1	5.5
Ctenochaetus striatus	1	1	2	1	5
Mene maculata	1	1	3	0	5
Lutjanus rivulatus	1	1	2.5	1	5.5

Table B4. *Gulf of Carpentaria sub-region local importance analysis for prioritisation of species.*

Species name	Cultural importance	Recreational importance	Economic importance	Conservation importance	Index
Lates calcarifer	2	3	1	1	7
Fenneropenaeus merguiensis	0	1	3	0	4
Penaeus esculentus	0	0	3	0	3
P. semisulcatus	0	0	3	0	3
Scylla serrata	2	3	2	0	7
Scomberomorus semifasciatus	1	1	1	1	4
Polydactylus macrochir	1	3	1	0	5
Eleutheronema tetradactylum	1	2	1	0	4
Dugong dugon	3	0	0	2	5
Chelonia mydas	3	0	0	3	6
Carcharhinus limbatus/C. tilstoni	1	0	1	2	4
Scomberomorus commerson	1	2	1	2	6
Lutjanus argentimaculatus	0	1	1	1	3
Lutjanus malabaricus	0	1	1	1	3
Lutjanus erythropterus	0	1	1	1	3
Lutjanus sebae	0	1	1	1	3
Lutjanus johnii	0	2	1	1	4
Sphyrna lewini	1	0	1	3	5

Table B5. *North-western Australia sub-region local importance analysis for prioritisation of species.*

Species name	Cultural importance	Recreational importance	Economic importance	Conservation importance	Index
Lates calcarifer	2	3	1	1	7
Lutjanus johnii	0	3	1	1	5
Protonibea diacanthus	1	3	1	2	7
Scomberomorus semifasciatus	1	2	2	1	6
Scylla serrata	2	3	2	0	7
Penaeus esculentus	0	0	3	0	3
Fenneropenaeus merguiensis	0	1	3	0	4
P. semisulcatus	0	0	3	0	3
Polydactylus macrochir	1	3	1	0	5
Scomberomorus commerson	1	3	1	2	7
Pristipomoides multidens	0	1	2	1	4
Dugong dugon	3	0	0	2	5
Chelonia mydas	3	0	0	3	6
Carcharhinus limbatus/C. tilstoni	1	0	1	2	4
Lutjanus malabaricus	0	1	1	1	3
Lutjanus erythropterus	0	1	1	1	3
Lutjanus sebae	0	1	1	1	3
Sphyrna lewini	1	0	1	3	5
Lutjanus argentimaculatus	0	1	1	1	3

ATSEA-2 Regional Project Management Unit

Jl. Mertasari No.140 Sidakarya,
Denpasar 80224, Bali, Indonesia

P: +62 361 448 4147
E: infoatsea2@pemsea.org
W: www.atsea-program.com