Arafura and Timor Seas Ecosystem Action

VULNERABILITY OF THE TIMOR SEA MARINE REGION TO CLIMATE CHANGE: SUMMARY

This report is prepared by Johanna Johnson, David Welch, Dieter Tracey, Handoko Susanto, Casandra Tania and Deti Triani for The Arafura and Timor Seas Ecosystem Action Phase 2 (ATSEA-2) Project.
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SECTION 1: INTRODUCTION

BACKGROUND

The Arafura and Timor Seas (ATS) region is shared by Indonesia, Timor-Leste, Australia and Papua New Guinea. The ATS region is within two Large Marine Ecosystems; the Indonesian Sea and the North Australian Shelf and is situated at the convergence of the Pacific and Indian Oceans. The ATS region has high biodiversity but is also under pressure due to unsustainable fisheries, habitat degradation, marine and land-based pollution, loss of biodiversity and increasing human populations. Climate change is expected to exacerbate these impacts and have profound effects on the status and distribution of coastal and marine habitats, the species they support and, as a result, the communities and industries that depend on them for food and livelihoods.

Map of the Arafura and Timor Seas region shared by Indonesia, Timor-Leste, PNG and Australia. (Source: ATSEA)

This summary for Timor-Leste is based on the results of a regional climate change vulnerability assessment conducted as part of Phase 2 of the Arafura and Timor Seas Ecosystem Action project (ATSEA-2). The assessment focused on marine and coastal ecosystems in the ATS region, and results provide details on the vulnerability of marine and coastal habitats, species of conservation interest and marine species important for fisheries in the region (Johnson et al. 2021a). Understanding the sources of vulnerability helps managers and communities to prepare for and respond to climate-driven impacts and identify effective and targeted adaptation measures.

LARGE MARINE ECOSYSTEM

The Timor Sea sub-region within the ATSEA-2 Project is part of the North Australian Shelf large marine ecosystem (LME) from the north coast of Australia to the Timor Sea and Torres Strait islands. It 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 have low nutrient levels. 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).

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 *Lutjanus 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.

ECOSYSTEM STATUS AND TRENDS

The Timor-Leste sub-region covered by this summary includes waters of Timor-Leste to the south and east and the shallow continental Timor Sea (50–120 m depth). Located in the western part of the ATS, this offshore sub-region is characterised by deeper waters, containing slope, rise and abyssal (deep reef) habitats, and several geomorphic features, including the submarine valleys of the Timor Trough (Alongi 2011). 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. Mangrove forests have patchy geographic distribution in Timor-Leste and are considered to be in poor condition, due to degradation from 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).

Coral reefs include coastal fringing and long patch reefs and cover 146 km^2 of the Timor-Leste nearshore area. Long stretches of sandy beach with strong waves and surf are common on the southern Timor-Leste coast, and as a result, the nearshore waters there are turbid most of the time, therefore, 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 coral reef assessment in Nino Konis Santana National Park, the northern mainland coast and 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.

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[1]).

An analysis under ATSEA-1 (ATSEA 2012) 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 habitats and 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. 78% of fisheries in the Northern Australian LME 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, inputs from oil and gas activities, land-based runoff from coastal development (Brodie et al. 2019), and waste from fishing and shipping vessels.

COMMUNITY VULNERABILITY TO CLIMATE CHANGE

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).

Another participatory community vulnerability assessment in Timor-Leste in four inland municipalities identified: strong winds, 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 zand implementation (UNDP 2018).

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[1] HTTPS://WWW.SEAGRASSWATCH.ORG/TIMOR-LESTE/#FOOTNOTE

SECTION 2: CLIMATE CHANGE PROJECTIONS

BACKGROUND

Global climate models (GCM) are the most common tool for climate change projections. However, their large spatial resolution (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. Projections of rainfall and air temperature are available at 20 km resolution (BMKG Indonesia), sea surface temperature (SST) and ocean chemistry (pH) at 5 km resolution (NOAA), sea-level rise, El Nino Southern Oscillation (ENSO), winds and waves, storms and cyclones at a regional scale (CSIRO Australia), and for solar radiation at a global scale (IPCC).

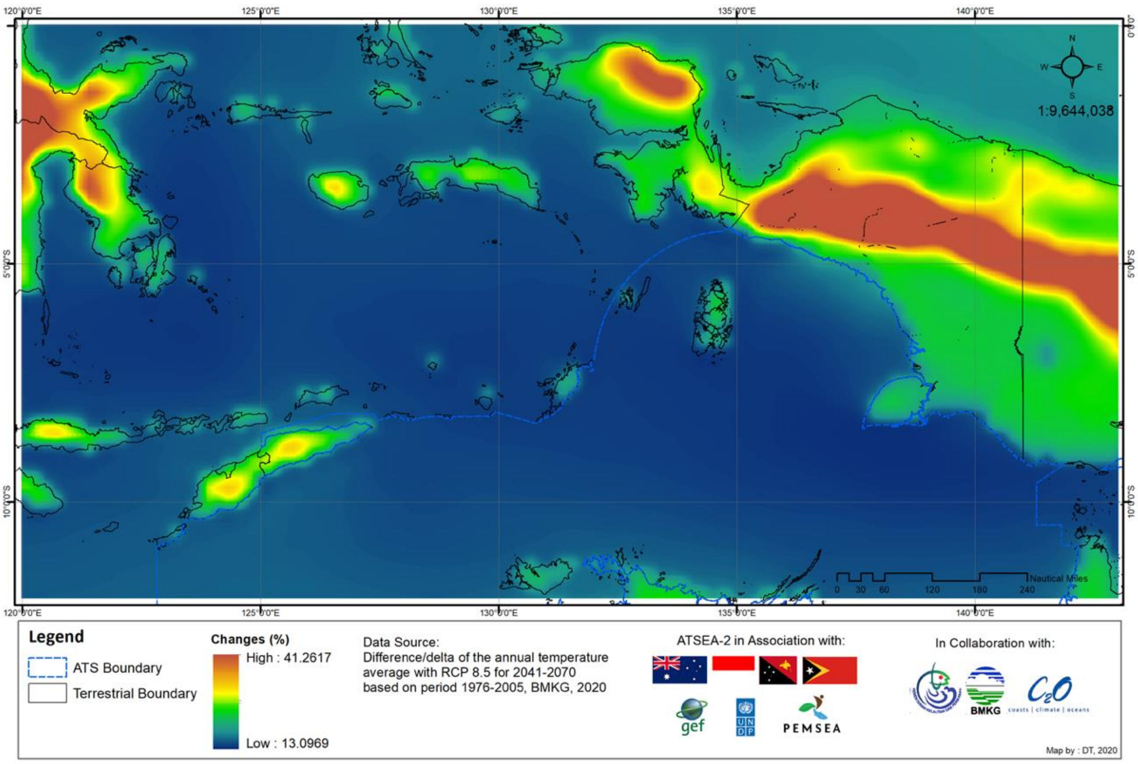
Global climate models consider a range of possible futures, known as 'emissions scenarios', that are based on different possible futures of what society will do to reduce greenhouse gas emissions (IPCC 2014). The climate change projections in this Guide are for a moderate warming scenario (RCP4.5) and a 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 strong efforts to cut greenhouse gas emissions in the next decade.

HOW TO INTERPRET THE CLIMATE CHANGE PROJECTIONS

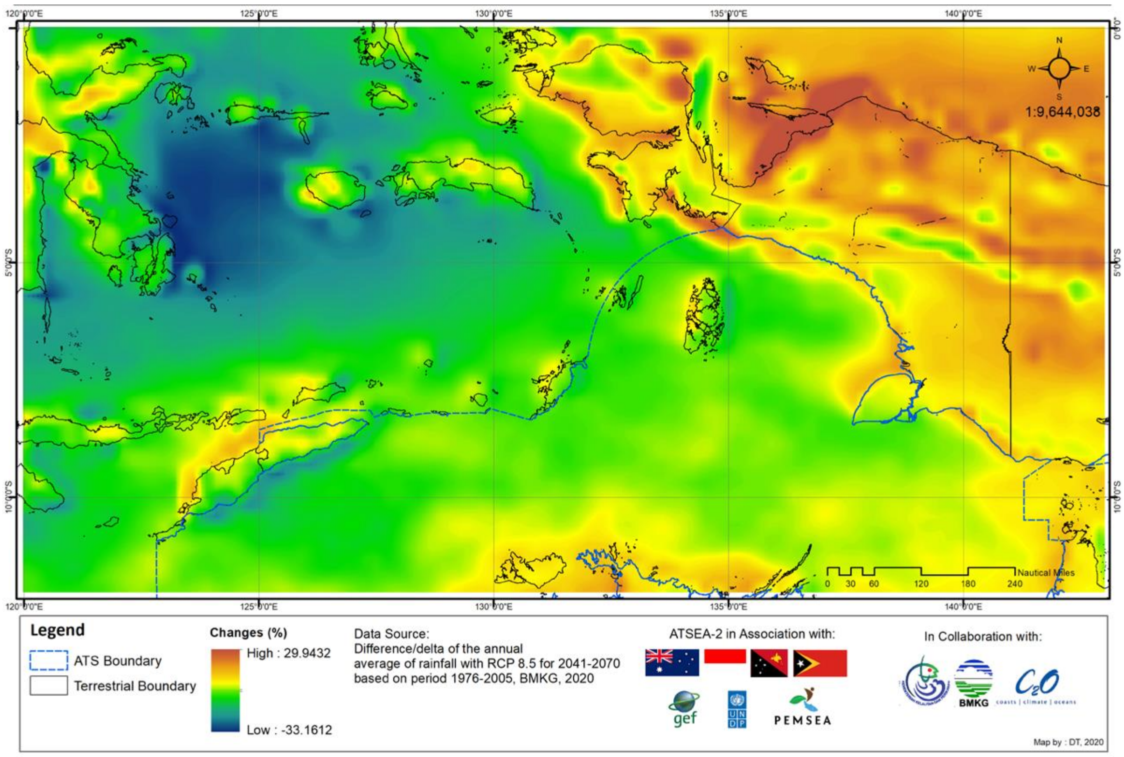
The climate change projections for the ATS region are provided as either maps showing how a particular climate variable will change between the current period and 2070, or as a range showing change into the future. The maps use colour to represent change, generally on a scale from a large change to a smaller change. For some variables, such as rainfall, the projected change ranges from negative (reduced rainfall) to positive (increased rainfall) and therefore the colours cover this full range of change. Each map caption explains what change the colours represent.

The maps can be used to view the projected climate changes that are expected to occur throughout the ATS region and inform local vulnerability assessments and adaptation planning.

AIR TEMPERATURE AND RAINFALL

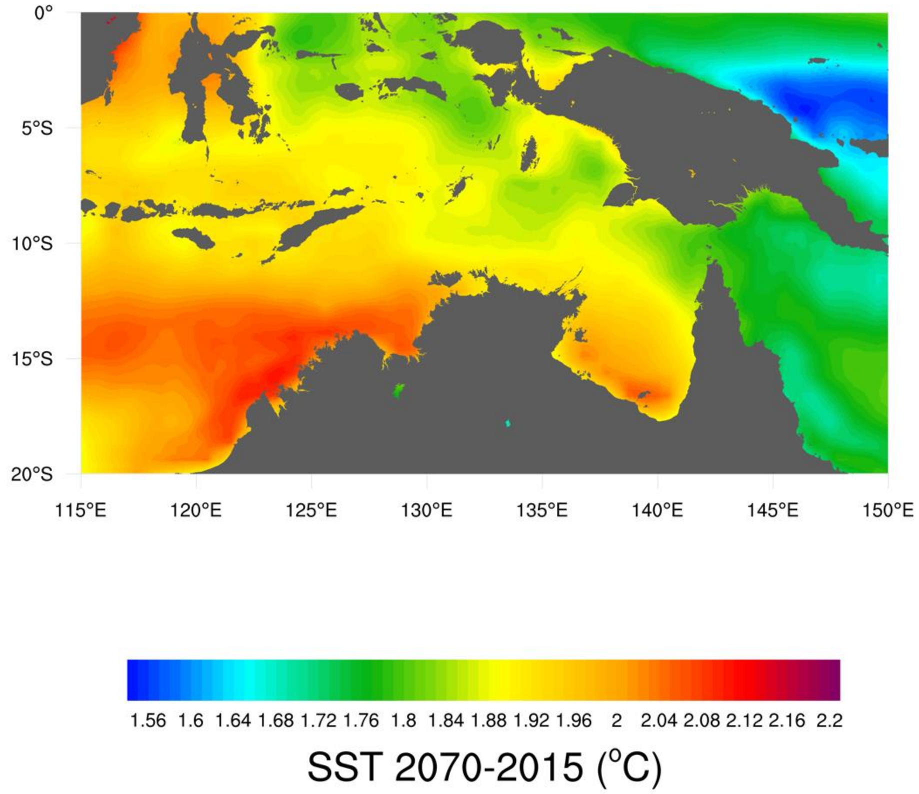


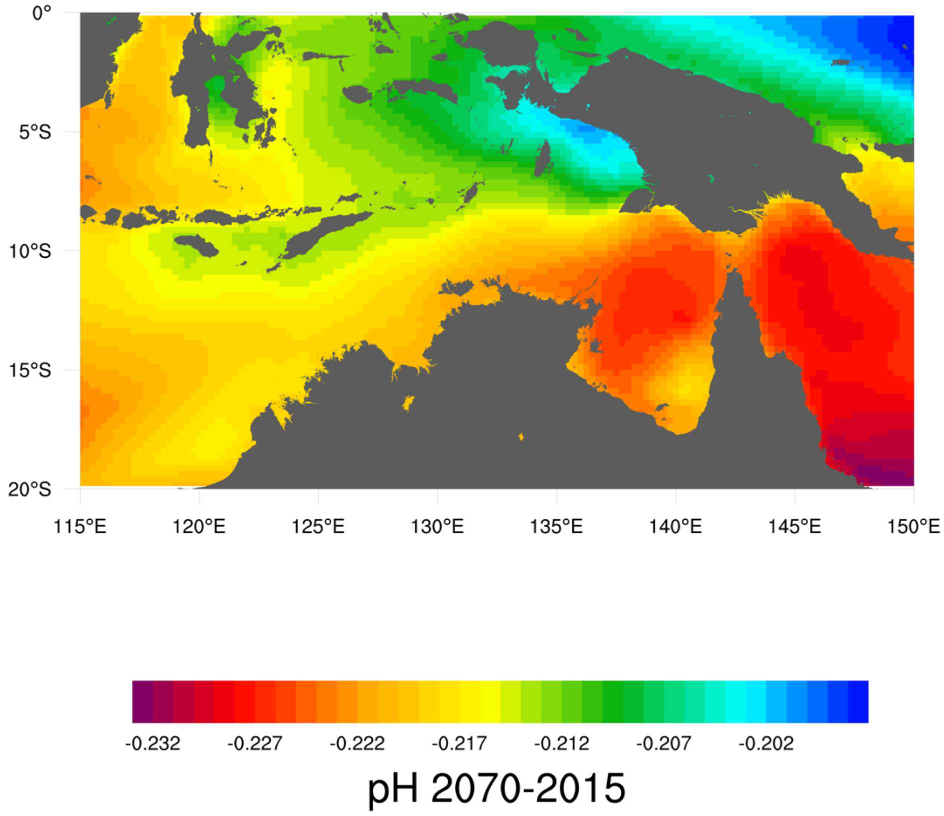
Changes in annual average of temperature with RCP 8.5 scenario for 2041-2070 in Eastern part of Indonesia



Changes in annual average of rainfall with RCP 8.5 scenario for 2041-2070 in Eastern part of Indonesia

SEA SURFACE TEMPERATURE (SST) AND OCEAN CHEMISTRY (pH)





SUMMARY OF TIMOR SEA CLIMATE CHANGE PROJECTIONS UNDER HIGH EMISSIONS SCENARIO (RCP8.5 OR SSP5-8.5) TO 2070	
VARIABLE	TIMOR SEA
Air temperature	+3.6 to +3.8 °C (land)
Rainfall	–25 to –33% (coastal); 0 to –5% (open ocean)
Sea surface temperature[1]	30.9 to 31.3 °C (+1.88 °C)
Ocean chemistry (pH)	–0.217 to –0.212
Storms and cyclones[2]	+3 to +21% maximum intensity; –6 to –34% frequency
Sea level rise	+0.5 to +0.6 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%

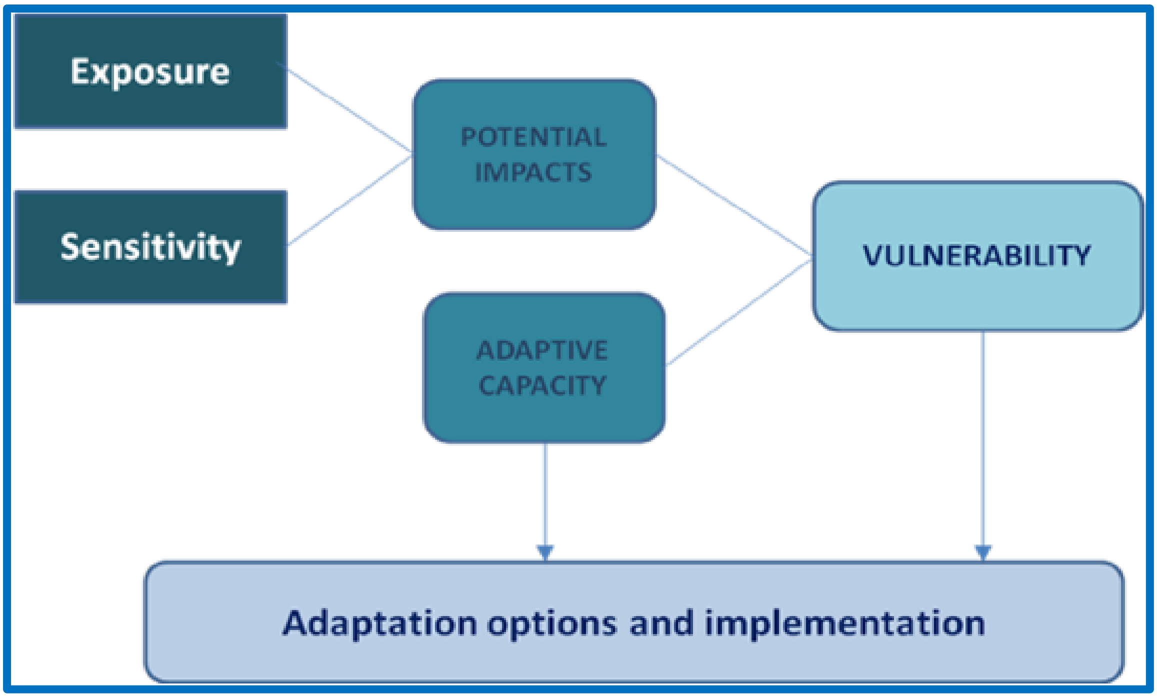
1. Increase relative to 2015 baseline
2. Global projections for 2100
3. Regional projections for 2050

SECTION 3: VULNERABILITY OF THE TIMOR SEA SUB-REGION

BACKGROUND

To prepare for and respond to climate change impacts it is necessary to understand the vulnerability (or risks) that climate change poses, driven by exposure to climate hazards, sensitivity and adaptive capacity. Understanding the sources of vulnerability is particularly important so effective and targeted adaptation actions can be identified.

The Intergovernmental Panel on Climate Change (IPCC) has defined vulnerability as the propensity or predisposition [of a system] to be adversely affected. Vulnerability encompasses a variety of concepts and elements including sensitivity [or susceptibility to harm] and lack of capacity to cope and adapt (IPCC 2014). The results of the regional climate change vulnerability assessment provide a clear guide as to the drivers of climate change vulnerability (or risk) for the ATS region that considers exposure, sensitivity and adaptive capacity.



Framework for assessing vulnerability based on the combination of exposure, sensitivity and adaptive capacity (Source: adapted from Schroter et al. 2004)

HOW REGIONAL VULNERABILITY WAS ASSESSED

The regional vulnerability assessment was conducted using a structured approach 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). In the IPCC framework, exposure to climate hazards combines with sensitivity to determine potential impacts, which are tempered by adaptive capacity to calculate vulnerability to climate change. The ATS regional assessment used indicators for exposure, sensitivity and adaptive capacity based on standard operational descriptions (see box), and criteria to conduct a comprehensive analysis of marine habitats and species (see Johnson et al. 2021a for detailed methods).

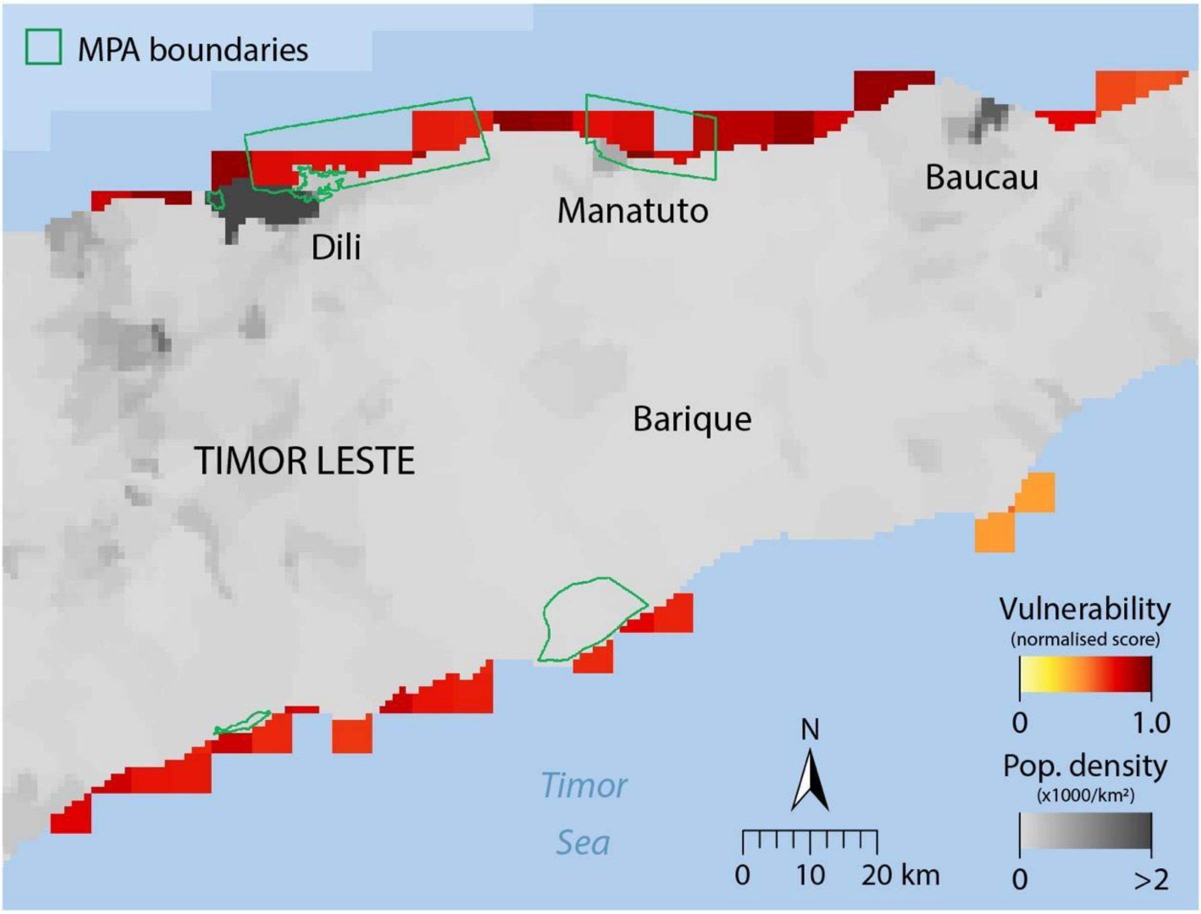
GENERAL OPERATIONAL DEFINITIONS FOR INDICATORS OF EXPOSURE, SENSITIVITY AND ADAPTIVE CAPACITY	
COMPONENT	OPERATIONAL DEFINITION
Exposure	Indicators that quantify the intensity or severity of physical environmental conditions that drive changes in state of the system
	Indicators aim to capture the expected influence of climate hazards
	Indicators may include future state may be derived from the analyses of historic, long-term trends and possible future conditions
Sensitivity	Indicators that describe the system's present state for specific properties that respond to 'exposure' factors arising from changes in climate
	While the present state is clearly the result of past processes and events, the indicators should be easy to observe, measure and monitor
	Some indicators are easier to measure using maps or specific methods
Adaptive Capacity	Indicators that characterise the ability of the system to cope with impacts associated with changes in climate
	Characteristics or processes that renew, replenish or replace conditions affected by 'sensitivity'
	Intrinsic characteristics or properties inherent to biophysical or socio-ecological systems

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 five spatial sub-units within the ATS project region – Timor Sea, Arafura Sea, western PNG, Gulf of Carpentaria, northern Australia – to deliver sub-regional results. The framework provides transparency for stakeholders since it identifies drivers of vulnerability that can inform the selection of suitable adaptation measures.

VULNERABILITY OF TIMOR SEA HABITATS

Vulnerability of all marine habitats assessed in the Timor Sea sub-region varies spatially, depending on their location. ***Coral reefs (shallow)*** around Timor-Leste are highly vulnerable to climate change, particularly reef habitats on the north coast. 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 heat stress, with coral bleaching impacts documented for reefs around the world due to marine heatwaves (extended periods of above average SST) in 1998, 2002 and 2016.

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 seaweeds) likely to become more dominant (Hoegh-Guldberg 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 fish and some invertebrates, since habitat disturbance has been shown to cause declines in reef fishery catches (Pistorius and Taylor 2009).



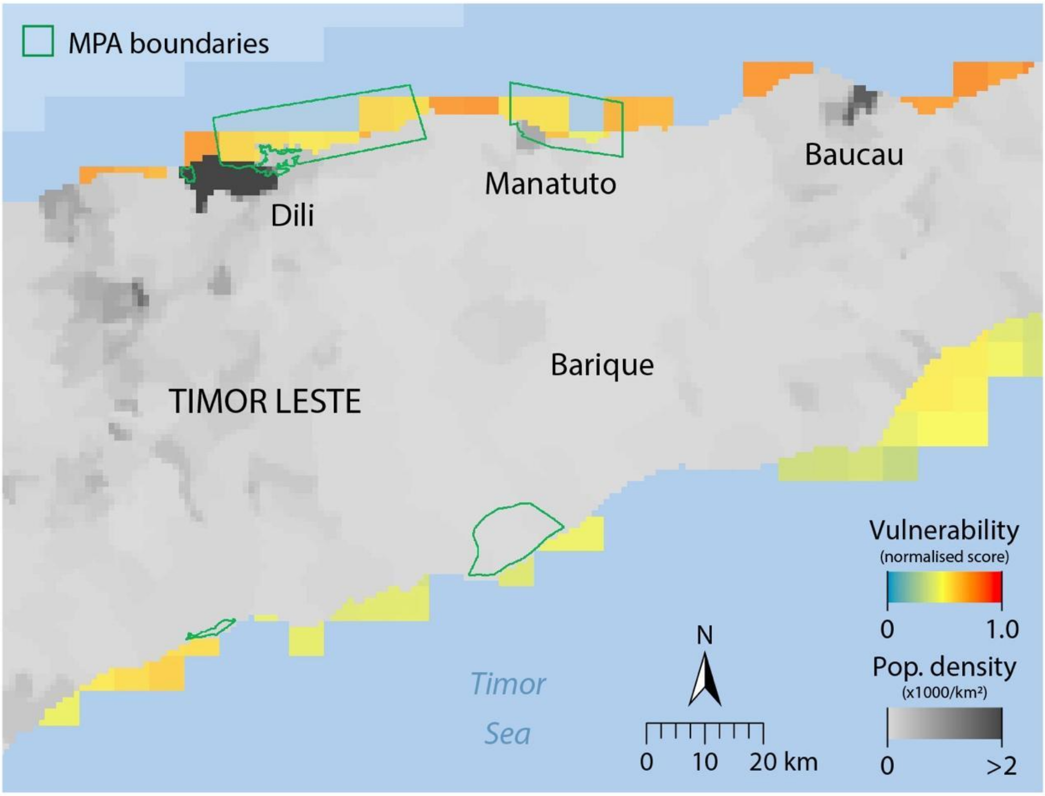
Relative vulnerability of shallow coral reefs (< 40m) in the Timor Sea sub-region. Colours represent vulnerability scores from 0 (yellow; not vulnerable) to 1.0 (dark red; very high vulnerability).

Importantly, coral reefs with poor current condition and lack of formal management will be more vulnerable to future climate change, highlighting the need for local actions to build resilience and minimise impacts. Therefore, adaptations that focus on addressing the source of vulnerability are most likely to be effective. Specifically:

- Establish local protected areas for coral reefs, to promote recovery and improve 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.

Seagrass meadows in Timor-Leste have moderate vulnerability to future climate change, particularly on the north coast. Increasing SST, sea-level rise and lack of formal management were all drivers of this vulnerability.

The dynamics of tropical seagrass meadows are heavily influenced by weather patterns, including flood and cyclone events that can physically damage seagrass, particularly in shallow areas (Waycott et al. 2011, Johnson et al. 2020), and deliver suspended sediments that increase turbidity and reduce light, resulting in reduced productivity and seagrass loss (Collier et al. 2016). Collectively, the impacts from climate change are projected to reduce seagrass condition and area, resulting in less suitable habitat for species, and reduced food resources for dugong and green turtles (Sobtzick et al. 2012, Johnson et al. 2020).



Regional relative vulnerability of seagrass in the ATS region. Colours represent vulnerability from 0 (white; not vulnerable) to 1.0 (dark red; very high vulnerability).

Ultimately, these climate-driven changes are expected to impact the condition and area of seagrass meadows, and adaptations should focus on addressing the source of vulnerability, particularly focussed in areas important for fisheries or species of conservation interest (e.g. dugong and green turtles). Specifically:

- Establish local protected areas for seagrass to promote recovery and improve condition.
- Implement management of non-climate pressures on seagrass meadows (e.g. intensive seaweed farming, overfishing, coastal mining and sand extraction).
- Reduce land-based inputs to nearshore seagrass habitats through integrated catchment management of deforestation, agriculture and coastal development.

The location of ***mangroves*** will determine their exposure to projected future climate change, particularly declining rainfall, sea-level rise. Their location on the coastal fringe and low-lying areas 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). Projected changes in rainfall, particularly reduced rain and changing seasonal cycle has implications for mangrove growth depending on whether the rainfall changes coincide with the peak growing season (Duke et al. 2012).

Importantly, mangroves with low connectivity (fragmented habitats) and limited formal management will be more vulnerable to future climate change, highlighting the need for local actions to build resilience and minimise impacts. Specifically:

- Establish local protected areas for 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 (e.g. clearing and development).

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 non-climate pressures will be important drivers of climate change vulnerability.

Projected changes in ocean circulation are expected to alter the timing, location, and extent of upwelling processes that support ***pelagic ocean habitat*** primary productivity. Changes in ocean temperature and the thermocline can also impact the availability of nutrients, affecting phytoplankton at the base of oceanic food webs and in turn, production of organisms at higher trophic levels in the food web, e.g tuna.

VULNERABILITY OF SPECIES IN TIMOR SEA

Species vulnerability was spatially variable in the Timor Sea sub-region, and the relative vulnerability of the 23 species assessed are listed below. The species assessed represent a selection of food, income and culturally important species, selected by stakeholders in Timor-Leste.

RELATIVE VULNERABILITY OF ALL SPECIES ASSESSED FOR THE TIMOR SEA SUB-REGION FROM HIGHEST TO LOWEST.

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

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 increases in SST. Another key driver was that many species are 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 because of climate change. For example, most species that had high-moderate exposure – octopus, snappers, surgeon fish, cods, emperors and fusiliers – are coral-reef associated species.

A key driver of sensitivity overall was that many species bear live young or 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.

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.

POTENTIAL IMPACTS AND FACTORS THAT INFLUENCE IMPACTS FOR MOST VULNERABLE 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 & 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.
Flowery cod	• Impacts are largely unknown. Research on another serranid, the leopard coralgrouper 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.
Mangrove red snapper	• Decreased rainfall will likely cause reduced recruitment success and growth in early life history stages, due to lowered productivity of estuarine environments, suggesting the potential for lower 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, this will be limited where there are extensive coastal infrastructure and development which act as local barriers to mangrove replenishment and migration. • 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). • Their current likely overexploited status and relatively low productivity (late maturing, long lived) hinders their capacity to adapt to climate-related impacts.
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.
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.
Striated surgeonfish	• Impacts largely unknown. Predicted declines in their preferred habitat, coral reefs, may result in lower abundance (Pratchett et al. 2011). • Projected sea surface temperature increases are likely to exceed known tolerance limits for this and other coral reef fish species, and is likely to reduce population size (e.g. Frisch et al., 2016; Munday et al., 2013; Pratchett et al., 2013).

Ruby snapper/ Crimson snapper/ Rusty jobfish	• Impacts are largely unknown, partly due to their preference for relatively deepwater habitats. Decreased rainfall will likely reduce nearshore waters productivity which may reduce recruitment and early life history survival depending on the extent that larvae and juveniles use these areas. • Their current likely overexploited status (based on overfished status in neighbouring Indonesia and each species are assumed to be part of a shared stock) and relatively low productivity hinders their capacity to adapt to potential climate-related impacts.
Moonfish	• Impacts are largely unknown. Their current likely overexploited status hinders their capacity to adapt to potential climate-related impacts.
Spotted sardinella	• Decreased rainfall will likely reduce nearshore waters productivity which will reduce growth, recruitment and abundance since, being a plankton feeder, are strongly influenced by nutrient availability (Dalzell, 1993; Brodie et al., 2007). • They are likely to be fully or overfished which will reduce their capacity to adapt to climate-related impacts.
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.
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 (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.
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 20142). • 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).
Yellowfin tuna	• Their overfished status1 (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.

ISSUES THAT CAN IMPACT FOOD SECURITY AND LIVELIHOODS

Due to global climate change, the oceans are 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 marine primary productivity (Bopp et al. 2013) and biodiversity (Jones and Cheung 2015). This will have consequences for fisheries catches in many parts of the world, including in the Timor Sea, impacting food security and livelihoods (Cheung et al. 2016, Golden et al. 2016, Lam et al. 2016).

For many of the fisheries species assessed, a consistent driver of vulnerability across sub-regions was their status as overfished or undefined (potentially overfished), and vulnerability results can be used to inform the most effective management actions at sub-regional and local scales. Some of the species that were consistently assessed across multiple sub-regions as being highly or moderately vulnerable to climate change are mangrove red snapper, barramundi and mud crab. These species, as well as many species assessed as being vulnerable in the Timor Sea sub-region, are important for food and income, and changes to their productivity will impact local food security and livelihoods.

Marine ecosystems in the Timor Sea also support internationally important megafauna, such as dugongs, marine turtles, sharks and rays, as well as fish and invertebrates that are important for industries that provide jobs and income for local people. Including demersal fisheries (e.g. coral trout and snappers), near-shore pelagic fisheries (e.g. grey mackerel and tuna), invertebrates fisheries (e.g. black teatfish and trochus), and tourism (e.g. reef scuba diving and whale watching). Maintaining the structure and function of marine ecosystems is vitally important to the continuation of these industries supporting local livelihoods, and therefore understanding the implications of climate change at a local level is key to future sustainability.

SECTION 4: RECOMMENDATIONS FOR LOCAL ACTIONS

Using the species vulnerability rankings can identify species to focus on for local action. Where species identified for action are likely to be part of a stock shared by adjacent jurisdictions, cooperative inter-jurisdictional management should be explored. 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.

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, Spanish mackerel). This resulted in all species being assessed as either overfished or likely to be approaching this status, or undefined, meaning they may 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 implemented (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.

FILLING DATA AND KNOWLEDGE GAPS

Data availability was highly variable, and some assessment criteria could not be applied because the required information was not available. 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. 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 sub-region were sometimes conflicting, suggested different levels of understanding or knowledge, and therefore some responses could not be used for the assessment. Therefore, a level of uncertainty exits in the scoring for the socio-economic indicators.

As additional data become available to fill data gaps, particularly through implementation of new activities under the ATSEA-2 Project, 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.

CONDUCT LOCAL ASSESSMENTS

While the Timor Sea sub-region results provide insight into the potential impacts and vulnerability of habitats and species to climate change, local actions are best founded on local information. Assessing the vulnerability of a local area considers the habitats, species and target fisheries at the local scale. It draws on the sub-regional results and local knowledge to select targets for action (adaptations) that address the drivers of climate change vulnerability at a local scale.

This identifies the species and habitats relevant to local communities for food, income and cultural purposes, to inform targets for action and inform relevant adaptation options.

A Guide for Decision-makers has also been prepared (Johnson et al. 2021b) and provides a non-technical summary of the main regional climate change vulnerability assessment results. It also provides decision-support tools for managers and/or NGOs as facilitators working with communities to use the sub-regional results to inform local assessments. The Guide for Decision-makers provides processes for users to understand and share the regional vulnerability results and apply these at local scales. Thereby facilitating targeted and appropriate adaptation actions for implementation at the community level.

REFERENCES AND FURTHER READING

ATSEA [Arafura and Timor Seas Ecosystem Action] program (2012) Transboundary Diagnostic Analysis for the Arafura and Timor Seas Region. Indonesia

Asian Development Bank (2014) State of the Coral Triangle: Timor-Leste. Mandaluyong City, Philippines: Asian Development Bank. ISBN 978-92-9254-526-0 (Print), 978-92-9254-527-7 (PDF), Publication Stock No. RPT146481-3.

Akib NAM, Tam BM, Phumee P, Abidin MZ, Tamadoni S, Mather PB, et al. (2015) High Connectivity in Rastrelliger kanagurta: Influence of Historical Signatures and Migratory Behaviour Inferred from mtDNA Cytochrome b. PLoS ONE 10(3): https://doi.org/10.1371/journal.pone.0119749

Alongi, D.M. (Editor), Edyvane, K., do Ceu Guterres, M.O., Pranowo, W.S., Wirasantosa, S., Wasson, R. (2011) Biophysical Profile of the Arafura and Timor Seas. Report prepared for the Arafura Timor Seas Ecosystem Action (ATSEA) Program. 32pp

Balston, J. (2009a) Short-term climate variability and the commercial barramundi (Lates calcarifer) fishery of north-east Queensland, Australia. Marine and Freshwater Research 60, 912-923.

Balston, J. (2009b) An analysis of the impacts of long-term climate variability on the commercial barramundi (Lates calcarifer) fishery of north-east Queensland, Australia. Fisheries Research, 99, 83-89.

Beale, CS, Stewart, JD, Setyawan, E, Sianipar, AB, Erdmann, MV. (2019) Population dynamics of oceanic manta rays (*Mobula birostris*) in the Raja Ampat Archipelago, West Papua, Indonesia, and the impacts of the El Niño–Southern Oscillation on their movement ecology. Divers Distrib. 2019; 25: 1472– 1487. https://doi.org/10.1111/ddi.12962

Bell, I., Ariel, E. (2011) Dietary shift in green turtles. In: McKenzie, L.J., Yoshida, R.L., and Unsworth, R. (Eds.), Seagrass-Watch News. Issue 44, November 2011. Seagrass-Watch HQ. 32 p.

Bell, J.D., Reid, C., Batty, M.J., Allison, E.H., Lehodey, P., Rodwell, L., Pickering, T.D., Gillett, R., Johnson, J.E., Hobday, A.J., Demmke, A. (2011) Chapter 12: Implications of climate change for contributions by fisheries and aquaculture to Pacific Island economies and communities. In: Vulnerability of tropical Pacific fisheries and aquaculture to climate change. Bell, J.D., Johnson, J.E., Hobday, A.J. (Eds) Secretariat of the Pacific Community, Noumea, New Caledonia.

Bell, J.D., Allain, A., Allison, E.H., Andréfouët, S., Andrew, N.L., Batty, M.J., Blanc, M., Dambacher, J.M, Hampton, J., Hanich, Q., Harley, S., Lorrain, A., McCoy, M., McTurk, N., Nicol, S., Pilling, G., Point, D., Sharp, M.K., Vivili, P., Williams, P. (2015) Diversifying the use of tuna to improve food security and public health in Pacific Island countries and territories. Marine Policy, 51: 584–591.

Blaber, S.J.M., Dichmont, C.M., Buckworth, R.C., Sumiono, B., Nurhakim, S., Iskandar, B., Fegan, B., Ramm, D.C., Salini, J.P. (2005) Shared stocks of snappers (Lutjanidae) in Australia and Indonesia: Integrating biology, population dynamics and socio-economics to examine management scenarios. Reviews in Fish Biology and Fisheries, 15(1-2), 111.

Boggs, G, Edyvane, K, de Carvalho, N, Penny, S, Rouwenhorst, J, P.Brocklehurst, Cowie, I, Barreto, C, Amaral, A, Smit, N, Monteiro, J, Pinto, P, Mau, R, Amaral, J, Fernandes, L (2009) Marine and

Coastal Habitat Mapping in Timor-Leste (North Coast) – Final Report. Ministry of Agriculture and Fisheries, Government of Timor-Leste.

Bopp, L., Resplandy, L., Orr, J.C., Doney, S.C., Dunne, J.P., Gehlen, M., Halloran, P. et al. (2013) Multiple stressors of ocean ecosystems in the 21st century: projections with CMIP5 models. Biogeosciences, 10(10): 6225–6245. Available https://doi.org/10.5194/bg-10-6225-2013

Brodie, J., Johnson, J.E., Waterhouse, J., Erdmann, S. (2019) Wastewater Pollution and Coral Reefs: Supporting Science. C_2O (Coasts Climate Oceans) for the United Nations Environment Programme (UNEP).

Brugére, C., De Young, C. (2015) Assessing climate change vulnerability in fisheries and aquaculture: Available methodologies and their relevance to the sector. FAO Fisheries and Aquaculture Technical Paper 597. Food and Agricultural Organization of the United Nations, Rome.

Buchary, E., Pitcher, T.J., Pramod G. (2008) An Estimation of Compliance of the Fisheries of Indonesia with Article 7 (Fisheries Management) of the UN Code of Conduct for Responsible Fishing. 38 pp. www.fisheries.ubc.ca/CodeConduct

California Environmental Associates (2018) Trends in Marine Resources and Fisheries Management in Indonesia: A Review. Prepared with the support of the David & Lucile Packard Foundation. 146pp.

Cheung, W.W.L., Reygondeau, G., Frölicher, T.L. (2016) Large benefits to marine fisheries of meeting the 1.5ÅãC global warming target. Science, 354(6319): 1591–1594. Available: https://doi.org/10.1126/science.aag2331

Collette, B.B., Nauen, C.E. (1983) FAO Species Catalogue. Vol. 2. Scombrids of the world. An annotated and illustrated catalogue of tunas, mackerels, bonitos and related species known to date. Rome: FAO. FAO Fish. Synop. 125(2):137.

Collier, C.J., Adams, M.P., Langlois, L., Waycott, M., O'brien, K.R., Maxwell, P.S., McKenzie, L. (2016) Thresholds for morphological response to light reduction for four tropical seagrass species. Ecological indicators, 67, pp.358-366.

Crespo, J.P. (2015) Day octopus, *Octopus cyanea*: Indonesia handline, trap, spear. Monterey Bay Aquarium Seafood Watch program report. https://seafood.ocean.org/wp-content/uploads/2016/10/Octopus-Day-Indonisia.pdf

Duke, N.C., McKenzie, J., Burrows, D. (2012) Mangrove and freshwater wetland ecosystems of Torres Strait: A review of current status. NERP project 2.2 Report. TropWater, James Cook University, Townsville, Australia, 45 p.

Edyvane, K, de Carvalho, N, Penny, S, Fernandes, A, de Cunha, CB, Amaral, A, Mendes, M., Pinto, P (2009) Conservation Values, Issues and Planning in the Nino Konis Santana Marine Park, Timor-Leste - Final Report. Ministry of Agriculture & Fisheries, Government of Timor-Leste.

Fabricius, K.E., Langdon, C., Uthicke, S., Humphrey, C., Noonan, S., De'ath, G., Okazaki, R., Muehllehner, N., Glas, M.S., Lough, J.M. (2011) Losers and winners in coral reefs acclimatized to elevated carbon dioxide concentrations. Nature Climate Change, 1(3), 165-169.

Fuentes, M.M.P.B., Hamann, M., Limpus, C.J. (2010) Past, current and future thermal profiles of green turtle nesting grounds: Implications from climate change. Journal of Experimental Marine Biology and Ecology, 383: 56-64. doi:10.1016/j.jembe.2009.11.003

Gales, N., McCauley, R.D., Lanyon, J., Holley, D. (2004) Change in abundance of dugongs in Shark Bay, Ningaloo and Exmouth Gulf, Western Australia: evidence for large-scale migration. Wildlife Research, 31: 283-290.Global Distribution of Coral Reefs (2010) UN Environment World Conservation Monitoring Centre: http://wcmc.io/MarineDataManual

Golden, C.D., Allison, E.H., Cheung, W.W.L., Dey, M.M., Halpern, B.S., McCauley, D.J., Smith, M. et al. (2016) Fall in fish catch threatens human health. Nature, 534: 317–320. Available: https://doi.org/10.1038/534317a

Halliday I.A., Robins J.B., Mayer D.G., Staunton Smith, J., Sellin, M.J. (2011) Freshwater flows affect the year-class strength of barramundi *Lates calcarifer* in the Fitzroy river estuary, central Queensland. Proceedings of the Royal Society of Queensland 116, 1-11.

Halliday, I.A., Saunders, T., Sellin, M., Allsop, Q., Robins, J.B, McLennan, M., Kurnoth, P. (2012) Flow impacts on estuarine finfish fisheries in the Gulf of Carpentaria. Final Report for FRDC Project Number 2007/002. 66pps.

Hawkes, L.A., Broderick, A.C., Godfrey, M.H., Godley, B.J. (2009) Climate change and marine turtles. Endangered Species Research, 7: 137-154.

Hoegh-Guldberg, O. (2011) The impact of climate change on coral reef ecosystems. In Coral reefs: an ecosystem in transition (391-403). Springer, Dordrecht.

IPCC [Intergovernmental Panel on Climate Change] (2019) Technical Summary [H.-O. Pörtner, D.C. Roberts, V. Masson-Delmotte, P. Zhai, E. Poloczanska, K. Mintenbeck, M. Tignor, A. Alegría, M. Nicolai, A. Okem, J. Petzold, B. Rama, N.M. Weyer (eds.)]. In: IPCC Special Report on the Ocean and Cryosphere in a Changing Climate [H.- O. Pörtner, D.C. Roberts, V. Masson-Delmotte, P. Zhai, M. Tignor, E. Poloczanska, K. Mintenbeck, A. Alegría, M. Nicolai, A. Okem, J. Petzold, B. Rama, N.M. Weyer (Eds.)].

IPCC [Intergovernmental Panel on Climate Change] (2014) Climate Change 2014: Impacts, Adaptation, and Vulnerability (Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change). New York, NY: Cambridge University Press. 2,621 pp. Available online at: http://ipcc-wg2.gov/AR5/report/final-drafts/

Jaine FRA, Rohner CA, Weeks SJ, Couturier LIE, Bennett MB, Townsend KA, Richardson AJ (2014) Movements and habitat use of reef manta rays off eastern Australia: offshore excursions, deep diving and eddy affinity revealed by satellite telemetry. Mar Ecol Prog Ser 510:73-86. https://doi.org/10.3354/meps10910

Johnson, J.E., Welch, D.J. (2016) Climate change implications for Torres Strait fisheries: Assessing vulnerability to inform adaptation. Climatic Change, DOI: 10.1007/s10584-015-1583-z

Johnson JE, Allain V, Basel B, Bell JD, Chin A, Dutra LXC, Hooper E, Loubser D, Lough J, Moore BR, Nicol S (2020) Chapter 10: Impacts of climate change on marine resources in the Pacific Island region. In: Climate Change Impacts in the Pacific, Lalit Kumar (Editor), Springer, Cham.

Johnson, J.E., Welch, D.J., Tracey, D., van Hooidonk, R. (2021a) Assessing the vulnerability of the Arafura and Timor Seas region to climate change. Report to the Arafura and Timor Seas Ecosystem Action Program (Phase 2). C_2O Consulting, Australia.

Johnson JE, Welch, DJ, Tracey D, Susanto H, Tania C, Triani D (2021b) Guide for Decision-Makers: Using the Arafura & Timor Seas Climate Change Vulnerability Assessment Results. C2O Consulting, prepared for the Arafura & Timor Seas Ecosystem Action Phase II Program. Bali, Indonesia

Jones, M.C., Cheung, W.W.L. (2015) Multi-model ensemble projections of climate change effects on global marine biodiversity. ICES Journal of Marine Science, 72(3): 741–752. Available: https://doi.org/10.1093/icesjms/fsu172

Kaufman, D., Kraay, A., Mastruzzi, M. (2008) Governance Matters VII: Aggregate and individual governance indicators 1996–2007. The World Bank, Washington, USA.

Klain, S., Eberdong, J., Kitalong, A., Yalap, Y., Matthews, E., Eledui, A., Morris, M., Andrew, W., Albis, D., Kemesong, P. (2007) Linking Micronesia and Southeast Asia: Palau sea turtle satellite tracking and flipper tag returns. Marine Turtle Newsletter, 118, 9-11.

Konservasi, Y., Nusantara, A. (2020) Snapper fishery profile in Aru district and surrounding areas, Indonesia Fisheries Management area WPP 718. Draft report prepared for the Accelerating EAFM implementation and progress of fisheries improvement project in red snapper fisheries, UNDP/ENV-ATSEA/84306/029/2019. 70p.

Lam, V.W.Y., Cheung, W.W.L., Reygondeau, G., Sumaila, U.R. (2016) Projected change in global fisheries revenues under climate change. Scientific Reports, 6: art:32607 [online] https://doi.org/10.1038/srep32607

Limalevu, L., McNamara, K.E. (2012) PACE-SD Guidebook: Participatory Assessment of Vulnerability and Adaptation. Pacific Centre for Environment and Sustainable Development, University of the South Pacific, Suva, Fiji.

Limpus, C.J. and Reed, P.C. (1985) Green sea turtles stranded by Cyclone Kathy on the south-western coast of the Gulf of Carpentaria. Australian Wildlife Research, 12: 523-533.

López-Angarita J, Hunnam KJ, Pereira M, Mills DJ, Pant J, Teoh SJ, Eriksson H, Amaral L and Tilley A. (2019) Fisheries and aquaculture of Timor-Leste in 2019: Current knowledge and opportunities. Penang, Malaysia: WorldFish. Program Report: 2019-15.

Marsh, H. and Kwan, D. (2008) Temporal variability in the life history and reproductive biology of female dugongs in Torres Strait: the likely role of sea grass dieback. Continental Shelf Research, 28: 2152-2159.

Meager, J.J. and Limpus, C.J. (2012) Marine wildlife stranding and mortality database annual report 2011. I Dugong. Conservation Technical and Data Report 2011, (1): 1-30.

Meynecke, J.O., Lee, S. Y., Duke, N., and Warnken, J. (2006). Effect of rainfall as a component of climate change on estuarine fish production in Queensland, Australia. Estuarine, Coastal and Shelf Science 69, 491–504.

Munday, P.L., Pratchett, M.S., Dixson, D.L., Donelson, J.M., Endo, G.G.K., Reynolds, A.D., and Knuckey, R. (2012) Elevated CO2 affects the behaviour of an ecologically and economically important coral reef fish. Marine Biology, DOI 10.1007/s00227-012-2111-6.

Pacifici, M., Foden, W.B., Visconti, P., et al. (2015) Assessing species vulnerability to climate change. Nature Climate Change, DOI: 10.1038/NCLIMATE2448.

Pecl, G.T., Ward, T.M., Doubleday, Z.A., Clarke, S., Day, J., Dixon, C., Frusher, S., Gibbs, P., Hobday, A.J., Hutchinson, N., Jennings, S., Jones, K., Li, X., Spooner, D., Stoklosa, R. (2014) Rapid assessment of fisheries species sensitivity to climate change. Climatic Change, 127(3-4), 505-520.

Pike, D.A., Stiner, J.C. (2007) Sea turtle species vary in their susceptibility to tropical cyclones. Oecologia, 153: 471-478.

Pike DA, Roznik EA, Bell I. (2015) Nest inundation from sea-level rise threatens sea turtle population viability. Royal Society Open Science, 2: 150127.

Pistorius, P.A., Taylor, F.E. (2009) Declining catch rates of reef fish in Aldabra's marine protected area. Aquatic Conservation: Marine and Freshwater Ecosystems, 19(S1), pp.S2-S9.

Pörtner, H.-O., Karl, D.M., Boyd, P.W., Cheung, W.W.L., Lluch-Cota, S.E., Nojiri, Y., Schmidt, D.N., Zavialov, P.O. (2014) Ocean systems. In: C.B. Field, V.R. Barros, D.J. Dokken, K.J. Mach, M.D. Mastrandrea, T.E. Bilir, M. Chatterjee et al., eds. Climate Change 2014: Impacts, adaptation, and vulnerability. Part A: Global and sectoral aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge, UK and New York, USA, Cambridge University Press. pp. 411–484. (also available at http://www.ipcc.ch/pdf/assessment-report/ar5/wg2/WGIIAR5-Chap6_FINAL.pdf

Pratchett, M.S., Bay, L.K., Gehrke, P.C., Koehn, J.D., Osborne, K., Pressey, R.L., Sweatman, H.P.A., Wachenfeld, D. (2011) Contribution of climate change to degradation and loss of critical fish habitats in Australian marine and freshwater environments. Marine and Freshwater Research, 62:1062-1081.

Pratchett, M.S., Messmer, V., Reynolds, A., Martin, J., Clark, T.D., Munday, P.L., Tobin, A.J., Hoey, A.S. (2013) Effects of climate change on reproduction, larval development, and population growth of coral trout (Plectropomus spp.). Final report to the Fisheries Research and Development Corporation, Project # 2010/554, Canberra, Australia, 69pp.

Robins, J.B., Mayer, D.G., Staunton-Smith, J., Halliday, I.A., Sawynok, B., Sellin, M.J. (2006) Variable growth rates of a tropical estuarine fish species (barramundi, *Lates calcarifer Bloch*) under different freshwater flow conditions. Journal of Fish Biology 69, 379–391.

Rohner, C.A., Pierce, S.J., Marshall, A.D., Weeks, S.J., Bennett, M.D., Richardson, A.J. (2013) Trends in sightings and environmental influences on a coastal aggregation of manta rays and whale sharks. MEPS, 482: 153-168. DOI: https://doi.org/10.3354/meps10290

Schroter and the ATEAM consortium (2004) Global Change Vulnerability – Assessing the European Human-Environment System. Potsdam Institute for Climate Impact Research, Potsdam, Germany.

Schroëter, D., Polsky, C., Patt, A.G. (2005) Assessing vulnerabilities to the effects of global change: an eight-step approach. Mitigation and Adaptation Strategies for Global Change, 10, 573-96.

Sherman, K. (2014) Adaptive management institutions at the regional level: the case of large marine ecosystems. Ocean & Coastal Management, 90, 38-49.

Sobtzick, S., Hagihara, R., Grech, A., Marsh, H. (2012) Report to the Australian Marine Mammal Centre and the National Environment Research Facility, June 2012.

Sojisuporn, P., Morimoto, A., Yanagi, T. (2010) Seasonal variation of sea surface current in the Gulf of Thailand. Coastal Marine Science, 34(1): 91-102.

Staunton-Smith, J., Robins, J.B., Mayer, D.G., Sellin, M.J., Halliday, I.A. (2004) Does the quantity and timing of fresh water flowing into a dry tropical estuary affect year-class strength of barramundi (*Lates calcarifer*)? Marine and Freshwater Research 55, 787-797.

Tibbetts, J.H. (2015) Managing Marine Plastic Pollution: Policy Initiatives to Address Wayward Waste. Environmental Health Perspectives 123:4 CID: https://doi.org/10.1289/ehp.123-A90

Tilley A, Hunnam KJ, Mills DJ, Steenbergen DJ, Govan H, Alonso-Poblacion E, Roscher M, Pereira M, Rodrigues P, Amador T, Duarte A, Gomes M, Cohen PJ (2019) Evaluating the Fit of Co-management for Small-Scale Fisheries Governance in Timor-Leste. Front. Mar. Sci. 6:392. doi: 10.3389/fmars.2019.00392

Tolan, JM, Fisher, M (2009) Biological response to changes in climate patterns: population increases of gray snapper (*Lutjanus griseus*) in Texas bays and estuaries. Fisheries Bulletin, 107: 36-44.

Tonmoy, F.N., El-Zein, A., Hinkel, J. (2014) Assessment of vulnerability to climate change using indicators: a meta-analysis of the literature. WIREs Climate Change, 5:775–792. doi: 10.1002/wcc.314.

UNDP [United Nations Development Programme] (2018) Community Vulnerability Assessment and Action Plan undertaken in 24 sucos across the Dili-Ainaro Road Development Corridor (DARDC) in Timor-Leste. UNDP, Dili, Timor-Leste.

USP-EU Global Climate Change Alliance (GCCA) (2013) Rapid Vulnerability and Adaptation Assessments of Six Communities in Timor-Leste. National Directorate for International Environmental Affairs & Climate Change, and USP, Suva, Fiji.

Waycott, M., L.J. McKenzie, J.E. Mellors, J.C. Ellison, Sheaves, M.T., Collier, C., Schwarz, A-M., A. Webb, A., Johnson, J.E., C.E Payri. (2011) Vulnerability of mangroves, seagrasses and intertidal flats. In: Bell JD, Johnson JE & Hobday AJ (Eds). Vulnerability of Tropical Pacific Fisheries and Aquaculture to Climate Change in the tropical. Secretariat of the Pacific Community, Noumea, New Caledonia.

Weaver, S. (2008) Climate Change and Food Security. A Briefing Paper prepared for an IPS Roundtable on Climate Change and Food Security Issues, 13 November 2008. Climate Change and Policy Studies.

Welch, D.J., Johnson, J.E. (2013) Assessing the vulnerability of Torres Strait fisheries and supporting habitats to climate change. Report to the Australian Fisheries Management Authority. C_2O Fisheries, Australia, 114pp. DOI 10.13140/2.1.4002.3846.

Welch, D.J., Saunders, T., Robins, J., Harry, A., Johnson, J.E., Maynard, J., Saunders, R., Pecl, G., Sawynok, B., Tobin, A. (2014) Implications of climate change on fisheries resources of northern Australia. Part 1: Vulnerability assessment and adaptations. FRDC Project No: 2010/565 Report. James Cook University, Townsville, 236pp.

Zamroni, A., Ernawati, T. (2019) Population dynamic and spawning potential ratio of Short mackerel (Rastrelliger brachysoma Bleeker, 1851) in the northern coast of Java. Indonesian Fisheries Research Journal, 25 (1): 1-10. http://dx.doi.org/10.15578/ifrj.25.1.2019.1-10

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