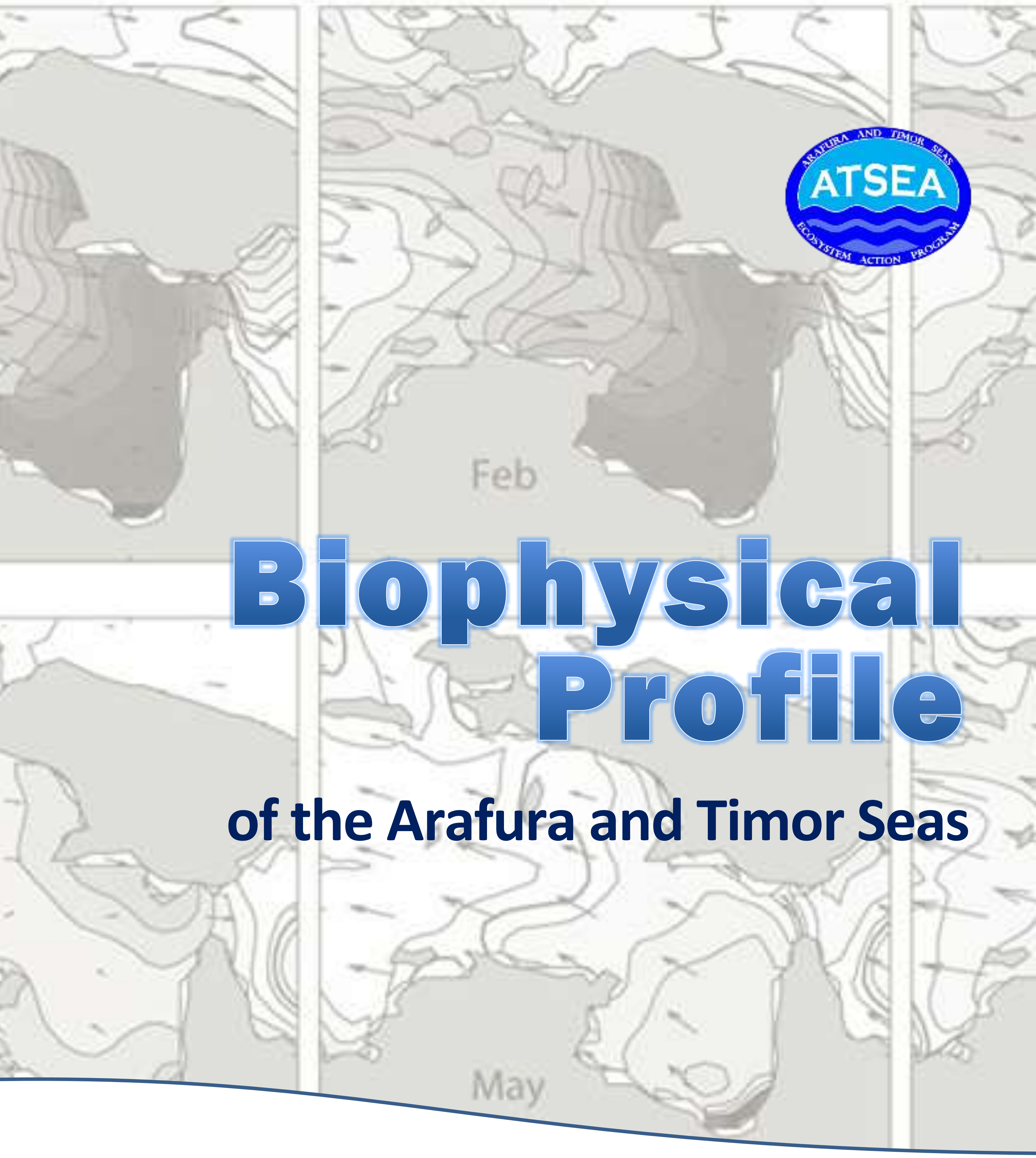

Biophysical Profile

of the Arafura and Timor Seas

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Biophysical Profile of the Arafura and Timor Seas

Report for the
Transboundary Diagnostic Analysis component of the
Arafura and Timor Seas Ecosystem Action Program

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Cover picture: Average monthly sea levels in the Gulf of Carpentaria during and after the NW monsoon. (image courtesy of Ken Ridgway, CSIRO)

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Forewords

In the process of undertaking a Transboundary Diagnostic Analysis (TDA) to assess the current state of the environment, resources and people in and around the Arafura and Timor Seas, the Arafura and Timor Seas Ecosystem Action (ATSEA) Program requires technical assessment and thematic reports directly related to ATS region such as Biophysical profile, Socio-economic profile, Causal chain analysis and prioritization of environmental concerns, and Governance analysis of drivers and impacts of environmental issues. These reports were used to prepare a separate regional TDA report which outline issues around identification of options to address national and transboundary problems proposed as part of a Strategic Action Program for the ATS region. TDA forms the basis for the development and agreement of a Regional Strategic Action Program and National Action Plans.

This report on the biopysical profile of the Arafura and Timor Seas (ATS) region contains overall views on the current condition of the region which discusses and identifies concerns and issues related to the region. The report provides important information and serves as major inputs in the TDA (Transboundary Diagnostic Analysis) process. The reports reflect a complex process of extracting relevant information and formulation of agreed regional priority issues by means of meetings and discussions with various stakeholders in national and regional levels.

The biophysical report discusses key characteristics of the Arafura and Timor Seas including Biogeography and Large Marine Ecosystems, Physical Setting, Climate, Ocean Circulation, Diversity of Seascapes, Key Coastal Habitats, 'Near-Pristine' Ecosystems, Global Stronghold for Marine Species and Ecological Connectivity. Furthermore, the report identifies 5 Primary Environmental Concerns (PEC) that have been agreed by the ATSEA Member Countries. The PECs include Unsustainable fisheries and decline and loss of living coastal and marine resources; Decline and loss of biodiversity and key marine species; Modification, degradation and loss of habitats, primarily concerning Mangroves, Coral Reefs and Seagrasses; Marine and land-based pollution due to Coastal Developments discussing Contaminants, Marine Debris and Sediments; and Impacts of Climate Change containing discussion on Predicted Impacts. Figures and tables help to clarify the case discussed.

ATSEA is eager to share the report with the relevant parties, stakeholders, academicians and general public as part of ATSEA obligation to inform public on the ATSEA Program. In this context, I am hoping that the publication of this report serves the mentioned purpose.

Jakarta, February 2012

Dr. Tonny Wagey
ATSEA Regional Project Manager

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1 INTRODUCTION

The warm tropical Arafura and Timor Seas (ATS) are crucial globally, linking the Indian and Pacific Oceans and playing an important role in global ocean circulation (Meyers 1996; De Dekker 1997). The world's climate is also greatly influenced by the El Nino-Southern Oscillation (ENSO) phenomenon and the Indian Pacific Warm Pool (de Dekker 1997; Cai *et al.* 2005; Zhong *et al.* 2005; Kug *et al.* 2006) that exists in these seas. At the regional scale, the ecosystems of both seas are important players economically and ecologically for the four littoral nations bordering the Arafura and Timor Sea: Australia, Indonesia, Timor Leste and Papua New Guinea.

The ATS region is extremely rich in living and non-living marine resources, including major fisheries and oil and gas reserves. Significantly, the ATS region exhibits high productivity that sustains both small- and large-scale fisheries, including several high-value, shared trans-boundary fish stocks (Zijlstra & Baars 1990; Blaber *et al.* 2005; Ovenden *et al.* 2009), that provide livelihoods for millions of people in the region, and make a significant contribution to food security for both, regional coastal communities and populations and also, large populations in the export market countries to the north, including China (Dalzell & Pauly 1989; Field *et al.* 2009). The ATS region forms a major part of the maritime boundary between Australia, Indonesia, Timor Leste and Papua New Guinea, providing important shipping routes, particularly connecting some Australian ports to Southeast and Northeast Asian ports and the northern Pacific Ocean. With this dependence and importance of the living and non-living resources of these two semi-enclosed seas, the sustainability and effective trans-boundary, regional management of these 'shared seas' remains a critical priority for the four nations bordering this region (Morrison & Delaney 1996; UNEP 2005).

The Arafura and Timor Seas are characterized by pronounced ecological connectivity (i.e. shared fish stocks and biodiversity, strong land-sea interactions), diverse seascapes, extensive coastal wetlands and shallow-water ecosystems and globally significant populations of marine species (especially megafauna). The region is part of the Coral Triangle which is considered to house the world's highest marine biodiversity. These seas contain the most pristine and some of the most highly threatened coastal and marine ecosystems in the world (Halpern *et al.* 2008; Tun *et al.* 2008; Burke *et al.* 2011), underscoring the urgent need for trans-boundary management.

These seas have been the subject of previous detailed UNEP GIWA assessments (UNEP 2005). In addition, major reviews and reports are also available for the marine ecosystems of northern Australia via two recent marine bioregional planning programs, i.e. North Marine Bioregional Plan and the Northwest Bioregional Plan (available on the Internet). The following biophysical profile summarises and builds on this previous work.

2 KEY CHARACTERISTICS of the ARAFURA and TIMOR SEAS

2.1 Biogeography and Large Marine Ecosystems

The waters of the tropical, semi-enclosed Arafura and Timor Seas (ATS) are shared by Indonesia, Timor-Leste, Papua New Guinea (PNG) and Australia. Biogeographically, the ATS region is located at the intersection of two major Large Marine Ecosystems (LMEs), the Northern Australian Shelf (NAS) waters to the south, and the Indonesian Sea (IS) to the north. The latter is an integral part of the Indo-Malay Pacific and 'Coral Triangle' global epicenter of tropical marine biodiversity (Allen & Werner 2002). The IS LME includes the world's largest archipelagic nation, Indonesia, with a coastline exceeding 84,000 km and an estimated 17,805 islands covering an area of 2.3 million km^2, of which 1.49% is protected. It also contains 9.98% and 0.75% of the world's coral reefs and sea mounts, respectively (Sea Around Us 2007). The NAS LME encompasses the northern continental shelf and margin of Australia and extends from the Timor Sea to the Torres Strait and includes the Arafura Sea and Gulf of Carpentaria (the largest tropical epicontinental sea in the world). The LME covers an area of nearly 800,000 km^2, of which 2.17% is protected, and contains 0.70% of the world's coral reefs (Sea Around Us 2007). Significantly, the region is also recognized as containing the most pristine, but also some of the most threatened, tropical coastal and marine ecosystems in the world (Halpern *et al.* 2008; Tun *et al.* 2008; Burke *et al.* 2011).

2.2 Physical Setting

While the ATS region is dominated by two shallow continental seas – the semi-enclosed Arafura Sea (~30 - 90 m depth) and the less enclosed Timor Sea (50 – 120 m depth, with small areas >3000 m) – the region has complex bathymetry, climate, water circulation, and diverse shallow- and deep-water habitats. The NAS LME is dominated by shallow (< 200 m) shelf waters and semi-enclosed gulfs (Gulf of Carpentaria, Van Dieman's Gulf, Joseph Bonaparte Gulf), with water depths rarely exceeding 70m across most of continental margin. The Gulf of Carpentaria, Arafura Shelf and the Sahul Shelf were drowned less than 18,000 years ago by the latest post-glacial marine transgression (Harris *et al.* 2008); these waters contain Australia's shallowest and most extensive shelf waters. In the eastern region of the ATS, the broad, continuous continental margin between Australia and Papua New Guinea formed an emergent land bridge during the last ice age. Despite high local currents, there is very little net exchange of water between the Pacific and Indian Oceans through the shallow Torres Strait (<15m at its shallowest). Within the Gulf of Carpentaria, 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.

The western and northern regions of the ATS (including the northwest margin of Australia and the IS LME) are characterised by deeper waters, containing slope, rise and abyssal habitats, and several major geomorphic features, including the submarine valleys of the Arafura Depression, the submarine terraces (120-250 m deep), and complex algal banks on the Sahul Shelf and the Timor Trough. The trough is a 850 km long, NE-SW depression (2-15 km wide, maximum depth = 3,200 m) that extends between the island of Timor and the Sahul Shelf . The Timor Trough is an integral part of the volcanic Banda Arc complex, the location of an active convergent plate margin. The IS LME is characterised by the convergence of three tectonic plates – the Eurasian, the Indo-Australian and the Pacific Plates – making the region geologically as well as topographically diverse.

2.3 Climate

The climate in the Timor and Arafura Seas is tropical maritime and is driven by the seasonal latitudinal movement of the Inter-Tropical Convergence Zone. The region is monsoonal, with tropical cyclones common in summer. The north Australian coastal areas show a gradation from the semi-arid area of northern Western Australia to the wet/dry monsoonal areas in the Northern Territory, which have a warm dry period from May to October with predominantly south-east trade winds, and a hot humid period from November to March. This hot humid period is associated with the north and north-west monsoonal maritime inflow which produces the 'wet'. The climate to the north of the Timor and Arafura Seas is similarly seasonal, but the greater topographic relief and mountainous interiors of the islands of Timor and New Guinea, particularly in Papua province, provide additional precipitation-producing mechanisms (Morrison & Delaney 1996).

Freshwater input to the Arafura Sea comes mostly from more than thirty southwest-flowing rivers in Papua and, secondarily, from some rivers flowing into the Gulf of Carpentaria and northern Australian shelf. Little freshwater flows from the Aru, Yamdena or Kei Islands to the ocean.

Freshwater input to the Timor Sea comes from northward-flowing rivers in northern Australia during summer, and seasonally from southward-flowing tributaries on Timor, although total annual precipitation on the island ranges from 1600 – 2300 mm/yr.

The mean annual surface water runoff from Australia into the Timor and Arafura Seas is 173.2 tetralitres/yr (Milliman & Farnsworth, 2011). A distinguishing feature of the coastline in the NAS LME region is the large number of unregulated rivers. As such, it is one of the few areas of Australia where most rivers remain unaltered by damming and/or removal of water and catchment modification. The drainage basin for the Gulf of Carpentaria is very large, measuring around 1,200,000 km^2 with a total annual runoff of $64k^3$. In many areas there is evidence of decelerating coastal plain progradation, with estuary infilling from the sea (Woodroffe 1995). The limited progradation, together with continuing Holocene sedimentation under a stable sea-level, has contributed to a coastal transition from widespread mangroves to widespread freshwater wetlands.

In Indonesia and Papua New Guinea, catchments draining into the Arafura and Timor Seas vary considerably from the dry Timor catchments to wet Papuan catchments. The topographic relief of the interior of New Guinea, with snow-capped mountains in excess of 5000 m, provides some high energy rivers, such as the Digul River. Well-developed mangrove waterways exist along much of the coast which is characterised by fine sediment and low relief. Supra-tidal mudflats are found along coastal areas throughout the southern ATS region, particularly the arid and dry-tropical coastline in of the southern Gulf of Carpentaria and the Kimberley. These flats concentrate salt and nutrients for extended dry periods, releasing salty, nutrient-laden water into the coastal zone during the wet season. The significance of these events to marine processes is unknown.

2.4 Ocean Circulation

As part of the Indian Pacific Warm Pool, the area plays a vital role in both global ocean circulation and the world's climate; and is where a large proportion of heat and moisture is transferred from the ocean to the atmosphere (Meyers 1996; de Dekker 1997). The warm ocean waters of the ATS (and the broader, IS LME) act as a 'heat engine' for global atmospheric circulation, with complex ocean-atmospheric dynamics thoroughly interrelated with the ENSO phenomenon. The major oceanographic feature of the ATS is the Indonesian Throughflow (ITF), a warm, low-salinity current flowing from the Pacific to the Indian Ocean, which crosses the north-western part of the ATS (Gordon & Fine 1996; Molcard *et al.* 2001; Gordon 2005) (Figure 1). The ITF carries up to 15,000,000 m^3/ s of water from the Pacific to the Indian Ocean and plays a vital role in driving the world's climate. The ITF is closely coupled to large-scale, climate phenomena, such as ENSO, the Australasian Monsoon and Indian Ocean Dipole, and at the regional level, plays a key role in shaping Indonesia and northern Australia's climate and marine ecosystems (Cai *et al.* 2005; Zhong *et al.* 2005; Kug *et al.* 2006).

With limited net flow through Torres Strait, three main outflows of the Throughflow transit through deeper ocean routes, with the two outflows through the Ombai Strait and Timor Passage accounting for > 80% of the total Indonesian Throughflow transport (–15 Sv) that enters the Indian Ocean (Gordon 2005). The ATS region thus represents a major nexus to further understand the role of this major boundary current. Water circulation is complex throughout the region, being a crucial factor driving the structure and function of the marine ecosystems and habitats in the ATS. Upper ocean circulation is determined mainly by the onset of the northwest and southeast monsoon seasons with parameters such as water density, temperature, pH and salinity driven by large-scale variations in river discharge, precipitation and major impinging ocean currents (Gordon & Fine 1996; Gordon 2005).

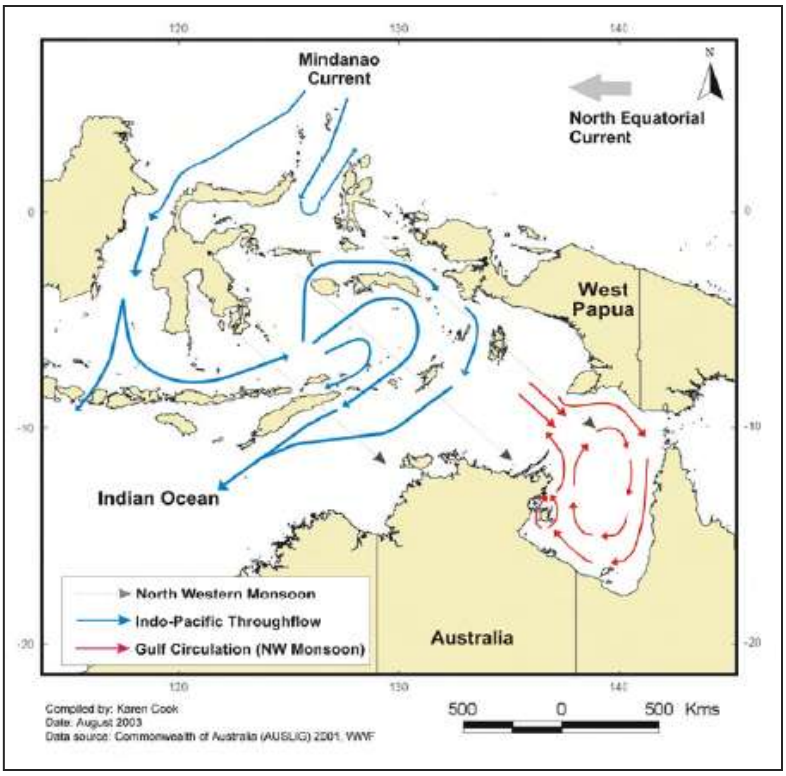

Figure 1. Diagram of Pacific to Indian Ocean Throughflow, northwest monsoon and Gulf of Carpentaria circulation pattern during the northwest monsoon.

There is seasonal fluctuation in sea-level in the Gulf of Carpentaria due to reversals in seasonal wind fields. The northwest monsoon winds set up water levels in the Gulf despite the available exit through Torres Strait, while the southeast tradewinds compound the subsequent geostrophic relaxation (Figure 2). Implications of this may be quite significant as the movement of water westward through the Arafura Sea may influence the onset of the Holloway Current and by extension the Leeuwin Current that affects the western seaboard of Australia (Ridgeway, *pers. comm.*).

The ATS is a high productivity ecosystem (>300 g $Cm^{-2}yr^{-1}$), although many areas beyond the shelf are oligotrophic. Northern Australian waters are dominated by picoplankton, especially cyanobacteria (Burford *et al.* 1999). Waters are relatively clear offshore and the euphotic zone can extend down to 100 m across the shelf. Primary productivity is limited by nutrient availability and the influence of winds and tides in mobilising sediments (Burford & Rothlisberg 1999). Nutrient discharge from rivers is restricted to the summer wet season and is highly variable within and between years. Tidal mixing is a major contributor to the nutrient dynamics of this generally shallow LME. Bottom friction acts in a manner analogous to wind stress on the surface to mix the water-column. Monsoonal winds and tropical cyclones also contribute to nutrient enrichment of shelf waters (Condie & Dunn 2006). Tropical cyclones have a pronounced effect on the continental shelf and on the coastal ecosystems of the ATS, and are a significant source of seabed disturbance, sediment movement and storm surges, breaking down stratified layers of water that form in deeper offshore waters during the wet season and measurably disrupting benthic (seabed) species in shallower waters (< 30 m).

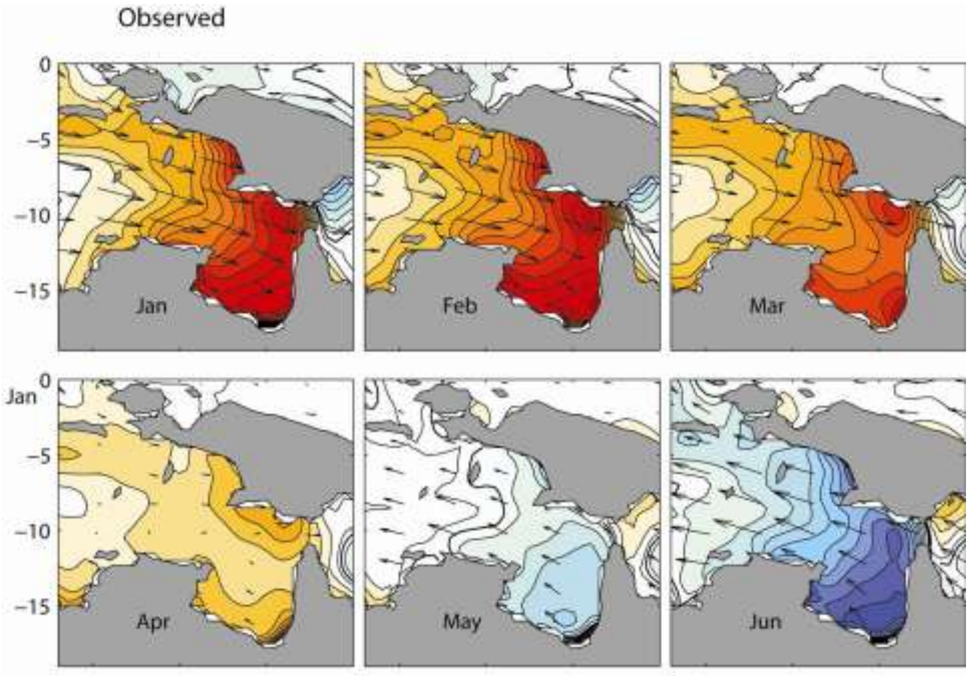

Figure 2. Average monthly sea levels in the Gulf of Carpentaria during and after the NW monsoon. (image courtesy of Ken Ridgway, CSIRO).

Localised upwellings of cooler water also occur in the ATS region as a result of internal tides - shelf waves that travel along the seafloor from the continental slope to the shelf - and topographic effects (Gordon 2005). The influence and extent of these upwellings are poorly understood. The Banda Sea and the Aru Sea are areas of extensive seasonal upwelling and downwelling in relation to the monsoons (Moore *et al.* 2003). During upwelling periods, biomass, marine productivity and rates of nutrient recycling are greatly enhanced (Zijlstra & Baars 1990). Other areas subject to upwelling episodes are the Ombai Strait, Savu Sea, Timor Sea, Gulf of Bonaparte and the Gulf of Carpentaria, especially during the monsoon seasons, and high fish catches have been related to such events. During the northwest monsoon, low-velocity upwelling occurs along coastal Timor, the western coast of Tanimbar, the southwestern coast of Papua near the Aru Islands, the northwestern coast of Australia, northern Gulf of Carpentaria, and along the Gulf of Carpentaria. Medium-scale upwelling is found on the northern coast of Timor and in Ombai Strait. Low-velocity downwelling has been found at the eastern tip of Timor, northern Tanimbar and to the northwest of the Aru Islands. Again, these are areas of either intense fishing or are an important part of migration pathways for many marine mammals. The large-scale significance of these upwelling-downwelling events to the ecology of marine food webs in this region is poorly understood.

2.5 Diversity of Seascapes

A key physical feature of the ATS (and particularly of the IS LME) is the diversity of seascapes due to the interplay between the complex geography and the biophysical processes in the region (Tomascik *et al.* 1997). At the evolutionary scale, the geological history and unique archipelagic nature of the IS LME region, and the interactions between the complex bathymetry, topography, oceanography and ecology, has resulted in a diverse range of distinct coastal, shelf and pelagic ecosystems and habitats. Numerous large and small islands partition marine waters into different seas connected by many channel passages and straits. The complex and rapid currents of the region are, in part, due to interactions with the complex archipelagic topography and seafloor features of the region.

Tides, seasonal monsoonal winds, rainfall and tropical cyclones also exert a significant influence on the biodiversity and habitats of the ATS through pronounced and seasonal effects on ocean currents, coastal boundary layers, vertical mixing and nutrient dynamics of shelf waters. Ambient water conditions throughout the ATS ranges from highly turbid conditions of the sheltered shores of the Aru Sea and the southern Gulf of the Carpentaria, to the clear waters of energetic coastlines of the islands of Nusa Tenggara Timor. Diversity of seascapes and distinct coastal and oceanic habitats is recognised as a major causal factor in the globally significant levels of coastal and marine biodiversity recorded in Indonesia and in the 'Coral Triangle' (Tomascik *et al.* 1997). High regional biodiversity is maintained because different types of reefs, with unlimited permutations of contrasting environmental conditions, are often found in close proximity to one another.

The deepwater trenches, passages and current systems of eastern Indonesia and the northern ATS region are increasingly being recognised as a global 'hotspot' and migratory pathway for many species of megafauna that frequently traverse through the region. The megafauna includes globally threatened cetaceans, such as blue, sperm, fin and humpback whales, turtles, elasmobranchs and other pelagic fish species (Dethmers *et al.* 2009). The Savu Sea, on the perimeter of the ATS, is recognised as one of the world's largest nurseries for six whale species, including humpback whales, pilot whales and the highly endangered blue whales. Whales frequently pass through the deep ocean trenches in the Savu and Alor Seas and come up to the reefs to feed.

The island of Timor is particularly important as a major and globally significant corridor for migratory marine species, being located between major outflow passages of the Indonesian Throughflow. The deepwater (3 km deep) passages of the Ombai Strait and Timor Passage, adjacent to the north and south coast of Timor, respectively, are major paths for migrating marine megafauna (Dethmers *et al.* 2009). Migration is facilitated by Timor's very narrow, active northern coastal margin where localised upwelling of deep, nutrient-rich, water, attracts marine predators and their prey very close to the shoreline. Any increase in numbers of cetaceans and the timing of cetacean migration in Timor Leste waters coincides with an increase in sea surface temperatures and with flow reversal and associated reduction in surface currents of the Indonesian Throughflow (Dethmers *et al.* 2009).

2.6 Key Coastal Habitats

Mangroves and freshwater and estuarine wetlands are a major feature of the sheltered, semi-enclosed waters of the ATS region. Indonesia (3, 112,989 ha) and Australia (977,975 ha) account for nearly 30% of the global area of mangrove forest (Giri *et al.* 2011). The coastal regions of Indonesia, Papua New Guinea and Australia contain the highest levels of mangrove diversity with 45, 44 and 39 species recorded, respectively (Spalding *et al.* 2010). The areal extent of mangroves in Timor Leste is unknown, but probably occupies a few thousand hectares of shoreline (Boggs *et al.* 2009). Mangroves are a valuable economic and ecological resource, being important breeding sites for a wide variety of wildlife (e.g., birds, fish, invertebrates); a renewable resource of timber; and accumulation sites for sediment, contaminants, carbon, and nutrients. They also offer some protection against coastal erosion, strong waves, high tides, and tsunami. The largest continuous area of mangrove forest in the ATS is along the southwest coast of Papua, although little of known of these forests.

Like mangroves, seagrasses are important coastal habitats because of their high rates of primary production, their ability to trap sediments and organic nutrients and their rich food chains. Tropical seagrasses are particularly important for turtle and dugong foraging, as well as critical nursery and feeding areas for penaeid shrimps, recreational and commercial fishes, crabs and marine crayfish. Some of the largest areas of seagrass in the ATS region are recorded in the shallow, sheltered waters of the Arafura Sea and Gulf of Carpentaria. The estimated 13,425 km^2 to 17,500 km^2 of seagrass in Torres Strait has enabled the region to be a globally important dugong and green turtle habitat. Seagrasses in the Gulf of Carpentaria are less extensive than Torres Strait, covering about 900 km^2 of seabed in the 1980s. The extent of seagrasses in the northwest of Australia remains largely unknown. Within the ATS, 12 species of seagrass have been recorded for Indonesia waters, while 15 species of seagrass are recorded for northern Australia. Within the Arafura Sea, seagrasses have been reported in the Maluku Tenggara region, in the surrounding areas of Kei, Yamdena and Aru Islands, with a total of 11 species found. In the Timor Sea, 7 species of seagrass are commonly found. On the Sahul Shelf, surveys of Ashmore Reef have recorded 5 species of seagrass and also the highest average seagrass cover (2%) of the reefs of the Sahul Shelf, with 22.13 km^2 of seagrass beds (>10% cover) (Brown & Skewes 2005). In Timor Leste, seagrass meadows are limited and primarily confined to inshore coral reefs and shallow coastal lagoons (Boggs *et al.* 2009). In a recent survey of the northern coast, a total of 5 species, and an estimated area of 2,200 ha of seagrass has been recorded (Boggs *et al.* 2009, Edyvane *et al.* 2009).

Due to the semi-enclosed nature of the ATS, coral reef development is largely restricted to the clearer waters (and energetic coastlines) of the offshore islands of eastern Indonesia, Nusa Tenggara Timur and Maluku region (Tomascik *et al.* 1997), Timor Leste (Boggs *et al.* 2009) and the edge of the continental margin of the northern Australian Shelf, the Sahul Banks (Heyward *et al.* 1997) and in the Torres Straits. In contrast, coral reefs along the southern coast of Papua are poorly developed due to high river flow and subsequent turbidity. In the Timor Sea, fringing coral reefs are found around the islands of Timor, Tikus, Burung, Kera, Semau, Kambing, Mera and Rote. The vast majority of the ATS is dominated by shallow shelf sediments and turbid waters – conditions unsuitable for reef development. On Australia's northern shelf, approximately 97% of the shelf is dominated by shallow-water sediments, mostly <70 m depth.

Along the continental margin within the NAS LME, extensive systems of reefs occur at the shelf edge (Heyward *et al.* 1997; Wells & Allen 2005). This shelf edge is characterised by a nearly continuous chain of submerged carbonate banks that rise from water depths of 150 m, with some banks rising from depths of 300m . There is also considerable difference between the reef fauna of these shelf edge coral reefs and reefs present on continental shorelines (Wells & Allen 2005). North of Ashmore Reef (Sahul Shelf), the reefs are made mostly of the coralline algae *Halimeda* as well as the skeletons of foraminifers and molluscs in lesser amounts. South of (and including) Ashmore Reef, the reefs are mostly constructed of hard corals skeletons. This zonation is caused by upwelling of cooler, nutrient-rich water from the Indian Ocean, which provides ideal conditions for hard coral development. North of this latitude, water temperatures are too high due to shallow water depths and throughflow of warm equatorial waters (Heyward *et al.*, 1997).

Reports on the nature and extent of coral reefs, particularly in the inshore regions of the ATS, are very limited. Coral development in the Gulf of Carpentaria is limited (Weipa, Wellesley Islands, Groote Eylandt, and Cape Wilberforce). However, a 2003 survey revealed large tabletop-like coral reef structures 40-50 m deep in the southern part of the Gulf, including the 100 km^2 Big Reef, which has luxuriant growth similar to platform reefs in the Great Barrier Reef. Similar, deeper water, reefs may occur in this area (Harris *et al.* 2008), including extensive, pristine fringing reefs in the Kimberly region.

2.7 'Near-Pristine' Ecosystems

In contrast to some of the densely populated northern (IS LME) regions of the ATS, the southern coastal and marine waters of the NAS LME are sparsely populated, with relatively undisturbed catchments, resulting in 'near- pristine', globally significant, marine habitats and biodiversity (Halpern *et al.* 2008). The NAS LME contains some of the largest, pristine catchments, tidal estuaries, coastal wetlands, coastal savannah, 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.

The coastal and marine biodiversity and resources of IS LME (and the Coral Triangle region) is under serious threat, with increased exploitation fuelled by exploding population growth (Tun *et al.* 2008; Burke *et al.* 2011). The extensive coastal zone of Indonesia supports approximately 60% of its 212 million people; 67% of Indonesia's 7,000 coastal villages are located adjacent to coral reefs and thus heavily dependent on the reefs and their associated products for consumption and livelihoods. In 2008, this serious and recognized threat to Indonesia's coral reefs (and food security) was the major catalyst for the formation of the major regional marine conservation program, the 'Coral Triangle Initiative' (Tun *et al.* 2008).

In a recent global re-assessment of coral reefs 'at risk', Indonesia and Timor Leste were identified as being in serious immediate social and economic vulnerability, with high to very exposure and reef dependence, and low to medium adaptive capacity (Burke *et al.* 2011).

Although a similar assessment for the region's mangrove forests has not been done, most of the tidal forests on the islands of Timor and eastern Indonesia have been greatly disturbed; near-pristine forests exist only in small patches along the southwest Papuan coast and along sheltered areas of the northern Australian coast.

2.8 Global Stronghold for Marine Species

Due primarily to remoteness and lack of human disturbance, the southern waters of the ATS are recognized as a major global stronghold for many coastal and marine megafauna including migratory, rare, threatened and endangered marine species, such as nesting colonies of shorebirds and seabirds, cetaceans (Corkeron *et al.* 1997), dugongs (Marsh *et al.* 2004; Saalfeld & Marsh 2004), sharks and rays, sawfish, turtles and sea snakes (Whiting & Guinea 2005). Many of these marine species and their habitats are undergoing rapid decline in the IS LME and also throughout Southeast Asia. With healthy populations, high species diversity and intact coastal, estuarine and marine habitats, the NAS LME is now a regional and global refuge for many species and will increasingly play a crucial role in maintaining biodiversity.

NAS LME waters contain 5 out of 7 world's turtle species, including globally significant populations of Green, Hawksbill and Flatback turtles, and the largest rookeries of Olive Ridley turtles in Australia and in the Southeast Asia-Western Pacific biome. All species within the NAS LME are exposed to significant threats to their survival. Two-thirds of the world's population of Flatback turtles breeds within the NAS LME with a major part of them foraging within the area.

2.9 Ecological Connectivity

Shallow continental shelves and semi-enclosed gulfs have resulted in strong connectivity in oceanographic processes and ecological processes, such as the movements of pelagic and migratory species. For instance, studies on offshore demersal snapper fisheries have clearly identified shared fished stocks in the ATS, such as the *Lutjanus malabaricus, L.erythropterus* and *Lutjanus argentimaculatus* (Blaber *et al.* 2005; Salini *et al.* 2006). This information has been critical in developing joint cooperative and complementary fisheries management arrangements in the ATS between Indonesia and Australia (Blaber *et al.* 2005). Similarly, recent genetic studies on two commercially harvested elasmobranch species (*Prionace glauca*, *Sphyrna lewini*) have shown no genetic differences between Australian and Indonesian populations – prompting calls for co-management of these shared stocks (Ovenden *et al.* 2009).

In addition to shared fish stocks, globally significant populations of migratory protected species (turtles, dugongs, cetaceans, sawfishes, elasmobranchs) are found throughout the ATS region, with major outflow passages of the Indonesian throughflow providing major migratory pathways for some of these species. Mark–recapture, satellite-telemetry studies and genetic studies are beginning to provide valuable information and insights about movements of individuals, and specifically, the magnitude and complexity of the migratory connectivity of key marine species (Stevens *et al.* 2000; Dethmers *et al.* 2006, 2010; Phillips *et al.* 2011, Sulaiman *et al.* in press).

Similarly, for the conservation and management of benthic ecosystems in the ATS, recent genetic studies on coral reefs in northwestern Australia are improving our understanding of the scale and patterns of dispersal and gene flow connectivity of coral species and isolated reef systems (Underwood *et al.* 2009). These connectivity studies are critical for spatial management of coral reef ecosystems, particularly in planning and establishing Marine Protected Areas.

The ATS region is also characterized by strong land-sea connectivity. High standing islands in the IS LME (Timor, Papua New Guinea) and large catchment areas in the NAS LME, result in high river discharge rates 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 & Farnsworth 2011). Rivers on the islands of Sumatra, Java, Borneo, Sulawesi, Timor and New Guinea are estimated to discharge about 4.2 X 10^9 t yr^{-1} of sediment (Figure 3). These islands represent only about 2% of the land area draining into the global ocean, yet they are responsible for as much as 20 - 25% of the sediment export (Milliman *et al.* 1999). This strong coupling of land-sea processes underscores the critical need to address integrated catchment management, in managing the ATS region.

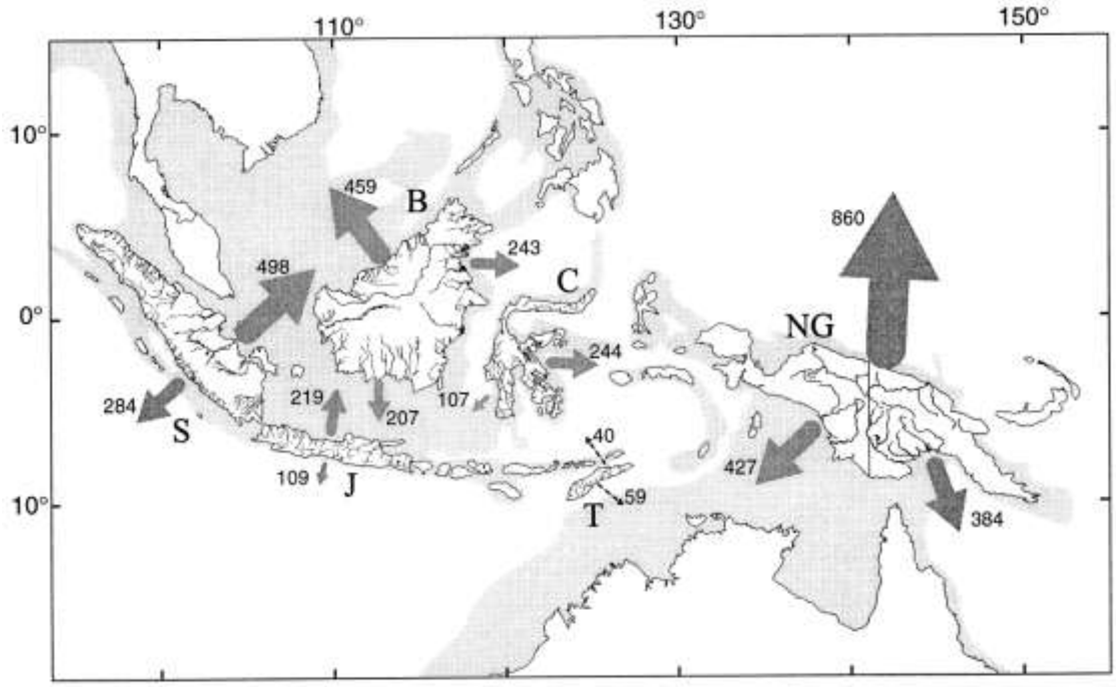

Figure 3. Sediment discharge (106 t yr-1) from islands in the ATS region. Arrow width is proportional to annual load. Letters S, J, B, C, T. and NG refer to Sumatera, Jawa, Borneo, Sulawesi, Timor and New Guinea, respectively (adapted from Milliman et al. 1999).

3 PRIORITY ENVIRONMENTAL CONCERNS

The Indonesian and Timorese coastal and catchment areas which border the Arafura and Timor Seas consist mostly of human populations following a traditional lifestyle. Human activity in these areas is commonly rural with limited areas of concentrated light industry and some scattered specific mining and logging operations; the northern Australian coast is sparsely populated by comparison.

Various companies are drilling, developing, and exploiting oil and gas reserves in the Timor Sea. Having so many people and industries within the ATS region translates over time into problems of sustainability and anthropogenic impact. There are five priority environmental concerns relating to the Arafura and Timor Seas:

- Unsustainable fisheries and decline and loss of living coastal and marine resources;
- Decline and loss of biodiversity and key marine species
- Modification, degradation and loss of coastal and marine habitats;
- Marine and land-based pollution (e.g. marine debris, sediments, oil spills)
- Impacts of climate change.

Nearly all of these concerns are interlinked; all are the result of human encroachment on poorly managed or unmanaged resources. Table 1 below gives an overview of the priority environmental concerns, key causal factors and impacts, and major references.

Table 1. Priority environmental concerns in the Arafura and Timor seas region

Priority Environmental Concerns	Key Causal Factors	Key Impacts
Unsustainable fisheries & decline & loss of living coastal & marine resources	illegal, unreported and regulated fishing; unsustainable practices; fisheries by-catch	• depletion of shared trans-boundary and pelagic fisheries – sharks/rays, red and goldband snappers, trepang, prawns/shrimp, tuna (Arafura Sea, Timor Sea) • over-exploitation of coastal fisheries resources – trepang, trochus, coral reef fisheries (Arafura Sea, Timor Leste, Gulf of Carpentaria) • fisheries 'by-catch' – shrimp/prawn trawling (Arafura Sea, Gulf of Carpentaria), red snapper (Timor Sea)
Modification, degradation & loss of coastal & marine habitats	coastal development, bottom trawling, fuel wood (mangroves), dynamite fishing, pollution (sediments)	• decline & loss of soft bottom habitats (bottom trawling) – Arafura Sea, Gulf of Carpentaria, Bonaparte Gulf • decline & loss of mangroves – Timor Leste (fuel wood), Aru Sea (coastal development) • decline & loss of coral reefs (sediments, dynamite fishing) – NTT, Maluku, Aru Sea, Timor Leste • decline & loss of seagrasses (sediments, dieback)

Priority Environmental Concerns	Key Causal Factors	Key Impacts
Marine & land-based pollution (e.g. marine debris, sediments, oil spills)	coastal development (nutrients, sediments), mining (sediments, toxicants), land degradation (sediments), oil spills, marine debris	• sediment runoff – land degradation (Dili, Timor Leste), mining activities (Gulf of Carpentaria, Aru Sea, Irian Jaya) • toxicants (coastal mining activities) – Gulf of Carpentaria (Nhulunbuy, Milner Bay, Bing Bong, Weipa, Karumba), Aru Sea (Irian Jaya), Kupang, Wetar Island • eutrophication - Darwin Harbour, Aru Sea • marine debris – Gulf of Carpentaria, Arafura Sea • oil spills & impacts – Timor Sea, southern NTT ('Montara' oil spill)
Decline & loss of biodiversity & key marine species	illegal harvesting, traditional indigenous harvest, fisheries by-catch (ghostnets, trawling, tuna long-lines), habitat loss	• marine turtles – Aru Sea, northern Australia (illegal harvesting, indigenous harvest, fisheries by-catch, marine debris, tuna long-lines) • dugongs – Aru Sea, northern Australia (indigenous harvest, fisheries by-catch, marine debris) • cetaceans – ATS (fisheries by-catch, shipping, seismic activities) • sharks/rays – ATS, northern Australia (IUU fishing, fisheries by-catch, indigenous harvest) • seasnakes – ATS, northern Australia (fisheries by-catch) • seabirds/shorebirds – ATS (fisheries by-catch, indigenous harvest)
Impacts of climate change		• ocean warming – dynamics of the Indo-Pacific Warm Pool, ocean thermostat • increased sea temperatures - northern seas warming, impacts on ocean processes, marine biodiversity (particularly marine reptiles, corals) • increased extreme climatic events (cyclonic activities, rainfall, drought) – increased cyclonic frequency & intensity • sea level rise – coastal flooding, saltwater intrusion, loss of coastal habitat & biodiversity

3.1 Unsustainable fisheries and decline and loss of living coastal and marine resources

Poorly managed or unmanaged extraction of fish, prawns and other biota, coupled with decreased viability of stock through pollution and disease, has led to overexploitation and, in many instances, to a decline in living resources within the Arafura and Timor Seas. The fisheries of the IS LME are very complex and diverse, reflecting the region's extraordinarily heterogeneous geography and species richness. While most of fish catch is artisanal, industrial fisheries contribute considerably more in terms of value since they target high-value shrimp and tuna stocks. Major species caught in the LME include tuna, sardines, anchovy, mackerel, as well as a range of reef fishes. Reef fisheries are vital to subsistence fishers in the region but are also important in supplying high value products for expanding international, national and local markets. Shrimp aquaculture has also increased rapidly during the last two decades in Indonesia.

Great uncertainties exist on the status of local fish stocks due to serious discrepancies in fisheries data and a potentially significant level of Illegal, Unreported and Unregulated (IUU) catches. In 2004, total reported landings reached 2.2 million t, with a value of US$ 1.2 billion. The mean trophic level of fisheries landings shows an increase from the early 1980s, an indication of increased reported landings of high trophic species such as tuna.

Overexploitation is widespread in the Indonesian Sea LME, with many fish stocks exploited well beyond biological limits, especially in the coastal zone, which is exploited by 85% of Indonesian fishers. In addition, foreign fleets continue to threaten Indonesian fisheries, but again, accurate data on the extent, the number of vessels and their mode of operations is inadequate. There is a live food fish trade that primarily targets groupers, Napoleon wrasse, and barramundi cod. Because of their particular life-history attributes, groupers are highly susceptible to overexploitation and the targeting of their spawning aggregations is a serious concern. In addition to taking adult groupers for direct food consumption, the live reef fish food trade also involves capture of wild fry and fingerlings supplying the grouper mariculture industry in Southeast Asia.

Arguably the best empirical evidence for overfishing comes from the Aru Sea, northern Arafura Sea, where high intensity fishing has caused overexploitation of demersal and shrimp stocks. This condition is reflected in smaller catch composition dominated by low-value shrimp and demersal fish species. Pelagic fish stocks are however still in a moderate state of exploitation. Shrimp harvests are beyond the maximum sustainable yield. Harvest level in 2001 was almost three-fold the MSY level. In 2007, the Ministry of Marine Affairs and Fisheries (MMAF) indicated that shrimp production declined to 260,000 t from 2001 level of 274,000 t (Figure 4).

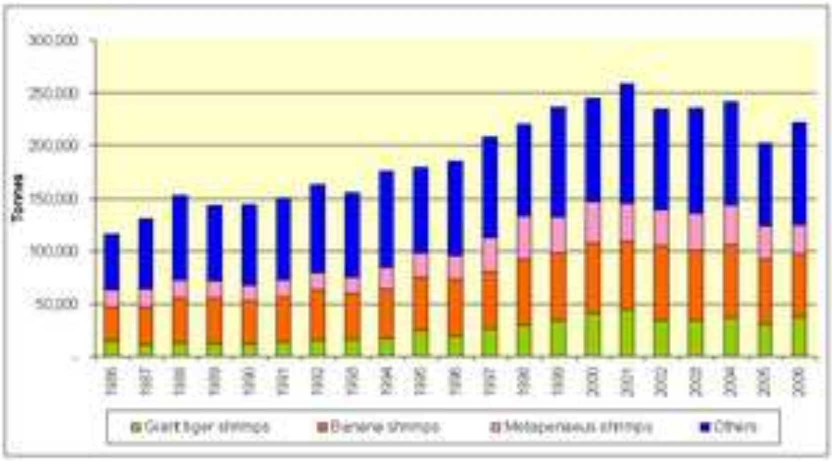

Figure 4. Shrimp production in Indonesia, 1986-2006. Source: MAFF, Indonesia.

MMAF further reported that catch per unit effort in the Arafura Sea declined from 95 kg/haul in 1974 to 38 kg/haul in 1996. There is evidence of changes in the composition of demersal fish catch as a result of heavy fishing pressure (Figure 5 & Figure 6). Analysis of species composition of caught fish for 1991, 1997 and 2003 showed that there were family variations in some major groups. There were sharp declines for the Sciaenidae group, which are the dominant species group caught in the Aru Sea. This has been observed for the family groups Pomadasydae, Synodontidae, Lutjanidae, Nemipteridae and Formionidae. On the other hand, there were signs of increasing numbers of fish caught from the family of small Leiognathidae and Mullidae. Smaller fish (TL<15 cm) have also dominated the composition of fish caught. The number of swimming crabs and squids also increased in fish catch in the Aru Sea. As a result of uncontrolled use of trawl fishing gear, the seabed has probably suffered considerable damage, made even worse by the disposal of large quantities of unwanted catch. Decomposition of this discarded by-catch tends to cause a decrease in dissolved oxygen.

Over the past several centuries many of Indonesia coral reefs have been heavily and chronically overfished, with a major loss of productivity and cascading effects to other components of the ecosystem. Overexploited stocks include many species of reef fish such as groupers and threatened and endangered species, such as sea turtle and dugong. Benthic invertebrates such as sea cucumbers and clams are also overexploited, particularly around major coastal population centres. Overexploitation of pelagic species such as shark, tuna and billfish is also evident. Catch per unit effort for this fishery has declined sharply, as has the size of the fish caught. There have also been local extinctions and reductions in market availability.

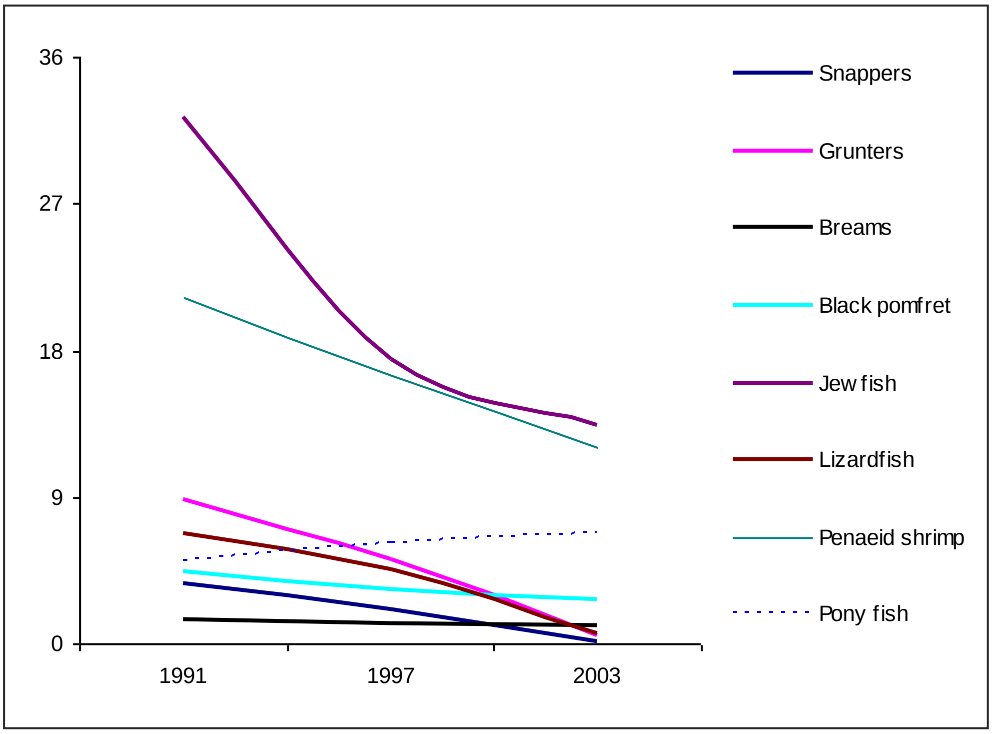

Figure 5. Trend of catch rate (%) of demersal fish in the Aru Sea. Source: MAFF, Indonesia

In contrast, fish stocks in the Northern Australian Shelf LME are small, but diverse. Commercially fished species include northern prawns, threadfin bream, skipjack tuna, Indo-Pacific anchovies, mud crab, barramundi, salmon, shark, Spanish mackerel, snappers and reef fish. In the southern Arafura Sea and Gulf of Carpentaria, the prawn fishery is almost fully exploited. Crustaceans and molluscs dominate the catch, particularly in the Gulf of Carpentaria where prawns are targeted. Shark populations have been significantly depleted as a result of the shark fin fishery. Total reported landings grew steadily to ~87,000 tonnes in 2004. The value of the reported landings showed a general increase, with a maximum value of just under US$ 300 million in 2001. Penaeid shrimps and tuna are the two most important groups in terms of value.

The long term trend of the Mean Trophic Index for the NAS LME is one of decline from 1950 to the mid-1980s, followed by an increase which coincides with the increased landings of tuna and other large pelagic species. The pattern is confirmed by the Fishing-in-Balance (FiB) index, which also suggests a steady expansion. Only a few of the exploited stocks can be considered collapsed or overexploited. The majority of the reported landings come from fully exploited stocks.

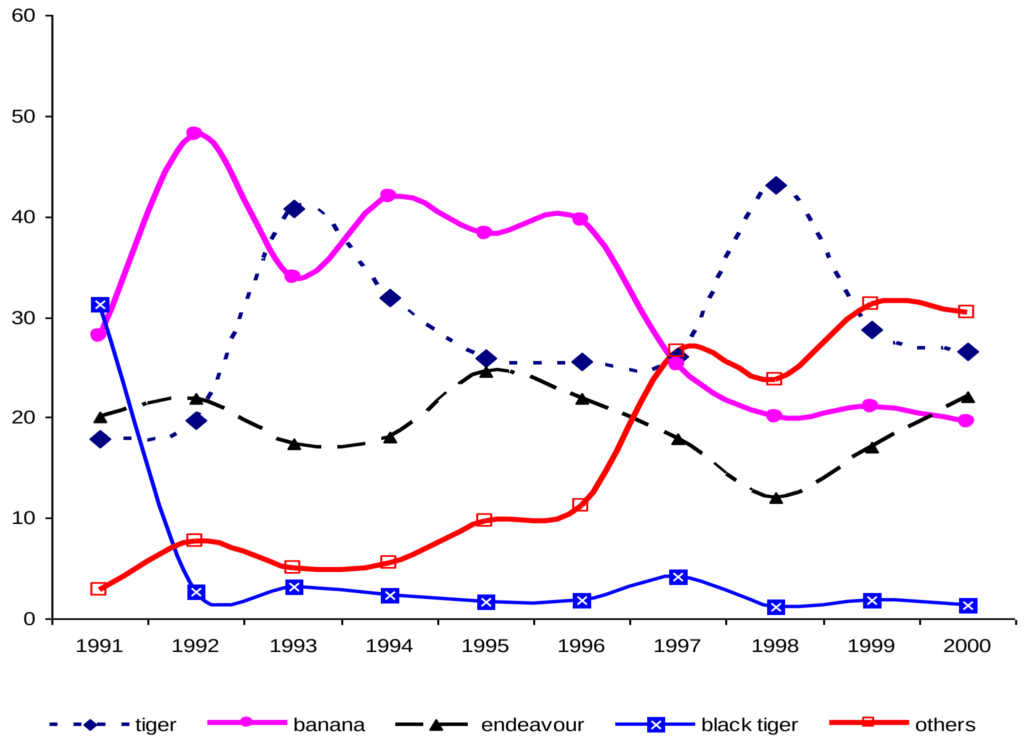

Figure 6. Annual changes in catch composition of the Aru Sea shrimp fisheries in 1991-2000. Source: MAFF, Indonesia

Sharks are predators and therefore of considerable ecological significance in the ATS region. Many species are top predators, feeding on large bony fishes as well as marine mammals and turtles. Fishing pressure, especially the commercial catch, is significant for some sharks. A limit on the shark by-catch was agreed for the NT barramundi and coastal line fisheries in 2002, and a ban on possession of sharks and shark products was also agreed for the Timor Reef, demersal, finfish trawl and Spanish mackerel fisheries. Deliberate post-capture mortality (e.g. finning) is a potential threat to populations under pressure. Shark finning is not specifically prohibited in the NT, but if any shark fins are taken, a set percentage of trunks or fillets must be kept on board. In Queensland the fins may only be removed if the shark body is retained. Since 1983, shark capture has been highly variable, fluctuating between 100 and 700 t. Sharks are also an incidental catch in commercial fisheries targeting other species, with NT landings from these fisheries ranging between 32 t and 64 t since 1994.

Research, through age-structure modelling, indicates that the overall stock should have been increasing since the mid-1980s, when foreign gill-netter catches were greatly reduced, but data on catch per unit effort from the NT gill net fishery indicate a substantial decline in relative abundance since then, probably due to a range of factors. Given these problems, the reliability for shark fishery stock assessment appears to be low, and the fishery is probably fully exploited.

3.2 Decline and loss of biodiversity and key marine species

Unsustainable direct harvesting by coastal communities and also indirect harvesting (via fisheries by-catch) is having a significant impact on populations of key marine species in the ATS region, particularly globally threatened marine megafauna (i.e. turtles, dugongs, seabirds/shorebirds, sea snakes, sharks and rays).

The area encompassing northern Australia, Papua New Guinea and eastern Indonesia supports the largest remaining direct harvest of green turtles in the world, and currently represents the greatest threat to the conservation of Australian green turtle stocks. Since the 1980s, this harvest has accounted for many tens of thousands, possibly up to 100 000 turtles, annually. Demographic modeling of Australian green turtle stocks has demonstrated that this harvest is clearly unsustainable – with only a small harvest of a few hundred adult females being sustainable from a stock with an annual nesting population of a few thousand. In Timor Leste, illegal turtle harvesting remains a major issue especially in the recently declared Nino Konis Santana National Park and Marine Park (Edyvane *et al.* 2009).

Populations of hawksbill turtle face major threats from direct harvest particularly in the Solomons and Papua New Guinea, with the northeast Australian hawksbill turtle stock declining at an unacceptable rate. Hawksbill and flatback turtle populations in northern Australia face major threats from the combined loss of eggs from predation by pigs in Cape York Peninsula, dogs and goannas in Arnhem Land and vehicle damage to nests and the harvest of eggs and turtles throughout the area. Of particular significance is the human harvest of hawksbill and flatback turtle eggs. For instance, almost 100% of the egg clutches of hawksbill are harvested on most inhabited Torres Strait islands and immediately adjacent hawksbill turtle rookeries; significant egg harvesting also occurs in northeast Arnhem Land. There is a high probability that the egg harvest alone could be sufficient to threaten the sustainability of this globally significant hawksbill turtle stock breeding within northern Australia.

Indirect harvesting and mortality is also a significant threat to turtle populations in the ATS region. The Northern Prawn Fishery and Torres Strait Trawl Fishery has in recent decades caused the death of possibly tens of green and hawksbill turtles, and hundreds of flatback and olive ridley turtles across a wide range of size classes. Further, trawl by-catch mortality has been identified as the primary cause of the recent decline in east Australian loggerhead turtle breeding numbers. With the regulated use of Turtle Excluding Devices (TEDs) now required in these fisheries, this mortality is expected to be much lower and trivial. However, flatback turtles from northern Australia are still caught and killed in trawl fisheries and gill net fisheries in adjacent Indonesian and Papua New Guinean waters. While the impact of gill net fisheries within northern Australian waters has not been quantified, the mortality associated with bottom-set shark fisheries indicates that inshore gill net fisheries bycatch needs careful assessment. Another significant source of indirect turtle mortality is from entanglement in lost or discarded nets. Within the ATS region, it is estimated that about 400 turtles die from this source annually along western Cape York Peninsula with a large proportion of them being olive ridley turtles.

The fate of dugong is not any better than for most species of turtle in the region. Hunted for thousands of years, often for its meat and oil, many populations are close to extinction. The IUCN currently lists the dugong as a species vulnerable to extinction. Despite being legally protected in many countries, the main causes of dugong population decline are hunting, habitat degradation, and fishing-related fatalities.

Within the Torres Straits, indigenous harvest of dugong is legal, but sustainability has been a concern since the early 1980s (Marsh *et al.* 2001, 2004). Indigenous harvest data for Torres Strait for the period 1973 to 2001 indicates a harvest approaching or exceeding 1000 animals/yr, excluding harvests from the Northern Peninsula area and the Papua New Guinea coast. Modelling suggests that the current present harvest is an order of magnitude too high (Marsh *et al.* 2004). The region can probably sustain a harvest of only about 100 dugong/yr. This number is exceeded by the Mabuiag community alone. Supporting the indigenous communities of the Torres Straits to manage their harvest sustainably (including the Northern Peninsula Area and the Papuan coast) has been identified as the most urgent management action required for dugongs conservation in the NAS LME.

Indirect harvest of dugongs through net entanglements is another major source of mortality. Data from 1979 (de Longh *et al.* 1998) stated that in Kobroor, Aru Timur, as many as 80 – 200 dugong were reported as being caught in shark nets, whereas in 1989 only 20 - 40 individuals were caught. In 1979 and 1980, about 550 – 1000 dugong were caught in Taiwanese nets used to catch sharks in several areas around Maluku. Similarly, in Australia, entanglement in large mesh (150 mm and greater) fishing nets is a documented source of dugong mortality. However, the data necessary to determine the magnitude of the impact of incidental catch on dugong populations in the Gulf of Carpentaria and Torres Strait are not available and are likely to be very difficult to collect in these remote areas. Fishing activities which could potentially affect dugong populations are commercial barramundi fishing using set nets, inshore shark fishing using pelagic nets, bait fishing using nets to catch bait for mud-crabbing and staked coastal nets used by coastal net fishery.

Less data is available on the non-commercial harvest of sharks and rays. Recreational fishers in the Northern Territory catch sharks while fishing for other species, mostly around Darwin, Cobourg Peninsula and the McArthur River. In 1995, over 80,000 individuals were caught, but only 18% were retained, giving a harvest of 15,000 individuals. Reef fishing accounted for most (74%) of the total shark catch. Indigenous fishing mostly takes place close to communities and outstations, in inland or near coastal waters. Sharks and rays are one of the more important groups of fish caught by indigenous coastal-dwelling people in the NT. In 2000, over 12,000 sharks and rays (not distinguished) were harvested, comprising just over 3% of the total finfish harvest (Coleman *et al.* 2003).

3.3 Modification, degradation and loss of habitats

Not only inhabitants, but physical habitats have been threatened by many human activities, leading to biodiversity loss and ecosystem collapse, in the ATS. The major challenge is the lack of quantitative data of habitat destruction. Modification of coastal habitats has resulted in major changes in population structure as well as functional group composition, notably on coral reefs, and massive changes in ecosystem services of coral reefs, seagrass beds and mangroves. For instance, the important nursery and feeding ground role of mangroves as well as seagrass beds for fish and marine mammals have been lost over extensive areas. Habitat modification and loss have also contributed to the decline in populations of marine mammals such as dugong (Marsh *et al.* 2001). Habitat degradation has significant trans-boundary implications in terms of reduced fish recruitment and impacts on migratory species as well as on biodiversity throughout the region.

Mangroves

The illegal harvest and loss of mangroves remains a critical coastal management issue, especially in Timor Leste, with total mangrove cover has being reduced by approximately 80% from 1940 to just 1,802 ha recorded in 2008 (Boggs *et al.* 2009). Mangrove trees are harvested for timber and fuel wood, and hinterland mangroves in Indonesia have been removed for shrimp and/or fish ponds. More than 50% of the region's mangroves have been lost, with 10% of the losses occurring between 1993 and 2003 (Giri *et al.* 2011). In contrast, there has been little clearing or destructive use of mangroves in northern Australia. Mangrove communities are extensively utilized by Aboriginal people, but this use appears to be sustainable and not deleterious in the long term.

CORAL REEFS

The situation for coral reefs is much more serious. Southeast Asia and the western Pacific contain more than 50% of the world's coral reefs (Bryant *et al.* 1998), but rapid growth in coastal human populations and an acceleration of coastal development and unsustainable fishing practices has led to a loss rate for coral reefs of 1–2%/yr (Bruno & Selig 2007).

Over the last 30 years there has been rapid population growth across the region resulting in a corresponding increase in coastal resource exploitation (Tun *et al.* 2008). Overfishing and unsustainable practices have led to declining fish stocks, pushing many fishers to resort to destructive fishing practices like bomb and cyanide fishing to obtain food and fish to sell. This is especially evident in Indonesia (Tun *et al.* 2008). In the latest global re-assessment of coral reefs, Southeast Asia recorded the highest level of local pressure on coral reefs, where nearly 95% of reefs are threatened, with ~50% in the high or very high threat category (Burke *et al.* 2011). Indonesia (second only to Australia in the total area of coral reefs that lie within its jurisdiction), recorded the largest area of threatened coral reef, with overfishing and destructive fishing pressures driving much of the threat, followed by watershed-based pollution and coastal development (Figure 7). In contrast, Australia's coral reefs are recognized as the world's least threatened, with an estimated 14% threatened by local activities and just over 1% at high or very high threat; watershed – and marine-based pollution is the dominant threat, but vast areas of Australian reefs are remote from such impacts (Burke *et al.* 2011). The ATS region thus includes some of the world's most unthreatened pristine reefs (i.e. NAS LME) and some of the most highly threatened reefs (IS LME) (Figure 8).

Although the population of eastern Indonesia is proportionately lower (about 35 million) than in western Indonesia, coastal communities are generally poorest in eastern Indonesia. Small communities lack social infrastructures which adds to the decline and, through their subsistence activities, these communities are pushing coastal resources beyond their capacity. An unfortunate outcome from this coastal fisheries dilemma is damage or destruction of mangroves, seagrass beds and coral reefs. While efforts to restore or rehabilitate damaged or destroyed mangroves and seagrass beds have seen some success, recovery of coral reefs is somewhat less successful.

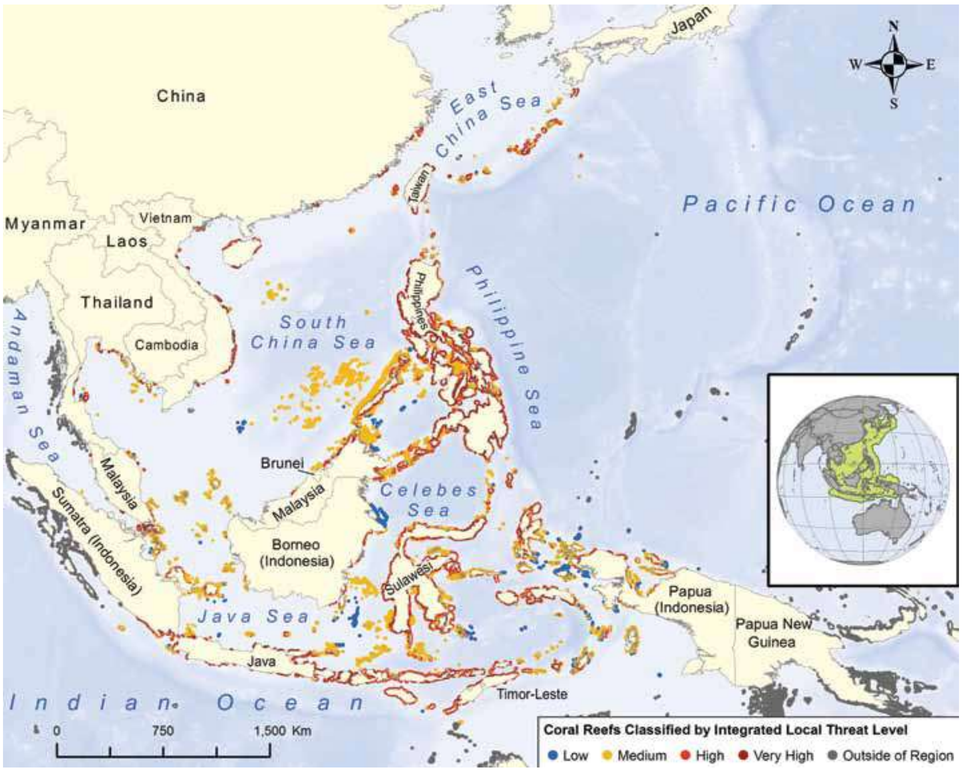

Figure 7. 'Reefs at Risk' in Southeast Asia from local threats (i.e. coastal development, watershed-based pollution, marine-based pollution and damage, and overfishing and destructive fishing) (adapted from Burke et al. 2011).

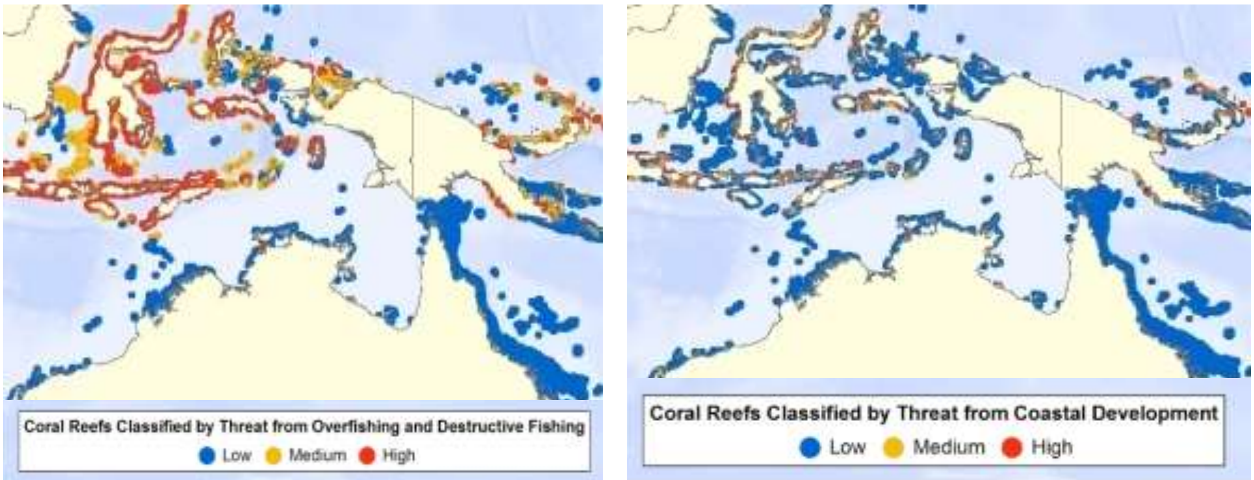

Figure 8. Reefs at Risk in the Arafura and Timor Seas (Source: Burke et al. 2011).

In the past fifty years, the proportion of degraded reefs in Indonesia increased from 10 to 50%. Between 1989 and 2000, Indonesian reefs with over 50% live coral cover declined from 36 to 29% (Wilkinson 2008). Surveys conducted in Indonesia over the past two decades shows that reef condition clearly improved from west to east (Suharsono 1997). In 2004, the percentage of reefs in good or excellent condition was 21% and 5.8% in western Indonesia, respectively, compared to 29.2% and 9.2% in lesser populated, eastern Indonesia (Table 2). Although the coral reefs of eastern Indonesia may be in better condition than those in the west, they are still declining at a rapid rate. In a 1999 survey, an estimated 31.8% of reefs in the far eastern region were found to be in poor condition, 10.0% in excellent condition, but only one location (Lucipora Islands, Maluku) was reported to be in excellent condition. Sites in Nusa Tenggara east of Lombok (Komodo, Rinca, Sumbawa) were reported to be in reasonable condition, although the Wetar Islands in the far east were reported as only fair, a condition attributed to gold mining. Central Maluku reefs also appear to be in reasonable condition apart from the Kai Islands. The protected areas of Cenderawasih Bay and Biak in West Papua are classified as good, but concerns have been expressed for the Padaido Islands where 4 of the 13 stations were classified as in poor condition.

Table 2. The status of coral reefs in Indonesia

Table 1. The Status Of Coral Reef In Indonesia (%) (Based On 648 Stations, 2004)

	No.Of Location	Excellent	Good	Fair	Poor
West	243	5.76	20.99	33.33	39.92
Central	210	6.19	31.43	45.24	17.14
East	195	9.23	29.23	33.08	28.46
Indonesia	648	6.69	26.59	37.56	29.16

• Excellent : 75-100 % living coral cover	• Fair : 25-49 % living coral cover
• Good : 50-74 % living coral cover	• Poor : 0-24 % living coral cover

Nevertheless, recent comprehensive threat assessment and modelling studies suggest that human activities threaten > 85% of Indonesia's coral reefs, with 50% at high threat (Burke *et al.*2011). Principal threats are overfishing and destructive fishing, which threaten 64% and 53% of Indonesia's reefs, respectively (Burke *et al.* 2002). However, the areas at risk from destructive fishing are probably underestimated because information is not available for many areas. Both coastal development and sedimentation from inland sources threaten about one fifth of the country's reefs. Coral reef monitoring between 2004 and 2008 indicates that reefs continue to show an overall decline in condition in Indonesia (Tun *et al.* 2008). This is supported by recent comprehensive, global threat and trend analysis of reefs at risk (Figure 9).

Damage to coral reefs from the use of explosives and poisons is catastrophic in the IS LME. On regularly bombed reefs, coral mortality can range from 50-80%, even in national parks. Around 65% of reefs in the Maluku islands had evidence of bomb damage (Burke *et al.* 2011).The effects of cyanide fishing are multiple. In addition to being broken to retrieve stunned fish, corals are also bleached by the cyanide and recovery may take up to half a century. As reefs become more damaged and unproductive, they are abandoned by fishers who move to new reefs to continue this pattern of destruction.

Figure 9. Change in local threats (i.e. coastal development, watershed-based pollution, marine-based pollution and damage, and overfishing and destructive fishing) to coral reefs in the ATS region between 1998 and 2007 (Source: Burke et al. 2011).

Indonesian coral reefs are also impacted by pollution (Tun *et al.* 2008; Wilkinson, 2008). Reefs subject to land-based pollution show 30-50% reduced diversity at 3m depth and 40-60% reduced diversity at 10m depth, relative to unpolluted reefs, implying a dramatic, rapid decrease in Indonesian reef-based fisheries. Mining and quarrying of coral is another significant threat to coral reefs and is widespread at both subsistence and commercial levels. In eastern Indonesia, only the Lucipora Islands located in the middle of the Banda Sea in Maluku can be regarded as in excellent condition.

Excessive runoff and sediment from land is the result of inappropriate agricultural practice, urbanization and construction processes, and has been a major factor in the decline of coral reefs. Close to the major urban centres, such as Makassar, the affected zone extends up to 50 km from the city.

While the status of Timor-Leste's coral reefs were predicted to be 'promising' due to limited commercial exploitation, recent reef fish surveys by Wong and Chou (2004), Dutra *et al.* (2008), Penny (2008) and Edyvane *et al.* (2009) suggest otherwise. While shallow, nearshore coral reef habitat in Timor Leste is limited (~2000 ha), with little lagoonal reef flat development (~458 ha), there is little evidence of habitat damage by dynamite blasting or coral bleaching (Penny 2008, Tun *et al.* 2008, Boggs *et al.* 2009, Edyvane *et al.* 2009). Assessments in 2004 and 2006 of coral reefs in Timor-Leste focused on Ataúro Island, where there are large areas of dead corals, probably due to destructive fishing. The larger commercial reef fish (groupers and snappers) are rarely observed, and it appears that smaller species, such as butterflyfish are being targeted by fishers. Similarly, recent surveys of the northern coast of Timor Leste have revealed a significant lack of reef sharks and low densities of large predatory reef fish species (Edyvane *et al.* 2009). Five distinct coral reef systems along the south coast of Timor- Leste are considered to be at medium to high risk of impact from the combined effects of coastal development, marine-based pollution, sedimentation, overfishing and destructive fishing (Burke *et al.* 2011). Coastal villages rely heavily on seafood from the nearby coral reefs; thus, there is a strong risk that reef degradation or over-harvesting could result in ecological collapse. Reef degradation and over-harvesting occurs throughout the country. Other human impacts include: blast fishing introduced by migrant fishermen along the northern coast; spear fishers destroying corals in attempts to increase fish catches; damage during the construction of fish traps; mining of coral for lime for chewing betel nut to reduce hunger pains; domestic debris that entangles the reef framework; cyanide fishing; and fishing with *Acanthua* tree branches which contain a toxin to stun fish.

While no hard coral species have become extinct, the 'Coral Triangle' is now recognized as having the highest proportion of vulnerable and near-threatened coral species. The chronic nature of anthropogenic disturbance in many parts of this region is being compounded by the effects of climate change (Carpenter *et al.* 2008). However, fishes, molluscs, echinoderms and other invertebrates may be even more vulnerable to extinction. Most coral species have a widespread range in the region, whereas all lobster species and half the fish and snail species have relatively restricted geographic ranges, which indicate that reef degradation could lead to associated extinction of taxa. Hard coral diversity remains high in Indonesia, with almost 600 species recorded. Many site-specific hot spots of coral diversity (with more than 200 species of hard coral) occur mostly on deeper offshore reefs.

Human impacts on northern Australian coral reefs including direct impact through commercial coral harvest are small and site-specific. For example, corals in Arnhem Land are in pristine condition (Veron 2000). The Torres Straits is a major shipping route and impacts on coral may be from oil spills and localized damage from groundings and bottom scouring; the same is true for some bays and harbors, such as Gove and Darwin Harbours (Alongi & McKinnon 2011).

SEAGRASSES

Seagrass meadows have declined precipitously within the ATS region, although data is sparse for most areas of Timor-Leste and eastern Indonesia. Widespread dieback of seagrasses has been reported in the central and northern regions of the Torres Straits, where > 1400 km^2 of seagrass was lost between 1989 and 1993. Major port and shipping activities at Weipa and Karumba, Gove and Macarthur River are potential threats to regional seagrasses. Cyclone-induced erosion has caused large loss of seagrasses (183 km^2) in the southern Gulf. Land-based threats to seagrass beds arise from debouching of extractive mining wastes and from pastoral lands. These activities can greatly increase the amount of sediment/turbidity and pollutants associated with runoff produced after monsoon rains. There is no doubt that similar impacts have occurred in eastern Indonesia and Timor-Leste.

Seagrass loss has been identified as a potential source of localised declines in dugong populations. In addition to anthropogenic impacts in the ATS region, natural events such as cyclones and floods can cause extensive damage to seagrass communities through severe wave action, shifting sand, adverse salinity changes and light reduction.

3.4 Marine and land-based pollution

Due to the lack of major urban settlements in the ATS region, major marine and land-based pollution impacts are largely localized and confined to coastal mining activities, poor catchment practices, offshore oil/gas exploration, and the effects of fisheries (e.g. marine debris, discarded fishing nets).

The coastal and marine ecosystems of northern Australia are regarded as intact, containing some of the most pristine ecosystems in the world (Halpern *et al.* 2008), due principally to low human population density. In the NAS LME, the dominant human impacts are primarily related to fisheries and terrestrial runoff from deforestation, overgrazing by livestock, and certain agricultural practices. The NAS LME is also threatened by an increase in shipping, mining activities in adjacent watersheds and by the production and transportation of oil and other hydrocarbons. There are accidental discharges of contaminants through spills and shipping accidents. However, compared with most other coastal and oceanic ecosystems, these impacts are quite modest.

In contrast, the IS LME is polluted in many coastal areas as detailed below.

Coastal Developments

Urban expansion and industrialization has resulted in coastal pollution from domestic, agricultural and industrial wastes in the IS LME. Water pollution is found in virtually all populated and/or highly industrialised areas of Indonesia and is known to cause massive fish kills, harvest failure from aquaculture and threats to human health. Industrial forms of water pollution are concentrated in the major urban centres, primarily the large cities of northern Java. Oil spills, slowly degrading toxic wastes from chemical as well as non-chemical industries, agricultural runoff and heavy metals threaten coastal waters. This has resulted in severe pollution in some areas. Because of inadequate sewage disposal and treatment throughout the region, microbial contamination is severe, especially around urban centres. Eutrophication is also severe around urban centres, particularly in areas with limited water circulation and where sewage, agricultural and/or industrial discharges are present. Siltation rates in the IS LME are among the highest in the world. Pollution by suspended solids is severe in coastal waters with high turbidity over wide areas. Close to the major urban centres, the affected zone can extend up to 50 km offshore. This has resulted mostly from extensive deforestation in many watersheds, compounded by high rates of erosion and industrial mining. Solid waste is a severe problem locally, particularly in the Java Sea and around the cities, towns and villages where waste management is inadequate.

Contaminants

Within the IS LME, chemical pollution from agricultural pesticides and industries is severe in localised areas. Mercury contamination from gold mining is widespread and is generating serious health as well as environmental risks in Indonesia; mercury levels in the tissue of fish near gold mines are higher than levels recommended by the WHO for safe fish consumption. The disposal of toxic materials from mines via submarine tailings placement is of special relevance to Indonesian marine life. In the next decade, the world's biggest copper and gold mine situated in Indonesia will discharge more than one billion tonnes of tailings over a wide area. This LME forms part of both the main and Ultra Large Crude Carrier oil tanker routes between the Indian and Pacific Oceans. Furthermore, there is regular discharge of ship ballast waters. In addition to spills, there is chronic pollution from oil production facilities and refineries.

Within embayments in northern Australian waters and off the southwest coast of Papua, contamination by heavy metals and other industrial solutes occurs in proximity to point-sources, such as refineries, mining processing plants, sewage treatment plants. For instance, there are areas in Darwin Harbour that have been impacted by a variety of pollutants. Even in remote areas, pollution is evident. In Gove Harbour, effluent from an alumina refinery results in precipitation and deposition of hydrotalcite, a mineral precipitate that smothers the seabed. The area affected is localized and algal mats at the sediment surface minimize the impact of this precipitate on epibenthic and pelagic organisms (Alongi & McKinnon 2011)

MARINE DEBRIS

Harmful marine debris is an international issue both in terms of its sources and impacts. For example, the majority of derelict fishing nets washing ashore on Australia's northern coastline originate from fishing activities beyond Australia's jurisdiction. Preliminary analysis of derelict fishing nets found in the Gulf of Carpentaria suggest that foreign fishing nets from fishing operations outside Australian jurisdiction are likely to comprise the greatest proportion (around 80%) of all nets washing ashore on beaches there. Foreign nets are causing some of the greatest harm to marine animals, especially marine turtles.

A proportion of debris, other than derelict fishing nets, in Australian waters could also have international origins. For example, thick rubber and plastic sheeting from which the soles of handmade thongs are made, believed to have originated from outside Australian waters, washes ashore on many parts of northern Australia. Numerous other items such as fishing net floats, sorting baskets, crates, buckets, hand reels, light globes, ropes and gloves, which may also be directly attributed to fishing and general shipping activities, are also found. Marine turtles are particularly vulnerable to floating debris as some species of marine turtles are thought to mistake plastic bags and other items for jellyfish, while other turtle species, especially hawksbills, eat encrusting organisms that grow on floating plastics and nets, become ensnared when attempting to feed.

SEDIMENTS

The transport of land-derived materials (sediment, nutrients, carbon and pollutants) from river catchments to the coastal zone, continental shelves and possibly the deep sea within the ATS region can have significant impacts on mangroves, seagrass meadows, and coral reefs, and can carry nutrients, pathogens, and pollutants into open water with possible impacts on organisms important for human livelihoods. Fine sediment can also reach deep basins where their impacts are likely to be small, but could be significant if they carry other materials into upwelling zones where they can impact fisheries. Dissolved nutrients and carbon can cause eutrophication in the nearshore zone where fish death is often the result. But increased loads of nutrients and carbon may also increase biological productivity in the photic zone. Pollutants such as metals and PAHs can seriously impact organisms in the coastal zone, and even in open water.

Rivers and tributaries on the islands of Timor, New Guinea and northern part of Australia are discharging sediments into the study area. For New Guinea, Sulawesi, Borneo and Timor, the most likely source of sediment in the ATS, the average sediment discharge estimate is ~3500t/km^2/yr. Total yield has increased by a factor of about 2 for Indonesia as a result of human activities; 55x10^6 t/yr (100 t/km^2/yr) reaches the Timor Sea from Australia, a value about twice the yield prior to human activities. About 128x10^6 t/yr (200 t/km^2/yr) reaches the Gulf of Carpentaria, which is also about twice the yield prior to human disturbance. In total, ~183x10^6 t/yr reaches the ATS from Australia, which is ~10 times less than derived from Indonesia (Milliman and Farnsworth 2011).

Unfortunately, there are few whole catchment studies of sediment sources in the region. In the Laclo catchment on the north coast of Timor Leste, < 5% of river sediment comes from sheet and rill erosion of hillslopes. Landslides and erosion of river channels appear to dominate. The same result was obtained in the Caraulun catchment on the south coast of Timor Leste. In short, the island is experiencing much greater loads of sediment debouching into the sea and probably affecting coastal habitats. Indeed, many mangroves along the south coast of Timor Leste have been buried under these enhanced loads.

Landslides are common within the Indonesia and in Timor Leste, triggered by rainfall and/or earthquakes. The seismically active parts of the region are therefore likely to be subject to landslides more than elsewhere. The area affected by landslides caused by earthquakes of magnitudes 6-6.5 (which are common in the region) is 1000-5000 km^2. This is a significant area on many of the islands, and is likely to generate 10^{-3} to 10^{-2} km^3 of sediment, much of which will reach rivers. Given the small size of catchments and their steepness, this sediment will reach the coast quickly.

Volcanoes are likely to be even larger sources of sediment. Sediment yields from volcanoes increase with catchment area with maximum specific yields of > 5000 $t/km^2/yr$. Deforestation and cultivation of the flanks of volcanoes has had a dramatic impact on erosion rates. This increased sediment yield is seen as the cause of the rapid expansion of river deltas, best documented on Java.

In Northern Australia, ~10% of the sediment reaching Lake Argyle in the Ord River catchment comes from sheet and rill erosion of hillslope surfaces. The remainder comes from gully and river channel erosion. In the Daly River catchment, 3 - 11% of sediment reaching the estuary comes from sheet and rill erosion, and the remainder mostly comes from river channel erosion, including riparian gullies and slumps.

The high-standing islands of the region, along with Papua New Guinea, Taiwan, and New Zealand, produce by erosion and transport a large fraction of the global flux to the ocean of particulate organic carbon. Measured loads combined with analysis of ^{14}C in the POC show that up to 92% is non-fossil; that is, it is derived from the modern biosphere rather than from erosion of rocks.

3.5 Impacts of Climate Change

There are a number of climate predictions relevant to the Timor and Arafura Sea region. These are:

- Projections for temperature indicate an increasing trend for target years 2020, 2050 and 2080 on the order of 0.8°C, 1.5°C and 2.2°C, respectively. No significant variability across the different seasons is expected.
- Extreme temperature events are expected to increase in frequency and duration, and temperatures may rise during these events by up to 2.3°C.
- Projections for rainfall indicate an increasing trend of 2%, 4% and 6% by 2020, 2050 and 2080, respectively, in line with an expected increase in the inter-annual variability of the Asian monsoon.
- The dry season will become drier.
- Extreme rainfall events are expected to increase in intensity but become less frequent, with a 50% decline in the number of tropical cyclones which will be shorter, on average, by 0.3 days but with a larger percentage producing higher wind speeds.
- Mean sea-level is predicted to rise by 3.2-10.0 cm by 2010, 8.9-27.8 cm by 2050 and 18-79.0 cm by 2095.
- Relative to the 1990s, ocean pH is expected to decline in the region by 0.16-0.17 by 2070.

On a global basis, concentrations of greenhouse gases (carbon dioxide, methane, nitrous oxide) are increasing and are expected to continue increasing for the foreseeable future. Increases in atmospheric gas concentrations will also have an impact on coastal and marine organisms in the region.

Predicted Impacts

Coastal Inundation

Low profile coasts, shallow continental shelves and macro-tidal conditions mean that the coastal and marine environments of the ATS region are particularly vulnerable to the impacts of climate change. By 2100, sea-level is projected to rise by between 18 and 59 cm. Such a rise in sea level is expected to increase the salinity of coastal groundwater as aquifers are affected by salt water intrusion. The low-lying coastal ecosystems of Northern Australia, such as mangroves and other wetlands, may be particularly vulnerable to climate change. Shallow-water and intertidal habitats are most vulnerable to sea-level rise, increased intensity of cyclones and increased temperatures. In particular, the interactive effects of rise in sea-level and cyclonic intensity, increased coastal inundation and storm surges may result in these ecosystems either retreating landwards as sea-level rises or disappearing if inundation is rapid and coastal relief is low. The Gulf of Carpentaria is an area of very active cyclogenesis (average: 2/yr) and importantly, cyclone tracks in the Gulf are among the most unpredictable. The southern shores of the gulf are at elevations < 5 m, including the southern gulf plain wetlands, and are particularly at risk from rising sea-level and storm events including tropical cyclone-induced, storm tide inundation.

Significantly, many of these vulnerable coastal ecosystems in the ATS are not only the site of globally significant coastal and estuarine wetlands (mangroves, saltmarshes, seagrasses, tidal mudflats) but, the sites of globally significant, nesting populations of marine megafauna, such as marine turtles, shorebirds and seabirds.

Many of northern Australia's freshwater lagoons and floodplains are vulnerable to climate change. The wetlands of northern Australia depend on finely-balanced interactions between freshwater and marine environments. In the World Heritage-listed wetlands of Kakadu National Park, the natural levees that act as a barrier between freshwater and saltwater systems are, in certain areas, only 20 cm high. Projected sea-level rise of another 59 cm by 2100 will adversely affect 90% of the Kakadu wetlands. Further, extensive seasonally-inundated freshwater swamps and floodplains often extend for approximately 100 km along rivers. The low relief of these areas means that even small rises in sea-level could result in relatively large areas being affected by salt-water intrusion. Within the Gulf of Carpentaria, the Southern Gulf Aggregation wetland covers 540,000 ha across an elevation of 0 - 10 m above sea-level and is particularly prone to the impacts of climate change. This wetland ecosystem represents one of the largest intact coastal wetlands in Australia, exhibiting a high diversity of landforms, including extensive intertidal saltpans, marine and intertidal flats with occasional seagrass beds, and is recognised as the third most important wetland for migrating waterbirds in Australia (and a major site in the East Asian-Australasian Flyway).

Predicted rises in sea-level up to nearly 80 cm by the end of the century will impact rocky intertidal, mud- and sand-flats, coral reef, seagrass and mangrove communities. The ability of an intertidal organism to successfully adapt to change in sea-level depends on a number of extenuating factors:

- Rate of sea-level rise;
- Slope of intertidal area;
- Topography;
- Accretion and erosion rates;
- Position in estuary/open coast.
- And intrinsic biological factors such as:
    - Ability/rate of recolonization (depends on dispersal and larval growth rates, etc);
    - Tolerance to other environmental changes or factors.

Mangroves, for instance, thrive in an environment where changes in environmental conditions are the rule rather than the exception. Their ability to survive sea-level rise will depend on accretion rate relative to rate of sea-level rise. Available data indicates that under the maximal predicted rate of sea-level rise of 9.4 mm/yr (79 cm by 2095), mangroves will more than keep pace. However, other data indicate possible whole-forest changes in community composition in relation to sea-level rise. So, mangroves will survive, but only the most flood-tolerant species.

The future of all intertidal communities will depend on the availability of space. If land is limited by seawalls or other constraints, then biota will be sharply reduced or will disappear.

Rising Temperatures

The impacts of global warming are likely to vary significantly throughout the region. Within the IS LME, analyses of SST data indicate that the warmest parts of the Western Pacific Warm Pool (WPWP) have warmed less over the past six decades than elsewhere in the tropical ocean, and has also shown that coral reefs within or near the WPWP reported fewer bleaching events relative to reefs in other regions (Kleypas *et al.* 2008). Recently, climatologists suggest that the presence of a sharp limit ('thermostat control') to the maximum SST around 29–31°C supports the existence of thermostat mechanisms in the WPWP that act to depress ocean warming (and coral bleaching) beyond certain temperature thresholds (Clement *et al.* 2005; Kleypas *et al.* 2008), although this is disputed (van Hooidonk & Huber 2009; Williams *et al.* 2009).

Within the Coral Triangle region, analyses of satellite-derived sea surface temperature (SST) and Degree Heating Weeks (DHW) to investigate thermal stress between 1985 and 2006, clearly indicate ocean warming of the region, with an upward trend in SST at an average rate over this period of 0.2°C/decade (Penaflor *et al.* 2009). However, warming is not uniform, with the waters of the northern and eastern parts of the Coral Triangle warming fastest, with eastern reefs, (southeastern Papua New Guinea) experiencing more thermal stress events. These stress events are more likely during La Niña. (Penaflor *et al.* 2009). In contrast, the inner seas of Indonesia had few occurrences of significant thermal stress. Penaflor *et al.* (2009) suggest that the low frequency of thermal stress events in these areas may possibly be due to the complex hydrodynamic processes in these areas (Gordon 2005). As such, the complex geometry and connectivity through straits and passages coupled with other factors such as surface heat flux, tidal mixing, and monsoonal winds drive the complex distribution of SST in this region. In the ATS region, the vulnerability of reefs to thermal stress and coral bleaching is likely to be reduced in the western region due to its complex bathymetry and deepwater outflow passages, and greater in the shallow, tidally dominated, shelf areas of the Sahul Shelf, Arafura Sea and the Gulf of Carpentaria. The lack of emergent coral reefs north and east of Ashmore Reef suggests that corals in the area are already at their thermal tolerance limit (Heyward *et al.* 1997).

Within the NAS LME, sea surface temperatures (SSTs) are significantly warming along the northwest (NW) and northeast (NE) coasts of Australia (Lough 2008). Analysis of annual maximum and minimum SSTs between 1950-2007 indicates that warming is comparable along the NE and NW coasts. Average climate zones have also shifted > 200 km south along the NE coast and about half that distance along the NW coast. If current trends continue, annual average SSTs in northern parts could be similar to 0.5°C warmer and those of more southern parts similar to 2.0°C warmer within the next century. These rapid changes in oceanic climate are already causing responses in Australia's northern tropical marine ecosystems and these responses, if present rates of warming continue, can only intensify.

Regarding future projections, recent modelling studies indicate a slow rate of warming in the western Pacific over the last few decades, but show the warm pool heating rapidly in the future instead of being constrained by an 'ocean thermostat' (Kleypas *et al.* 2008). Current observations indicate that sea temperatures on the Sahul Shelf are already exceeding the'ocean thermostat' (i.e. 29-31°C) (Bradley Opdyke, pers. comm.). In the global assessment of reefs at risk in Southeast Asia, Burke *et al.* (2011) project that by 2030, 99% of reefs in Southeast Asia will be threatened from both warming and acidification, with more than 80% at high, very high, or critical levels. In 2050, all reefs will be threatened, with about 95% at the highest levels.

The pattern of coral bleaching across the Arafura-Timor Seas region is unlikely to be uniform owing to spatial and seasonal differences in sea surface temperatures and currents, and the influence of the Indian Pacific Warm Pool. However, unlike other biological consequences of climate change, the database for coral bleaching is extensive. There have been at least seven major coral bleaching events in the Coral Triangle between 1979 and 2005, including several pan-global bleaching events since 2002, all associated with ENSO events. The CT as a whole is known to experience a pronounced increase in SST during phases of ENSO. Coral bleaching strongly affects local and regional species distributions and densities of nearly all hermatypic corals; species replacement may also occur resulting in range shifts in the most affected coral species.

Climate change is also one of the major hazards facing the long-term future of global biodiversity. Some key marine species likely to be particularly affected by rising air and sea temperatures in the region include marine turtles and sea snakes, and also, coral reefs (Heyward *et al.* 1997). Global climate change could have profound effects on marine turtle population dynamics in the ATS through: (1) shifts in nesting phenology leading to trophic mismatch for the oceanic hatchling stage; (2) increases in nesting beach temperature that determine hatchling sex ratios and incubation success; (3) inundation of nesting beach habitat; (4) increased disease transmission; and (5) changes in migration behaviour.

However, not all impacts of higher, and more variable, temperatures may be negative. For instance, mangrove photosynthesis may increase with increased growth of forests. This enhancement may be stronger considering concomitant rises in atmospheric CO_2 concentrations and greater precipitation; mangrove growth is likely to increase in response to warmer, less saline, more CO_2- rich conditions, although changes in species distributions is likely. Any functional enhancement of mangrove forests may however be counterbalanced by responses to other changes in climate, as detailed below.

Ocean Acidification

Ocean pH is being lowered as a direct result of the massive amounts of human-produced CO_2 being released into the atmosphere and dissolving in the ocean to form carbonic acid which releases hydrogen ions. The hydrogen ion concentration in ocean water has increased since industrialisation by approximately 30% or 0.1 pH unit. Further acidification is inevitable as CO_2 already in the atmosphere and being added currently will continue to dissolve in seawater. A wide range of marine organisms is expected to be negatively affected by the decline in pH, most especially organisms that secrete calcium carbonate shells.

Calcification is sensitive to changes in pH because it affects the saturation state of seawater. Seawater saturated or supersaturated in calcium will facilitate formation of $CaCO_3$ shells. Seawater at lower pH becomes undersaturated, making construction of shells more difficult. If pH is low enough, shells that have already been formed may undergo dissolution.

Most experimental studies on coccolithophores, pteropods, foraminifera, coral, calcareous macroalgae, mussels, oysters, echinoderms and crustaceans show reduced net calcification rates in response to elevated CO_2 and lower pH. The evidence strongly indicates that dissolution rates will become greater than rates at which organisms calcify, resulting in an overall reduction in biogenic $CaCO_3$ in the ocean.

What this means for the Arafura and Timor Seas is a future with declining numbers of calcareous organisms, most spectacularly, of coral reefs. It is estimated that nearly one-third of all coral species within the Coral Triangle face elevated risk of extinction as a direct result of climate change and other anthropogenic impacts. Pelagic and other benthic communities will also be affected as a lowering of pH will affect the metabolic energy balance of many marine organisms. For instance, squid are intolerant to short-term exposure to high CO_2 seawater, but some fish appear to be more tolerant. The community composition of plankton will be altered because pteropods, foraminiferans, coccolithophores and crustaceans, such as pelagic copepods and shrimp, will find it much more difficult to calcify under lower pH conditions. The same is envisioned for benthic communities on both hard and soft substrates, with the loss of some species of echinoderms, molluscs and crustaceans, especially many commercially-viable and artisanal species.

Extreme Events (rainfall, cyclones)

More rain and more variable rainfall will result in more variable salinity, especially in intertidal and shoal estuarine and marine habitats. Euryhaline organisms will tend to be favoured over stenohaline organisms; truly marine species will be less likely to migrate to less salty, shallow-water habitats. More tolerant species will survive but many species more sensitive to climate change will disappear.

Greater variability in salinity will affect metabolic rates and osmotic balance of most marine organisms; presuming that more variable conditions will require more changes in an organism's metabolism, these additional physiological changes will result in more expenditure of energy and possibly less energy shunted for growth and reproduction.

More intense storms and cyclones will result in fewer organisms less able to tolerate and adapt to shallow tropical waters, especially intertidal organisms, and will result in scouring of many biota from hard substrates. Conversely, drier conditions will increase salinities to intolerable levels for many species; either scenario would lead to a decline in densities as well as species diversity.

The expected climatic events and the probable impacts on marine biota and their ecosystems in the Timor and Arafura Seas are overwhelmingly negative. Even positive impacts such as an increase in mangrove production may have negative consequences in the long-term if habitat destruction continues and only the most tolerant plant and animal species survive. These impacts on the marine biome will have substantial social and economic impacts in Timor Leste, Indonesia and Australia. Artisanal and commercial fisheries will decline due either to decreased fisheries productivity or to enhanced production of undesirable species at the expense of more eatable organisms. If true, the decline in fisheries will affect food security and livelihoods, as well as having carry-on effects to each nation's economy and social structure. Moreover, a decline in coral reefs and mangroves will affect shoreline stability, tourism, groundwater resources, sewage, and flood mitigation, increasing poverty, malnutrition, food prices, unemployment, poor health and urban migration.

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