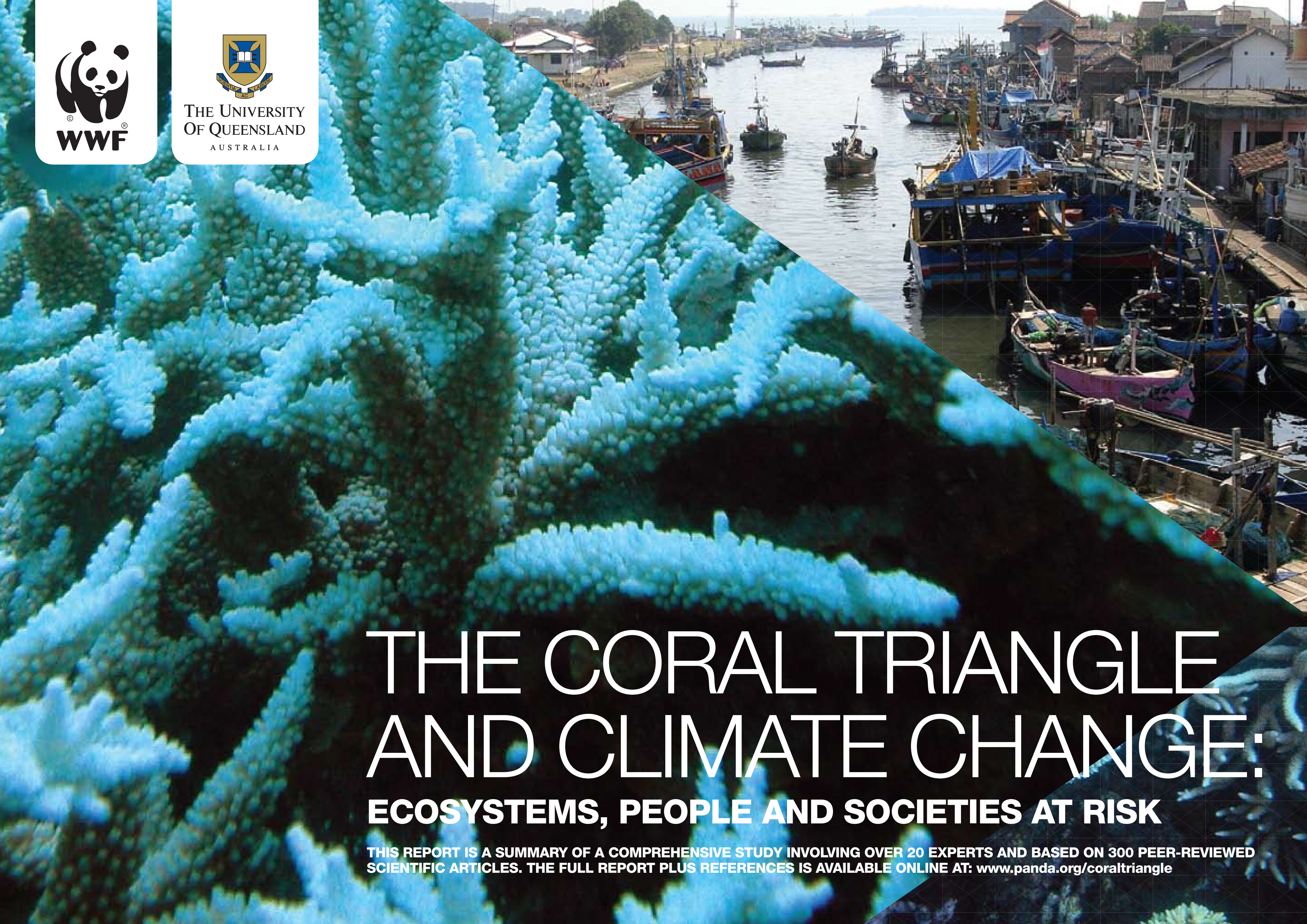

WWF

THE UNIVERSITY OF QUEENSLAND
AUSTRALIA

THE CORAL TRIANGLE AND CLIMATE CHANGE:

ECOSYSTEMS, PEOPLE AND SOCIETIES AT RISK

THIS REPORT IS A SUMMARY OF A COMPREHENSIVE STUDY INVOLVING OVER 20 EXPERTS AND BASED ON 300 PEER-REVIEWED SCIENTIFIC ARTICLES. THE FULL REPORT PLUS REFERENCES IS AVAILABLE ONLINE AT: www.panda.org/coraltriangle

The Coral Triangle is defined by marine zones containing at least 500 species of reef-building coral. The Coral Triangle supports livelihoods and provides income and food security, particularly for coastal communities. Resources from the area directly sustain more than 100 million people living there.

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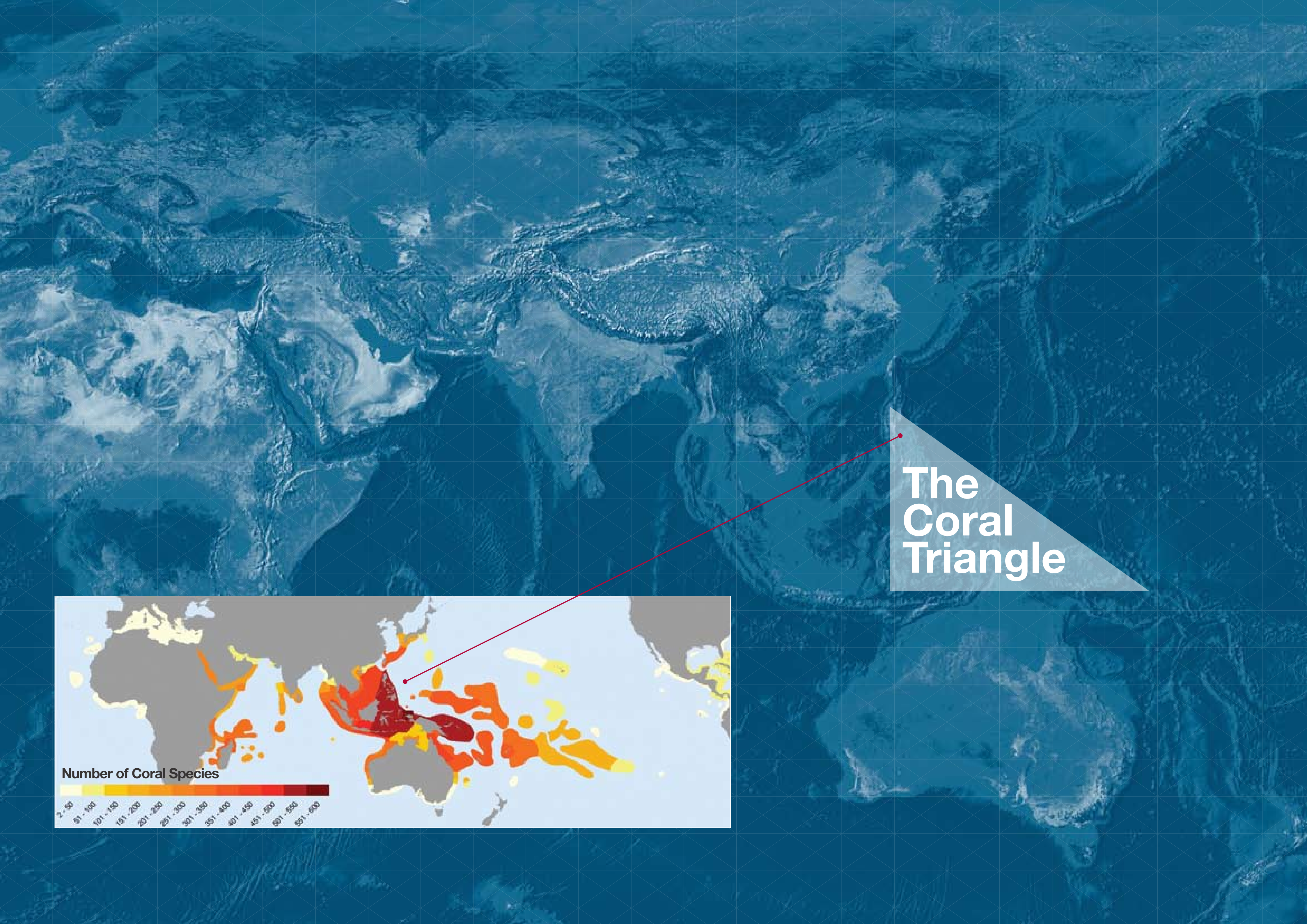

The Coral Triangle
Number of Coral Species
2 - 50
51 - 100
101 - 150
151 - 200
201 - 250
251 - 300
301 - 350
351 - 400
401 - 450
451 - 500
501 - 550
551 - 600

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Full report is available at: **www.panda.org/coraltriangle**

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Photography by Ove Hoegh-Guldberg, University of Queensland (except where indicated)

Contents

About This Report

The Coral Triangle is the world's centre of marine life, with more species living in this area than anywhere else on the planet. It sparkles as the biological treasure chest of our planet, with many of its mysteries and species yet to be discovered.

Over thousands of years, people have built communities and businesses around this remarkable biological wealth. Today the region supports multi-billion dollar tuna, fishing and tourism industries, and over 100 million people rely directly on its coastal resources for their food and livelihoods.

Unfortunately, the relationship between people and coastal ecosystems is now under extreme threat from climate change, as well as escalating local and regional environmental pressures. Regional and international action is urgently needed to avoid an ecological and human catastrophe.

This report sets out the full extent of the threats and proposes solutions to the challenges facing the Coral Triangle and its people. Based on a thorough consideration of the climate, biology, economics and social characteristics of the region, it shows why these challenges are increasing, and how unchecked climate change will ultimately undermine and destroy ecosystems and livelihoods in the Coral Triangle.

The report offers two possible scenarios for the future. In one world, the international community continues down a track towards catastrophic climate change and the Coral Triangle countries do little to protect coastal ecosystems from the onslaught of local threats. In this world, the biological treasures of the region are destroyed by rapid increases in ocean temperature, acidity and sea level, while the resilience of coastal ecosystems deteriorates under ineffective coastal management. Poverty increases, food security plummets, economies suffer and coastal people migrate increasingly to urban centres.

In the other world, effective action is taken by world leaders to curb the build up of greenhouse gases, leading to the stabilisation of concentrations of atmospheric CO_2 at the lower end of IPCC projections in the latter half of this century. Climate change is challenging but manageable, and the Coral Triangle region decisively reduces other environmental stresses arising from overfishing, pollution, declining coastal water quality and health. In this world, because the impacts are less and growth strategies are more focused on people than profits, communities and economies continue to grow sustainably into the future.

World leaders have a choice. They have a chance to make a difference, to the future of our planet's biological inheritance and the lives of millions of vulnerable people living within the Coral Triangle, or not. By making tough decisions today, they can take us towards that better world, one in which the threat of climate change has been reduced, and human communities and coastal resources can exist in harmony.

Professor Ove Hoegh-Guldberg
University of Queensland

James P. Leape
Director General WWF International

"...it shows why these challenges are increasing, and how unchecked climate change will ultimately undermine and destroy ecosystems and livelihoods in the Coral Triangle."

Executive Summary

The Coral Triangle stretches across six countries in Southeast Asia and the Pacific (Indonesia, Philippines, Malaysia, Papua New Guinea, Solomon Islands and Timor Leste) and is the richest place on earth in terms of biodiversity. In no more than 1% of the Earth's surface, evolution has produced species and ecosystems that are unrivalled in number, colour and diversity. Within its seas, lie the richest marine communities and ecosystems found anywhere on planet Earth. With over 30% of the world's coral reefs, including 76% of the world's reef building corals and over 35% of the world's coral reef fish species, the Coral Triangle is remarkable and invaluable.

This wonderful cauldron of evolution should be protected in its own right. Its value, however, is much greater. In addition to the unique biological diversity of the Coral Triangle, over 150 million people from some of the most diverse and rich cultures on our planet live there. These people depend on healthy ecosystems such as coral reefs, mangroves and seagrass beds to provide food, building materials, coastal protection, support industries such as fishing and tourism, and many other benefits. The services that these ecosystems provide support over 100 million people who live along the coasts of the Coral Triangle islands.

Unfortunately, the coastal ecosystems of Coral Triangle are deteriorating rapidly and 40% of coral reefs and mangroves have already been lost over the past 40 years. Coastal deforestation, coastal reclamation, declining water quality, pollution, sewage, destructive fishing and over-exploitation of marine life have had a severe impact on these essential ecosystems. This is placing many communities and businesses within the Coral Triangle at risk.

Climate change is now joining the stresses that are affecting Coral Triangle ecosystems and people. Changing weather patterns are causing floods, landslides and severe storms in some areas, and crippling drought in others. Rising sea levels are putting pressure on coastal communities through storm surges and inundation of fresh water supplies. Under our present trajectory of unfettered growth in greenhouse gas emissions, many parts of the Coral Triangle will be largely unliveable by the end of this century.

Climate change is already having a big impact on coastal ecosystems by warming, acidifying and rising seas. Reefs in the Coral Triangle have experienced severe mass coral bleaching and mortality events as temperatures have periodically soared. These splendid reef systems will disappear if these events continue to increase in intensity and frequency.

Climate change is also threatening coastal mangroves within the Coral Triangle, which are highly sensitive to rising sea levels. A multitude of other changes are destabilising critically important ecosystems along the coasts. Stresses arising from climate change are also amplifying the impacts of local stresses, leading to an accelerated deterioration of coastal ecosystems.

While coastal ecosystems are facing enormous pressures from both local and global factors, many areas within the Coral Triangle show significant ecological resilience and are therefore among the most likely to survive the challenging times ahead. High levels of biodiversity, coupled with fast rates of growth and recovery, put many Coral Triangle ecosystems in a favourable position to survive climate change. Some parts of the Coral Triangle may have inherently slower rates of change in sea temperature and acidity, representing a potential refuge in an otherwise rapidly changing world.

This summary report assembles a large amount of information on the climate, biology, economics and social dynamics of the Coral Triangle region and builds a picture of two possible future scenarios. These scenarios are based around decisive international action (or non-action) on climate change, combined with effective action (or non-action) on reducing the impacts of local environmental stresses. They are based on extensive information about how ecosystems, people and economies within this region might fare in these very different worlds (for full details: www.panda.org/coraltriangle).

Consideration of these two scenarios leads to the irrefutable conclusion that stabilising atmospheric carbon dioxide (CO_2) at or below 450 parts per million (ppm) is absolutely essential if Coral Triangle countries are to meet their objective of retaining coastal ecosystems and allowing people to prosper in the coastal areas of the Coral Triangle. The second major conclusion is that changes to Coral Triangle ecosystems are inevitable due to the lag effects of climate change and ocean acidification on coastal and marine systems and associated terrestrial habitats.

To address the threat of these profound and negative changes in the productivity of the system, the essential goal must be to maintain ecosystems in their most healthy state in order to maximise ecological resilience to climate change. Secondly, dependent communities will need to adjust to their practices to take into account the inevitable changes that will be occurring in coastal areas. Therefore, the region-wide national commitment to address the serious threats to coastal systems is essential. Coordination and collaboration is necessary to reduce the stresses that coastal resources currently face from deteriorating water quality, overexploitation of marine resources, destructive fishing, pollution and shipping activity in the region.
Even if the world succeeds in reducing emissions, and slowing down or halting climate change impacts, enough change is already occurring to indicate that action on global climate change without dealing with these serious local issues will be ineffective, and vice versa.

This report delivers a sombre warning that decisive action must be taken immediately or a major crisis will develop within the Coral Triangle over the coming decades. There are a number of actions, which, if taken up by regional and world leaders, will help Coral Triangle countries avoid this crisis. The policy steps recommended by this report include:

1. CREATE A BINDING INTERNATIONAL AGREEMENT TO REDUCE THE RATE AND EXTENT OF CLIMATE CHANGE.

To do this, emissions should peak no later than 2020, and global warming limited to less than 2°C above pre-industrial temperatures (i.e. atmospheric $CO_2 < 450$ ppm) by 2100. This will require steep global cuts in emissions that are 80% below 1990 levels by 2050. Inherent to this recommendation is the creation of an aggregate group reduction target for developed countries of 40% below 1990 levels by 2020, and a reduction from business-as-usual emission levels for developing countries of at least 30% by 2020.

2. TAKE IMMEDIATE ACTION TO ESTABLISH NATIONAL TARGETS AND PLANS TO MEET THESE COMMITMENTS SUCH THAT THE INTERNATIONAL AGREEMENT CAN BE ACHIEVED.

This report shows that nations in the Coral Triangle region have a great deal at stake if climate change continues unchecked. They must become part of the solution. They must do this expeditiously. Lag-times and non-linear responses in the climate system mean that every day we wait to take action, the problem becomes protracted and dramatically more difficult to address successfully.

3. PURSUE THE ESTABLISHMENT OF INTEGRATED COASTAL ZONE MANAGEMENT ACROSS THE REGION.

This step is essential if the current decline in the health of coastal ecosystems is to be reversed. This should include implementation of policies that eliminate deforestation of coastal areas and river catchments, reduce pollution, expand marine protected areas, regulate fishing pressures and abolish destructive practices. It is important that these actions not aim to restore or protect ecosystems for past conditions, rather they must prepare for conditions under a changing climate.

4. SUPPORT THE ESTABLISHMENT OF A GLOBAL FUND TO MEET THE ADAPTATION NEEDS OF DEVELOPING COUNTRIES.

While some of the cost of adapting to climate change can be met by redirecting current resources that are being used in a manner that is vulnerable to climate change, the growing challenge of climate change will result in new and increasing costs. Funds will be required to meet these costs given the nature of the problem and that the disproportionate brunt of the hardship caused by the problem is borne by developing countries. International funds will be necessary to meet these needs.

5. BUILD ADJUSTABLE FINANCIAL MECHANISMS INTO NATIONAL BUDGETING TO HELP COVER THE INCREASING COSTS OF ADAPTATION TO CLIMATE CHANGE.

Climate change will require not only new funds, but also a reassessment of current spending so that funds are not spent in ways that are not 'climate-smart', in other words, on efforts that are not resilient to climate change. Every effort should be made to avoid spending funds and taking actions that exacerbate the problem of climate change.

6. ESTABLISH GOVERNANCE STRUCTURES THAT INTEGRATE RESOURCE AND DEVELOPMENT MANAGEMENT TO PROVIDE ROBUST PROTECTION OF BOTH IN THE FACE OF CLIMATE CHANGE.

Adaptation plans cannot be developed on a sector-by-sector basis. Doing so risks creating problems such as adaptation being effective against one issue but maladaptive against another. It will be important to plan holistically and create governance structures that can support, implement and monitor these efforts.

7. BUILD THE SOCIO-ECOLOGICAL RESILIENCE OF COASTAL ECOSYSTEMS AND DEVELOP STAKEHOLDER AND COMMUNITY ENGAGEMENT PROCESSES FOR COMMUNITIES TO IMPROVE THEIR ABILITY TO SURVIVE CLIMATE CHANGE IMPACTS.

Involving coastal people and communities in planning provides greater stability and efficacy for solutions to social and ecological systems within the Coral Triangle. Fundamentally, it will be local knowledge that generates innovative adaptation strategies which may prove most successful. Reducing the influence of local stress factors on coastal ecosystems makes them able to better survive climate change impacts. Protecting the diversity of components (communities, populations, and species) under the guidance and actions of local people strengthens the resolve of these systems in the face of climate change.

8. CRITICALLY REVIEW AND REVISE CONSERVATION AND DEVELOPMENT EFFORTS AT THE LOCAL, NATIONAL AND REGIONAL LEVELS FOR THEIR ROBUSTNESS IN THE FACE OF CLIMATE CHANGE.

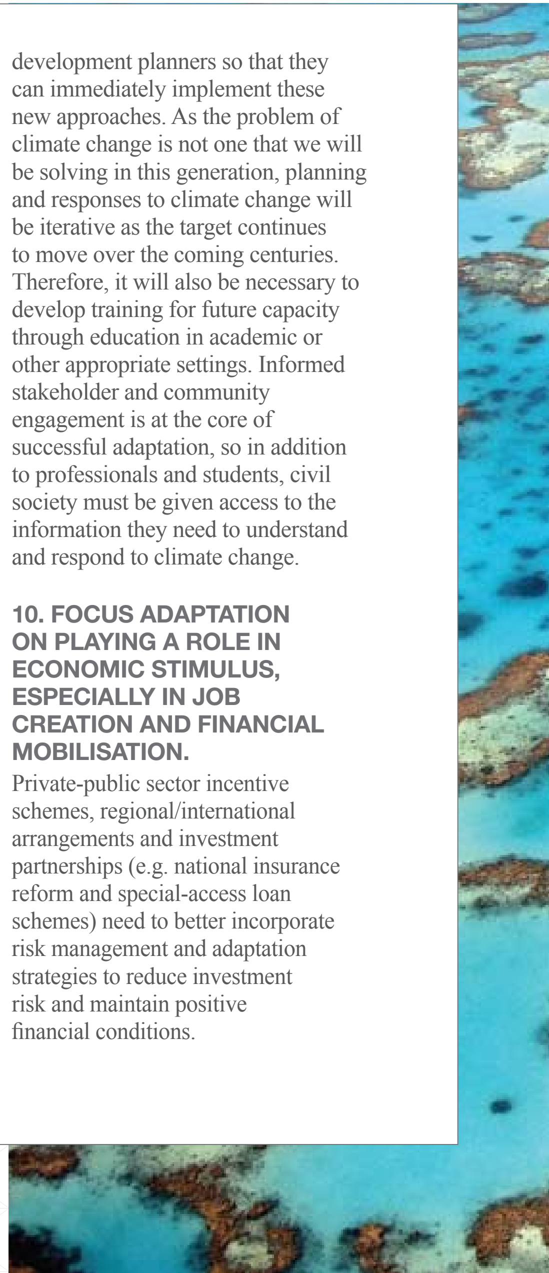
Business-as-usual conservation and development will not achieve success. The new mode of action requires integration between conservation and development, and the realisation that many past approaches are no longer effective due to the impacts of climate change.

9. BUILD CAPACITY TO ENGAGE IN PLANNING FOR CLIMATE CHANGE.

Climate change planning, both mitigation and adaptation, will require that we educate current and future leaders and practitioners, as well as the concerned constituencies. Mechanisms must be created to train current resource managers and development planners so that they can immediately implement these new approaches. As the problem of climate change is not one that we will be solving in this generation, planning and responses to climate change will be iterative as the target continues to move over the coming centuries. Therefore, it will also be necessary to develop training for future capacity through education in academic or other appropriate settings. Informed stakeholder and community engagement is at the core of successful adaptation, so in addition to professionals and students, civil society must be given access to the information they need to understand and respond to climate change.

10. FOCUS ADAPTATION ON PLAYING A ROLE IN ECONOMIC STIMULUS, ESPECIALLY IN JOB CREATION AND FINANCIAL MOBILISATION.

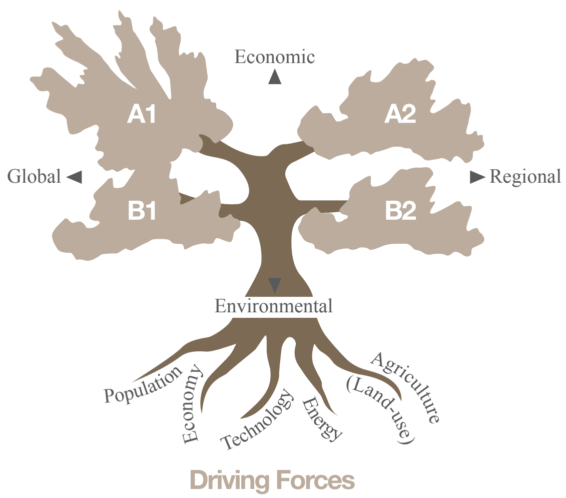
Private-public sector incentive schemes, regional/international arrangements and investment partnerships (e.g. national insurance reform and special-access loan schemes) need to better incorporate risk management and adaptation strategies to reduce investment risk and maintain positive financial conditions.



The Imperative:
Which Future Will We Choose?

The central objective of this study was to explore how the future will unfold if we do or do not take action on climate change and other serious threats to coastal ecosystems in the Coral Triangle. To do this, scenarios were constructed from comprehensive information on environmental, biological, economic and social drivers within the Coral Triangle, based on updated global scenarios originally established by the Intergovernmental Panel on Climate Change (2001). The latter were modified to include new and compelling science published since the release of the IPCC's Fourth Assessment Report in 2007. These scenarios form credible pictures of the future, which served to illustrate the outcome of particular decisions that we make today. The data sets and the complete description of these scenarios are included on the website for this report (www.panda.org/coraltriangle).

Figure 1. Schematic representation of the four major SRES scenarios (source IPCC 2001). Different worlds represent different combinations of global/regional and economic/environmental drivers, and arise from a range of driving forces (represented as roots to the tree). A1 and B1 are global scenarios that are dominated to different extents by economic (A1) versus environmental (B1) motivations. It is important to note that economic and environmental goals may not necessarily oppose each other and certainly synergise in many circumstances (e.g. Triple Bottom Line).



BEST OR WORST CASE SCENARIO?

At the outset, it is sobering to note that the pathway that the world is on today exceeds the worst-case scenario described in this report. At current growth rates of CO_2 emissions (>2 ppm year-1), we are currently travelling along a trajectory which exceeds even the disastrous A1 Fuel Intensive (A1FI) scenario of the IPCC. Given the growing evidence of runaway climate change, feedback amplification and other dangerous "surprises" (e.g. sudden breakdown of polar ice), following this pathway would result in rapid global change with ensuing social, political and economic changes that are likely to be devastating and unmanageable (and hence, not predictable to any degree of certainty from 2060 or thereabouts). Needless to say, this scenario must be avoided at all costs. There is no longer any doubt that we must make dramatic changes to our energy use to reduce our greenhouse gas emissions.

The Special Report on Emissions Scenarios (SRES) of the IPCC defines four basic scenarios (see FIGURE 1) based on their degree of economic versus environmental motivation, and global versus regional focus. Two possible future worlds are examined in this report. The first world takes only moderate steps to deal with climate change, continues to globalise and is driven by purely economic imperatives (A1 scenario - here termed "worst case"). In the second world, strong action is taken on climate change, and robust regional and international commitments exist that ensure environmental concerns and human welfare are tightly integrated with economic goals and objectives (B1 scenario – here termed "best case").

WORST CASE (A1B) SCENARIO: FAILURE TO REDUCE CLIMATE CHANGE AMID ESCALATING LOCAL THREATS

The A1 scenario describes a future world typified by very rapid economic growth, a global population that peaks in mid-century and declines thereafter, and the rapid introduction of new and more efficient technologies. Major underlying themes are convergence among regions, capacity building, and increased cultural and social interactions, with a substantial reduction in regional differences in per capita income. The A1 scenario has three options that describe alternative directions of technological change in the energy system. The three A1 options are distinguished by their technological emphasis: fossil-intensive (A1FI), non-fossil energy sources (A1T), or a balance across all sources (A1B).

Given that the A1FI scenario is considered too dangerous a future for the planet by most experts, the report assumes that the world will move steadily away from fossil fuels and develop technological capacity to use a range of economically viable energy solutions, including both renewable sources and systems designed to make fossil fuel use environmentally safe (such as carbon sequestration). This is the A1B scenario, which involves economic-growth orientated balanced-energy use. Given the serious challenges presented by the A1B world in which atmospheric CO_2 exceeds 750 ppm and global temperature rises more than likely to exceed 3°C, this was adopted as the worst-case scenario of this study.

The full report discusses the complete set of demographic, social and economic trends associated with the A1B scenario. In this scenario, demographic and economic trends are closely linked, as affluence is correlated with long life and small

families (low mortality and low fertility). Global population grows to some 9 billion by 2050 and declines to about 7 billion by 2100. The average age of citizens increases, with the needs of retired people met mainly through their accumulated savings in private pension systems.

The A1B scenario sees concentrations of 710 ppm CO_2 by 2100, through a path taking it from 360 ppm in 2000 to about 410 ppm in 2020, 430 ppm in 2040, 550 in 2060, and 630 in 2080. All areas of the Coral Triangle will have carbonate ion concentrations (critical for marine calcification) by 2050 that are less than 200 µmol kg^{-1} H_2O (i.e. the concentration required to maintain carbonate coral reefs). The best-estimate of the increase in global temperature (nb: tropical sea temperatures mirror global temperatures) will be more or less 2.8°C above today by 2100, with a very high chance that it will exceed 3 or even 4°C. While sea levels are projected by the IPCC (2007) to increase by an average of 28 cm by the end of century, most recent estimates suggest that the minimum sea level rise is more likely to one metre by 2100.

IMPLICATIONS OF THE A1B SCENARIO FOR THE CORAL TRIANGLE

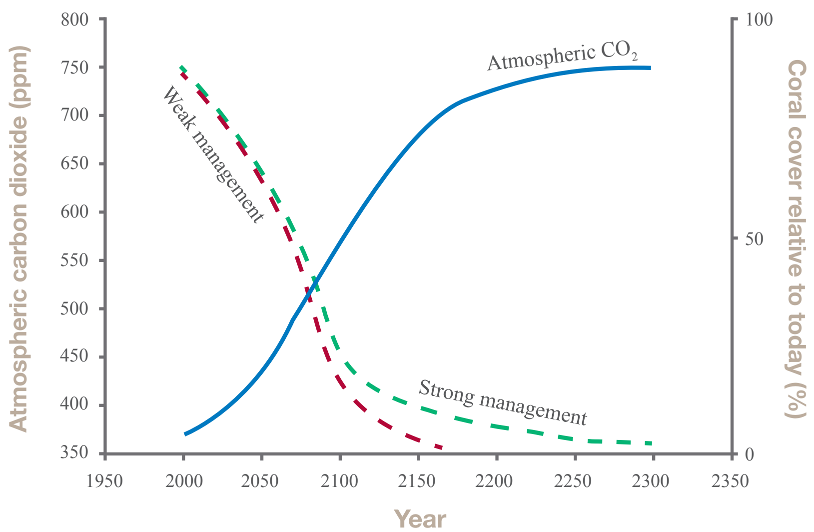
A basic outcome of the A1B scenario is that poorer countries and their people bear the negative impacts of climate change. Within the Coral Triangle, this places the Solomon Islands, Papua New Guinea and Timor-Leste in the most vulnerable category, especially as these countries will experience serious impacts as global temperatures rise beyond 3^0C. All Coral Triangle countries are considered to be developing countries, although Malaysia, with Indonesia and the Philippines following closely, may be on their way to newly industrialised status. This development may accelerate during the first two or three decades of this century in a strong global economic growth scenario, before the full impact of climate change begins to have major impacts on the economy of these countries. Within the Coral Triangle, however, Sabah and Eastern Indonesia are significantly poorer than the rest of the countries to which they belong, so national trends in development may not apply as strongly to areas of these countries associated with the Coral Triangle.

The rapidly changing climate associated with the A1B scenario leads to major impacts on the Coral Triangle through changing precipitation and soaring temperatures by 2050. The Philippines, Sabah and parts of Indonesia (Sumatra, Java and West Papua) are hit hard by increasingly intense rainfall events which are alternated with long, severe droughts (in some areas), and in the case of the Philippines, catastrophic typhoons. Rising seas steadily inundate coastal communities across Indonesia, further exacerbating the impacts of the increases in rainfall and storm activity. These trends cause increasing dislocation of people and communities through flooding and storm damage, with growing scale and frequency as the century unfolds.

Coastal ecosystems are impacted heavily from warming seas which cause increased coral bleaching and mortality (Figure 2). Rapidly increasing sea levels remove mangroves and inundate coastal groundwater supplies. These changes result in the progressive loss of most mangroves and coral reefs over the next 50 years. These changes degrade habitats that are required by thousands of organisms, including important fisheries species. The result of these changes is that coastal fisheries are severely degraded by 2100. The ability of reef systems to provide food for coastal populations decreases 50% by 2050, and 80% by 2100 (compared to their ability to provide food today).

Foreign aid to alleviate these food shortages dwindles as richer nations face their own escalating problems and costs from climate change, and as the regularity and scale of these disasters expands. Tens of millions of people in the Coral Triangle region have to move from rural and coastal settings due to the loss of homes, food resources and income, putting pressure on regional cities and surrounding developed nations such as Australia and New Zealand.

Figure 2. Hypothetical trajectory of the concentration of atmospheric CO_2 and coral cover in a A1B world.



Key Characteristics
of the Worst-case Scenario

The key features of the worst-case (A1B) scenario for the Coral Triangle are summarised below.

DOWNWARD SPIRAL IN COASTAL ECOSYSTEM HEALTH AND BIODIVERSITY

Given that atmospheric CO_2 will exceed 700 ppm under the A1B scenario, the health of coastal ecosystems such as coral reefs will steadily decrease to a very low level by the end of the century. There will be few coral reefs, mangroves and seagrass beds that survive given the high sea temperatures, low pH, suboptimal carbonate ion concentrations, and rapidly rising sea levels. Strong management efforts to reduce local threat factors will have minimal affect on the decline, and there will be little chance of these ecosystems recovering for hundreds of years. The loss of these important habitats will see approximately 40-50% of marine species decrease to very low abundance, and many will be driven to extinction.

INCREASING VULNERABILITY OF COASTAL COMMUNITIES

Rapidly rising sea levels will lead to the steady loss of coastal land and the inundation of coastal freshwater supplies. Together with increasing storm intensity, some parts of the Coral Triangle will experience reduced protection from ocean waves, leading to an increasing frequency and scale of damage to coastal communities and infrastructure. The extent of these changes will depend on the rate of sea level rise although even the most optimistic projections of sea level change under the A1B scenario will cause major disruption to coastal communities. Increases in sea level of one metre or more will put tens of millions of people and their communities under extreme pressure. Many millions will have to move from coastal areas under these scenarios, with serious consequences for inland agriculture and other land use.

REDUCED FOOD SECURITY

The decreased productivity of coastal ecosystems will reduce the food resources and income available to coastal communities in the Coral Triangle. By 2050, coastal ecosystems will only be able to provide 50% of the fish protein that they do today, leading to increasing pressure on coastal agriculture and aquaculture. Access to water for coastal agriculture, however, is likely to decrease sharply due to saltwater inundation of coastal groundwater as sea levels rise, while aquaculture is likely to suffer from the impact of reduced water quality caused by the loss of mangrove systems and other coastal ecosystems. The reduced availability of food in addition to the deterioration of water supplies is likely to cause increased health problems and rising infant mortality. National and international aid resources may reduce as a result of these wide-scale problems.

SOCIAL DISRUPTION

The movement of people from communities in search of food and income will lead to the breakdown of traditional societies, and increase social disruption. The pressure on coastal infrastructure from sea level rise together with reduced food availability is likely to cause social disruption on large scales. Traditional fishing communities increasingly migrate to cities and towns. As a result of the increasingly desperate conditions within crowded urban environments, traditional, family and cultural integrity are lost. Commercial fisheries are likely to put further pressure on regional communities and their coastal resources. Fishery resources skyrocket in price with increased demand, as do the activities of illegal and unreported fisheries.

DETERIORATING REGIONAL SECURITY

While understanding and projecting how regional security will change is a complex task, reduced food and water security and the resulting social disruption represents a potent threat to regional security. Radicalisation of some sectors of the community may follow, increasing tensions and civil unrest within the Coral Triangle region.

“By 2050, coastal ecosystems will only be able to provide 50% of the fish protein that they do today.”

Table 1: IPCC scenarios: likelihood that each will stabilise at particular increases in CO_2 concentrations

Scenario	Temperature change (^{0}C)		CO_2 ppm abundance in 2100	Likelihood that temperature change will be in range (crude measure based on IPCC 2007)				
	Best estimate	Likely range		1-1.99^{0}C	2-2.99^{0}C	3-3.99^{0}C	4-4.99^{0}C	5^{0}C+
B1	1.8	1.1 - 2.9	545	50%	50%			
A1T	2.4	1.7 - 3.8	578	14%	48%	38%		
B2	2.4	1.7 - 3.8	616	14%	48%	38%		
A1B	2.8	1.7 - 4.4	710	11%	37%	37%	15%	
A2	3.4	2.0 - 5.4	846		29%	29%	29%	12%
A1FI	4.0	2.4 - 6.4	964		15%	25%	25%	35%

Source: Based on IPCC 2007 Synthesis Report, Table 3.1.

Notes:

1. These estimates are from various sources including a large number of Atmosphere-Ocean General Circulation Models (AOGCMs). They do not take account any deterioration of climate change prospects after IPCC 2007 was finalized. The estimates are therefore conservative.
2. Temperature changes are expressed as the increase from 1980-1999 to 2090-99. To express the change relative to the period 1850-1899 add 0.5^{0}C.
3. The three A1 scenarios are A1T (non-fossil energy resources), A1FI (fossil-intensive), and A1B (balance across all energy resources). A1 and A2 are driven by economics (mostly short-term gains), globally and regionalized, respectively. B1 and B2 put more emphasis on protecting environmental resources, again either in a global context or in a world with many regions working independently.

Best Case (B1) Scenario:

Decisive international action on climate change while building sustainable coastlines and communities

The central elements of the B1 scenario family are a high level of environmental and social consciousness combined with a globally coherent approach to more sustainable development. In this storyline, governments, businesses, the media, and the public pay increased attention to the environmental and social aspects of development. Globally, appreciation of the importance of triple bottom line solutions that balance economic, ecological and social needs grows. As in the A1B world, technological change plays an important role.

Economic development in B1, however, is balanced, and efforts to achieve a more equitable distribution of income are effective. As in A1, the B1 storyline describes a fast-changing and convergent world, but their priorities differ. Whereas the A1 world invests its gains from increased productivity and know-how primarily in further economic growth, the B1 world invests a large part of its gains in improved efficiency of resource use, equity, social institutions and environmental protection. A strong welfare net prevents social exclusion on the basis of poverty. However, counter-currents may develop and in some places people may not conform to the main social and environmental intentions of the mainstream. The income redistribution and high taxation levels required may adversely affect the economic efficiency and functioning of world markets.

Referring to Table 1, the best-estimate stabilisation level for scenario B1 is 1.8°C above today's temperature, with a 50% risk that global temperature might stabilise between 2 and 3°C.

The target of 545 ppm CO_2 in 2100 is likely to become rapidly unacceptable according to the latest science (detailed in the full report), as is the path towards that target: 405 ppm in 2020, 425 in 2040, 490 in 2060, and 535 ppm in 2080. This puts increasing pressures on policies to drastically reduce emissions, possibly starting from 2015.

The challenge of staying within sustainable levels of atmospheric greenhouse gases (below 450 ppm) remains a formidable one. In the best case world, these challenges are met with determination (requiring the world to decisively leave the current business–as-usual pathway).
Under this scenario, temperatures increase an additional 2.2°C by 2100. The reduction in emissions to 90% of today's level by 2050 has a small but significant impact on the rate of temperature change relative to the A1B trajectory, with this difference increasing to become very significant by the end of the century.

As the concentration of CO_2 increases in the atmosphere, Coral Triangle

"Effective management of coastal resources through a range of options including locally-managed regional networks of marine protected areas, protection of mangrove and seagrass beds and effective management of fisheries results in a slower decline in these resources."

waters experience carbonate ion concentrations that approach but stay slightly above the critical value of 200 µmol kg^{-1} H_2O by 2060 due to continuing proactive efforts for deep cuts in the use of fossil fuels. Like the A1B scenario, sea level rise is projected to increase around 25-35 cm by the end of century (IPCC 2007) but most recent estimates foresee the minimum sea level rise in the vicinity of 50 cm by 2050.

IMPLICATIONS OF THE B1 SCENARIO FOR THE CORAL TRIANGLE

The impacts of a changing climate have large effects on coastal areas of the Coral Triangle and the availability of protein from fisheries is reduced to half of present levels. Sea levels increase by 50 cm by 2050, as in the worse-case scenario. While this may look pessimistically like the worst-case (A1B) world, there are some important differences.

One of the characteristics of the B1 scenario is that communities remain reasonably intact, and hence are in a better position to cope with fairly severe hardships surrounding the gradual 50 cm sea level rise by 2050 on coastal fishing, agricultural and urban communities. More intact communities are able to absorb greater challenges and hardships (some of which we cannot hope to predict) through greater economic, social and cultural resilience. Investment in infrastructure and resource management at the village and township level lead to greater supply of natural and social capital with which to respond to the challenges.

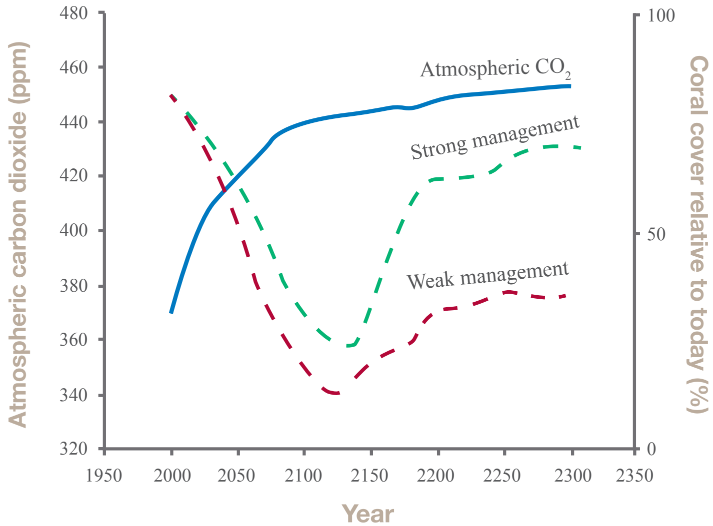
In this world, atmospheric CO_2 content begins to stabilise around the middle to late part of the century. It continues to find solutions to continue reducing CO_2 emissions through strict international control. Sufficient food resources remain available to enable Coral Triangle communities to survive despite decreases in the productivity of coastal fisheries. Areas with low food supplies, including those in the three largest Coral Triangle countries (Indonesia, Philippines and Malaysia) have been supported in this interconnected and significantly richer world.

While the B1 world is certainly not without its challenges, it experiences environmental challenges that are relatively smaller than those seen in the A1B the world (but which are still significant relative to today). Disturbances to rainfall patterns cause serious problems in parts of the Coral Triangle, and typhoons in the Philippines increase in intensity. Moderately severe droughts push some communities into periodic hardship. While these conditions cause some dislocation of people and communities through flooding, sea level rise and storm damage, the scale and frequency of the impacts decrease dramatically toward the latter part of the century.

Warming and acidifying seas kill coral and decrease reef calcification as atmospheric CO_2 approaches 450 ppm. Carbonate ion concentrations are low but remain above the 200 µmol.kg^{-1} H_2O, leading to reduced coral growth as well as cover (but not as low as in A1B, c.f. Figure 2 with Figure 3). Increasing sea level plus rising storm intensity lead to reductions in the overall extent and condition of mangrove and seagrass beds, with consequences for habitats and species abundance across the coastal zone. As in the A1B scenario, warming and acidifying seas drive a steady deterioration of coastal ecosystems, with the difference that effective management leads to a delay in their decline (green line in B1 figure), then recovery and expansion of these ecosystems in the early part of next century. Effective management of coastal resources through a range of options including locally-managed regional networks of marine protected areas, protection of mangrove and seagrass beds and effective management of fisheries results in a slower decline in these resources.

Due to the B1 world being a richer and more connected world towards the latter part of this century, greater amounts of development aid at both national and international levels help coastal communities cope with the changes that they face. While there are movements of people increasingly towards urban centres as coastal ecosystems decline, the reduced rate of climate change enables other resources such as agriculture and aquaculture to fill important gaps in food supply.

Figure 3. Hypothetical trajectory of the concentration of atmospheric CO_2 and coral cover in a B1 world.



Key Characteristics
of the Best-case Scenario

The key features of the best-case (B1) scenario for the Coral Triangle are summarised below.

REDUCED BUT EVENTUALLY REBOUNDING COASTAL ECOSYSTEM HEALTH AND BIODIVERSITY

The atmospheric CO_2 concentrations stabilise at or just below 450 ppm under the modified B1 scenario.

Until atmospheric CO_2 stabilises, coastal ecosystems will continue to face stress from rising sea temperatures, reduced carbonate concentrations and rising sea levels. The abundance of healthy corals, mangrove and seagrass communities will decline but will eventually rebound as atmospheric CO_2 stabilises. Under this scenario, strong management efforts to reduce the impacts of local stress factors and to protect important habitats and refugia have a large positive influence on the abundance and health of coastal ecosystems.

CHALLENGED BUT RESILIENT COASTAL COMMUNITIES

Coastal communities will still face significant challenges despite the implementation of effective measures to stabilise atmospheric CO_2.

As with the worst-case scenario, rising sea levels lead to the steady loss of land and the inundation of coastal water supplies, and the risk of damage from storms increases with storm intensity and higher sea levels. These challenges start to increase steadily over the next couple of decades but will start to decrease around 2050. Coastal communities have more resources and are more confident about meeting the challenges. Significant numbers of people will still have to be absorbed into urban areas as their communities are inundated, but the numbers of people moving will be far less than that seen in the A1B scenario.

STABILISED FOOD SECURITY

As in the A1B scenario, the productivity of coastal ecosystems will decrease, with the result that there is 50% less protein from coastal resources by 2050. The difference, however, is that alternative resource options exist through agriculture and aquaculture, which occur within a B1 landscape that is more environmentally aware than the A1B. Finding alternative water resources may represent important challenges to coastal communities for the first part of the century as saltwater driven by rapid sealevel rise inundates groundwater. The more intact mangrove systems, having been protected and managed, will help maintain water quality along coastlines which adds to the resilience of coastal ecosystems, slowing their decline until they start to recover at the end of the century. Local communities collaborate with regional bodies on integrated coastal management, with many traditional societies playing direct and important roles. Coastal ecosystems like coral reefs benefit from integrated marine protected areas, and provide sustainable resources. Carefully constructed regional policies on fishing preserve and strengthen regional economic benefits. Although food and water security are reduced, communities suffer less from health issues and infant mortality is lower, and receive greater support from national and international aid sources.

REDUCED SOCIAL CHALLENGES

The movement of people out of their communities in search of food and income has been reduced, resulting in a lower level of social disruption. People are in a much better situation under this scenario compared to the A1B scenario, especially towards the later part of the century. This more collaborative and integrated world leads to a strengthening of social bonds between people and their coastal resources, maintaining social resilience and traditional values and beliefs. The latter is used to support local, community-based management of marine protected areas, and regulation of local fisheries. Commercial fishing is regulated by a regional set of agreements among Coral Triangle nations, leading to a stabilisation of fish stock numbers and availability.

STRENGTHENED REGIONAL SECURITY

The reduced levels of poverty as well as the preservation of strong community ties lead to reduced mobility of people and the resulting social disruption. There is correspondingly less marginalisation of sectors of society within the region. Within a world that is more connected and environmentally sensitive, these trends mean that regional security is significantly strengthened. Partnerships like the Coral Triangle Initiative form important mechanisms by which issues are resolved peacefully across the region, with benefits for all partners, and are extended to other challenges facing CT6 nations.

The common set of goals for the Coral Triangle serves as a uniting purpose for the region, with benefits to a wider sphere of national and regional objectives.

The Global Challenge:
Climate Change

Climate change is one of the defining issues of our time, and is set to radically transform the world we live in. It has been driven by rapid increases in atmospheric greenhouse gases (primarily CO_2) arising from the burning of fossil fuels by industrialised countries. Atmospheric concentrations of CO_2 are now 37% higher than they have been at any time in the past 650,000 years, and probably the last 20 million years. These changes have resulted in a dramatic warming of the planet, which is 0.7°C above pre-industrial temperatures, and is currently increasing at the rate of 0.12°C per decade. Rates of change are also several orders of magnitude higher than anything seen in the last million years. The impacts have already been dramatic. The loss of over 70% of the summer ice that has been stable in the Arctic Ocean for many thousands of years emphasies the seriousness of the situation for the environment and for humanity.

IMPACTS HAVE ALREADY BEGUN

Predicting how local environments will change in a rapidly warming world is challenging, especially for a region like the Coral Triangle. Ultimately, the accuracy of any projection depends on how atmospheric CO_2 continues to change, aspects of climate inertia, and the degree to which models can be downscaled to the regional level. Nonetheless, there are general trends emerging in the climate of the Coral Triangle region which allow us to project with some certainty how conditions will change over the next 50 to 100 years. It should be stressed that these projections are likely to be conservative, with many leading scientists now concluding that we are likely to see the upper extremes of these projections eventuate.

CORAL TRIANGLE SEAS WILL BE WARMER BY 1-4°C

The annual, maximum and minimum temperatures of the oceans surrounding the coastal areas of the Coral Triangle are warming significantly (0.09 – 0.12°C per decade, Figure 4, Table 2) and are projected to increase by 1-4°C toward the end of this century (Figure 5). This will put pressure on coral reefs through increased bleaching, disease and mortality. Increases of more than 2°C will eliminate most coral dominated reef systems.

ACIDIC SEAS WILL DRIVE REEF COLLAPSE

Ocean acidification has already driven pH downward by approximately 0.1 pH units due to absorption by the surface oceans of approximately 30% of the extra CO_2 injected into the atmosphere from the burning of fossil fuels and other human activities. This is driving carbonate ion concentrations downward, thereby reducing the ability of corals and other marine calcifiers to build their skeletons. Available evidence suggests that these conditions will become "marginal" for coral reefs of the Coral Triangle within the period 2020-2050 (Figure 6), with the real possibility that many coral reefs will begin to crumble and disappear as corals fail to maintain the calcium carbonate structures that underpin them. This will have huge consequences for the tens of thousands of species dependent on coral reefs. On longer timescales, protection of coastal cities and infrastructure from ocean waves by coral reefs may disappear, which could be catastrophic for millions of people, especially when combined with rapid sea level rise and more intense storms.

LONGER AND MORE INTENSE FLOODS AND DROUGHTS

There are some indications that equatorial Pacific rainfall, especially in the vicinity of the ITCZ (Inter-tropical Convergence Zone), will increase although there are conflicting scenarios provided by different climate models. Even without changes in average rainfall, it seems likely that rainfall events will become more extreme and the annual variability of monsoon rainfall will increase. There is evidence that this key change has already begun to occur. Importantly, the intensity of drought will be greater in a warmer world, severely affecting large parts of the Philippines and other areas of the Coral Triangle (Figure 7).

SEA LEVELS RISING 0.5, 1.0 OR 6.0 METRES?

Sea level has already increased and projections from the Fourth Assessment Report of the IPCC suggest that seas will rise by 30 to 60cm by 2100. Further research since the IPCC's Fourth Assessment Report (June 2007, Table 3) suggests that these projections may have underestimated sea levels by a considerable amount. Most sea level experts now project that the minimum sea level rise is likely to be one metre by the end of the century. Palaeological evidence reveals that major ice sheets on the planet can break down over decades (much more rapidly than previously thought), with huge consequences for the sea level. Many scientists are now warning that rapid ice sheet discharges from Antarctica and Greenland are almost inevitable, leading to the prospect of sea levels increasing by as much as four to six metres over the next several hundred years. These higher levels of change represent a major unknown in the future of all coastal societies; the impacts shown in this report indicate potentially catastrophic consequences for the Coral Triangle and its people.

MORE INTENSE CYCLONES AND TYPHOONS

There is no clear consensus amongst global climate models as to whether the location or frequency of tropical cyclones/typhoons will change in a warming world but they all agree that storms will become more intense (greater maximum wind speeds and heavier rainfall). Indeed, there is substantial evidence that this is already occurring. Large parts of the Coral Triangle lie outside the cyclone/typhoon belts and may be unaffected. However, the Philippines and Solomon Islands, which are affected by typhoons and cyclones, are likely to experience changes in their intensity and impact.

EL NIÑO-SOUTHERN OSCILLATION EVENTS

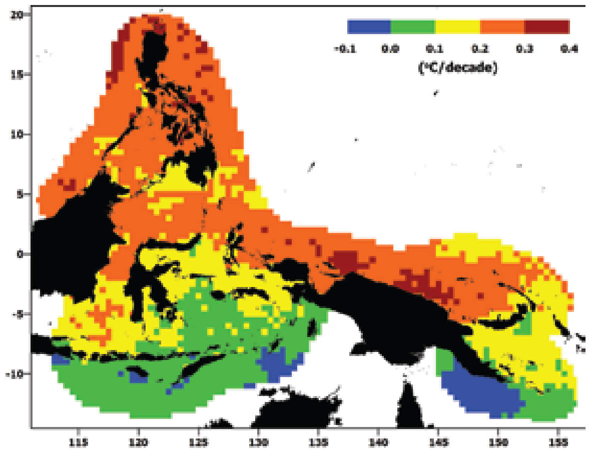
These large-scale perturbations to the global climate have a major influence on sea temperature and rainfall within the Coral Triangle. There is no clear consensus as to how the frequency and intensity of El Niño and Southern Oscillation events will change in a warming world although there is growing evidence that the Pacific is likely to become more "El Niño like". This phenomenon is likely to continue as a significant source of annual climate variability in the Coral Triangle region.

MANY OTHER PARAMETERS WILL CHANGE

Given the complexity of the types of changes that are occurring, and will occur, within the Coral Triangle, many other aspects of the Coral Triangle region may change as well.

In this respect, we know very little about how ocean circulation within the Coral Triangle will change under the influence of increasing sea temperatures and ocean dynamics. Changes in the circulation of oceans within the Coral Triangle would have significant impacts on the climate and biology of the region.

Figure 4: Rapid changes in the sea surface temperature are already occurring in the Coral Triangle. Changes across the coral triangle over the period 1985-2006. Note the very high rates of increase in sea temperature in the northern parts of the Coral Triangle. This suggests that within a very short period of time, temperatures may exceed those that corals can tolerate. (Peñaflor et al., Coral Reefs in press; with kind permission of Springer Science and Business Media).



The Global Challenge: Climate Change

Table 2: Temperatures are sharply increasing across the Coral Triangle region.
Linear trend, 1950-2008 and temperature difference (1989-2008)-(1950-1969) for three Coral Triangle regions and global land and sea temperatures and tropical ssts (all values significant at 5% level).

°C per decade

	Global Land & Sea	Tropical sea surface Temperature	CT Region 1	CT Region 2	CT Region 3
Trend	0.12	0.08	0.12	0.09	0.11
Difference (°C)	0.45	0.29	0.49	0.37	0.44

Location of 3 CT-SST regions

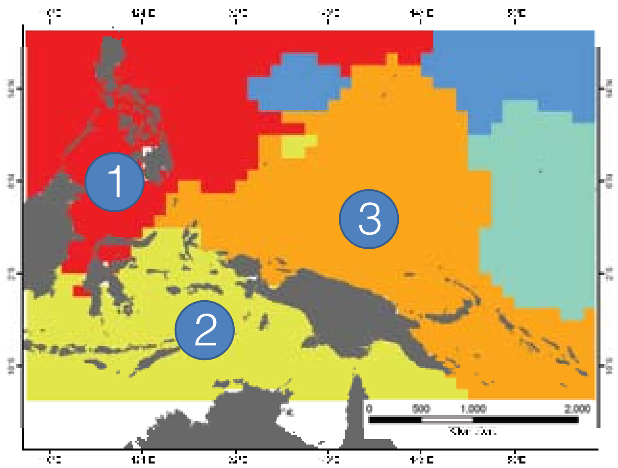
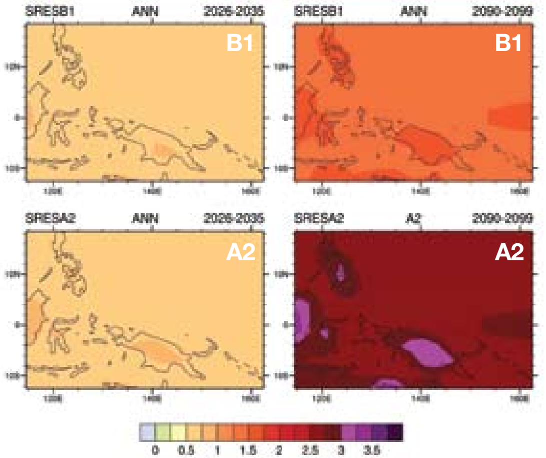


Table 3: Projected global temperature changes, sea-level rise (relative to 1980-99) and CO_2 concentrations for various sres scenarios (Bindoff et al., 2007; Meehl et al., 2007). The last column lists the expected outcome under each scenario.

Scenario	Temperature	Sea level rise	CO_2	Outcome for coral reefs
B1 (modified)	+1.8 (1.1-2.9) °C	0.18-0.38 m	450 ppm	Decrease of coral communities to 10-30% of today's abundance; reef structures struggle to maintain themselves. Reducing the impact of local stressors becomes extremely important under this scenario.
A2	+3.4 (2.0-5.4) °C	0.23-0.51 m	750-800 ppm	Complete collapse of coral communities due to mass coral bleaching and mortality, and conditions which will slow and reverse coral reef accretion and maintenance.
A1FI	+4.0 (2.4-6.4) °C	0.26-0.59 m	950-1000 ppm	Complete collapse of coral communities. Must be avoided at all costs.

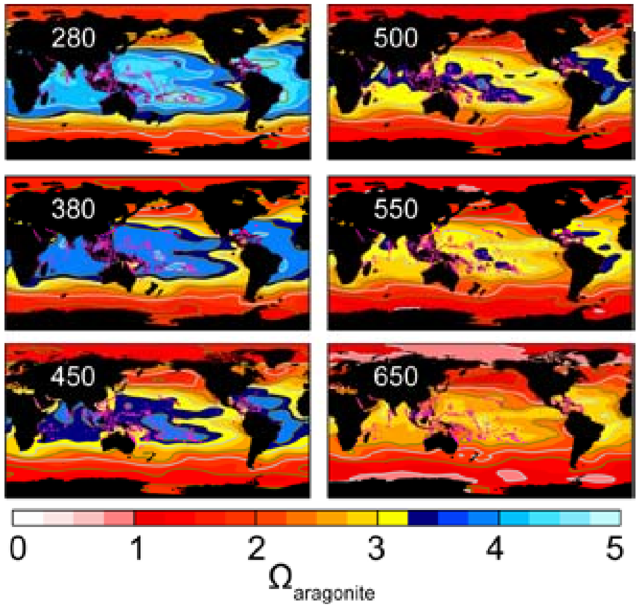
Sea temperatures will increase

Figure 5: Trends in ocean temperature will continue and will intensify under both B1 and A2 (and A1B) scenarios. Multi-model annual mean surface temperature differences (C°) for B1 (top row) and A2 (bottom row) for period 2026-2035 and 2090-2099 (relative to 1980-1999). (Data provided by Julie Arblaster based on Meehl et al., 2007).



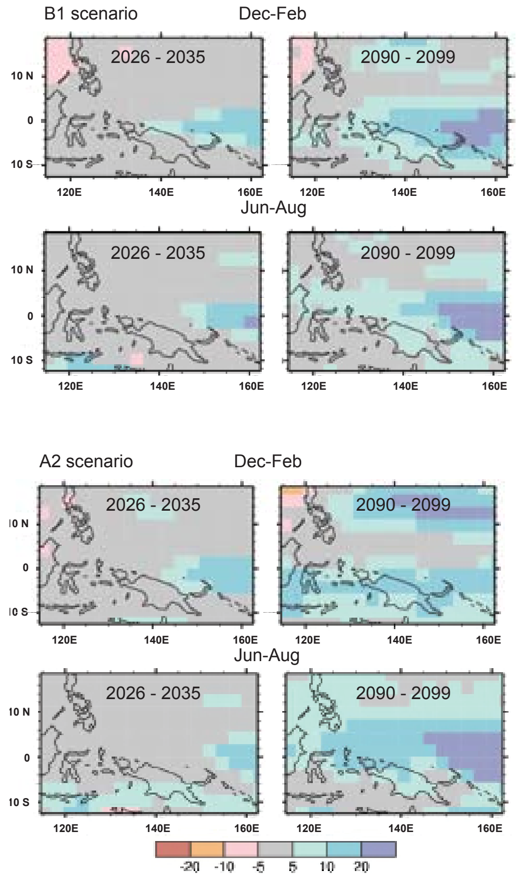
Ocean acidity will rise

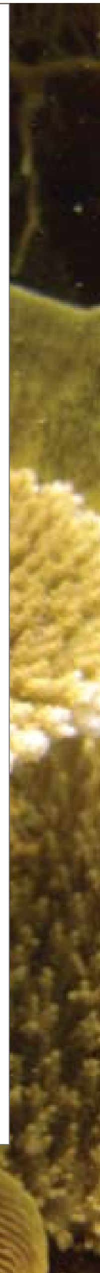
Figure 6. Reef calcification will decrease to very low levels if atmospheric CO_2 increases above 450 ppm. Projected changes in the aragonite saturation state (i.e. availability of calcium and carbonate ions required for calcification) of sea water as a function of atmospheric CO_2 concentration (white number in each panel, ppm). The pink dots represent the current distribution of carbonate coral reef ecosystems. The regions suitable for coral reefs are defined by the blue areas – note that the conditions necessary for carbonate reef development contract to the equator (and the Coral Triangle) with increasing levels of atmospheric carbon dioxide (reprinted with permission from Science Magazine, Hoegh-Guldberg et al. 2007).

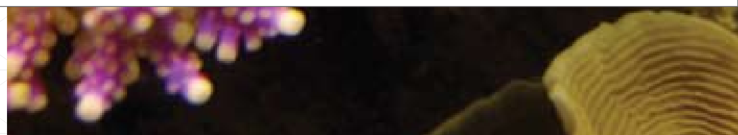


Rainfall patterns are likely to change

Figure 7: Major changes in precipitation will cause larger flood events and longer droughts. Multi-model seasonal precipitation differences (%) for B1 (top) and A2 (bottom) scenarios during Dec-Feb versus Jun-Aug for periods 2026-2035 and 2090-2099.







Small Changes Have Big Impacts

The coastal ecosystems that define the Coral Triangle are extremely sensitive to changes in the environment around them. While the change in global temperature may seem small (e.g. 0.09 – 0.12°C per decade), climate change is already having a major impact on coastal ecosystems. Warming over the past century has pushed ecosystems such as coral reefs closer to their environmental limits, with the effect that natural variability (e.g. a warmer than average year) puts these important ecosystems under serious pressure. When combined with environmental stresses such as poor water quality, pollution or unsustainable fishing, these changes will eliminate functional coral reefs and other ecosystems like mangroves from the coastlines of the Coral Triangle. As has been argued elsewhere in this report, the consequences of these changes for coastal communities are extremely serious.

CORAL REEFS WILL BEGIN TO DISAPPEAR AS CO_2 CONCENTRATIONS APPROACH 450 PPM

Small increases in sea temperature of only 1-2°C above today's summer sea temperatures will cause serious coral bleaching, disease and mortality. In 1998, the world lost 16% of its corals in a single global cycle of mass coral bleaching, which involved sea temperatures reaching 1-3°C above the long-term average for a few months. Coral reefs across the Coral Triangle have been hit hard by mass coral bleaching events which have become more frequent and intense since the early 1980s. In many cases, particularly where reefs have been well managed, they have recovered. At the same time, however, ocean acidification is driving another set of insidious changes in the health of coral reefs. Ocean acidification occurs when CO_2 enters the ocean and reacts with water, creating a dilute acid. The increasing acidity reduces the availability of carbonate ions in seawater, which allow corals and other organisms to make their calcium carbonate skeletons. Atmospheric concentrations of CO_2 that exceed 450 ppm slow the calcification of corals to the point where they will struggle to maintain the reefs that they build today. These changes are not merely academic predictions; recent research has shown that the calcification of corals in places like Thailand and Australia's Great Barrier Reef has already slowed by 15% since 1990.

MANGROVES AND SEAGRASS BEDS ARE SEVERELY THREATENED BY SEALEVEL RISE

Mangroves and seagrass beds are also crucial components of the coastal ecosystems of the Coral Triangle. Like coral reefs, mangrove and seagrass ecosystems provide habitat for thousands of species, and ecosystem services that are essential to the functioning of the coastline and to its human inhabitants. Increasing sea level represents the greatest threat to mangroves, especially when the rate of change exceeds the rate of change in the surface elevation of mangrove sediments. These changes result in a landward migration of mangroves, which occurs if the rate of sea level rise remains small and where suitable land is available for this landward migration. Increasingly strong storms in many parts of the Coral Triangle (e.g. Philippines) will increase damage to mangroves through defoliation. In turn, this will result in increased wave action and serious damage to seagrass beds.

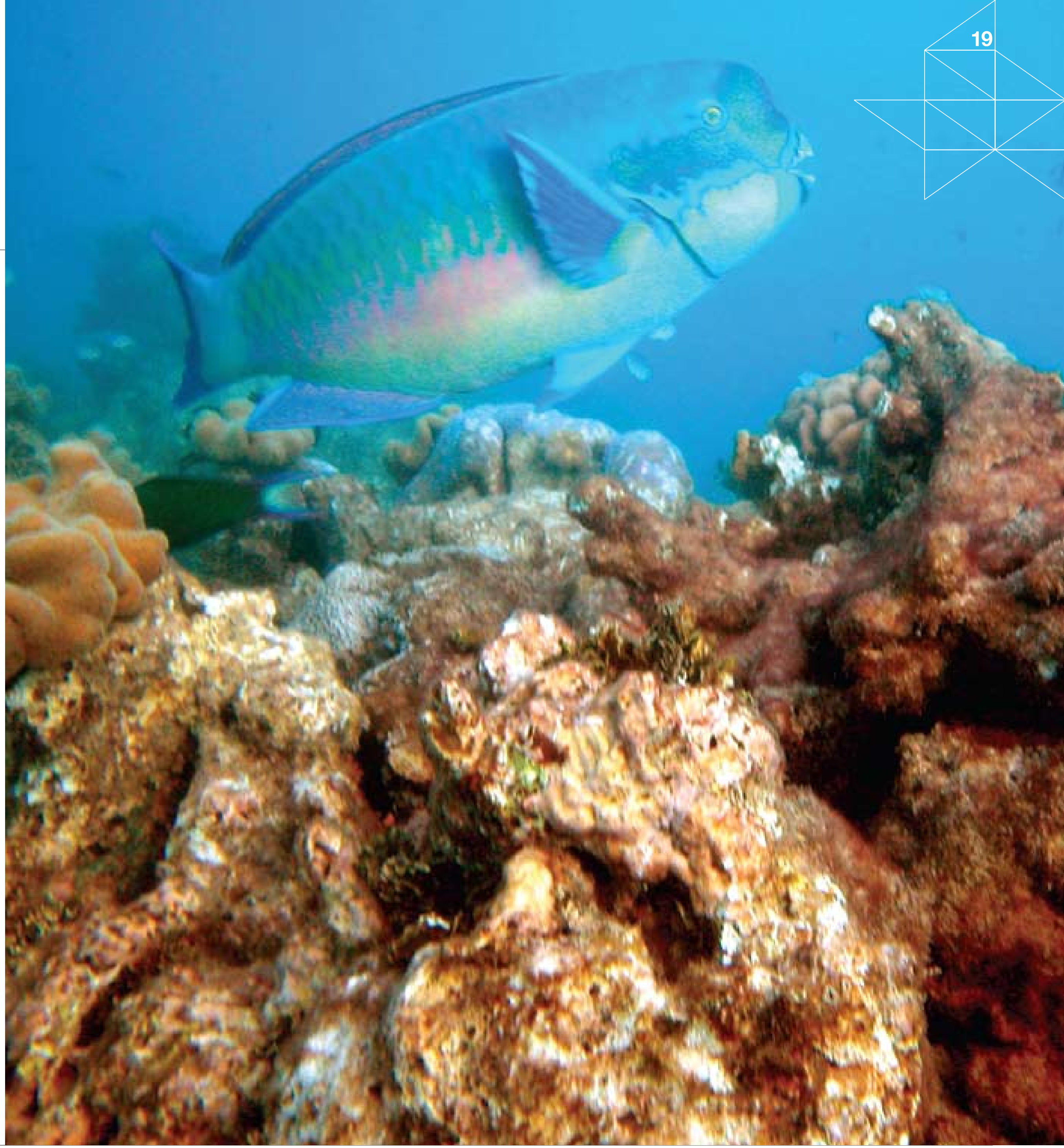
NOT JUST ABOUT CORALS, MANGROVES AND SEAGRASS

Corals, mangroves and seagrass are centrally important organisms which construct the habitat for hundreds of thousands of other organisms. In the case of fish, the elimination of coral reefs compromises the survival of at least 30 to 50% of species that need corals and the reefs they build for food, shelter and reproduction. Similar relationships exist between many organisms that live in mangroves and seagrass beds. The loss of these key organisms would mean enormous changes to the productivity of coastal regions and their ability to support people and societies. To lose them would be to forego any chance of sustainable future economic prosperity.

INTERACTIONS BETWEEN GLOBAL AND LOCAL FACTORS

Global and local factors causing stress on coastal ecosystems do not act independently. For example, coral reefs that have experienced significant mortality from global warming will recover many times faster if seaweed-eating (herbivorous) fish are protected. This is because corals need these herbivorous fish to control seaweeds so that corals can recruit and grow into places where they have been eliminated. If seaweeds become too abundant, corals will be lost through smothering and failed recruitment. Similarly, the impacts of global warming combined with ocean acidification cause a greater impact on corals than each factor on its own. Recent research has shown that corals will bleach and die at much lower temperatures if exposed to ocean acidification at the same time. The interaction of local and global factors suggests an important opportunity for reducing the impacts of global change on coral reefs. For example, improving water quality or protecting herbivorous fish populations have the potential to increase the ecological resilience of coral reefs to the impacts of global warming and ocean acidification. These strategies will buy important time for coastal ecosystems in the Coral Triangle while the international community struggles to achieve deep reductions in greenhouse gas emissions.

"In the case of fish, the elimination of coral reefs compromises the survival of at least 30 to 50% of species that need corals and the reefs they build for food, shelter and reproduction."



The Coral Triangle:
The Earth's Storehouse of Biological Diversity

"If we look at a globe or a map of the Eastern Hemisphere, we shall perceive between Asia and Australia a number of large and small islands, forming a connected group distinct from those great masses of land and having little connexion with either of them. Situated upon the equator, and bathed in the tepid water of the great tropical oceans, this region enjoys a climate more uniformly hot and moist than almost any other part of the globe, and teems with natural productions which are elsewhere unknown."

Alfred Russell Wallace, *The Malay Archipelago (1869)*

HUNDREDS OF THOUSANDS OF UNIQUE SPECIES IN 1% OF EARTH'S SURFACE

The Coral Triangle lies in the waters of six countries in Southeast Asia: the eastern half of Indonesia, Philippines, Malaysia (Sabah), Timor-Leste, Papua New Guinea, and the Solomon Islands, occupying approximately 6.8 million square kilometres (just over 1% of the Earth's surface). In this area, there are over 18,500 islands, of which only a small fraction are inhabited. With so many islands, the coastline of this region is impressive and stretches 132,800 kilometres. The dominance of the region by islands dictates an enormous influence of the ocean over the physical and biological characteristics of the region.

A living specimen of the unique coelacanth *(Latimeria manadoensis)* discovered off Manado, Sulawesi in 1997 by Dr Mark V Erdmann (photographer).

EVOLUTION'S CAULDRON

The 19th-century biologist, Alfred Russell Wallace, became fascinated by the incredible biological diversity of the Coral Triangle, and was among the first to recognise its central importance to the biodiversity of the planet. Today, the significance of this megadiversity is recognised by the fact that four the world's 25 terrestrial biodiversity hotspots (selected for their species richness and threatened status) are found within the Coral Triangle region. Rich mountain forests and woodlands cover the islands of the Coral Triangle, providing habitats for thousands of unique species. Beneath the waters exists a similarly impressive biological diversity, with enormous numbers corals, fish, crustaceans and most other types of marine organisms. More marine species exist in the Coral Triangle than are found in all the other tropical oceans put together. The Coral Triangle bubbles with life like an evolutionary cauldron.

KEY COASTAL ECOSYSTEMS

There are a number of centrally important coastal ecosystems which underpin the biodiversity and human dependants of coastal regions within the Coral Triangle. Like reef-building corals, the highest concentration of mangrove and seagrass species occurs in the Coral Triangle. All three of these organisms are the architects of vast and important coastal ecosystems and have their biodiversity within the Coral Triangle.

CORAL REEFS

Coral reefs cover over 100,000 square kilometres of the Coral Triangle, which represents roughly one third of all the coral reefs in the world. At the heart of these reefs are reef-building corals that form an intimate association with tiny single-celled algae which in turn allow corals to build the magnificent calcium carbonate reef structures. The renowned structures of coral reefs provide a habitat for thousands of fish, invertebrates, plants and other species, making coral reefs the most biologically complex ecosystem on the planet. While scientists do not have a precise figure, it is estimated that anywhere between one and nine million species live on coral reefs like those of the Coral Triangle, many of which are unknown to science.

MANGROVE FORESTS AND SEAGRASS BEDS

Mangroves forests and seagrass beds are important and often underappreciated components of the coastal ecosystems within the Coral Triangle. Occupying large parts of the coastal areas within the Coral Triangle, these two ecosystems also provide important habitats and ecological services across the region. Mangrove and seagrass beds provide shelter to countless numbers of species, and resources that are critical to fisheries, coastal processes and people. These ecosystems are also intimately connected to coral reefs through the flow of energy and nutrients from one ecosystem to another. Many important fisheries species spend some of their life cycle within seagrass meadows and mangrove ecosystems. Charismatic mega-fauna like dugongs and sea turtles are wholly dependent on the presence of healthy seagrass meadows for survival.

Coral Triangle Boundary source: Green and Mous (2008), © The Nature Conservancy Green

UNMATCHED BIODIVERSITY

The proportion of global marine biodiversity found within Coral Triangle is nothing short of astounding. The Coral Triangle includes a third of all coral reefs, and includes 11 distinct ecoregions and 32 functional seascapes. In total, the Coral Triangle has 605 reef-building corals amounting to 76% of the world's total species complement. Within the Coral Triangle, the highest number coral species is found near the Bird's Head Peninsula of Indonesian Papua, which hosts 574 species. Individual reefs there have over four times the total number of species of reef-building corals than in the entire Atlantic Ocean.

> "The Coral Triangle includes a third of all coral reefs ... along 132,800 km of coastline."

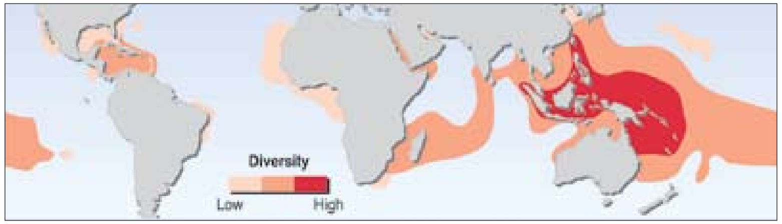
The major marine biodiversity is not simply restricted to corals. The Coral Triangle contains 52% of Indo-Pacific reef fishes (37% of all reef fish species in the world). Major groups, including molluscs, soft corals, crustaceans and many other types of organisms have their highest concentration of biodiversity within the Coral Triangle. While many live on coral reefs, others live in the mangrove forests and seagrass meadows. Each year sees the discovery of hundreds of new species from the rich ecosystems of the Coral Triangle.

AN URGENT CONSERVATION PRIORITY

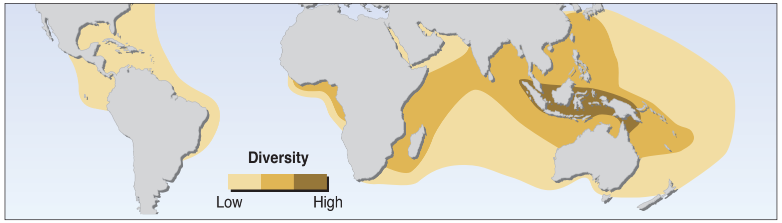
The megadiversity found on land and along the rich coastlines of the Coral Triangle dictate that the region has a special place in the biological inheritance of the Earth. This natural treasure chest is also of enormous importance to the well-being of people and societies in the region. Protecting it has become a priority for governments and conservation groups the world over.

Global Distribution of Coral, Mangrove and Seagrass Diversity

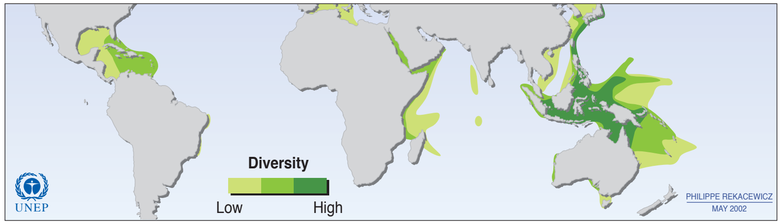
Coral Distribution



Mangrove Distribution



Seagrass Distribution



Source : UNEP-WCMC, 2001.

Figure 8. Global distribution of coral, mangrove and seagrass diversity (courtesy UNEP-WCMC, 2001)

The Coral Triangle:
The Earth's Storehouse of Biological Diversity

Table 1: Key geographic, demographic, economic and environmental data for the Coral Triangle countries

	Indonesia	Malaysia	Philippines	Timor Leste	PNG	Solomon Islands	Total or average
Geographic indicators							
Total land area (thousand km^2)*	1,919	330	298	15	463	28	3,053
Coastline in CT (thousand km)**	66.8	4.5	34.3	0.8	16.5	9.9	132.8
Coral reef area (thousand km^2)*	51.0	3.6	25.8	0.8	13.8	5.8	100.8
Mangrove area (thousand km^2)*	42.6	6.4	1.6	1.5	5.4	0.6	58.1
Number of coral species (Veron, 2009)	574	540	533	514	514	507	530 (CT total = 605)
Number of fish species (Allen, 2008, Table 1)	2122	1549	1790	1500	1635	1371	1693 (CT total = 2230)
Number of mangrove species*	45	36	30	na	44	22	35
Number of seagrass species*	13	12	19	na	7	3	11
Percent reefs at risk*	82	91	97	46	46	46	68
Demographic indicators							
Population (millions)**	242	26	98	1.1	6.1	0.6	374
Growth rate (% per annum)	1.1	1.7	2.0	2.0	2.1	2.4	1.9
Life expectancy at birth	70.1	73.9	71.3	60.2	57.0	63.2	66.0
Median age (years)	28.1	24.9	22.5	21.8	21.7	19.8	23.1
Urban population (% total)	48	61	63	27	13	17	38
Urban population increase (% per anum)	4.4	4.3	3.7	3.4	2.5	4.2	3.8
Urban/total rate of increase (ratio)	4.0	2.5	1.9	1.7	1.2	1.8	2.2
Fish consumption (kg/person per year)	21.3	59.8	28.8	10.0	19.6	49.2	31.5
Economic indicators							
GDP per capita (PPP, US$)	$3,900	$15,700	$3,400	$2,500	$2,300	$1,900	$4,950
GDP growth (per annum)	5.9	5.5	4.6	2.5	6.3	10.0	5.8
Inflation (CPI growth) rate	10.5	5.8	9.3	7.8	8.8	6.3	8.1
Unemployment rate	10.5	3.6	7.3	20-40	> 80	na	7.1
Environmental indicators							
Forested area (% land area)	48.8	63.6	24.0	53.7	65.0	77.6	55.5
Deforestation rate (average p.a. 1990-2005)	1.6	0.4	2.2	1.2	0.4	1.4	1.2
National protected areas (% land area)	14.3	30.7	8.2	4.6	1.6	0.1	9.9
CO_2 emissions (tons per annum per capita)	1.4	6.4	1.0	0.2	0.4	0.4	1.6
Growth in CO_2 emissions 1990-2003	29.4	64.7	43	na	3.4	6.2	29.3

*From Spalding et al. (2001); **Length of coastlines within the Coral Triangle - Nate Peterson, Stu Sheppard, The Nature Conservancy, based on Shuttle Radar Topography Mission (SRTM; NASA) using metadata from SRTM Waterbodies: U.S. Geological Survey Center for Earth Resource Observation and Science (EROS), National Aeronautics and Space Administration (NASA), National Geospatial-Intelligence Agency (NGA), ESRI, 20061001, ESRI® Data & Maps 2006 World, Europe, United States, Canada, and Mexico, ESRI, Redlands, California, USA

Coastal People, Communities and Economies at Risk

Over 370 million people live within the six countries that make up the Coral Triangle, where population growth rates range from 1.1% (Indonesia) to 2.4% (Solomon Islands). Of these people, 150 million live inside the Coral Triangle, with approximately 100 million people being directly dependent in one way or another on the resources flowing from coastal ecosystems.

COASTAL ECOSYSTEMS ARE CRITICAL TO LIVELIHOODS

Coastal ecosystems are crucial for human survival within the Coral Triangle region. In addition to providing daily food and income to millions who forage along the shoreline to support their families, coastal ecosystems provide a huge range of other services. Commercial fisheries provide important income for individuals and for regional governments. The role of coastal ecosystems goes far beyond these immediate economic benefits. Coral reefs provide coastal barriers which protect people, infrastructure and cities against wave action and storm damage. Mangroves and seagrass beds stabilise sediments, and support fisheries by providing habitats for juvenile fish and invertebrates. These ecosystems are particularly crucial as coastal filters, trapping sediments and nutrients, as well as absorbing pollutants flowing from the land to the sea. Together with coral reefs, these ecosystems are critically important to the stability and health of coastal environments.

HEALTHY ECOSYSTEMS MEAN HEALTHY COMMUNITIES

Given the many benefits which flow from coastal ecosystems and support people, it is not surprising to find that the deterioration of coastal ecosystems is often associated with poverty and hardship among coastal people. In the best circumstances, coral reefs and other coastal ecosystems provide food and materials for coastal people. When the systems deteriorate, the ability of these ecosystems to provide support for people is severely diminished. The results of these changes can mean further poverty, and may even mobilise people towards large cities and urban environments, where they join already disenfranchised people in large sprawling settlements. This breaks up families, disrupts communities and destroys cultures. For this reason, action to preserve the Coral Triangle is not only about protecting biodiversity, it is also about securing the resources that allow tens of millions of people to live sustainably and continue to engage in vibrant local economies.

SUSTAINING ECONOMIC GROWTH INTO THE FUTURE

Ultimately, healthy communities within the Coral Triangle region will need to be able to sustain their income and economic strengths over the coming decades. Maintaining healthy businesses based on industries such as well-managed and sustainable fisheries will continue to reap tremendous benefits for the people of the Coral Triangle. Fisheries provide a vital source of income for Coral Triangle countries which export fisheries products worth over US$9 billion each year.

These export fisheries, however, depend heavily on the health of coastal ecosystems, with many species spending the first stages of their life in mangroves and seagrass beds. The destruction of these coastal ecosystems will have dire consequences for fisheries.

Climate change may have other impacts such as changing sea temperature and driving valuable pelagic fishing opportunities out of national waters."

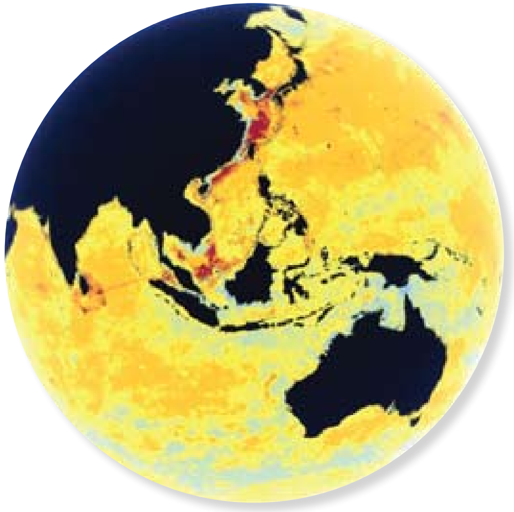
Industries such as tourism are growing steadily and providing increasing international earnings and employment opportunities within the Coral Triangle region. Tourism depends heavily on coastal ecosystems providing tourist incentives such as clean beaches and clear coastal water for swimming, as well as diverse reef communities for tourists to experience through boating, scuba and snorkelling.

The rich and unique environmental assets of the Coral Triangle underpin the future economic benefits for the region. Not to take care of these resources could mean losing them. In many ways, the choice that leaders of the Coral Triangle countries face is about sustainable economic growth. Effective action on climate change and the many stresses that threatened crucial coastal ecosystems will safeguard economies and protect the livelihoods of a vast number of people. That choice should be easy to make.

Escalating Environmental Challenges

Rapid population growth within the coastal areas of the Coral Triangle has put its precious resources under extreme stress (Figure 9). These stresses mean that over 40% of the coral reefs and mangroves of the region have disappeared over the last 40 years. These changes have already had huge consequences for the ability of coastal ecosystems to support people, communities and economies. Unfortunately, these same stresses are also growing fast.

Figure 9. The extent to which human impacts can be detected within the Coral Triangle, from information provided to Google Earth by Halpern et al. (2008). The key to the different colours is shown below



The threats to healthy coral reefs, mangrove forests and seagrass beds within the Coral Triangle can be divided into two broad categories. The first set contains 'local' threats, which originate directly from activities within the region. Deforestation of mangroves, destruction of seagrass beds, declining water quality, pollution, over-exploitation of marine species, sewage discharge, and destructive fishing practices are some of the many direct impacts that humans have inflicted on the ecosystems of the Coral Triangle. The second category includes global threats from climate change, which have already been addressed.

Key local threats to coastal ecosystems in the Coral Triangle are as follows:

COASTAL DEVELOPMENT

Expansion of urban and agricultural activities has directly and indirectly affected coastal ecosystems. Land reclamation to build human dwellings, airports and tourist venues has removed coral reefs and mangroves from coastal areas. Corals have also been mined directly for coral rock and lime for cement to provide building materials to expand cities and townships. Mangroves, seagrass beds, salt marsh and coral reefs have also been destroyed by dredging and port development. The growth of urban centres along coastlines has led to the increased influx of sewage and garbage into the sea. Coastal ecosystems like coral reefs need clear and low-nutrient waters to thrive, and will disappear once coastal waters become clouded with sediment and laden with nutrients such as nitrogen and phosphorus. Sediments reduce the amount of light falling on coral and other photosynthetic organisms, while elevated nutrients tend to tip the balance away from coral-dominated reefs to those dominated by organisms such as seaweeds. Sediment can also physically smother coral reefs. Seagrass beds are destroyed when water becomes too turbid or full of nutrients. Overall, about 25% of coral reefs in the Coral Triangle are threatened by coastal development (Figure 11A).

POLLUTION FROM SHIPPING

Southeast Asia is a major hub for shipping traffic, which includes several mega-ports as well as a complex network of shipping channels. One of the two most important sea lanes in Southeast Asia passes through the Straits of Lombok and Makassar which form part of the Coral Triangle; shipping activities are also growing in sea lanes in Sawu Sea, Arafura Sea, Banda Sea, Seram Sea and Maluku Sea. A number of threats arise from this intense shipping activity including oil spills, pollution from ports, ballast/bilge discharge, as well as waste and garbage disposal. Ships discharging bilge and ballast water may also release oil, nutrients, chemical pollutants and invasive species. Impacts arise from groundings and anchor-damage, leading to the physical destruction of coral reefs. Shipping activities currently threaten 7% of coral reefs in the Coral Triangle and are growing (Figure 11B).

Figure 10. Distribution and intensity of land-use change throughout Southeast Asia (Source: Burke et al. 2002).

The Escalating Environmental Challenges

LAND-BASED RUN-OFF

Intact coastlines function as filtration systems for water running into the sea. Coral reefs and seagrass thrive along undisturbed coastlines where clear water allows light to penetrate and drive the photosynthesis of symbiotic corals and other coral reef organisms such as giant clams and macro-algae. The low nutrient concentrations of these areas discourage phytoplankton blooms. The conversion of coastal forests and landscapes for use in agriculture and aquaculture diminishes the ability of coastal areas to retain soil and nutrients, which otherwise run off into coastal areas. Road construction and other infrastructure activities in coastal areas can therefore have serious affects on adjacent water quality. When coupled with poor tillage practices and the loss of riparian (fringing) vegetation along the banks of rivers and creeks flowing into coastal areas, these activities can have devastating effects on coastal ecosystems.

The growth of heavily populated regions such as those in the Philippines and many parts of Indonesia has resulted in almost all natural forests and landscapes being altered (Figure 10). Coastal water quality is of increasing concern in areas such as the Solomon Islands, where unrestrained logging continues. Approximately 21% of the coral reefs of Southeast Asia are threatened by run-off. This figure is higher in the Philippines and parts of Indonesia, where up to 35% of coral reefs are threatened by nutrients and sediments running off destabilised coastal areas.

OVERFISHING

The coastal ecosystems of Coral Triangle have come under severe threat from two types of fishing activity. The first involves small-scale fisheries that may account for as much as 40 to 95% of total marine fisheries production, as seen in Indonesia and the Philippines respectively. People, many disadvantaged and poor, forage daily for fish, invertebrates and seaweeds to eat or sell in local markets. The second involves commercial fisheries which target species such as tuna, as well as reef fish for the live fish restaurant trade and aquarium markets. Many fish species play key ecological roles in coastal ecosystems, such as grazing marine plants and maintaining the ecological balance between organisms like corals and seaweeds. Other fish and invertebrate species are critical to maintaining healthy sediments through other ecological roles. Fish populations on many reefs have plummeted as results of unsustainable fishing practices and ecosystems have deteriorated as key ecological functions have disappeared.

Fishing pressure has escalated in line with population growth, and represents one of the most significant threats facing coastal ecosystems within the Coral Triangle. Few countries or coastlines remain unaffected. The over-exploitation of fish stocks involves a complex set of threats involving both internal and external pressures, cultural and economic constraints, and is closely connected to human livelihoods and poverty. The live fish trade for restaurants in major Asian cities is an excellent example. The trade involves cartels that provide boats to impoverished people who then over-harvest large fish from remote coastal areas (e.g. Napoleon wrasse and groupers), which are shipped to major cities such as Hong Kong and Singapore. The live fish trade crosses international boundaries and circumvents the ability of local people to control the state of their fish stocks.

Overfishing represents one of the greatest challenges to the Coral Triangle region. Approximately 64% of coral reefs are at medium to high threat from overfishing. The Philippines is the most severe case with over 70% of their coral reefs threatened by overfishing (Figure 11C). Similar although less publicized threats from overfishing exist for seagrass and mangrove forests. In these cases, ecosystems shift as ecological functional groups are removed, with consequences for overall coastal ecosystem health.

DESTRUCTIVE FISHING

Expanding coastal populations with limited financial resources has led to the proliferation of destructive fishing practices. Destructive fishing has taken a toll on habitats as well as on non-target species. In addition to the impact of anchors and nets on coral reefs from regular fishing and trawling activities, there are two main fisheries techniques that cause major direct damage to coral reefs: using poison and using explosives. Approximately 50% of coral reefs in Southeast Asia are at risk from destructive fishing practices. The proportions are highest in the Philippines, with 66% of reefs being threatened by destructive fishing, and Indonesia, where more than half of the reefs are threatened (Figure 11D).

Fishing Using Poison

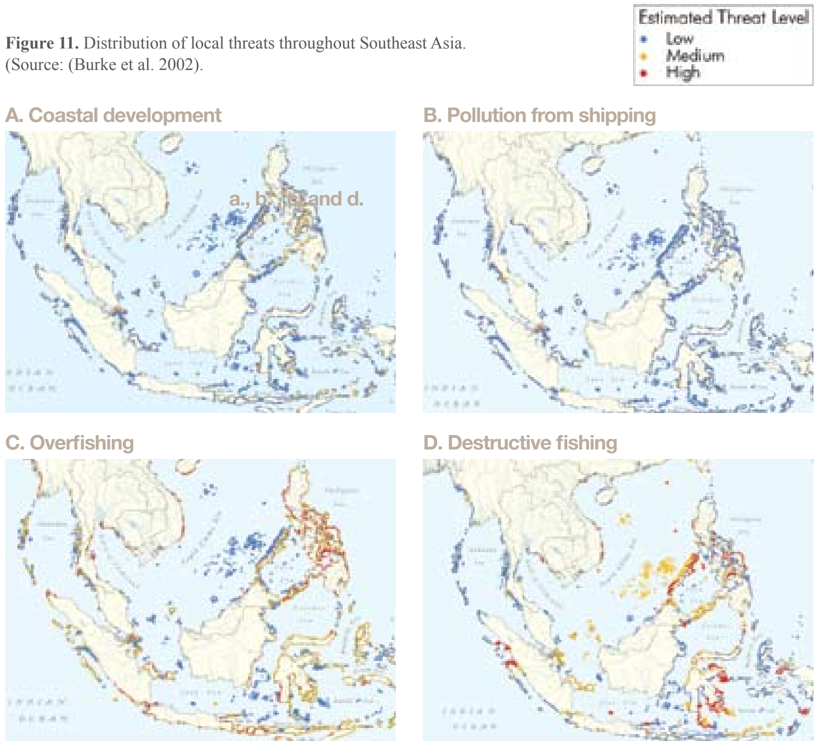
Fishing using poison has long been used throughout Southeast Asia by coastal communities. Products extracted from mangroves and other plants are put into the water by the fisher, impairing or killing the fish prior to collection. At low density and under traditional control, poison fishing is unlikely to have a major impact on coastal ecosystems. The use of poisons today has proliferated across the Coral Triangle, with the possible exception of the Solomon Islands. Modern poison fishers use sodium or potassium cyanide, or insecticides, delivering the poison to the fish in plastic squirt bottles that are operated by divers. The poison anaesthetizes the fish, making them easy to capture. The live fish and aquarium trades both use poisons extensively. The impacts range from non-specific and widespread impacts on other fish, to direct impact on corals and other organisms. The application of even dilute solutions of cyanide will disrupt photosynthesis and cause corals to bleach and die, and if applied at higher concentrations will kill entire communities of corals. The full extent of the use of poison for fishing is unknown, largely because it targets some of the more pristine and isolated coral reefs where observations are limited or difficult. The limited information available on fish poisoning suggests that it is widespread in the Philippines, Malaysia (Sabah) and Indonesia.

Fishing Using Explosives

Fishing using explosives (or blast fishing) is currently outlawed throughout Southeast Asia. Despite this, it is regularly used on coral reefs in the Coral Triangle, particularly in Indonesia. Blast fishing originated after World War II when the combatant armies left behind large numbers of unexploded shells, which were used as a source of explosives for use in fishing. Most of the stocks of explosives from WWII have been used up or removed, and blast fishers now use dynamite from building sites, or potassium nitrate, which is an artificial fertilizer that can be prepared as an explosive using commercial fuses or blasting caps. There are also reports of small scale fishers obtaining explosives from commercial and government sources. Blast fishing kills fish by rupturing their internal organs through the pressure wave that is created by the blast. Once an explosive has been set off, fishers enter the water and collect the stunned and dead fish. The ecological costs of blast fishing have been huge in Southeast Asia. A typical one kilogram bomb (often devised using explosive materials delivered inside a beer bottle) will leave a crater of coral rubble 1-2 m in diameter, which may take 20 to 30 years to recover. In some regions, blast fishing is so common that reefs have been completely destroyed. Reefs that are bombed regularly usually exhibit less than 10% coral cover and a vastly reduced reef framework. With the three-dimensional typography of the reef gone, most of the other organisms that normally inhabit coral reefs disappear as well.

While blast fishing and the use of poisons is less prevalent on the Pacific side of the Coral Triangle, the targeting of fish during spawning aggregations is of increasing concern. The cascading impacts of removing fish in massive numbers during these most important and vulnerable stage in their life cycles can have major impacts on the longevity of fisheries, the health of coral reefs and coastal ecosystems.

Figure 11. Distribution of local threats throughout Southeast Asia. (Source: (Burke et al. 2002).



Conclusion:
Urgent Action Now

This report investigated the conclusions of over 300 published studies and consulted over 20 experts on different aspects of the future of the Coral Triangle. This information was used to explore how this region might change based on the decisions that we take today.

In doing so, the study participants were struck by the urgency surrounding the question of climate change. There appears to be little doubt in the minds of hundreds of scientists that a failure to act on climate change will lead to regrettable and potentially catastrophic consequences for the world. We confirm those perspectives for the Coral Triangle and its people. These looming changes will also be amplified by the impact of many other environmental threats to coastal ecosystems that arise from declining water quality, destructive activities, over-exploitation and pollution. Failure to act to reduce these threats will ultimately spell out a gloomy economic and social future for the Coral Triangle and its people .

These problems are not insurmountable. Effective and early action on greenhouse gas emissions can address the climate change problem. Broad commitments throughout the Coral Triangle region will reduce and reverse the decline in the health of coastal ecosystems. The challenge, however, is to build the international partnerships and take the bold steps to set the world on a different pathway. If this is done, then the dividends to ecosystems, people and governments will be enormous.

International leaders have an important responsibility to invest now in actions that will make a major difference to the future of the Coral Triangle region. In building these scenarios, it is hoped that the difference between making effective decisions (and not) has been made clear, and that the decisions of our leaders will take us on a new pathway to a better future.

“Failure to act to reduce these threats will ultimately spell out a gloomy economic and social future for the Coral Triangle and its people.”

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Authors and Expert Reviewers

Professor Ove Hoegh-Guldberg is Director, Centre for Marine Studies, at The University of Queensland, and Deputy Director of the ARC Centre for Excellence for Coral Reef Studies (www.coralcoe.org.au). Ove leads an active research group of more than 25 researchers (www.coralreefecosystems.org), is currently Queensland Smart State Premier's Fellow and has published over 140 scientific papers on coral reefs and environmental change. Ove is a member of the Royal Society (London) working group on ocean acidification and chairs the Global Environment Facility/World Bank Coral Reef Targeted Research and Capacity Building for Management Program (CRTR) Working Group on Coral Bleaching and related ecological impacts (www.gefcoral.org). He won a Eureka Prize in 1999 and runs the popular blog: www.climateshifts.org.

Hans Hoegh-Guldberg runs Economic Strategies, a company he founded in 1984. He specialises in applied ecological and cultural economics, and has produced a large number of studies in the music, literature and other cultural sectors. He is on the board of the Music Council of Australia and edits its knowledge base. Twelve years ago he became involved in scenario planning (Indonesia) and shortly thereafter in the economics of coral reefs and climate change. He co-authored "Pacific in Peril" (2000) and "The Implications of Climate Change for Australia's Great Barrier Reef" (2004). He is currently completing a two-year climate change project on the Florida Keys for NOAA.

Professor J. E. N. (Charlie) Veron is best known as the author of the three volume publication - Corals of the World. He is also the senior author of the major electronic products Coral ID and Coral Geographic. Veron is the author of 100 scientific articles, including 14 books and monographs. He is former Chief Scientist of the Australian Institute of Marine Science. He has been the recipient of the Darwin Medal, the Silver Jubilee Pin of the Australian Marine Sciences Association, the Australasian Science Prize, the Whitley Medal and received special mention in the Eureka Awards.

Dr Alison Green is Senior Marine Scientist with The Nature Conservancy's Asia Pacific Conservation Region, and is the strategy lead for establishing resilient networks of marine protected areas in the Conservancy's Coral Triangle Program. Her role is to co-ordinate high priority research and provide scientific advice for The Nature Conservancy's Coral Triangle Program, particularly in the fields of coral reef ecology, biodiversity, monitoring and measuring success, and the design and implementation of resilient networks of marine protected areas (MPAs). Recently, she led the scientific design of a resilient network of MPAs in Kimbe Bay, Papua New Guinea, and is currently involved in designing several MPA networks in the Coral Triangle. She has also led several rapid ecological assessments in Indonesia, Papua New Guinea and the Solomon Islands, and played a lead role in delineating the Coral Triangle.

Professor Ed Gomez is a world renowned coral reef biologist from the University of the Philippines where he has maintained an active research laboratory and academic group. He currently serves as the Coordinator of the Centre of Excellence for the Philippines and Southeast Asia under the Global Environment Facility/World Bank Coral Reef Targeted Research and Capacity Building for Management Program, where he also serves as a Co-Chair of the CRTR Restoration and Remediation Working Group. He has 140 technical publications to his credit and continues to publish actively.

Dr Janice Lough is a Senior Principal Research Scientist at the Australian Institute of Marine Science where she leads the Responding to Climate Change Research Team and is also a partner investigator with the ARC Centre of Excellence for Reef Studies. Her current research focuses on the possible impacts of a changing climate and increasing CO_2 on coral reef ecosystems and extracting pre-instrumental histories of reef climates and environments from the annual records contained in long-lived massive corals. She has published over 100 scientific articles in these and related areas.

Melanie King is the Executive Officer for the Global Environment Facility/World Bank Coral Reef Targeted Research and Capacity Building for Management (CRTR) Program based at The University of Queensland, and has been involved in the administrative and project management fields for 20 years. Her experience working on natural resource management projects includes Australia, Cook Islands, Maldives, Philippines, Mexico and Zanzibar. During this time she has developed a sound knowledge of country and donor policies and management actions regarding coastal resources, and recently completed her Masters in Governance and Public Policy, focusing upon policy, institutional arrangements and organisational structures in Small Island States.

Dr Ambariyanto is a marine scientist at Diponegoro University, Semarang, Indonesia. His research interest is mainly on marine endangered species, and coral reef and mangroves rehabilitation and conservation. He has been working closely with coastal communities along the Java Island coastal area, helping related government agencies as well as other marine and fisheries related NGOs.

Dr Lara Hansen has directed research on the biological effects of global change (including UV-B and climate change) since 1990. Her primary focus is the redesign of conservation strategies to incorporate responses to climate change. She is currently engaged in developing the field of adaptation, building capacity and achieving implementation through an organisation she co-founded in 2008, EcoAdapt. Recognition for her research on the biological effects of stresses combined with global change is exemplified by being a Switzer Environmental Fellow in 1995 and an EPA Bronze Medalist in 2002. Dr Hansen was the Chief Climate Change Scientist for WWF-US, leading their Impacts and Adaptations program, from 2001 to 2008.

Dr Josh Cinner is a researcher at the ARC Centre of Excellence in Coral Reef Studies and he explores how socio-economic factors influence the ways in which people use, perceive, and govern natural resources, with a specific focus on coral reef social-ecological systems. He often works closely with ecologists on interdisciplinary research topics such as defining the socio-economic factors that drive successful conservation, understanding resilience and thresholds in coral reef social-ecological systems, examining and operationalising vulnerability to environmental change, and examining the applicability of Western conservation models in developing countries.

Geoff Dews is an Adjunct Senior Lecturer at the Centre for Marine Studies, The University of Queensland. Geoff is a marine resource specialist with extensive consulting experience in the Asia-Pacific region, including Melanesia. Since the beginning of the 1990s he has been involved in international development projects both as technical advisor and team leader. He has been Team Leader for long-term projects in the Republic of Maldives and Timor Leste undertaking strategic environmental assessments and developing coastal management plans. Geoff currently works for the Centre for Marine Studies at The University of Queensland and is involved in work in Solomon Islands and Cook Islands as a coastal catchment technical advisor. He is also the coordinator and key presenter of the Coastal Resource Management short course offered by the Centre for Marine Studies at the University of Queensland each year.

Dr C. Mark Eakin is the Coordinator of the Coral Reef Watch program of the US National Oceanic and Atmospheric Administration (NOAA), which uses satellite data to observe environmental changes that threaten the health of corals and coral reef ecosystems. His background is in coral reef ecology, reef carbonate budgets, and paleoclimatology, currently focusing on the influence of climate change and ocean acidification on coral reefs. He has twice received the Bronze Medal from the US Department of Commerce for his work on climate variability and change.

Tyler Christensen is a coral reef scientist, a contractor with I.M. Systems Group at NOAA's Coral Reef Watch program. Her focus is on international programs: developing satellite data products for global coral reef managers, improving product delivery, and building capacity for the use of NOAA's satellite data. She is a member of the GEF/World Bank CRTR Program's Remote Sensing Working Group.

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Dr Garry Russ is a Professor of marine science at James Cook University, and a program leader at the ARC Centre of Excellence in Coral Reef Studies. His research interests are use of no-take marine reserves as fisheries-management tools and coral reef fisheries. He has an extensive international reputation and has published over 150 peer-reviewed papers on fisheries, conservation and coral reefs, specialising in southeast Asian and western Pacific countries.

Ms Heidi Schuttenberg is a PhD student at James Cook University where she specialises in how to understand and strengthen effective coral reef governance in relationship to the better management of coastal environments and ecosystems. She was co-author on the book "A Reef Manager's Guide to Coral Bleaching" and over 10 articles on issues related to governments, marine conservation and coral reefs.

Dr Michael Abbey is responsible for assessing, developing and managing international fisheries collaboration between the United States National Oceanic and Atmospheric Administration Fisheries and the Asia-Pacific region. He is the NOAA Fisheries liaison to the Coral Triangle Initiative and the Coral Reef Conservation Program - International Working Group.

Dr Rosemary A. Kosaka works as an economist in the Office of Science and Technology at the United States National Oceanic and Atmospheric Administration (NOAA) and is editor of a new annual statistical series reporting economic information about domestic fishing activities and fishing-related industries. She also contributes to ongoing and emerging economics research and data collection activities focused on aspects of U.S. marine ecosystems.

Dr Alexander Tewfik works at the WorldFish Center on the implementation of practical and participatory systems for the diagnosis, restoration and adaptive management of coastal habitats, resources and livelihoods in Indonesia and the Solomon Islands. Prior to WorldFish, he spent more than 10 years conducting applied ecological research in coastal systems throughout the Caribbean and Central America. He has published a number of peer-reviewed papers on small-scale invertebrate fisheries, marine managed areas, impacts of disturbance and habitat restoration.

Dr Jamie Oliver has worked for the WorldFish Center since 2000, first as senior scientist for coral reef projects and then as Director of Science Coordination. He is also the Secretary for the WorldFish Board of Trustees and the Chair of the International Coral Reef Action Network Steering Committee. Prior to WorldFish, he was the Director of Information Support at the Great Barrier Reef Marine Park Authority and a senior scientist at the Australian Institute of Marine Science. He has published extensively in the area of climate change and coral reefs and will help coordinate input from ReefBase.

Eileen L. Peñaflor is a PhD student at the Marine Science Institute, University of the Philippines. She is also a part of the World Bank/GEF Coral Reef Targeted Research and Capacity Building for Management Program - Remote Sensing Working Group. She's currently working on her dissertation investigating the surface warming and thermal stress patterns in the Coral Triangle. Her interest is mainly on the use of satellite-derived data for coastal and ocean studies.

EXPERT REVIEWERS

Professor Angel Alcala is currently the director of the Commission on Higher Education-Silliman Zonal Research Center, as well as the director of the Silliman University Angelo King Center for Resources and Environmental Management, in the Philippines. Dr Alcala has produced more than 60 scientific papers on marine issues and has presented at numerous international conferences. Dr Alcala has more than thirty years of experience in tropical marine resource conservation and coral reef research. The author of numerous papers, Professor Alcala has focused on marine reserves (particularly their effect on the fishery production of surrounding areas), and the ecology and mariculture of molluscan and fish species. He regularly works local communities and local governments in the Philippines on coastal resource management.

Dr Lauretta Burke is a Senior Associate in the People and Ecosystems Program of the World Resources Institute (WRI). She is a geographer and spatial modeller, who specializes in providing tools and information to guide sustainable resource management. Lauretta leads the "Reefs at Risk" project series (was lead author on "Reefs at Risk SE Asia"), evaluating threats to the world's coral reefs, as well as WRI's efforts on economic valuation of coastal resources. Prior to joining WRI, she analysed the potential impact of climate change on fisheries, wetlands and biological diversity for U.S. EPA's Global Climate Change Program.

Dr Margaret "Meg" Caldwell, JD is the Executive Director of the Center for Ocean Solutions, a collaboration between Stanford University (including Hopkins Marine Station), the Monterey Bay Aquarium, and the Monterey Bay Aquarium Research Institute (MBARI). The Centre's mission is to elevate the impact of the natural, physical and social sciences on ocean policy by integrating cutting-edge science and technology with economic, social, and political expertise to develop practical solutions to the major challenges facing the oceans. Meg is a member of the Stanford Law School faculty where she directs the Environmental and Natural Resources Law and Policy program. Her teaching and scholarship is at the interface of law, science and policy, presently focusing on governance of coupled coastal and marine ecosystems and human communities.

Professor Suharsono Prof. Dr. Suharsono is Director of Research Centre for Oceanography in Indonesia Institute of Sciences (LIPI). He was studied in Newcastle University UK in ecology coral reef. He is a senior researcher in the area of coral reef ecosystems and took the lead of Coral Reefs Rehabilitation and Management Program (COREMAP) to monitoring status of coral communities in Indonesia. Suharsono is a member of The International Society for Reef Studies (ISRS) and as Indonesian Focal point on Coral Working Group-CITES and International Coral Reef Initiative.

Dr Marea Hatziolos is a marine ecologist and a senior specialist in coastal and marine management in the Environment Department of the World Bank. Her work focuses on improving policies and practices for sustainable use of marine resources and conserving marine biodiversity through an ecosystem approach to development planning and management. She is the team leader for a global partnership between the GEF, the World Bank, the University of Queensland and some 40 research institutions world-wide to support science based management of coral reefs through the Coral Reef Targeted Research and Capacity Building for Management Program. In addition to her work on ecosystem based-adaptation to climate change, she is part of an international working group on valuation of marine ecosystem services and leads the Bank's work on integrated coastal management and coral reefs and climate change.

Dr John Cordell is an environmental anthropologist specializing in coastal management. He currently operates a non-profit research center in Berkeley, California, USA, The Ethnographic Institute. Ethnographic is dedicated to assisting tropical small-scale, artisanal fishing, communities sustain their culturally-based livelihoods. Studying at Stanford University, and teaching at University of California Berkeley, University of Queensland, and University of Sao Paulo in Brazil, Cordell also engaged in extensive fieldwork and writing about fishing societies in Bahia, Brazil and in Torres Strait.

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