**Target 10: Vulnerable ecosystems (coral reefs)**

By 2015, the multiple anthropogenic pressures on coral reefs, and other vulnerable ecosystems impacted by climate change or ocean acidification are minimized, so as to maintain their integrity and functioning.

**Preface**

This analysis evaluates trends in indicators of coral reef health and the implications of these trends for biodiversity in 2020 and 2050. It discusses progress towards increasing the area of coral reefs under full protection, but also the challenges involved in curbing the effects of rising human populations and climate change. Although this chapter focuses on shallow water corals, it is recognised that deep water corals are also highly threatened by anthropogenic activities and climate change (Roberts and Cairns 2014).

The level of human dependence on coral reefs is high. Approximately 850 million people live within 100 km of coral reefs and are dependent on reefs either for food, livelihood, coastal protection, or amenity. Of these, 275 million people live in the direct vicinity of coral reefs (Burke et al. 2011). People living on small-island states tend to be the most reef-dependent, in part because of paucity of alternative livelihoods. More than 94 countries and territories provide reef-based tourism which accounts for more than 15% of gross domestic product in 23 countries.

Most of the ecosystem functions of reefs, such as the provision of productive fisheries, tourism appeal, and coastal protection from storms, are founded on having a complex reef structure that keeps accreting (growing). A structurally complex reef provides habitat (and hiding places) to support high levels of biodiversity (Gratwicke and Speight 2005), which span a diversity of fishes and invertebrates, many of which remain poorly documented. If a reef is to continue functioning then it must at least have net growth – i.e., that the deposition of a carbonate skeleton by corals and calcareous algae must exceed the rate at which the skeleton is removed by physical damage and the erosion caused by a host of taxa including burrowing algae, sponges, and worms. The balance of reef construction and erosion is known as a carbonate budget (Stearn et al. 1977). Perhaps that greatest threat to coral reef biodiversity is the long-term loss of reef habitat that could occur if carbonate budgets become persistently negative (erosive).

1. Are we on track to achieve the 2015 target?

1. Status and trends

1.a. Local threats

Vulnerable habitats like tropical coral reefs are threatened by both local and global stressors. These threats affect not only the corals, but also coral reef associated communities that form the reef ecosystem. Local stressors include over-harvesting of fisheries (McManus 1997),
destructive fishing methods (e.g., explosives, cyanide), marine-based pollution and damage 
(e.g., oil and gas installations, shipping and anchor damage), watershed-based pollution 
(e.g., nutrients and fertilizer runoff, Richmond et al. 2007), and coastal development (e.g., 
sewage discharge, dredging), and marine recreation (e.g., diving and boating). Global 
stressors are principally rising sea temperatures, which reduce coral calcification and can 
elicit coral bleaching events, and ocean acidification, which has a variety of deleterious 
impacts on reef systems (Hoegh-Guldberg et al. 2007). Superimposed upon these threats are 
natural perturbations such as cyclones (Rogers 1993). According to the Reefs at Risk 
Revisited report, the percentage of reef area rated as threatened increased by 30% in the 
decade from 1997 to 2007 (Burke et al. 2011). Threat levels were estimated by integrating 
indicators of local and global threats within a geographic information system (GIS). Much of 
the elevated increase (80%) was driven by rising threats from fishing in the Indian and Pacific 
Oceans, largely because of elevated density of coastal populations (Burke et al. 2011). The 
main conclusions about current local anthropogenic impacts include: 1) More than 60% of 
the world’s coral reefs are under immediate and direct threat from one or more local 
stressors; 2) Of local stressors, fishing is the most pervasive threat, affecting more than 55% 
of reefs. Coastal development and watershed-based pollution each threaten about 25% of 
reefs. Marine-based pollution threatens about 10% of reefs; 3) Local pressures are most 
severe in Southeast Asia, where nearly 95% of reefs are threatened and 50% are in the ‘high’ 
or ‘very high’ threat category (Fig 10.1, Table 10.1). Indonesia has the largest area of 
threatened reef followed by the Philippines (Burke et al. 2011). Although much of this threat 
stems from fishing, it should be noted that land based activities also impact heavily upon the 
reef (e.g., Brodie et al. 2012, see Box 10.2), and these cumulative impacts need to be 
addressed through sound coastal zone management.

![Coral Reefs of the World Classified by Threat from Local Activities](image)

**Figure 10.1.** Distribution of coral reefs classified by human threat level. Red represents very high; 
orange – high; yellow – medium; and blue – low threat (Source: Burke et al. 2011).

**Table 10.1.** Geographic trends in reef threat from Reefs at Risk Revisited

<table>
<thead>
<tr>
<th>Region</th>
<th>Source of threat</th>
<th>Percentage of reefs</th>
<th>By threat category</th>
</tr>
</thead>
<tbody>
<tr>
<td>Southeast Asia</td>
<td>Main threat is from overfishing and destructive fishing</td>
<td>95%</td>
<td>High / Very high 50%</td>
</tr>
<tr>
<td>Atlantic Ocean</td>
<td>Multiple threats, Bahamas have largest reef area at low threat</td>
<td>75%</td>
<td>30%</td>
</tr>
</tbody>
</table>
Indian Ocean Fishing most widespread threat 65% 35%
Middle East Multiple threats. Exceptions include Chagos 65% 20%
Wider Pacific French Polynesia, the Federated States of Micronesia, Hawaii and the Marshall Islands have some of the lowest sources of local stress. 50% 20%

Australia Least threatened globally** 14% 1%

* Includes 4 local threats (coastal development, watershed-based pollution, marine-based pollution and damage – such as oil exploration and shipping – and fishing impacts) and 1 global threat (historical coral bleaching events in last 10 years).

** Although Australian reefs were considered to be the least threatened globally in 2011, new analyses of long-term monitoring and survey data have revealed that coral cover has decreased dramatically from a mean of 28% to 14% between 1985 and 2012 (De’ath et al. 2012). The causes of such decline were attributed to cyclones (48%), coral predation by crown-of-thorns starfish (42%), and coral bleaching (10%). Of these, only coral predation is likely to be caused by local human impacts (principally high nutrient runoff).

In addition, international market demand for reef resources, such as aquarium fish and corals, directly affect the integrity of reef ecosystems through the removal of reef organisms and modifying habitat. This reinforces the need for national as well as international legislation that not only focuses on reducing fishing pressure, but also regulates trade in reef organisms. In the past decade, there has been an overall declining trend in the trade of wild corals (Fig. 10.2); however, it should be noted that while coral rock and dead coral trade is declining, the trade in live coral is increasing (Wood et al. 2012).

Figure 10.2. Trend in the trade of wild corals 2002-2011, as reported by exporter countries. Source: CITES trade data.

1.a.ii. Global threats

Reefs are principally impacted by two processes at the global scale (Hoegh-Guldberg et al. 2007, Pandolfi et al. 2011, Frieler et al. 2012). The first is rising sea surface temperatures, that are currently increasing at rates of 0.2°C decade⁻¹ in SE Asia (Penaflor et al. 2009) and up to 0.5°C decade⁻¹ in the Caribbean (Chollett et al. 2012). Long-term rising sea temperatures can be a chronic stressor that reduces the calcification rate of corals (Carricart-Ganivet et al. 2012). Higher temperature also predisposes corals to ‘coral bleaching’ which is a serious disruption of the symbiosis between the coral host and the dinoflagellate algae that live within its tissues. Recent ENSO (El niño-Southern Oscillation) events have caused massive coral bleaching, often followed by extensive mortality, at regional and global scales. The
most severe global event occurred in 1998, but other events have occurred at regional scales in 2005 and 2010 (Eakin et al. 2010) and their frequency is expected to increase under global warming (Frieler et al. 2012). A global representation of bleaching events and severe thermal stress is given in Fig. 10.3.

![THERMAL STRESS ON CORAL REEFS, 1998 – 2007](image)

**Figure 10.3.** Thermal stress on coral reefs (1998-2007)

The second major stressor is ocean acidification (OA) which occurs as atmospheric carbon dioxide continues to be absorbed by the ocean. OA can impede the rate of calcification and interfere with a range of biological processes, including the sensory capabilities of fish (Munday et al. 2009) and corals (Doropoulos et al. 2012), and the competitive interactions between algae and coral (Diaz-Pulido et al. 2011). Although these two global stressors are unavoidable and cannot be directly mitigated in the near term, it is still essential to take international actions to diminish climate change impacts, even if results from these actions may only manifest in the long term.

Management action is hampered by a lack of understanding about whether the effect of multiple global and local stressors is synergistic or not (Gurney et al. 2013). It is likely that multiple stressors can act synergistically, though the outcomes will vary according to the stressors involved. For instance, studies of fishing and bleaching impacts on Kenyan corals found no evidence of synergisms (Darling et al. 2010) whereas the dual impacts of rising sea temperature – chronic reductions in coral calcification and more frequent bleaching – are predicted to have synergistic impacts on coral reef resilience (Bozec and Mumby 2014).

1.a.iii. Trends in reef health

Overall trends of reef health, measured by the cover of living coral, are generally strongly negative. For example, average Caribbean coral cover has declined, on average, from around 50% in the 1970s to approximately 10% by 2000 (Fig. 10.4, (Gardner et al. 2003). Bruno and Selig (2007) analysed coral cover from various data sets across the Indian and Pacific Oceans and found an overall average loss of 0.72% y\(^{-1}\). However, both studies show marked intra-regional variability in these overall trends. For example, the Caribbean still includes countries where coral cover can exceed 50%, such as Bonaire. Much of the net loss appears to be attributable to the severe global bleaching event of 1998.
Figure 10.4. Average trends of coral cover in the Caribbean, showing a fall from around 50% in the 1970s to 10% in 2002 (after Gardner et al 2003).

It is insightful to examine cases where corals still have the resilience required to bounce back after disturbance. In 1997, Connell (1997) found marked evidence of recovery in the Indo-Pacific but little in the Caribbean. Revisiting this question, Roff and Mumby (2012) found only a single recovery trajectory in the Caribbean, whereas striking coral recovery is still reported from many sites in the Indo-Pacific (e.g., Adjeroud et al. 2009, Halford and Caley 2009). It seems that reef resilience is particularly impaired in the Caribbean, in part because of few fast-growing coral species, relatively few herbivorous fish species, and a predisposition of seaweed to bloom (Roff and Mumby 2012). But even relatively well-managed systems in the Pacific can show a net “ratcheting down” of coral cover as they experience repeated disturbance over a short period of time. A recent report concluded that the average state of the Great Barrier Reef has declined by around 50% of living coral over the last 25 years (De’ath et al. 2012).

Here, we attempted to estimate the degree to which global change (rising sea temperature and OA) may have affected coral communities (Wolff et al. in review). This study suggests there have been increasing levels of climate stress from the 1970s to 2000 (Fig. 10.5). Present levels of stress vary markedly around the world, being relatively low in Australia, the south Pacific, north Asia, and the tropical Western Atlantic.
Figure 10.5. Models global of climate-related stress upon corals in 2000, 2025, and 2050 based on AR4 SRES A2, from which AR5 RCP8.5 was derived (Wolff et al in review).

1.a.iv. What has been done to protect reefs?

Marine protected areas (MPAs), if well enforced and integrated with coastal watershed management, can mitigate the multiple local anthropogenic stressors on coral reefs, thereby increasing the resilience of reefs and making them less susceptible to environmental and climate stressors such as coral bleaching. For instance, no-take MPAs have been used effectively to rebuild fish stocks (Russ et al. 2008) on coral reefs and even help corals recover after bleaching (Mumby and Harborne 2010). Approximately 27% of the world’s reefs are located inside MPAs. However, many MPAs turn out to be ‘paper parks’ due to lack of enforcement capacity; an analysis of effectiveness concluded that only about 15% of reserves have reduced the threat from fishing (Burke et al. 2011). Nevertheless, many new coral reef MPAs are now being planned (Fig. 10.6), although it should be noted that the coverage of many large MPAs was found to be strongly biased away from areas of greatest threat.
Figure 10.6. Map of recently established large-scale MPAs or MPA initiatives. Red numbers indicate regional MPA initiatives involving more than one country; bold numbers indicate MPAs that are pending establishment; * indicates MPAs that are less than 500,000 km² in size; ** indicates MPAs that are larger than 500,000 km² in size; and ^ indicates regional initiatives for which MPA area is not specified. See Appendix 10.1 for more details. Note that locations of MPAs are indicative of general area only, and not precise.

1.8. Projecting forward to 2020

Target 10 is one of the few Aichi 2020 targets with a goal for 2015 rather than 2020. While it is possible that non-linear responses of coral reefs to stress and disturbance might cause sudden flips to degraded states (Mumby et al. 2013), it is difficult to see how current trends as described in section 1.a. will substantially change by 2015 compared to our analysis of current trends; therefore, we focus this analysis on trends out to 2020. Human population in coral-reef countries is expected to increase by nearly 15% between 2010 and 2020 (UN Department of Economic and Social Affairs 2004). Thus, while it is difficult to project future changes in local threats, recent trends and the expanding human population suggest that threat levels will continue to increase. Sectors which impact upon coral reefs, such as marine tourism and agricultural development, also show increasing trends. For instance, the area of industrial oil palm plantations in Southeast Asia has grown continuously since 1990, with greatest growth since 2007, and it is expected that this growth trend will continue to 2030 (Miettinen et al. 2012). Further, global tourism is projected to grow at an average rate of 4.1% to 2020 (UNWTO 2001). This has implications for reef biodiversity hotspots, such as the Coral Triangle, where coastal and marine tourism growth has been strong (Crabtree 2007). While marine ecotourism can potentially be a sustainable alternative to fishing for coastal communities (Fabinyi 2010), mass tourism that is not within the physical limits of the environment may further degrade reef and coastal habitats (Teh and Cabanban 2007). International trade is another factor that can likely impact coral reef biodiversity, with trade...
in wild corals projected to increase to 2020 (Fig. 10.7). (note that this extrapolation is likely to be revised)

Fig 10.7. Statistical extrapolation of the increase in the trade of wild corals to 2020. Long dashes represent extrapolation period. Short dashes represent 95% confidence bounds. Horizontal dashed grey line represents model-estimated 2010 value for indicator. Extrapolation assumes underlying processes remain constant. Data from CITES trade database.

Studies of recent rises in the sea temperature in coral reef areas (post 1985) find striking regional variability. In SE Asia, for example, mean rates of warming are 0.2°C/decade but some areas in southern Asia have actually net cooling (Penaflor et al. 2009). Similarly, average rates of recent warming are 0.29°C/decade in the Caribbean, but warming is most intensive in the south and net cooling occurred around parts of Florida (Chollett et al. 2012). Temporal trends in ocean acidification during this period are generally unclear, though intensification has been predicted for the northern Caribbean, where data are available (Gledhill et al. 2008).

Despite the anticipated increase in threat and ineffectiveness of many MPAs, the designation of protected area status continues to increase. Some countries, including the United States, Kiribati, Australia, and the United Kingdom have declared massive MPAs over coral reef regions (Fig. 10.6). In addition, several regions, including the Caribbean and Micronesia, have signed up to ambitious targets to protect large areas of coast within the next decade or two (Fig. 10.6). Not all areas are intended to become no-take marine reserves, but the increased level of protection should increase the efficacy of management and reduce the probability of destructive activities.
1.c. Country actions and commitments

Relatively few countries have established national targets, or similar elements, related to this Aichi Biodiversity Target. (Note, however that a number of National Biodiversity Strategies and Action Plans (NBSAPs) examined are from countries which do not have coral reefs). Many countries note the growing role of climate change as a main driver of biodiversity loss in their NBSAP. Those national targets that have been established are generally in line with the Aichi Biodiversity Target. However there tends to be a general emphasis on building resiliency to climate change.

Few targets explicitly refer to reducing anthropogenic pressures on coral reefs. Similarly, few targets explicitly refer to reducing anthropogenic pressures on ecosystems which are vulnerable to climate change. Two examples which are counter to this trend are Finland and Brazil which have both established national targets which refer to reducing anthropogenic pressures on vulnerable ecosystems.

2. What needs to be done to reach the Aichi Target?

2.a. Actions

While there are a number of regional initiatives aiming to protect coral reefs and associated ecosystems (such as mangroves and seagrass systems), multiple stressors, including both global stressors (e.g., rising sea temperature, the effects of tropical storms and rising sea levels, as well as ocean acidification,) and local stressors (e.g., overfishing, destructive fishing practices, nutrient runoff, land-based and sea-based pollution, coastal development, tourism and recreational use, etc.), continue to impact these ecosystems. Therefore, there is an increasingly urgent need for countries and relevant organizations to consolidate and further strengthen current efforts at local, national, regional and global levels to manage coral reefs as socio-ecological systems undergoing change. The target will not be met by 2015. Against this background, possible key actions to achieve this target at the earliest possibility and before 2020 include:

(a) Reducing the impacts of multiple stressors, in particular by addressing those stressors that are more tractable at the regional, national and local levels; i.e.:

(i) Sustainably manage fisheries on coral reefs and closely associated ecosystems (such as mangroves and seagrass systems), including by empowering local and indigenous communities and individuals involved in local fisheries (Targets 6);
(ii) Managing land-based and sea-based sources of nutrients and pollution (Target 8);

(iii) Increasing the spatial coverage and effectiveness of marine and coastal protected and managed areas in coral reefs and closely associated ecosystems (Targets 11); and

(iv) Managing coastal development to ensure that the health and resilience of coral reef ecosystems are not adversely impacted and promoting sustainable coral reef tourism, including through the use of guidelines for tourists and tour operators.

(b) Enhancing the resilience of coral reefs and closely associated ecosystems through ecosystem-based adaptation to enable the continued provisioning of goods and services (Target 14));

(c) Maintaining sustainable livelihoods and food security in reef-dependent coastal communities and provide for viable alternative livelihoods, where appropriate (Target 14).

Further, there is a need for action at the national level to identify other ecosystems that are vulnerable to climate change and related impacts and to implement measures to improve their resilience. Such ecosystems include mountain ecosystems (e.g.: cloud forests, páramo), and other ecosystems particularly vulnerable to changes in temperature and precipitation patterns as well as low lying ecosystems vulnerable to sea-level rise.

The programme of work on marine and coastal biodiversity (decision VII/5) provides the main guidance for this target concerning coral reefs and associated ecosystems. Paragraph 8 of decision X/33, on biodiversity and climate change, provides relevant guidance on this target applicable to all ecosystems.

To reduce the level of anthropogenic stressors on coral reefs to a point where losses of reef function are minimised, it is necessary to maintain net reef accretion (i.e., a positive carbonate budget). This is not a biodiversity target per se (though it does require moderately healthy food web structure) but is likely the most effective single indicator to maintain the habitat quality on which much biodiversity depends (see next section for further details).

Some immediate actions that can be taken to reduce local human pressure upon coral reefs and maintain habitat quality include:

1) Reducing fishing effort in a manner that will be supported and complied with by fishing communities. Community involvement in the decision making process and MPA monitoring is a key element to achieving this, as demonstrated by the management of a Locally Managed Marine Area network in Fiji (Weeks and Jupiter 2013);

2) Implementing integrated coastal zone and watershed management to mitigate pollutants and other impacts of land based activities on coral reefs (e.g., Jakobsen et al. 2007; Brodie et al. 2012);
3) Shift from mass tourism to the development of marine ecotourism that is within the limits of acceptable change (e.g., Teh and Cabanban 2007);

A recent study modelled the trajectories of Caribbean coral reefs under various management scenarios on greenhouse gas (GHG) emission levels (business as usual and low carbon economy), and evaluated their expected carbonate budgets (Kennedy et al. 2013). The study found that positive carbonate budgets could be maintained at least towards the end of this century but only if compelling action is taken to reduce GHG emissions (to the most optimistic scenarios being considered by the IPCC) and if local threats including overfishing and water quality are managed (Fig. 10.8). Thus, the achievement of Target 10 requires a strong global commitment to reducing GHG emissions, ideally following Representative Concentration Pathway 2.6.

Figure 10.8. Projected carbonate budgets of a Caribbean reef under climate change and ocean acidification with and without local protection of herbivores under scenarios of realistic GHG emissions (top) and aggressive reduction (bottom). Initial conditions of reefs are either degraded with 10% coral cover (A, B, E, and F) or healthier with 20% coral (C, D, G, and H). Herbivorous fish are either overfished or fully protected (denoted with parrotfish symbols). Each plot displays 20 simulations, with outputs generated at 6 month intervals and run for years 2010–2080. Vertical blue bars indicate point at which the projected budget becomes negative (<−0.1 kg for >5 years). Source: Kennedy et al (2013).

The exploitation of herbivorous fish can lead to an increase in fleshy seaweeds (macroalgae) that pre-empt space for coral settlement and then compete with those corals that do manage to settle (Williams and Polunin 2000, Hughes et al. 2007, Mumby et al. 2007). Herbivores are usually protected inside no-take marine reserves but, while useful, this step fails to address concerns over the loss of reef habitat quality in areas subjected to exploitation. Seascape-wide management of herbivory requires fishery regulations including reductions in the use of fish traps (Hawkins et al. 2007) and species-level catch limits or bans. For example, herbivore fisheries have been prohibited in Belize, Bermuda and Bonaire.
Begin Box 10.1 - Reducing local threats through private coral reef management

Local anthropogenic threats pose the greatest risk to coral reefs in Southeast Asia. However, reef management in the region is often limited by lack of funds and resources. One approach for overcoming this challenge is the use of private sector resources for coral reef conservation. The establishment of the Sugud Islands Marine Conservation Area (SIMCA) in Sabah, Malaysia was initiated by owners of the sole dive resort situated within SIMCA, for the purpose of protecting the area’s coral reefs and marine environment. The SIMCA was officially declared an IUCN category II conservation area in 2001. Reef Guardian, a conservation organisation, manages conservation activities to reduce local threats to the coral reefs within SIMCA. These include enforcement patrols to regulate illegal fishing, turtle monitoring and conservation, coral reef and environmental monitoring, sewage and wastewater treatment, removal of coral predators (crown of thorns), and conducting education programmes for school children to raise awareness about marine conservation. Reef Guardian’s conservation work is funded by conservation fees charged to visitors to the dive resort, donations, and grants. This private management approach has helped to mitigate the impacts of tourism and fishing on SIMCA’s reefs, resulting in improved biodiversity conditions. For instance, coral cover and fish abundance is greater within SIMCA compared to fished areas, and the number of turtle nestings shows an increasing trend through time. See www.reef-guardian.org. Reference: Teh et al. (2008).

End Box 10.1

MPAs are now being planned with multiple stressors in mind. Designation of an MPA will not reduce impacts of climate change or OA, but it is possible to identify regions of the ocean that have a more benign physical environment (West and Salm 2003, McLeod et al. 2012). For example, Mumby et al. (2011) used a climatology of satellite-derived sea surface temperature (SST) measurements to identify those areas where corals are likely to be best acclimated to stress and subjected to relatively mild acute bleaching events (Fig. 10.9). In principle, locating MPAs in the most benign areas allows for a targeted reduction in biological stresses (e.g., restored food webs and less competition from algae) in areas that have relatively low physical stress.

The local stressors modelled by Kennedy et al (2013) included the exploitation of herbivorous fish and nitrification of watersheds. Nutrient and sediment runoff can be reduced by cutting back on the use of fertilizer, stabilizing soils by keeping riparian watersheds forested, and maintaining estuarine habitats including mangroves and marshlands.
Figure 10.9. Stratification of coral reefs of the Bahamas based on their thermal characteristics. Two aspects of thermal stress are recognised - chronic stress that represents usual summer temperatures - and acute stress that occurs during episodic bleaching events. Ordering all four environments from the most benign to stressful gives A, C, B, and D respectively. After Mumby et al. (2011).

Begin Box 10.2. - Reducing land based threats to coral reefs

Agricultural run-off has increased levels of sediments, nutrients, and pesticides on the Great Barrier Reef (GBR), leading to degraded water quality. This has detrimental long term impacts on reef health, as pollutants change the environmental conditions for reef species and ecosystems. In response, the Australian and Queensland governments have introduced several policy initiatives and regulations. The Reef Plan, introduced in 2003, aims to stop and reverse the decline in GBR water quality by reducing source pollutant loads and rehabilitating reef catchment areas that play a role in removing water borne pollutants. A component of the Reef Plan was Reef Rescue, an AUD 200 million investment by the Australian Government to fund voluntary programmes for on the ground work, monitoring, and research. Land management activities funded by Reef Rescue mainly targeted the sugarcane and grazing industries; projects included introduction of new farming practices, fencing along streams for cattle management, modification to fertiliser and pesticide application gears, and modifying cultivation and tillage equipment and practices. In 2009, the Queensland Government introduced the Great Barrier Reef Protection Amendment Act, which provides for the implementation of fertiliser, pesticide and erosion management regulations for the GBR. Despite these useful management actions, it is expected that improvements to water quality and reef health may not be detectable for several decades.


End Box 10.2.
2.b. Costs and Cost-benefit analysis

Mitigating anthropogenic threats to coral reefs require cost-effective land and marine based conservation actions. A study by Klein et al (2010) calculated the rate of return on investing in two conservation actions to mitigate high impact threats for the 16 ecoregions in the Coral Triangle. The analysis involved estimating the cost of effectively managing coral reefs and terrestrial protected areas, based on the assumption that protection linearly reduced the threat in each ecoregion. Depending on ecoregion, estimated annual management costs for coral reefs ranged from US$15 300/km² to US$383 500/km². An earlier study modelled the change in coral cover in Montego Bay, Jamaica, arising from different interventions (e.g. sediment traps, building a large scale waste treatment facility, solid waste collection, Ruitenbeek et al. 1999). Costs associated with mitigating actions that increased coral abundance by up to 20% had a present value of US$153 million over 25 years. Achieving a 10% increase in coral abundance had a present value cost of US$12 million. The study showed that the optimal intervention may depend on targeted coral quality levels, such that the lowest cost management intervention may not be the most optimal. While these studies focused on the cost-effectiveness of protecting coral reefs, it is also important to consider that conservation actions which reduce fishing effort will impose substantial costs on fishers’ livelihoods and food security in the short term. The Higher Level Panel estimates that achieving Target 10 will require an initial investment of US$ 600 - 900 million, with average annual expenditures of US$ 80 - 130 million to for the period 2013 - 2020, and recurrent expenditures of US$ 6 – 10 million. Despite an immediate cost, conservation makes economic sense because of the potential future benefits it generates. For instance, reef conservation in the Caribbean was estimated to avert potential annual services losses ranging between US$ 350 – 870 million (Burke et al. 2008).

Economic valuation of coral reef goods and services in different countries have provided a wide range of estimates, mainly due to the different services and time frames that are used in the valuation process (Table 10.2). Nevertheless, based on these studies, it is reasonable to conclude that the global net present value of coral reefs reaches billions of US$. While the economic values presented here are unlikely to reflect potential non-monetary costs arising from the cascading effects of reef habitat and ecosystem loss, they are nonetheless important for demonstrating the magnitude of economic benefits derived from coral reef ecosystems.

Table 10.2. Economic valuation of coral reef goods and services in different countries. Compiled by the Higher Level Panel report.

<table>
<thead>
<tr>
<th>Country</th>
<th>Value</th>
<th>Services/Value</th>
<th>Source</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sri Lanka</td>
<td>NPV of US$ 14 – 750 million/ ha over 20 years</td>
<td>Multiple services, especially tourism and erosion control</td>
<td>Berg et al. (1998)</td>
</tr>
<tr>
<td>Phi Phi Islands, Thailand</td>
<td>US$497 million / year, including $205 million recreational values</td>
<td>Use and non use values</td>
<td>Seenprachawong (2003)</td>
</tr>
<tr>
<td>Great Barrier Reef, Australia</td>
<td>NPV of US $53 billion (100yrs, 2.65% discount rate)</td>
<td>Range of values, especially tourism, non-use and coastal protection</td>
<td>Oxford Economics (2009)</td>
</tr>
<tr>
<td>Region</td>
<td>Value</td>
<td>Services</td>
<td>Reference</td>
</tr>
<tr>
<td>---------------</td>
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</tr>
<tr>
<td>Belize</td>
<td>US$ 268-370 / km²/year</td>
<td>Tourism, fisheries, shoreline protection</td>
<td>Burke et al. (2008)</td>
</tr>
<tr>
<td>Northern Marianas</td>
<td>US$ 0.8 million / km²</td>
<td>Multiple goods and services</td>
<td>van Beukering et al. (2006)</td>
</tr>
<tr>
<td>Pacific Islands</td>
<td>US $506 – 17,873 / ha/year</td>
<td>Tourism, coastal protection, fisheries and other services</td>
<td>Various</td>
</tr>
</tbody>
</table>

3. **What are the implications of not reaching the Target for biodiversity in 2015?**

The direct impact of anthropogenic impacts tends to be either a loss of coral species or a shift in species composition to one able to tolerate more stressful conditions. Coral bleaching commonly leads to an immediate loss of the most thermally-sensitive corals (Edwards et al. 2001). A long-term study found that a major bleaching event led to an immediate loss of coral species richness (van Woesik et al. 2011). However, while total richness recovered after 10 years, the assemblage of corals changed. Ascertaining exactly how coral assemblages will change in the long-term is challenging but a shift towards thermally-tolerant species and those that are able to recover from partial mortality is likely (van Woesik and Jordan-Garza 2011), as is an overall reduction in coral species richness and abundance.

Other forms of local impact, such as sedimentation, have a fairly predictable impact on coral assemblages as it tends to favour a particular subset of species, such as *Turbinaria mesentaria* (Anthony 2006) that can tolerate higher sediment and make greater use of heterotrophy. The impacts of climate change on non-coral invertebrates have been understudied (Przeslawski et al. 2008), making it difficult to make predictions at this stage. The impacts of a loss of living coral and habitat complexity are fairly profound on coral reef fish, particularly those of smaller size that are more vulnerable to predation (Wilson et al. 2006).

A bleaching event and plague of crown-of-thorns starfish in Papua New Guinea led to a vast loss of coral from around 65% to 20% over 8 years (Jones et al. 2004). Over 75% of fish species declined in abundance with 50% declined to less than half their original abundance (Fig. 10.10). Similar events were also reported from French Polynesia (Kayal et al. 2012).

Elsewhere, many studies have quantified a strong negative relationship between the structural complexity of reefs and fish species richness (Luckhurst and Luckhurst 1978, Graham et al. 2006).
Figure 10.10. Loss of coral cover and reef fish species richness from Kimbe Bay. Species richness calculated for the fish families Acanthuridae, Chaetodontidae, Labridae, and Pomacentridae (Jones et al 2004).

4. What do scenarios suggest for 2050 and what are the implications for biodiversity?

In coral reef countries, total human population is set to increase by 27% between 2010 and 2050 (UN Department of Economic and Social Affairs 2004). It is likely that anthropogenic impacts will at least increase from current baselines, perhaps strongly given the increased pressure on coastal resources. Rising sea temperatures are expected to cause more intense and frequent bleaching. Using a consortium of global circulation models, Frieler et al (2012) estimate that damaging bleaching conditions would affect approximately >90% of the world’s reefs under RCP8.5 and 60% of reefs under the more optimistic GHG emissions scenario, RCP3PD. Damaging bleaching conditions were defined as occurring when events exceed 2°C heating months with a return time < 5 years. Ocean acidification will continue and affect the biology and ecology of reef ecosystems, though the precise consequences are difficult to estimate for 2050 because many experimental studies simulate environments further into the future.

The consequences for coral reef biodiversity are, of course, uncertain by 2050 but are likely to be highly influenced by the trajectory taken for GHG emissions. It is even more difficult to estimate the potential consequences on other non-coral vulnerable ecosystems which are relatively less documented. Maintenance of positive carbonate budgets is possible with aggressive action on emissions and effective local management (Kennedy et al. 2013). Of significant concern is how changes in reef state and ecological processes will affect functions like fisheries productivity and coastal protection (Pratchett et al. 2011). At this point, few quantitative predictions have been made for future coral reef ecosystem function. A recent
study predicted that a loss of coral reef habitat complexity (i.e., flat reefs), which would occur if carbonate budgets remained strongly negative, would reduce the productivity of Caribbean reef fisheries by at least 3-fold (Rogers et al. 2014).

If climate change and ocean acidification continue to follow current trajectories then the outlook for coral reefs is poor (e.g. Fig. 10.8). Local conservation actions to manage fisheries and water quality will remain fundamentally important in reducing rates of reef decline and helping build recovery capacity. Even the least resilient reefs – those of the Caribbean – are projected to fare better if managed locally, possibly buying a few decades for more assertive action to reduce greenhouse gas emissions (Edwards et al. 2011, Kennedy et al. 2013). However, if coral cover continues to decline, particularly under frequent coral bleaching, then there is a very real risk that carbonate budgets might become negative. Recent evidence from the Caribbean suggests that at least 10% coral cover is needed to maintain positive reef growth (Perry et al. 2013). The longer-term outcome of this is a flattening of reef structures and a decline in key ecosystem services (Pratchett et al. 2014). The first services to be affected will be reef fisheries production and biodiversity because both respond rapidly to a loss of habitat structure (Graham et al 2006). In the longer term, the ability of reefs to provide shoreline protection from storms will also decline.

Finally, while coral reefs have been chosen as the vulnerable ecosystem of focus in this report, the threats and actions described in this chapter are equally relevant for other vulnerable ecosystems, particularly of those that are relatively less well documented. A case study on identifying vulnerable seamounts for conservation is provided in Box 10.3.

Begin Box 10.3 - Identifying vulnerable marine ecosystems for conservation

Conservation of Vulnerable Marine Ecosystems of the deep sea, including cold-water coral (CWC) aggregations and sponge fields, is a global priority (FAO 2009). Cold-water coral ecosystems have been identified as biodiversity hotspots (Watling et al. 2011), and are of significant ecological and economic value (Foley et al. 2010). In contrast to tropical reefs, the cold temperatures and inconstant food supply found on the deep-sea floor implies that most of its sessile inhabitants have reduced growth rates, long reproductive cycles and low rates of recruitment. Such life history characteristics imply that cold-water ecosystems have a reduced capacity to recover from any disturbance events (Williams et al. 2010). Anthropogenic activities such as bottom fishing and hydrocarbon drilling are among the major threats to these fragile ecosystems (Davies et al. 2007; Roberts et al. 2009). Cold water reefs or gardens are found mainly on seamounts slopes (Genin et al., 1986). To conserve these vulnerable ecosystems, a framework for locating potential ecologically or biologically significant seamount areas based on the best information currently available was developed (Taranto et al., 2012, Fig. 10.11). This framework combines the likelihood of a seamount constituting an ecologically or biologically significant area (EBSA) and its level of human impact, and can be used to locate priority areas for seamount conservation at global, regional and local scales. This framework will also allow the identification of ecologically or biologically significant seamount areas with high data uncertainty and is thus in urgent need of research. If this knowledge is translated into policy action, the methodology may constitute an important step forward in the implementation of conservation measures in deep sea habitats and open ocean waters and help to fulfill the international commitments signed under the Convention on Biological Diversity.
Fig. 10.11. Seamount EBSA portfolio plot based on EBSA likelihood scores and threat scores for eight case studies (left) and for the whole dataset (right). The upper right seamounts (red) are very high and high EBSAs with very high and high threats, while the upper left seamounts (green) are very high and high EBSAs with medium and low threats. In the bottom are the medium and low EBSAs with low (blue) and high (yellow) threats. Error bars represent the data uncertainty index (see methods) proportional to data availability and quality. Text and figure provided by Telmo Morato (see Taranto et al. 2012)

End Box 10.3

5. Uncertainties and data requirements/ gaps

There are many uncertainties in projecting the future biodiversity and functioning of coral reefs (Mumby and Van Woesik 2014). First, there are uncertainties in the level of stress experienced by reefs. For example, global circulation models (GCMs) need to be downscaled and there remains significant uncertainty over how ocean chemistry is modified in coastal environments. In particular, the metabolism of reef organisms can modify the biogeochemical environment substantially (Kleypas et al. 2011, Anthony et al. 2013). In other words, natural daily fluctuations in sea water chemistry might be equivalent to the projected impacts of climate change on mean oceanic conditions over many decades. While a process like ocean acidification will slowly reduce the mean oceanic saturation states of aragonite and calcite, it is not clear how such changes influence the dynamic environment experienced by most corals.

A second source of uncertainty is the response of reefs and organisms to a changing environment (Pandolfi et al. 2011). The response of individual species to stress varies dramatically (Comeau et al. 2013) and while there may be an overall negative trend (Chan and Connolly 2013), the outcome can be highly variable from one ecological community to another. Moreover, in addition to there being no theoretical impediment to evolution of corals to bleaching (Day et al. 2008), some have argued that the high rate of somatic mutation in organisms like corals provides a greater opportunity for genetic adaption than has been previously considered (van Oppen et al. 2011).
Third, many physiological studies of climate change response use treatments that simulate environments far into the future. Thus, the response of animals and plants to conditions expected in 2020 and 2050 are difficult to evaluate. One reason for this is the existence of trans-generational plasticity (Franks and Hoffmann 2012). Most studies of coral reef organismal response to climate change have been undertaken for a single generation. Yet, multi-generational studies are finding considerable scope for altered fitness, possibly through epigenetic effects (Miller et al. 2012).

Fourth, although it seems likely that some reefs will slip into net erosive structures (negative carbonate budgets), a loss of reef structure and complexity is not instantaneous. Yet, there has been virtually no attempt to predict the actual rate at which reef structures will erode, particularly in environments with more erosive chemistry (OA). Moreover, changes in reef structure and the emergence of novel reef communities (Yakob and Mumby 2011) could have surprising ecological outcomes. For example, habitat structure can mediate predator-prey interactions of reef fish (Hixon and Beets 1993, Sym and Jones 2000). But habitat complexity could change in surprising ways through a combination of net reef erosion and a shift in coral species composition. How such uncertain shifts might then influence the multitude of fish species' interactions is almost impossible to predict at this stage. Moreover, some coral reef communities are predicted to experience alternate attractors, such that a small increase in stress (e.g., bleaching mortality, nutrients, fishing) could result in a drastic and undesirable change in community structure, including a loss of species, that resists management efforts to reverse the decline (Mumby et al. 2013).

### 7. Dashboard – Progress towards Target

<table>
<thead>
<tr>
<th>Element</th>
<th>Current Status</th>
<th>Comments</th>
<th>Confidence</th>
</tr>
</thead>
<tbody>
<tr>
<td>Multiple anthropogenic pressures on coral reefs are minimized, so as to maintain their integrity and functioning</td>
<td><img src="progressicon.png" alt="Progress Icon" /></td>
<td>Pressures such as land-based pollution, uncontrolled tourism still increasing, although new marine protected areas may ease overfishing in some reef regions</td>
<td>High</td>
</tr>
<tr>
<td>Multiple anthropogenic pressures on other vulnerable ecosystems impacted by climate change or ocean acidification minimized, so as to maintain their integrity and functioning</td>
<td>Not evaluated</td>
<td>Insufficient information was available to evaluate the target for other vulnerable ecosystems including seagrass habitats, mangroves and mountains</td>
<td></td>
</tr>
</tbody>
</table>

Compiled by: Peter J Mumby and Louise Teh.
NBSAPs and National Reports: Kieran Mooney / CBD Secretariat
Dashboard: Tim Hirsch

Version history: 24 Nov 2013 PM, 15 Dec 2013 PL, 18 Dec CBK, 9 Jan 2014 PJM, 17 Feb LT
7. References cited


### Appendix 10.1

Table 10. Recent initiatives to increase the area of coral reefs under protection.

<table>
<thead>
<tr>
<th>INITIATIVE</th>
<th>TIME FRAME</th>
<th>DESCRIPTION/GOAL</th>
<th>AREA PROTECTED</th>
<th>OUTCOME OF INITIATIVE</th>
<th>TYPE of INITIATIVE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Micronesia Challenge</td>
<td>2006 – 2020</td>
<td>Effectively conserve at least 30% of near shore marine resources</td>
<td>Not specified</td>
<td>MPAs and regional trust fund for providing sustainable revenue stream</td>
<td>Regional – FSM, Marshall Islands, Palau, Guam, CNMI</td>
</tr>
<tr>
<td>(Established)</td>
<td></td>
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<tr>
<td>Caribbean Challenge</td>
<td>2007-2020</td>
<td>Protect at least 20% of the near-shore marine and coastal habitats by establishing a network of 20 million acres of marine parks across the territorial waters of at least 10 countries.</td>
<td>20 million acres (80,397 km²)</td>
<td>National systems of protected areas and sustainable financing tools</td>
<td>Regional- The Bahamas, Dominican Republic, Jamaica, Saint Vincent and the Grenadines, Saint Lucia, Grenada, Antigua and Barbuda as well as Saint Kitts and Nevis. Endorsed by 5</td>
</tr>
<tr>
<td>(Established)</td>
<td></td>
<td></td>
<td></td>
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</tr>
<tr>
<td>Coral Triangle Initiative</td>
<td>2009-2020</td>
<td>Place 20% of each major marine and coastal habitat under protected status by 2020</td>
<td>Not specified</td>
<td>Effectively managed linked network of multiple use MPAs, sustainable financing plan</td>
<td>Regional – Philippines, Indonesia, Malaysia, Timor-Leste, Solomon Islands, Papua New Guinea</td>
</tr>
<tr>
<td>(Established)</td>
<td></td>
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<tr>
<td>Western Indian Ocean Coastal</td>
<td>Declared in 2012, Target 2032</td>
<td>Commit to island conservation and sustainable livelihoods, including responding to climate change threats</td>
<td>Not yet determined</td>
<td>Not yet determined</td>
<td>Regional - Comoros, Reunion, Kenya, Madagascar, Mauritius, Mozambique, Seychelles, Zanzibar</td>
</tr>
<tr>
<td>Challenge</td>
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<tr>
<td>INITIATIVE</td>
<td>TIME FRAME</td>
<td>DESCRIPTION/GOAL</td>
<td>AREA PROTECTED</td>
<td>OUTCOME OF INITIATIVE</td>
<td>TYPE of INITIATIVE</td>
</tr>
<tr>
<td>------------------------------------------------</td>
<td>------------</td>
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</tr>
<tr>
<td>Fiji (Established)</td>
<td>2005-2020</td>
<td>Effectively manage and finance at least 30% of inshore areas by 2020</td>
<td>30% of ~30,000 km(^2) (high water mark to outer barrier reef)</td>
<td>Locally managed marine areas (multiple use)</td>
<td>National - Fiji</td>
</tr>
<tr>
<td>Papahanaumoku-</td>
<td>2006</td>
<td>Ecosystem protection, and preserve ecosystem function, key processes, recover resources where necessary</td>
<td>362,075 km(^2)</td>
<td>World Heritage Site – no take marine reserve</td>
<td>National - USA</td>
</tr>
<tr>
<td>uakea Marine National Monument (Established)</td>
<td></td>
<td></td>
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<tr>
<td>Phoenix Islands Protected Area (Established)</td>
<td>2008</td>
<td>Biodiversity conservation while allowing for sustainable economic opportunities</td>
<td>408,250 km(^2)</td>
<td>UNESCO World Heritage Site</td>
<td>National - Kiribati</td>
</tr>
<tr>
<td>Marine National Monuments -</td>
<td>2009</td>
<td>Protect and conserve biodiversity</td>
<td>Pacific Remote Islands (199,480 km(^2)), Marianas Trench (250,487 km(^2)), Rose Atoll (34,800 km(^2))</td>
<td>No-take marine reserve</td>
<td>National - USA</td>
</tr>
<tr>
<td>Pacific Remote Islands, Marianas Trench, Rose Atoll (Established)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Chagos Marine Reserve (Established)</td>
<td>2010</td>
<td>Biodiversity conservation</td>
<td>640,000 km(^2)</td>
<td>No-take marine reserve</td>
<td>National - UK</td>
</tr>
<tr>
<td>Australian Commonwealth Marine Reserves (Established)</td>
<td>2012-2020</td>
<td>Add to Australia’s existing system of marine reserves managed primarily for biodiversity conservation and sustainable use in some areas</td>
<td>2.3 million km(^2) – Reserves with coral habitats: Coral Sea (989,482 km(^2)), North (157,483 km(^2)), and North-west (335,437 km(^2))</td>
<td>Marine reserve with multiple use zones</td>
<td>National - Australia</td>
</tr>
<tr>
<td>Indonesia (Established)</td>
<td>2012-2020</td>
<td>Establish and effectively manage 20 million ha of</td>
<td>20 million ha (200,000 km(^2))</td>
<td>MPA network (multiple use)</td>
<td>National - Indonesia</td>
</tr>
<tr>
<td>INITIATIVE</td>
<td>TIME FRAME</td>
<td>DESCRIPTION/GOAL</td>
<td>AREA PROTECTED</td>
<td>OUTCOME OF INITIATIVE</td>
<td>TYPE of INITIATIVE</td>
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<td>----------------------------------------------------</td>
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</tr>
<tr>
<td>Primeiras and Segundas Marine Protected Area (Pending)</td>
<td>Declared 2012</td>
<td>Protect marine biodiversity and manage marine resources for sustainable future</td>
<td>10,409 km²</td>
<td>MPA (multiple use?)</td>
<td>National - Mozambique</td>
</tr>
<tr>
<td>Cook Islands Marine Protected Area (Pending)</td>
<td>Proposed 2012</td>
<td>Proposal to protect around 50% of country’s EEZ as a multiple use marine park</td>
<td>1,065,000 km²</td>
<td>Multiple use marine park and establishment of trust fund Marine Protected Area (multiple use?)</td>
<td>National - Cook Islands</td>
</tr>
<tr>
<td>New Caledonia Marine Protected Area (Pending)</td>
<td>Declared 2012</td>
<td>Commitment to create MPA under Pacific Oceanscape Programme</td>
<td>1.4 million km²</td>
<td>Marine Protected Area (multiple use?)</td>
<td>National – New Caledonia</td>
</tr>
<tr>
<td>Maldives (Pending)</td>
<td>2013-2017</td>
<td>Pledge for entire country and EEZ to be a Biosphere Reserve by 2017</td>
<td>Size of Maldives EEZ is ~90,000 km² (coral reefs and lagoons ~21,300km²)</td>
<td>UNESCO Biosphere Reserve</td>
<td>National - Maldives</td>
</tr>
</tbody>
</table>