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BACKGROUND DOCUMENT ON ACHIEVING AICHI BIODIVERSITY TARGET 10 FOR CORAL REEFS AND CLOSELY ASSOCIATED ECOSYSTEMS

Revised note by the Executive Secretary

1. In decision XI/18 A, the Conference of the Parties to the Convention on Biological Diversity took note of the urgent need to update the specific work plan on coral bleaching (appendix 1 of annex I to decision VII/5), taking into consideration other global impacts on coral caused by climate change, most notably, projected impacts of ocean acidification, but also the effects of tropical storms and rising sea levels, and recognized that the projected impacts of ocean acidification need to be integrated into management frameworks alongside interaction with local stressors.

2. In the same decision, the Conference of the Parties requested the Executive Secretary to collaborate with Parties, other Governments, relevant organizations, and indigenous and local communities to develop proposals to update the specific work plan on coral bleaching through an addendum to the workplan.

3. Pursuant to the above request and in support of updating the specific work plan on coral bleaching, the Secretariat commissioned the preparation of a background document on Achieving Aichi Biodiversity Target 10 for Coral Reefs and Closely Associated Ecosystems, which characterizes the vulnerability of shallow coral reefs in low latitudes to climate change, ocean acidification and other major stressors, highlights implications of this vulnerability for related ecosystems and reef-dependent communities, and discusses various approaches to managing multiple stressors and improving the resilience of coral reefs.

4. This background document is being submitted to support the consideration by the Subsidiary Body of the draft priority actions to achieve Aichi Biodiversity Target 10 for coral reefs and closely associated ecosystems, as an addendum to the programme of work on marine and coastal biodiversity in order to update the specific workplan on coral bleaching[1] of the programme of work.

5. This document will be revised in the light of the deliberations of the Subsidiary Body and taking into account peer-review comments. Comments should be sent to secretariat@cbd.int.

* UNEP/CBD/SBSTTA/18/1.

[1] Appendix 1 of annex I to decision VII/5.

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BACKGROUND DOCUMENT ON ACHIEVING AICHI BIODIVERSITY TARGET 10 FOR CORAL REEFS AND CLOSELY ASSOCIATED ECOSYSTEMS

Executive Summary

Warm water coral reefs are considered to be one of the most stressed ecosystems globally and are extremely vulnerable to the effects of climate change. Coral reefs have been steadily declining over the last half-century through the combined impacts of both local and global (climate-induced) stressors. Reefs exposed to chronically high levels of local stressors such as over-exploitation of reef resources and various types of pollution have become severely degraded. Global stressors, particularly increasing ocean temperature and acidification are projected to have devastating effects on coral reefs within this century, irrespective of the projected emission scenarios for atmospheric CO_2. Taking management action to reduce or eliminate local stressors of coral reefs and associated ecosystems will increase their resilience to the effects of climate change and provide more time for reef-dependent communities and other stakeholders to adapt to their changing marine and coastal environment.

The current version of the specific work plan on coral bleaching was developed a decade ago to primarily address the significant effects of mass coral bleaching events on coral reef ecosystems. Although it comprehensively addresses the impacts of thermal stress on reef-building corals, it does not fully consider the projected effects of other global stressors on coral reef ecosystems, particularly ocean acidification but also tropical storms and rising sea levels. The interactions between multiple stressors, both local and global, and how this alters their impact on coral reef organisms and habitats is also a critically important factor to consider for ecosystem management.

This report provides a review of current understanding and management of coral reefs that focuses on the following four main points in order to support a revision of the specific work plan on coral bleaching:

(a) Understand the vulnerability of corals to multiple stressors;

(b) Plan proactively for climate risks and associated secondary effects, applying ecosystem-based adaptation measures;

(c) Manage coral reefs as socio-ecological systems undergoing change due, in many cases, to climate change; and

(d) Formulate adaptation strategies that aim to enhance the resilience of ecosystems to enable the continued provisioning of goods and services.

A wide range of global and local stressors for reef-building corals have recently been assessed to identify the type of interactions occurring between two or more stressors in terms of whether they are synergistic, additive or antagonistic. Significant synergistic interactions occur between ocean warming and acidification, leading to increased stress, bleaching and disease for corals. Increasing temperature has a range of effects on other stressors, most of which are deleterious. Important combinations of both global and local stressors include disease, temperature and water quality or the interaction between overfishing, bleaching, nutrient pollution and macroalgae. It is important to identify all types of stressor interactions that affect reefs so that management can prioritize action for synergistic interactions. Further work is required to assess multiple stressor interactions and effects. In addition to assessing stressor effects on corals, a summary of known impacts on reef fish and fisheries is provided along with information on the vulnerability of ecosystems closely associated with coral reefs, such as mangroves and seagrass beds.

The use of vulnerability assessments to better understand the linkages between the social and ecological aspects of vulnerability to climate change is becoming more established. Techniques have been developed to determine the socio-ecological vulnerability of coral reefs and dependent communities for particular climate change scenarios such as mass coral bleaching effects on reef fisheries and fishing communities. Further development of vulnerability assessment methodologies and variables is required to enable use in a range of different contexts and for a variety of global

stressors, particularly ocean acidification. There is a need to expand the use of vulnerability assessments at the national level to identify those coral reefs and communities most vulnerable to climate change. Increasing social resilience to climate change impacts requires managers to identify measures that can reduce sensitivity and increase adaptive capacity of reef-dependent communities or stakeholders according to their local context. This will, in part, require a more comprehensive understanding of coral reef livelihoods.

Long-term planning for climate-induced risks in combination with local stressors and drivers affecting coral reef socio-ecological systems is required at the national and regional level. The use and cost-effectiveness of ecosystem- and resilience-based management frameworks for coral reefs and adjacent ecosystems, including those in watersheds, should be considered alongside more conventional planning approaches. Research should focus on identifying and addressing the most damaging multiple stressor impacts, developing vulnerability assessments, enabling resilience-based management within an adaptive and ecosystem-based framework, and further quantifying the goods and services provided by reefs and associated systems. Forecasting the effects of global and local stressors on coral reefs and the provision of goods and services from altered ecosystems, in combination with management effectiveness and population growth scenarios, is also highly important to determine whether coral reefs can continue to provide important benefits for reef-dependent societies, coastal regions or nations, such as coastal protection, nutrition or livelihood support.

A summary of current tools and approaches to improve coral reef socio-ecological resilience to climate change is provided. These include the use of marine protected areas, locally marine managed areas, marine and terrestrial spatial planning, watershed management, fisheries management (especially outside of specific managed areas), ecosystem-based management and adaptation planning, reef restoration, and the use of diagnostic monitoring, spatial assessment and modelling techniques. Approaches to increase the effectiveness of tools or approaches to combat the impacts of global stressors on coral reefs and adjacent ecosystems are highlighted, such as developing well-designed representative protected area networks, increasing the coverage of locally managed marine areas or improving national recognition of devolved or community-based coral reef management. Further improvement of techniques for coral reef management is also required, such as the development and validation of ecosystem-based adaptation tools and indicators or active reef restoration techniques. Information on potential alternative conservation strategies is also provided.

The effects of global stressors on coral reefs are unavoidable and pose a high level of risk to biodiversity and society. It is critically important to strategically plan and act now in order to increase coral reef resilience over the next few decades, to minimize the loss of biodiversity and ecosystem services from coral reefs and provide as much time as possible for reef-dependent societies to adapt. With this in mind, a series of recommendations for action have been developed to update the current work plan on coral bleaching. These action points are based on suggestions provided in a previous background document[2], this report, selected recent global studies or policy action frameworks for coral reefs and submissions received in response to a formal CBD notification.

1. Introduction and Background

Tropical coral reefs are the world's most biodiverse marine ecosystems[3], home to one-third of all described marine species[4] and one of the most socioeconomically valuable biomes[5]. They are also regarded as one of the most stressed ecosystems globally and amongst the most vulnerable to future

[2] UNEP/CBD/SBSTTA/16/INF/11
[33] Knowlton, N. et al., 2010. Coral Reef Biodiversity. In; Life in the World's Oceans, McIntyre, A. (ed.). Wiley-Blackwell, Oxford.
[4] Reaka-Kudla, M.L. (1997) Global biodiversity of coral reefs: a comparison with rainforests. In: Reaka-Kudla, M.L., Wilson, D.E. (eds.) Biodiversity II: Understanding and Protecting Our Biological Resources. Joseph Henry Press.
[5] Moberg, F. and Folke, C. 1999. Ecological goods and services of coral reef ecosystems. Ecological Economics 29: 580-586.

climate change, threatening ecosystem function and the goods and services provided to millions of people who depend on coral reefs for food, income, coastal protection and other services[6][7]. The distribution and abundance of reef-building coral populations is decreasing rapidly in most parts of the world under increasing levels of local and global drivers of stress[8][9][10]. Coral reefs that are exposed to chronically high levels of local stress have already been changed into highly degraded states in some locations[11][12]. Given the dependence of human communities on coral reefs these changes are likely to have serious long-term consequences for people, communities and nations[13]. Moreover, the number of people living along tropical coastal areas is expected to at least double by the end of the century[14] and the number of reef fishers to increase from 6 million[15] to between 7 and 10 million[16].

Coral reef ecosystems are particularly sensitive to climate-induced stressors that alter the temperature and carbonate chemistry of seawater. There is considerable scientific consensus that coral reefs require atmospheric carbon dioxide concentrations to be below 350 ppm to be free from climate-induced degradation[17][18]. Coral bleaching, along with disease, are critical drivers of the decline of reef building corals. Increasing frequency of severe bleaching events is likely to increase the risk of extinction for corals and associated reef fauna[19]. Recent modelling assessments of the effect of thermal stress alone indicate that at least 98% of coral reef ecosystems will be subject to long-term degradation if there is a 2°C rise in temperature, with the figure falling to 89% (63-100%) with a 1.5°C increase[20]. These projections suggest that most coral reefs will experience extensive degradation over the next few decades given the present behaviour of corals to thermal stress. Even under the strongest mitigation scenario of the IPCC AR5 (RCP3-PD), there is widespread projected long-term degradation of coral reefs[21][22] as a result of thermal stress and annual severe bleaching events. The onset of the latter varies according to latitude but overall, 90% of coral reefs are projected to experience annual severe bleaching events before 2055 under RCP 8.5[23].

[6] Hoegh-Guldberg O. 2011. Coral reef ecosystems and anthropogenic climate change. Regional Environmental Change 11: 215-227.
[7] Hoegh-Guldberg O, et al. 2007. Coral reefs under rapid climate change and ocean acidification. Science 318: 1737-1742.
[8] Bruno, J.F. and Selig, E.R. 2007. Regional decline of coral cover in the Indo-Pacific: timing, extent, and subregional comparisons. PLoS ONE, 2: e711.
[9] De'ath, G. et al., 2012. The 27-year decline of coral cover on the Great Barrier Reef and its causes. Proc. Natl. Acad. Sci. USA 109: 17995-17999.
[10] Gardner, T.A. et al., 2003. Long-term region-wide declines of Caribbean corals. Science 301: 958
[11] Hughes TP, et al., 2003. Climate change, human impacts, and the resilience of coral reefs. Science 301: 929-933.
[12] Bellwood, D.R. et al., 2004. Confronting the coral reef crisis. Nature 429, 827–833.
[13] Hoegh-Guldberg, O. 2014. Coral reef sustainability through adaptation: glimmer of hope or persistent mirage? Curr. Opinion Environ. Sust. 7: 127-133.
[14] Ibid.
[15] Teh, L., et al., 2013. A global estimate of the number of coral reef fishers. PLoS ONE 8: e65397.
[16] Reigl, B. and Tsounis, G. 2014. Editorial Overview: Environmental change issues: Coral reefs sustainability and its challenges. Curr. Opinion Environ. Sust. 7: iv-vii.
[17] Veron, J.E.N., et al., 2009. The coral reef crisis: The critical importance of <350 ppm CO_2. Marine Pollution Bulletin 58.
[18] Veron, J.E.N. 2011. Ocean acidification and coral reefs: An emerging big picture. Diversity 3: 262-274.
[19] Carpenter, K.E. et al. 2008. One-Third of Reef-Building Corals Face Elevated Extinction Risk from Climate Change and Local Impacts. Science 321, 560
[20] Frieler, K. et al., 2013. Limiting global warming to 2°C is unlikely to save most coral reefs. Nature Climate Change. doi: 10.1038/nclimate1674
[21] Ibid.
[22] Van Hooidonk, R. et al., 2014. Opposite latitudinal gradients in projected ocean acidification and bleaching impacts on coral reefs. Global Change Biology. Doi: 10.1111/gcb.12394
[23] Ibid.

Furthermore, coral reefs will be subject to an increase in ocean acidification, which generally decreases calcification in corals [24] and promotes the dissolution of calcium carbonate [25] and bioerosion[26] leading to structurally weaker reefs[27]. Increasing ocean acidity is projected to contribute significantly to habitat and biodiversity loss as the complex reef structure decays. The long-term maintenance of reef structures requires that the production of calcium carbonate, mainly by corals, exceeds its rate of erosion (i.e. that the carbonate budget is positive)[28] and that coral larvae can successfully settle onto the reef. Carbonate budgets and coral settlement are both negatively affected by ocean acidification. Small reductions in calcification can tip reefs into a state of net erosion[29]. Recent modelling projections for the effects of ocean acidification indicate that under emission scenario RCP 8.5, more than 90% of coral reefs will experience a 5% decline in calcification rates by 2040[30] which may result in a state of net erosion for many reefs.

Global stressors such as ocean warming and acidification also have synergistic effects on several reef-building corals[31], which enhance mortality[32] and are likely to drive coral reefs into a state of net erosion[33]. Significant local stressors on coral reefs such as overfishing and pollution compound the effects of climate change by reducing ecosystem health and resilience. Global and local stressors can also interact synergistically to increase the impact on reef ecosystems. Identifying synergisms will enable the prioritisation of management actions to minimise the most severe interactions[34].

However, there is also considerable variability in the coral calcification response to acidification, which along with spatial variation in bleaching susceptibility and recovery, and potential rates of adaptation to rapid warming for corals[35] (but see also Hoegh-Guldberg, 2014[36]) suggests that a large-scale structural collapse of coral reefs in the 21st century may be too simplistic. Instead a spatially patchy response is likely with more resistant and less stressed coral reefs persisting while highly stressed reefs decline and change into non-coral dominated systems.

An extensive loss of coral reef ecosystems would lead to large-scale loss of global biodiversity[37] and substantially alter the provision of ecosystem goods and services[3839]. The functional loss of coral reefs

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[24] Kroeker, K. et al., 2013. Impacts of ocean acidification on marine organisms: quantifying sensitivities and interaction with warming. Global Change Biology 19: 1884-1896.
[25] Tribollet, A., et al., 2009. Effects of elevated $pC0_2$ on dissolution coral carbonates by microbial euendoliths. Global Biogeochemical Cycles 23, GB3008.
[26] Wisshak, M. et al., 2012. Ocean acidification accelerates reef bioerosion. PLoS ONE 7(9), e45124.
[27] Manzello, D.P. et al., 2008. Poorly cemented coral reefs of the eastern tropical Pacific: Possible insights into reef development in a high-$C0_2$ world. Proc. Nat. Acad. Sci. 105: 10450-10455
[28] Perry, C. T. et al., 2012. Estimating rates of biologically driven coral reef framework production and erosion: a new census-based carbonate budget methodology and applications to the reefs in Bonaire. Coral Reefs 31: 853-868.
[29] Van Hooidonk, R. et al., 2014. Opposite latitudinal gradients in projected ocean acidification and bleaching impacts on coral reefs. Global Change Biology. Doi: 10.1111/gcb.12394
[30] Ibid.
[31] Anthony, K.R.N., et al., 2008. Ocean acidification causes bleaching and productivity loss in coral reef builders. Proc. Nat. Acad. Sci. 105: 17442-17446.
[32] Manzello, D.P. et al., 2008. Poorly cemented coral reefs of the eastern tropical Pacific: Possible insights into reef development in a high-$C0_2$ world. Proceedings of the National Academy of Science U.S.A. 105: 10450-10455
[33] Andersson, A.J. and Gledhill, D. 2013. Ocean acidification and coral reefs: effects on breakdown, dissolution, and net ecosystem calcification. Annual Review of Marine Science 5: 321-348.
[34] Ban, S.S. et al., 2014. Evidence for multiple stressor interactions and effects of coral reefs. Global Change Biology 20: 681-697
[35] Pandolfi, J.M. et al., 2011. Projecting coral reef futures under global warming and ocean acidification. Science 333: 418-422.
[36] Hoegh-Guldberg, O. 2014. Coral reef sustainability through adaptation: glimmer of hope or persistent mirage? Curr. Opinion Environ. Sust. 7: 127-133.
[37] Carpenter, K.E. et al. 2008. One-Third of Reef-Building Corals Face Elevated Extinction Risk from Climate Change and Local Impacts. Science 321, 560
[3838] Bell, J.D. et al., 2013. Mixed responses of tropical Pacific fisheries and aquaculture to climate change. Nat. Clim. Change 3: 591-591.

will threaten the physical structure of reefs and limit their coastal protection function from the impact of storms and waves. Significant economic losses are likely if reef-dependent industries such as coastal tourism and fisheries decline. The global 1998 bleaching event caused losses of up to $8 billion in the Indian Ocean alone[40], while the total cost of coral bleaching to 2050 is projected to be more than $100 billion worldwide[41]. A loss of coral reef fisheries may also jeopardise the livelihoods and food security for millions of people dependent on reef fish and invertebrates for income and nutrition. The combined effects of ocean warming and acidification on coral reefs will erode habitats for reef-based fisheries, increase exposure of coastlines to waves and storms and degrade environmental features important to industries such as tourism[42].

Given the severity of the coral reef crisis and the level of risk to biodiversity and human society it is critically important to strategically plan and act now in order to increase socio-ecological resilience over the next few decades so that coral reefs and closely associated ecosystems and-dependent people can better cope with climate change impacts. Reducing local stressors can reduce the impact of global stressors and maintain the most diverse and productive reefs for as long as possible[43]. Minimising local stressors on coral reefs through a fully integrated ecosystem-based approach that considers both land and marine-based drivers of degradation will help to protect biodiversity and maintain the provision of essential ecosystem goods and services. Without substantial action, the cumulative and synergistic effects of climate change and direct human impacts are likely to drive many coral reef ecosystems into a highly degraded state. Eliminating overfishing of reef species with key ecological functions and reducing nutrient and sediment pollution to acceptable levels, as part of a resilience-based approach to coral reef management, will particularly help to prevent a shift to an ecosystem not dominated by reef-building corals. Protecting the most resilient coral reefs from as many local stressors as possible is regarded as the best way to slow down the rate of coral demise[44]

Actions to improve coral reef resilience must also address governance, awareness and political will as well as direct human pressures[45]. To change people's attitudes and behaviour at the local level there will need to be a better understanding of the motivations and livelihoods of coastal and watershed communities [46]. At the sub-national and national level there is insufficient and appropriate management in many countries with extensive coral reefs, making it imperative to build capacity to implement the management interventions required. Existing national plans for coral reef and coastal zone management should be supported to enable effective implementation involving all relevant government departments. Where these plans are inadequate, emphasis must be put on revising and updating them to take into account the urgent need for action. The importance of local community-based management or co-management arrangements for coral reefs and closely associated ecosystems cannot be understated, and should be fully recognised and supported at the sub-national, national and regional level.

In decision X/29 (paragraph 74) the Conference of the Parties (COP) to the Convention on Biological Diversity requested the Executive Secretary to prepare a report on the progress made in the

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[39] Pratchett, M.S. et al., 2008. Effects of climate-induced coral bleaching on coral reef fish: Ecological and economic consequences. Oceanogr. Mar. Biol. Ann. Rev. 46: 251-296.

[40] Cesar, H. & C.K. Chong. 2005. Economic Valuation and Socioeconomics of Coral Reefs: Methodological Issues and Three Case Studies. In: Ahmed, M., C.K. Chong and H. Cesar (eds). 2005. Economic Valuation and Policy Priorities for Sustainable Management of Coral Reefs. 2nd Edition. WorldFish Center Conference Proceedings 70.

[41] Cesar, H., et al.,. 2003. The economics of worldwide coral reef degradation. Cesar Environmental Economics Consulting (CEEC).

[42] Wong, P.P. et al 2014. Coastal Systems and Low Lying Areas. In: Climate Change 2014: Impacts, Adaptation, and Vulnerability. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. [Final Draft Report]

[43] Scientific Consensus Statement on Climate Change and Coral Reefs. 2012. Center for Ocean Solutions, Monterey, California.

[44] Ibid.

[45] Wilkinson, C. 2004. Status of Coral Reefs of the World: 2004. Australian Institute of Marine Science, Townsville, Australia.

[46] Cinner, J. 2014. Coral reef livelihoods. Current Opinion in Environmental Sustainability. 7: 65-71

implementation of the specific work plan on coral bleaching, adopted in decision VII/5 (appendix 1 of annex 1). This report[47] was made available for consideration at the sixteenth meeting of the Subsidiary Body on Scientific, Technical and Technological Advice (SBSTTA) in 2012.

In decision XI/18 A, the Conference of the Parties (COP) to the Convention on Biological Diversity, recalling Aichi Biodiversity Target 10, expressed its deep concern that climate change will increase the severity and incidence of coral bleaching and ocean acidification in the twenty-first century (paragraph 7).

In paragraph 9 of the same decision, the COP took note of the urgent need to update the specific work plan on coral bleaching (Appendix 1 of annex I to decision VII/5[48]), taking into consideration other global impacts on coral caused by climate change, most notably, projected impacts of ocean acidification, but also the effects of tropical storms and rising sea levels, and recognized that the projected impacts of ocean acidification need to be integrated into management frameworks alongside interaction with local stressors.

In paragraph 13 of this decision, the COP requested the Executive Secretary to collaborate with Parties, other Governments, relevant organizations, and indigenous and local communities to develop proposals to update the specific work plan on coral bleaching through an addendum to the work plan that addresses the needs set out in paragraph 11:

(a) Understand the vulnerability of corals to multiple stressors;

(b) Plan proactively for climate risks and associated secondary effects, applying ecosystem-based adaptation measures;

(c) Manage coral reefs as socio-ecological systems undergoing change due in many cases to climate change; and

(d) Formulate adaptation strategies that aim to enhance the resilience of ecosystems to enable the continued provision of goods and services.

The COP requested the Executive Secretary to submit the draft addendum for consideration at a meeting of the Subsidiary Body prior to the twelfth meeting of the COP.

This document provides a review of current scientific knowledge and conservation management suggestions for warm water coral reefs and closely associated ecosystems with regard to the four points outlined above to support the development of the draft addendum. Taking these points into consideration, along with initial recommendations to update the work plan submitted to SBSTTA 16, and recognising recent calls for action[49 50 51 52] to increase coral reef resilience and management effectiveness, a series of recommendations for updating the specific work plan on coral bleaching are provided in the final section. These recommendations are summarised as in Annex 5 as *Priority Actions to Achieve Aichi Biodiversity Target 10 for Coral Reefs and Closely Associated Ecosystems.*.

2. The vulnerability of coral reefs to multiple global and local stressors

This section provides an update on the latest scientific information available regarding the vulnerability of coral reef organisms and ecosystems to multiple stressors. These include both global stressors linked to climate change (e.g. coral bleaching, ocean acidification, rising sea levels and

[47] UNEP/CBD/SBSTTA/16/INF/11
[48] http://www.cbd.int/decision/cop/default.shtml?id=7742
[49] International Coral Reef Initiative Framework for Action 2013. ICRI 2013. http://www.icriforum.org/icri-documents/icri-key-documents/framework-action-2013
[50] Scientific Consensus Statement on Climate Change and Coral Reefs. 2012. Center for Ocean Solutions, Monterey, California. http://hopkins.stanford.edu/climate/fulltext.pdf
[51] Burke, L., Reytar, K., Spalding, M. and Perry, A. 2011. Reefs at Risk Revisited. World Resources Institute, Washington DC, USA. 114 pp. http://www.wri.org/publication/reefs-risk-revisited
[52] Harding, S., et al. 2010. GLOBE Action Plan for Coral Reefs. GLOBE International Commission on Land-Use Change and Ecosystems. https://static.zsl.org/files/globe-action-plan-for-coral-reefs-1300.pdf

tropical storms) and more local impacts on coral reefs such as overfishing, habitat loss and degradation, pollution and sedimentation). An overview of the interactions between various global and/or local stressors and their effects on reef-building corals and other organisms is provided. The linkages between global or local stressors and the incidence of coral disease are also explored.

Understanding the cumulative impacts of stress on ecosystems and rethinking of management philosophies to explicitly incorporate multiple, interacting stressors is regarded as a critical challenge for twenty-first century conservation[53]. Coral reefs are widely considered to be one of the most stressed ecosystems globally[54] [55] and therefore, understanding and managing multiple stressor interactions on these ecosystems is particularly urgent[56]. There have been a number of reviews on the effects of multiple stressors on coral reef ecosystems in recent years[57][58][59]. As well as describing and summarising the reported effects of both global and local stressors on corals or coral reef ecosystems, one of these reviews has also critically assessed research conducted to date to verify the type of effect caused by interacting stressors. The combined effect of multiple stressors can be additive, synergistic or antagonistic (Figure 1). More simple additive effects are those where the combined impact of two stressors is equal to the sum of their individual effects. Synergistic effects are non-additive interactions between two or more stressors that are characterised by a combined impact that is greater than the sum of individual impacts[60][61]. Lastly, antagonisms are interactions where the combined impact is less than the sum of individual effects (Figure 1). Synergistic effects are of greatest concern as they can accelerate biodiversity loss[62] and impair the functioning of marine ecosystems[63]. Research studies for ecosystems have therefore tended to focus on identifying synergisms among stressors as these interactions cause more rapid declines in ecosystems than additive or antagonistic interactions[64]. However, assessments of reviews of multiple stressor effects on ecosystems involving two stressors have shown that antagonisms are just as common as synergisms[65] and that non-additive effects (synergistic and antagonistic combined) are more frequent than additive ones[66]. Antagonistic effects should therefore be taken into consideration when prioritising management actions, in order to maximise efforts on reducing synergisms and not waste effort or limited resources on tackling

[53] Paine, R.T. et al. 1998. Compounded perturbations yield ecological surprises. Ecosystems 1: 535-545.

[54] Carpenter, K.E. et al., 2008. One-third of reef-building corals face elevated extinction risk from climate change and local impacts. Science 321: 560-563.

[55] Hoegh-Guldberg, O. and Bruno, J. 2010. The impact of climate change on the world's marine ecoystems. Science. 328; 1523-1528.

[56] Ban, N. et al. 2014. Evidence for multiple stressor interactions and effects of coral reefs. Global Change Biology 20: 681-697

[57] Ateweberhan, M. et al. 2013. Climate change impacts on coral reefs; Synergies with local effects, possibilities for acclimation, and management implications. Mar. Pollut. Bull. 74: 526-539. http://dx.doi.org/10.1016/j.marpolbul.2013.06.011**.**

[58] Ban, N. et al. 2014. Evidence for multiple stressor interactions and effects of coral reefs. Global Change Biology 20: 681-697. doi: 10.1111/gcb.12453

[59] Darling, E.S. and Cote, I.M. 2013. Vulnerability of coral reefs. Climate Vulnerability Volume 4, Chapter 4.21. http://dx.doi.org/10.1016/B978-0-12-384703-4.00427-5**.**

[60] Folt, C.L. et al. 1999. Synergism and antagonism among multiple stressors. Limnol. Oceanogr. 44: 864-877.

[61] Breitburg, D. and Riedel, G. 2005. Multiple stressors in marine ecosystems. Marine Conservation Biology. Norse, E. and Crowder. L. (eds.). Island Press pp. 416-431.

[62] Brook, B.W. et al. 2008. Synergies among extinction drivers under global change. Trends Ecol. Evol. 23: 453-460.

[63] Hoegh-Guldberg, O. and Bruno, J. 2010. The impact of climate change on the world's marine ecoystems. Science. 328; 1523-1528.

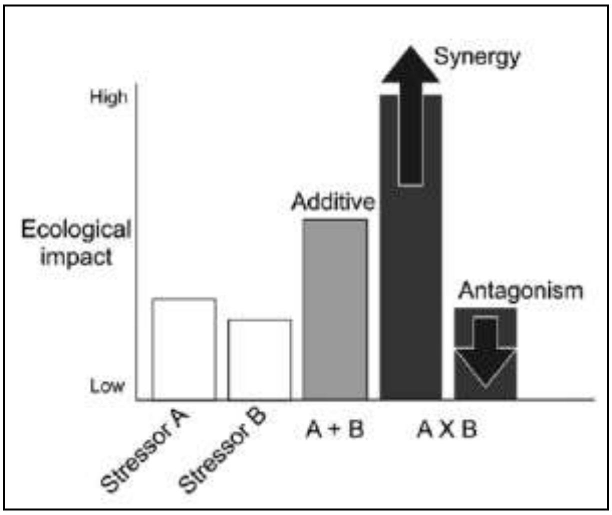
[64] Brown, C.J. et al. 2013. Managing for interactions between local and global stressors of ecosystems. PLoS ONE 8 (6): e65765. doi: 10.1371/journal.pone.0065765.

[65] Ibid.

[66] Ban, N. et al. 2014. Evidence for multiple stressor interactions and effects of coral reefs. Global Change Biology 20: 681-697

antagonisms. When there are more than two stressors involved, there can often, but not always, be a synergistic outcome[67].

Figure 1: Interaction between two stressors can result in simple additive effects, synergies or antagonisms (after Darling and Cote, 2013)



For coral reef ecosystems, identifying synergisms between stressors enables the prioritisation of management to mitigate the most severe interactions or take early preventative action to minimise the interactive impact[68]. Evaluation of cumulative impacts of multiple stressors is regarded as critical to forecast future ecological change on coral reefs and effectively manage the combined impacts of multiple stressors[69]. Interactive effects on reef-building corals are summarised for global stressor interactions (Table 1) and those between global and local stressors (Table 2). It is thought that ocean acidification (OA), perhaps in synergy with temperature increase, may have been inhibiting coral growth since 1990 on the Great Barrier Reef[70], while an 11% decrease in coral growth, associated with OA, has been reported over the last 30 years within the Caribbean[71].

Detailed information of the independent effects of warming and acidification on reef-building corals is not provided in this document. Reviews of the impacts of ocean acidification on marine biodiversity[72] and a range of marine organisms[73][74][75] are available. As well as acting independently, the warming and acidification effects interact synergistically to amplify effects on corals (Table 1).

Table 1: Interactive effects between global (climate-induced) stressors
(after Ateweberhan et al. 2013 and references therein)

Climate Change Factor	Interactive effect
Warming / Increased Temperature	• **Induces coral bleaching**; bleached corals are more sensitive to diseases and have lowered calcification rates; affects post-

[67] Crain, C.M. et al. 2008. Interactive and cumulative effects of multiple human stressors in marine systems. Ecol. Lett. 11: 1304-1315.
[68] Ibid
[69] Darling, E.S. and Cote, I.M. 2013. Vulnerability of coral reefs. Climate Vulnerability Vol. 4, Chapter 4.21.
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	bleaching disturbance recovery through negative impacts on reproduction, development and recruitment • Extreme temperatures will reduce calcification • **Induces coral disease**; disease stressed corals are more sensitive to bleaching and have reduced calcification rates; affects post-disturbance recovery through negative impacts on reproduction, development and recruitment
Ocean Acidification: reduced carbonate and aragonite concentration	• **Results in reduced calcification**; corals with reduced calcification are more sensitive to bleaching and disease; affects post-disturbance recovery through negative impacts on reproduction, development and recruitment • **Results in the dissolution of aragonite and calcite skeleton**; weakened skeleton is more sensitive to the impact of bioeroders and storms

Acidification is thought to be a potential trigger for coral bleaching[76,] inducing stress by influencing key physiological functions in corals such as photosynthesis, respiration and reproduction[77,78,79]. Acidification may also slow down post-bleaching recovery of corals[80] and affect different life-history processes in corals such as reproduction, larval development and settlement. Early life stages are also more vulnerable to bleaching[81]. Both bleaching and acidification can therefore negatively affect the recruitment and competitive ability of corals, which may facilitate a shift in community structure to one dominated by fleshy algae[82]. The presence of fleshy algae can also induce stress in corals via the release of dissolved compounds, causing microbe-induced coral mortality[83]. Overfishing of reef herbivores can exacerbate the problem by reducing herbivory, resulting in higher cover of fleshy algae[84] and increased coral mortality. Adding another stressor to the mix in the form of nutrient pollution can promote the growth and competitive advantage of fleshy algae[85] and further reduce the health of corals. Ocean acidification and warming can also lower the threshold at which overfishing of herbivores leads to coral-algal phase shift[86].

Infectious diseases in reef-building corals have been a major cause of coral reef degradation in recent years[87] and have increased in frequency, severity, the number of species infected and the spatial extent

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of outbreaks[88]. There is a clear positive relationship between seawater temperature and the incidence of disease in corals such as black band[89], white pox[90], dark spots and yellow band[91]. Elevated seawater temperatures may affect basic physiological responses of corals to pathogens[92] so that normally harmless coral pathogens become virulent in periods of high temperatures[93]. Corals stressed by elevated temperatures may also be more susceptible to infection leading to increased epidemic potential such that a small rise in temperature may be sufficient to switch diseases to an epidemic phase in tropical waters[94]. Disease incidence also increases in corals following bleaching events[95], suggesting that highly stressed (bleached) corals have reduced immunity to respond to injury and infection[96]. Other stressors such as destructive practises that mechanically damage and weaken corals can make them more susceptible to infection, disease and bleaching.

Coral disease dynamics, which are thought to be crucially influenced by climate change, are linked to both warming and pollution, and also interact with bleaching and acidification effects[97]. In particular, poor water quality caused by local anthropogenic stressors such as increased sedimentation and nutrient levels[98] is closely linked with coral disease prevalence. Pathogen growth and virulence can be enhanced by increased temperature[99] and increased nutrient availability[100] while coral host susceptibility to infection can also be affected by stress due to increased irradiance[101], acidification[102], pollution[103], and sedimentation[104]. The effect of ocean acidification on coral diseases is not as well-known as the interaction between warming, bleaching and disease. However, acidification is expected

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to play a major role in coral reef community development by enhancing coral stress through interactions with other stress factors[105].

Pollutants also interact with climate-induced responses by corals. Elevated nutrient levels can increase coral susceptibility to bleaching and decrease calcification rates as well as promote algal growth, thereby increasing macroalgal competition with corals (Table 2). For example a synergistic interaction between nutrients and acidification enhanced the growth of the white plague pathogen *Aurantimonas coralicida*[106]. Apart from elevated nutrient levels, a wide range of chemical pollutants are known to affect reef-building corals and other reef taxa. These include oil and oil dispersants, industrial chemicals from discharges, pesticides from runoff, antifouling compounds and specific chemicals (e.g. cyanide) used in unsustainable fishing practises[107]. However there has been little research to date on the interaction between non-nutrient pollutants and other stressors in terms of effects on corals[108].

[105] Sokolow, S., 2009. Effects of a changing climate on the dynamics of coral infectious disease: a review of the evidence. Diseases Aquat. Organ. 87: 5-18.

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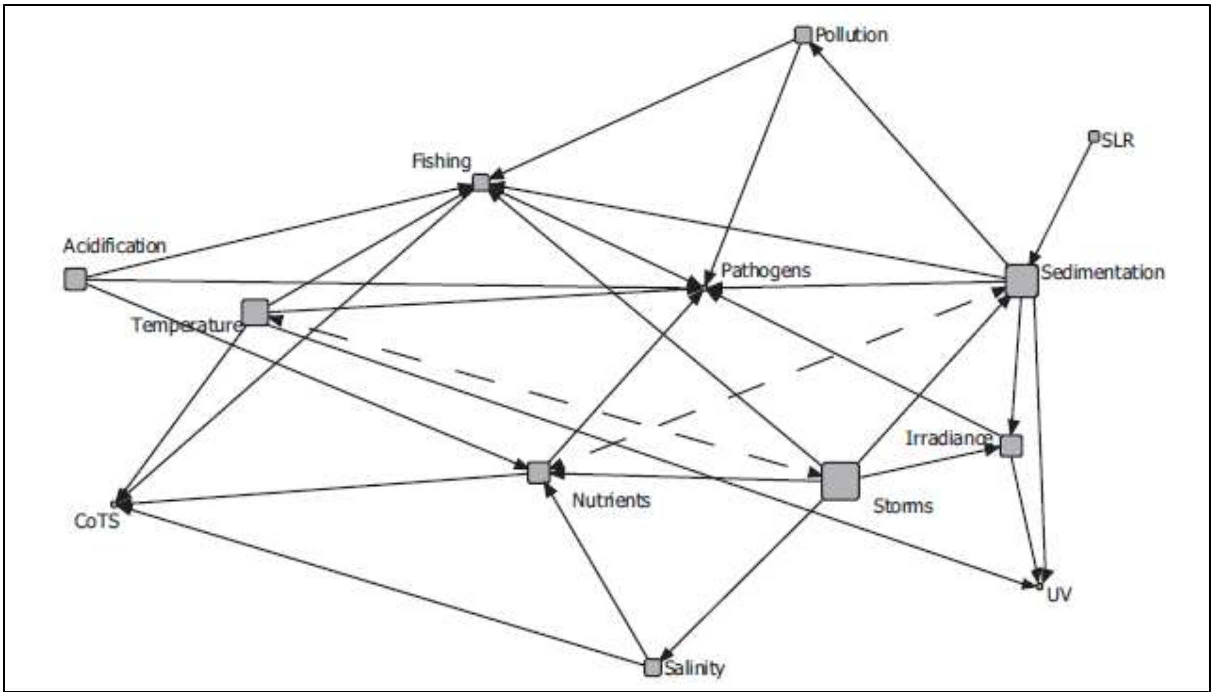
[108] Ban, S.S. et al. 2014. Evidence for multiple stressor interactions and effects of coral reefs. Global Change Biology 20: 681-697

Table 2: Interactive effects of local stressors on climate change factors and marine diseases (after Ateweberhan et al. 2013 and references therein)

Climate Change Factor	Relationship with climate change factors			
	Sedimentation and Turbidity	**Nutrients**	**Overfishing**	**Destructive Practises**
Coral Bleaching	• Increase coral susceptibility to bleaching • Decrease post bleaching recovery by smothering corals and limiting settlement of coral larvae	• Increase coral susceptibility to bleaching through imbalance of nutrients in surrounding water that induces biochemical changes in cells • Decreases post bleaching recovery through reduced reproductive output and by promoting growth of competitive algae, coral disease and increase of bioerosion and breakage	• Resistance to bleaching may decrease due to reduction in biomass and functional diversity in reef fishes • Reduction in post bleaching recovery by promotion of over-dominance of fleshy macroalgae and soft-bodied reef invertebrates. • Loss of hard substrata due to intensified bioerosion and expansion of 'urchin barriers' associated with loss of keystone predators	• Physical destruction may result in partial mortality and weakening, increasing susceptibility to bleaching • Reduces post-bleaching recovery through reduced reproductive potential, development and recruit survival.
Ocean acidification	• Sedimentation stressed corals are more likely to have reduced calcification	• Both positive and negative effects of elevated nutrient levels reported. Most studies suggest negative effects on calcification, skeletal extension and density, and direct mortality. • Promotes overgrowth of fleshy macroalgae, reducing the competitive capacity of corals	• Promotes overgrowth of fleshy macroalgae and bioeroders that could induce stress and diseases causing reduced calcification	• Physically damaged corals have lower skeletal growth
Coral Disease	• Increases susceptibility to disease; promote growth of disease-causing micro-organisms and disease inducing fleshy macroalgae	• Induce proliferation of disease causing micro-organisms and bioeroders • Intensify growth of fleshy macroalgae that induce coral disease	• Reduction of keystone predatory fishes promotes the population explosion of prey organisms that become vulnerable to marine diseases • Reduction of herbivorous organisms promotes overgrowth of fleshy macroalgae that induce coral disease	• Corals suffering mechanical damage are more sensitive to diseases • Damaged corals may have low capacity for post disturbance recovery due to reduced reproductive potential (trade-off between recovery and reproduction)

A recent comprehensive review of multiple stressor interactions in coral reef ecosystems conducted a qualitative meta-analysis of relationships between stressors for 176 studies that examined at least two of thirteen selected stressors[109]. The selected stressors were: ocean acidification, Crown-of-Thorns (CoTs) starfish outbreaks, eutrophication, fishing pressure, increased ocean temperatures, irradiance, pathogen-induced disease, pollution, reduced salinity, storms, terrestrial sedimentation, ultraviolet radiation (UV), and sea level rise (SLR). A network analysis approach for analysing stressor interactions was used to identify the most influential or most influenced stressors (Figure 2). This approach can help to focus efforts on reducing stressors that are likely to have the most deleterious effects on coral reefs[110]. The network analysis identified temperature, sedimentation and storms as the most influential factors on other stressors while the most influenced stressors were pathogens, nutrients and CoTs. A summary of the stressor-stressor interactions and the direction of influence (reinforcing, mitigating and mixed or no effect) is provided in Annex 1.

Figure 2: Network diagram of stressor-stressor relationships for coral reef ecosystems (after Ban et al., 2014).



Note: Node size reflects the number of other stressors that are directly or indirectly mediated by that node. Unidirectional relationships are depicted by solid lines, bidirectional relationships are depicted by dashed lines.

Sedimentation was found to directly affect irradiance, nutrient loading, pathogen loading, pollution, fishing (catches) and ultraviolet exposure. The effects of nutrients, disease and pollution were reinforced by sedimentation whilst a mitigation effect was found for irradiance and UV exposure. Tropical storms have a direct influence on nutrients, UV exposure, fishing, salinity, temperature and sedimentation. While storms cause both direct and indirect damage to reefs, the latter by reinforcing nutrient, sediment and salinity effects, they can also mitigate the influence of some stressors by reducing waters temperatures[111] and irradiance[112]. However the increased damaging effects of more intense tropical storms coupled with a mix of warming, disease or acidification effects on corals, are

[109] Ban, S.S. et al. 2014. Evidence for multiple stressor interactions and effects of coral reefs. Global Change Biology 20: 681-697

[110] Ibid

111 Carrigan, A.D. and Puotinen, M.L. 2011. Assessing the potential for tropical cyclone induced sea surface cooling to reduce thermal stress on the world's coral reefs. Geophysical Research Letters 38: 1-5.

[112] Van Woesik, R. et al., 1995. Effects of cyclone 'Joy' on near-shore coral communities of the Great Barrier Reef. Mar. Ecol. Prog. Ser. 128: 261-270.

likely to interact synergistically to reduce the ability of coral reefs to recover from episodic storm or mass bleaching events[113].

The network analysis identified temperature as a highly influential stressor with more than half of the studies assessed reporting a reinforcing effect on another stressor[114]. In particular temperature reinforced the effects of UV radiation[115] and pathogen growth[116] and virulence[117], and may also interact synergistically with storm frequency[118] although this has been questioned[119]. Overall increasing water temperatures has a range of effects on other stressors that affect coral reefs and most of these effects appear to be deleterious[120].

A second qualitative meta-analysis of 111 quantitative experimental studies that examined the effect of two or more stressors on a third dependent variable revealed that more than half (54%) reported a synergistic effect, 15% reported an antagonistic effect and 30% reported an additive effect or no significant interaction[121]. The most studied response variables in multi-stressor studies were coral bleaching/symbiont photosynthesis, coral calcification, coral cover, coral mortality and observation of coral disease symptoms. There were only a few studies that examined the effect of pathogens, sea level rise, storms or pollution interacting with any other stressor, suggesting that these areas are a potential research gap in terms of coral responses to multiple stressors. In particular there are significant gaps in the interaction pairs of nutrients and irradiance, and nutrients and pollution[122]. A summary of the complete set of measured effects is provided in Annex 2[123].

Diagnostic Coral Reef Monitoring and Assessment

As well as identifying the types of interactions between the multiple stressors affecting corals and coral reef ecosystems it is also important to be able to detect the sub-lethal effect of stressors on reef organisms so that action can be taken quickly to mitigate the effect of one or more stressors on a coral reef ecosystem. Traditional coral reef assessment and monitoring efforts often use mortality as the major metric of change, which is a very crude estimate of stress that does not allow for management intervention in a timely or effective manner[124]. For this reason, techniques that can detect stress at sub-lethal levels and which identify cause-and-effect relationships are critical for addressing coral reef decline[125]. The use of proactive bioindicators for detecting stress on coral reefs is a relatively new and

[113] Salvat, B. and Wilkinson, C. 2011. Cyclones and climate change in the South Pacific. Rev. Ecol. (Terre Vie) 66: 105-115.
[114] Ban, S.S. et al. 2014. Evidence for multiple stressor interactions and effects of coral reefs. Global Change Biology 20: 681-697
[115] Anderson, S. et al., 2001. Indicators of UV exposure in corals and their relevance to global climate change and coral bleaching. Human and Ecological Risk Assessment 7: 1271-1282.
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[117] Banin, E. et al., 2003. Superoxide dismutase is a virulence factor produced by the coral bleaching pathogen *Vibrio shiloi*. Current Microbiology 46: 418-422.
[118] Anthes, R.A. et al., 2006. Hurricanes and global warming – Potential linkages and consequences. Bulletin of the American Meteorological Society 87: 623-628
[119] Hetzinger, S. et al., 2008. Caribbean coral tracks Atlantic Multidecadal Oscillation and past hurricane activity. Geology 36: 11-14.
[120] Ban, S.S. et al. 2014. Evidence for multiple stressor interactions and effects of coral reefs. Global Change Biology 20: 681-697
[121] Ibid
[122] Ibid
[123] Reference details of the experimental studies summarised in Annex 2 are available in Supplementary Table 5 of Ban et al., 2014.
[124] Richmond, R.H. and Wolanski, E. 2010. Coral Research: Past Efforts and Future Horizons.
[125] Ibid

developing area of research. For reef-building corals the potential sub-lethal biological responses that can be detected in a short time are[126]:

- Changes in the expression of genes involved in the sensing, reacting to and arbitrating environmental stress;
- Shifts in the relative abundance and nature of proteins designed to ameliorate stress at the subcellular level;
- Changes in the physiology of an organism such as the production of mucus in corals, shifts in respiration or the photo-physiological performance of symbiotic zooxanthellae; and
- Changes in the relative abundance and diversity of the prokaryotic community associated with coral tissues and mucus.

Techniques to measure changes in mucus production by corals or in the composition of the bacterial community are still in very early stages of development and are not currently available for practical use[127]. Gene expression analysis to identify sub-lethal effects of stressors for reef-building corals is also still at a rather early stage of development but has recently been reported for *Montastrea cavernosa* on south Florida reefs[128]. Gene expression responses are regarded as excellent candidates for further development as the technique should be able to provide detailed information on the type of stressor affecting a coral[129].

To measure changes in proteins, a bio-indicator technology, cellular diagnostics, has been developed to assess the condition of reef-building corals at the sub-lethal level[130]. This is especially useful for assessing the impact of less obvious and often more chronic stressors of coral reef organisms such as land-based sources of pollution. Cellular diagnostics is a systematic approach to defining and integrating cellular biomarkers based on their functionality within a cell and determining how alterations in the behaviour of a set of cellular proteins may reflect overall cellular integrity or performance[131]. The technique can be applied to a variety of coral reef species and can provide data on stress at sub-lethal level, when intervention and mitigation have the greatest chance of success[132]. Using this technique a Molecular Biomarker System (MBS) for detecting heat and light stress in Caribbean coral species was successfully developed[133]. The MBS technique can also differentiate between global and local stressors, and also between different types of bleaching[134]. Cellular diagnostics can be a very quick method to detect a sub-lethal effect as these protein molecules respond rapidly to stress, and the time for processing and analysing samples can be within hours depending on the specific methodology used[135].

The above techniques are however rather costly and require a considerable amount of equipment and expertise for the processing and analysis of samples. Their practical feasibility in less developed coral

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[126] Reinemann, D.R. 2008. The development of proactive monitoring tools for coral reef management. University of Hawaii. Masters Thesis. 112 pp

[127] Ibid

[128] Edge, S.E. et al., 2013. Sub-lethal coral stress: Detecting molecular responses of coral populations to environmental conditions over space and time. Aquatic Toxicology 128-129: 135-146

[129] Reinemann, D.R. 2008. The development of proactive monitoring tools for coral reef management. University of Hawaii. Masters Thesis. 112 pp.

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[135] Bromage, E. et al., 2009. Quantification of coral heat shock proteins from individual coral polyps. Mar. Ecol. Prog. Ser. 376: 123-132

reef nations with limited technical and logistical resources may therefore be questionable. The techniques also involve the collection of numerous samples of coral tissue, which may not be permitted by resource managers and can be subject to transport restrictions under international treaties[136].

The use of low-cost bioindicators of coral reef health for application in countries with limited technological resources was explored at a workshop in 1995[137]. One of the ideas proposed was the use of reef-dwelling foraminifera, with particular emphasis on taxa hosting algal symbionts, and led to the development of the Foraminifera in Reef Assessment and Monitoring (FoRAM) Index[138]. This index is a foraminiferal-based indicator to distinguish whether water quality supports recruitment and proliferation of calcifying, photosynthesising holobionts, namely reef-building corals. It has been used in both the Caribbean and Indo-Pacific to date but is not thought to be suitable for some regions and habitats[139]. Other recommended bioindicators for water quality are the degree of external bioerosion and the abundance of macrophytes[140]. Low-cost bioindicators can be used to make an initial assessment of reef health that can help to decide whether more detailed diagnostic assessments are warranted.

Carbonate budgets have also been recently proposed as a management tool for assessing and monitoring coral reef condition. The 'ReefBudget' methodology has been developed to quantify biological carbonate production states in Caribbean reefs and has the potential to be adapted for use in other coral reef regions[141].

Sea level rise, tropical storms and closely associated ecosystems

Sea level rise can also have ecological impacts on coral reefs and associated ecosystems, which can depend on the geological character of the shoreline and topography[142]. In regions where topography is low and/or shoreline sediments are easily eroded, it is likely that sedimentation will increase with a corresponding decrease in water quality that could adversely affect coral reefs and other sensitive habitats[143]. Greater inundation of reef flats can erode residual soils and lagoon deposits[144] and produce greater sediment transport[145]. Rising sea level will also result in increased wave damage to coral reefs and other coastal ecosystems[146], as well as disrupting coastal communities, especially when combined

[136] Hallock, P. et al., 2004. Coral reef risk assessment from satellites to molecules: A multi-spatial approach to environmental monitoring and risk assessment of coral reefs. Env. Micropaleontology, Microbiology and Meiobenthology 1: 11-39.
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with storm surges[147]. Modelling of climate change scenarios suggests that functional coral reefs can help to dissipate wave energy and reduce wave impacts on land[148]. There is some evidence that coral reef growth can keep pace with recent sea level rise[149150] and it is thought that a number of coral reefs could cope with the maximum rate of sea level rise of 15.1 mm yr^{-1} projected for the end of this century[151152]. However, favourable reef growth depends on coral net accretion rates which in turn are affected by local conditions such as turbidity or water quality (nutrient levels) and will be subject to the influence of future projected levels of global stressors, notably warming[153]. Therefore the ability of coral reefs to keep up with sea level rise is likely to be strongly linked to the degree of particular local stressors in the short to mid-term and the impact of global stressors over the long-term.

The impact of multiple global stressors on mangrove and seagrass ecosystems, which are closely associated with coral reefs, also needs consideration especially if ecosystem-based management is proposed. Mangrove ecosystems are regarded as highly vulnerable to the direct effects of climate change, specifically to changes in precipitation, seawater acidity, cyclones and storms and sea level[154]. Of these sea level is projected to be the greatest climate-induced threat to mangroves globally[155]. Elevated CO_2 levels will benefit mangroves by increasing photosynthesis and mangrove growth rates[156]. Changes in precipitation may also have a significant effect on mangroves. Decreased precipitation can result in a decrease in mangrove productivity, growth and seed survival[157] and cause a decrease in mangrove area and diversity[158]. Conversely increased precipitation can increase mangrove area, growth rates and diversity in some species[159]. However, there may be negative impacts on marine and estuarine species inhabiting mangrove systems through increased runoff, changes in salinity and subsequent effects on critical life history stages.

Direct negative impacts of climate change on mangroves will predominantly come from the effects of tropical storms and rising sea level. Mangroves are sensitive to strong winds associated with cyclones and storms, which damage foliage, desiccate plant tissues and increase evaporation rates and salinity stress[160]. Increased wave surge during cyclones erodes sediments in the seaward zone and reduces plant stability, while stronger surges in severe conditions can remove mangrove plants from the

[147] Nicholls, R.J. and Cazenave, A. 2010. Sea-level rise and its impact on coastal zones. Science 328: 1517-1520
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[154] McLeod, E. and Salm, R.V. 2006. Managing Mangroves for Resilience to Climate Change. IUCN, Gland, Switzerland. 64 pp.
[155] Field, C.D. 1995. Impacts of expected climate change on mangroves. Hydrobiologia 295 (1-3): 75-81.
[156] United Nations Environment Programme. 1994. Assessment and monitoring of climate change impacts on mangrove ecosystems. UNEP Regional Seas Reports and Studies. Report No. 154.
[157] Ellison, J.C. 2000. How South Pacific mangroves may respond to predicted climate change and sea-level rise. Chapter 15, p. 289-301. In: Gillespie, A, and Burns, W. (eds) Climate Change in the South Pacific: Impacts and Responses in Australia, New Zealand, and Small Island States. Kluwer Academic Publishers, Dordrecht.
[158] Snedacker, S.C. 1995. Mangroves and climate change in the Florida and Caribbean region:scenarios and hypotheses. Hydrobiologia 295: 43-49.
[159] Field, C.D. 1995. Impacts of expected climate change on mangroves. Hydrobiologia 295 (1-3): 75-81.
[160] Ellison, J.C. 2009. Geomorphology and sedimentology of mangrove swamps. In: Wolanski et al. (eds) Coastal Wetlands: An Integrated Approach. Elsevier Science, Amsterdam pp. 564-591.

seaward edge[161]. The projected increased intensity of cyclones in many tropical regions will damage mangrove ecosystems along and adjacent to cyclone paths but trees can eventually recover from the extreme events and recolonize damaged habitats given the opportunity.

Sea level rise is regarded as the greatest climate change-induced challenge to mangrove ecosystems. Mangroves are able to adapt to sea level rise if it occurs slowly enough, if there is adequate expansion space landwards and if other conditions are met[162]. A key factor is the provision of sediment to enable the build-up of mangrove soil surface. In areas of high to medium sedimentation the rate of mangrove soil rise can match or exceed the rate of sea level rise allowing mangrove habitats to remain stable or even expand. Where sedimentation levels are low then mangrove soils cannot keep pace with sea level rise and there is a loss of habitat at the seaward edge, although mangrove trees may colonise new tidal areas landwards if conditions are favourable[163]. There is both historical and recent evidence of mangrove surface elevations keeping pace with sea level rise, although recent data are only from a few sites[164]. Landward migration of mangroves can occur where not blocked by infrastructure and where topographical conditions are favourable.

Shallow seagrass beds provide important nursery habitats for a number of coral reef fish and invertebrate species and are also important fishing areas for traditional fishers and gleaners in many coral reef nations. Seagrass beds are considered to be vulnerable to climate change effects, specifically through increased thermal stress, increased storm incidence and changes in freshwater flows[165]. Although elevated CO_2 levels are likely to be beneficial to seagrass ecosystems by increasing productivity, biomass and reproductive output[166], it is becoming more widely accepted that future climate scenarios with increased temperature may be highly detrimental to shallow intertidal seagrass beds. Projected increases in temperature are likely to cause changes in the species composition, distribution and relative abundance of seagrass. In the Pacific loss of seagrass habitat is expected through increased burning of leaves at low tide, reduced light, algal overgrowth, smothering by sediments and scouring by storm surge[167]. A long-term study over 16 years has recently correlated elevated temperature and reduced river flow with lower biomass of seagrass beds in northern Australia[168]. Increased incidence of intense cyclones is also expected to have a strong but relatively localised influence on seagrass beds. Severe storms can devastate seagrass beds through the combined effects of physical disturbance, reductions in light and salinity, and movement of sediments[169]. Shallow subtidal and intertidal habitats will suffer the most damage where wave energy is greatest.

Any climate change-induced loss of mangrove or seagrass ecosystems through complete removal or degradation will have an impact on the abundance and diversity of marine species that rely on their habitats for food and shelter. Reduced coverage or structural complexity of vegetated habitats can be

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[161] Waycott, M. et al., 2011. Vulnerability of mangroves, seagrasses and intertidal flats in the tropical Pacific to climate change. In: Vulnerability of tropical Pacific fisheries and aquaculture to climate change. Bell, J.D. et al. (eds.). Secretariat of the Pacific Community. Chapter 6: 297-368.

[162] McLeod, E. and Salm, R.V. 2006. Managing Mangroves for Resilience to Climate Change. IUCN, Gland, Switzerland. 64 pp.

[163] McIvor, A.L. et al., 2013. The response of mangrove soil surface elevation to sea level rise. Natural Coastal Protection Series: report 3. Cambridge Coastal Research Unit working Paper 42. The Nature Conservancy and Wetlands International. 59 pp.

[164] Ibid.

[165] Rasheed, M.A. and Unsworth, R.K.F. 2011. Long-term climate-associated dynamics of a tropical seagrass meadow: implications for the future. Mar. Ecol. Prog. Ser. 422: 93-103.

[166] Palacios, S.L. and Zimmerman, R.C. 2007. Response of eelgrass *Zostera marina* to CO2 enrichment: possible impacts of climate change and potential for remediation of coastal habitats. Mar. Ecol. Prog. Ser. 344: 1-13.

[167] Bell, J.D. et al. (eds.), 2011. Vulnerability of Tropical Pacific Fisheries and Aquaculture to Climate Change. Secretariat of the Pacific Community.

[168] Rasheed, M.A. and Unsworth, R.K.F. 2011. Long-term climate-associated dynamics of a tropical seagrass meadow: implications for the future. Mar. Ecol. Prog. Ser. 422: 93-103.

[169] Waycott, M. et al., 2011. Vulnerability of mangroves, seagrasses and intertidal flats in the tropical Pacific to climate change. In: Vulnerability of tropical Pacific fisheries and aquaculture to climate change. Bell, J.D. et al. (eds.). Secretariat of the Pacific Community. Chapter 6: 297-368.

expected to reduce recruitment success for many species of fish and invertebrates in the absence of other shelter[170]. Any loss of functional coral reef ecosystems that are closely associated with mangroves or seagrass beds may also result in further degradation of vegetated systems through the removal of the main physical barrier along the coast and the subsequent increased exposure to storm surges and wave action.

Global Stressor effects on Coral Reef Fish Assemblages and Fisheries

Coral reef fish populations are both directly and indirectly affected by climate and ocean change. The main (indirect) effect of climate change on coral reef fish populations to date is the loss of coral reef habitat through mass coral bleaching events[171]. A loss of reef structure and habitat can have profound effects on the abundance, diversity and community structure of coral reef fish assemblages[172]. Herbivorous fish populations, a key functional group that maintain critical ecosystem functions in coral reefs, can be vulnerable to climate-induced disturbance effects over the long-term as the complex reef structure is lost over time[173]. The whole process of coral mortality, the loss of reef structure and a decline in reef fish biomass is thought to take several decades[174][175]. Other disturbances to coral reefs that result a loss of reef structure such as destructive fishing practises can also cause changes to reef fish populations.

The influence of other disturbance factors, particularly overfishing, can make it difficult to detect the effects of coral bleaching on coral reef fisheries. The effects of overfishing on reef fish populations are particularly strong and can mask any short-term changes that occur through climate-induced bleaching. There are no reported studies showing that severe bleaching events have affected total catch, catch composition or value of fisheries[176]. Fishing can reduce the resilience of fish populations to the effects of climate change by causing changes in the size and age structure of populations leading to greater variability in annual recruitment[177].

The direct impacts of increasing temperature and ocean acidification on reef fish populations are not thoroughly understood at the present time but recent research does suggest that some reef fish are sensitive to both effects[178]. The majority of coral reef fish have a narrow thermal tolerance range, making them sensitive to temperature changes and rising temperatures are likely to result in changes to reef fish community structures[179]. Projected increases in SST may also affect reef fish populations by interfering with reproduction, recruitment and juvenile growth[180]. Higher temperatures also

[170] Pratchett, M.S. et al., 2011. Vulnerability of coastal fisheries in the Pacific to climate change. In: Vulnerability of tropical Pacific fisheries and aquaculture to climate change. Bell, J.D. et al. (eds). Secretariat of the Pacific Community. Chapter 9: p. 493-576

[171] Pratchett, M.S. et al., 2008. Effects of climate-induced coral bleaching on coral reef fish: Ecological and economic consequences. Oceanogr. Mar. Biol. Ann. Rev. 46: 251-296.

[172] Ibid.

[173] Graham, N.A.J. et al., 2006. Dynamic fragility of oceanic coral reef ecosystems. Proc. Natl. acad. Sci. 103: 8425-8429.

[174] Graham, N.A.J. et al., 2007. Lag effects in the impacts of mass coral bleaching on coral reef fish, fisheries, and ecosystems. Conserv. Biol. 21: 1291-1300

[175] MacNeil, M.A. et al., 2010. Transitional states in marine fisheries: adapting to predicted global change. Phil. Trans. R. Soc. B 365: 3753-3763

[176] Pratchett, M.S. et al., 2008. Effects of climate-induced coral bleaching on coral reef fish: Ecological and economic consequences. Oceanogr. Mar. Biol. Ann. Rev. 46: 251-296

[177] Brander, K.M. 2007. The role of growth changes in the decline and recovery of North Sea Atlantic Cod stocks since 1970. ICES J. Mar. Science 64: 211-217.

[178] Munday, P.L. et al., 2012. Impact of global warming and rising CO2 levels on coral reef fishes: what hope for the future? J. Exp. Biol. 215: 3865-3873.

[179] Munday, P.L. et al., 2012. Impact of global warming and rising CO_2 levels on coral reef fishes: what hope for the future? J. Exp. Biol. 215: 3865-3873.

[180] Pratchett, M.S. et al., 2011. Vulnerability of coastal fisheries in the Pacific to climate change. In: Vulnerability of tropical Pacific fisheries and aquaculture to climate change. Bell, J.D. et al. (eds.). Secretariat of the Pacific Community. Chapter 9: p. 493-576.

increase the metabolic and growth rates of larvae, which may also affect survival and recruitment[181]. The synergistic effects of elevated CO_2 and increasing water temperatures may have substantial negative effects on the aerobic capacity of tropical fishes[182]. As rising water temperatures increase oxygen limitation in tropical regions, rising CO_2 levels could compound this problem and lead to range contractions and population declines in tropical fish communities[183].

Elevated CO_2 has a dramatic effect on a wide range of behaviours and sensory responses of reef fish with consequences for timing of settlement, habitat selection, predator avoidance and individual fitness[184]. As for temperature, there is considerable inter-specific variation in sensitivity to increased acidity but changes in reef fish community structure are highly likely to occur. Moreover, the dramatic effect of elevated CO_2 on the sensory responses and behaviour of tropical reef fishes suggest that any interactive effects with other stressors will have a more substantial impact on the demography of tropical fish communities than has been observed to date[185].

It is difficult to predict the direct effects of climate change on coral reef fisheries in terms of catches and value, although it is clear that the composition and distribution of reef fish populations will change over time as temperature and acidity levels rise. Moderate increases in temperature will most likely affect reproductive output and the development and survival of larval stages, making fished populations more vulnerable to periodic collapse due to greater inconsistency in the supply and survival of larvae[186]. Ocean acidification is also expected to compound the negative effects of increasing temperature, while impaired larval behaviour caused by increased acidity could affect recruitment and increase the risk of population decline.

As coral reefs become more degraded the composition of future reef fish populations will change with a predicted increase in species that do not have strong associations with hard corals or which exploit habitats that become more common as coral cover declines[187]. It will be important to determine whether these altered fish communities are able to support coastal fishing communities in the future or whether alternative sources of nutrition or income will be required. Projections for the Pacific indicate that production of coral reef fish is likely to decline by 20% by 2050 under the A2 SRES emissions scenario[188].

3. Management of coral reefs as socio-ecological systems

It is generally accepted that to effectively manage coral reefs it is necessary to manage the actions of people that either directly utilise reef resources or indirectly affect the reef ecosystem. Management efforts and frameworks need to consider both the socioeconomic and ecological characteristics and factors that are influencing the condition of coral reefs. In more developed nations there are sufficient technical and financial resources to develop and implement mainly top-down management programmes through national or sub-national agencies. In less developed nations, capacity for management and governance if often insufficient to support effective management of coral reef

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[181] Sponaugle, S. et al., 2006. Temperature-mediated variation in early life history traits and recruitment successes of the coral reef fish *Thalassoma bifasciatum* in the Florida Keys. Mar. Ecol. Prog. Ser. 308: 1-15.

[182] Munday, P.L. et al., 2009. Interacting effects of elevated temperature and ocean acidification on the aerobic performance of coral reef fishes. Mar. Ecol. Prog. Ser. 388: 235-242.

[183] Munday, P.L. et al., 2012. Impact of global warming and rising CO_2 levels on coral reef fishes: what hope for the future? J. Exp. Biol. 215: 3865-3873.

[184]. Ibid

[185] Ateweberhan, M. et al. 2013. Climate change impacts on coral reefs; Synergies with local effects, possibilities for acclimation, and management implications. Mar. Pollut. Bull. 74: 526-539

[186] Pratchett, M.S. et al., 2011. Vulnerability of coastal fisheries in the Pacific to climate change. In: Vulnerability of tropical Pacific fisheries and aquaculture to climate change. Bell, J.D. et al. (eds.). Secretariat of the Pacific Community. Chapter 9: p. 493-576.

[187] Ateweberhan, M. et al. 2013. Climate change impacts on coral reefs; Synergies with local effects, possibilities for acclimation, and management implications. Mar. Pollut. Bull. 74: 526-539 (and references therein).

[188] Bell, J.D. et al., 2013. Mixed responses of tropical Pacific fisheries and aquaculture to climate change. Nat. Clim. Change 3: 591-591.

ecosystems and the coastal zone. Therefore bottom-up approaches for socio-ecological management are more practical in these cases. This section mainly focuses on management measures for the latter situation in less developed countries (LDCs) and small island developing states (SIDS). Examples of top-down management frameworks are provided in the next section.

A major focus in recent years has been to conduct vulnerability assessments of both coral reef ecosystems and the coastal communities that often rely on them for food and/or income[189][190][191]. Evaluating the links between the social and ecological dimensions of vulnerability to climate change is regarded as a priority for reducing impacts on coral reefs and increasing food security[192]. Vulnerability, in the context of social and environmental change, is defined as the state of susceptibility to harm from perturbations[193], but has also been described as the opposite of resilience. Vulnerability is made up of three main elements; (1) exposure, (2) sensitivity and (3) adaptive capacity. Detailed descriptions of these vulnerability components are available in published vulnerability or adaptation frameworks[194][195]. Understanding these three elements enables managers or decision makers to evaluate the nature and magnitude of the climate change threat, detect key sources of vulnerability and identify actions to reduce or deal with the threat under each element[196].

Recent studies have conducted socio-ecological vulnerability assessments on reef-dominated coasts in Kenya[197] and Australia[198] for particular climate change scenarios. In Kenya the vulnerability of small-scale fishers to climate-induced mass coral bleaching events and their effects on reef fisheries was assessed for a range of fishing pressures. In Australia the vulnerability of two major coastal industries (commercial fishing and tourism) to extreme weather events (cyclones and flooding) was determined on the Great Barrier Reef (GBR). These two studies provide examples of how socio-ecological vulnerability assessments can be used for climate-induced impacts on coral reefs and for different types of dependent marine resource users.

Both studies based their vulnerability assessments on a conceptual framework[199] that incorporates two vulnerability models: one that represents the components of ecological vulnerability to exposure to climate change, and a second that represents social vulnerability to changes in the ecological system (Figure 3).

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[189] Marshall, N.A. et al. 2010. A framework for social adaptation to climate change: Sustaining tropical coastal communities and industries. IUCN, Gland, Switzerland, 36 p.

[190] Cinner, J, et al., 2012. Vulnerability of coastal communities to key impacts of climate change on coral reef fisheries. Global Environmental Change. Doi: 10.1016/j.glenvcha.2011.09.018

[191] Cinner, J, et al., 2013. Evaluating social and ecological vulnerability of coral reef fisheries to climate change. PLoS ONE 8: e74321. Doi: 10.1371/journal.pone.0074321

[192] Hughes, T.P. et al., 2003. Climate change, human impacts, and the resilience of coral reefs. Science 301: 929-933

[193] Adger, N.W. 2000. Vulnerability. Global Environmental Change 16: 268-281.

[194]. Marshall, N.A. et al. 2010. A framework for social adaptation to climate change: Sustaining tropical coastal communities and industries. IUCN, Gland, Switzerland, 36 p.

[195] IPCC. 2007. Climate change 2001: impacts, adaptation, and vulnerability. Intergovernmental panel on climate change, Geneva, Switzerland, 21 p

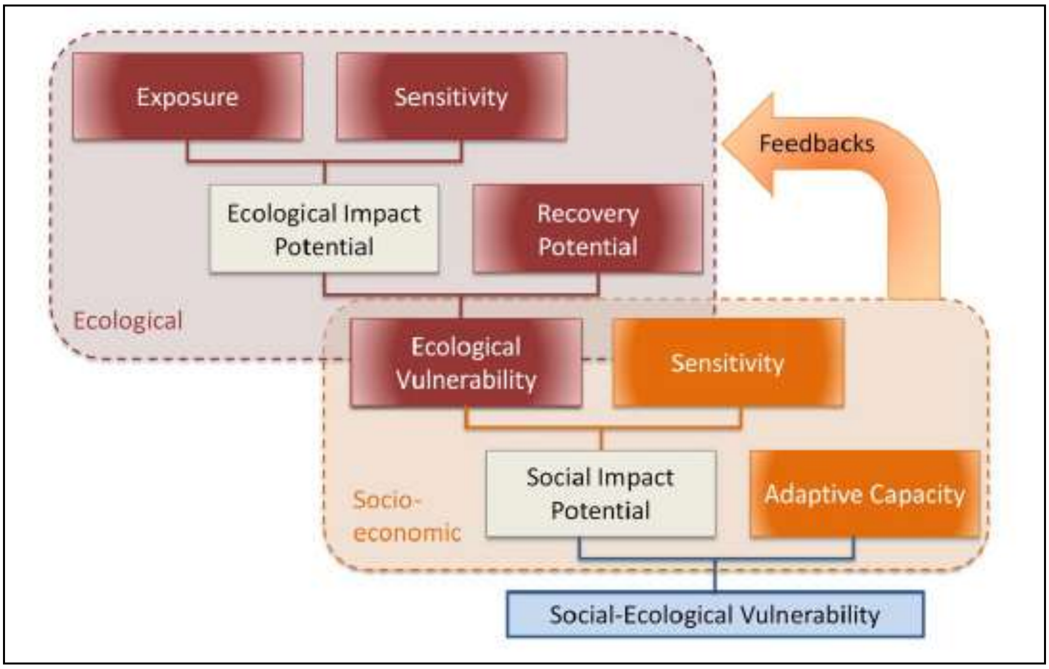
[196] Marshall, N.A. et al. 2010. A framework for social adaptation to climate change: Sustaining tropical coastal communities and industries. IUCN, Gland, Switzerland, 36 p.

[197] Cinner, J, et al., 2013. Evaluating social and ecological vulnerability of coral reef fisheries to climate change. PLoS ONE 8: e74321. Doi: 10.1371/journal.pone.0074321

[198] Marshall, N.A. et al., 2013. Social vulnerability of marine resource users to extreme weather events. Ecosystems 16: 797-809.

[199] Marshall, N.A. et al. 2010. A framework for social adaptation to climate change: Sustaining tropical coastal communities and industries. IUCN, Gland, Switzerland, 36 p.

Figure 3: Heuristic framework for linked socio-ecological systems (after Cinner et al., 2013)



The co-dependency of the ecological and social systems means their vulnerabilities are intrinsically linked. In this framework the exposure term for the social subsystem model comprises the vulnerability term from the ecological subsystem model[200]. The concept of resource dependency was used to represent the sensitivity of resource users to changes in the condition of the GBR on which their businesses depend. Resource dependency is becoming widely used to characterise the strength of linkages between social and ecological systems[201]. For small-scale fishing communities in Kenya resource dependency on coral reef fisheries not only represents a means of livelihood but can also be the main source of protein for fishers and their families.

Each type of socio-ecological vulnerability assessment will require a specific combination of ecological and socio-economic metrics. In the example for Kenya a suite of ecological sensitivity and ecological recovery potential indicators were developed for both corals and fish[202] in relation to the climate-induced impact of mass coral bleaching events. To assess the vulnerability of the ecosystem to another type of global (e.g. tropical storms or ocean acidification) or local (e.g. sedimentation or elevated nutrients) stressor will require a tailored combination of sensitivity and recovery potential indicators. Ideally a wide range of indicators could be developed to enable vulnerability assessments for multiple stressors. However it may be difficult to tease apart the effects of a number of stressors of varying intensity in a single assessment.

The Coral Triangle Initiative in the Philippines has produced a practical users' manual[203] for three types of coastal vulnerability assessments that are designed to be used at the local government or community level by coastal managers and site level practitioners (Table 3). Of these the tool for understanding the resilience of fisheries (TURF) is the only one that combines both biophysical and socio-economic variables. All three techniques involve the community or stakeholders in a participatory assessment process. The more rapid scoping assessment (ICSEA-C-Change VA tool)

[200] Marshall, N.A. et al., 2013. Social vulnerability of marine resource users to extreme weather events. Ecosystems 16: 797-809

[201] Tidball, A. and Stedman, R.C. 2012. Positive dependency and virtuous cycles: from resource dependency to resilience in urban socio-ecological systems. Ecol. Econ. doi: 10.1016/j.ecole-con.2012.10.0045.

[202] Cinner, J, et al., 2013. Evaluating social and ecological vulnerability of coral reef fisheries to climate change. PLoS ONE 8: e74321. Doi: 10.1371/journal.pone.0074321

[203] MERF. 2013. Vulnerability Assessment Tools for Coastal Ecosystems: A Guidebook. Marine Environment and Resources Foundation Inc. Quezon City, Philippines. 162 pp.

produces a lower resolution of analysis but can help to evaluate data for finer detail vulnerability assessments using the other two techniques (CIVAT and TURF). These finer-scale assessments require additional data collection using relatively simple monitoring protocols that can be undertaken by local stakeholders after orientation and training[204].

Table 3: Comparative Description of Coastal Vulnerability Assessment Tools developed in the Philippines (adapted from MERF, 2013)

Tool	Scope	CC Impacts	Other Features
ICSEA-C-Change **Integrated Coastal Sensitivity, Exposure and Adaptive Capacity to Climate Change VA Tool**	Integrated (biodiversity, coastal integrity, fisheries). Biophysical	Sea Level rise, Waves and storm surges Sea surface temperature Rainfall	Provides rapid scoping and reconnaissance Can compare sites according to relative vulnerability Determines which thematic areas are most vulnerable and require a more detailed assessment
CIVAT **Coastal Integrity VA Tool**	Coastal Integrity Biophysical	Sea level rise Waves	Incorporates natural habitats in an assessment of the physical coastline Can compare sites according to relative vulnerability Considers natural and anthropogenic drivers of physical coastal processes
TURF **Tool for Understanding Resiliency of Fisheries**	Fisheries Biophysical, with a socio-economic component	Waves and storm surges Sea surface temperature	Incorporates socio-economic variables

Understanding and reducing the linkages between poverty, marine resource dependence and over-exploitation of coral reef fisheries are particularly needed in many less developed countries where local reliance on coral reef resources can be high. Conducting socio-ecological vulnerability assessments enables the identification of the most vulnerable reef areas and coastal communities (or other resource users) in terms of high social sensitivity and low adaptive capacity[205]. Status, trends and possible opportunities for adaptation to climate change to increase social resilience through reducing sensitivity and increasing adaptive capacity can be then identified. Reducing social sensitivity is mainly concerned with measures and actions to reduce the dependence of communities on marine resources or livelihoods that are most vulnerable to climate change. Measures include diversifying livelihoods or diversifying fishing to target less impacted species (Table 4) whilst also adopting adaptive management approaches for fisheries that are more flexible to cope with extreme events[206]. However, it is important to take into account the local context when considering the use of alternative livelihoods to reduce reef-dependence and fishing pressure on reefs[207]. In some cases alternative income projects in reef fisheries have not resulted in reduced fishing effort or lower

[204] Ibid
[205] Adaptive capacity is the ability to anticipate and respond to changes, and to minimise, cope with, and recover from the consequences of change (Adger, W.N. and Vincent, K. 2005. Uncertainty in adaptive capacity. CR Geoscience 337: 399-410).
[206] Cinner, J, et al., 2012. Vulnerability of coastal communities to key impacts of climate change on coral reef fisheries. Global Environmental Change. Doi: 10.1016/j.glenvcha.2011.09.018
[207] Cinner, J. 2014. Coral reef livelihoods. Current Opinion in Environmental Sustainability. 7: 65-71

environmental impacts on coral reefs. A comprehensive understanding of reef-dependent people's livelihoods is required that involves analyses of the incentives, constraints and aspirations that drives people's behaviour[208]. Actions to change the behaviour and livelihoods of coral reef resource users are likely to be more successful when people's social context is fully understood.

Adaptive capacity is thought to be an aspect of social vulnerability that is most open to influence and has been suggested as a focus for adaptation planning[209]. In Kenya there was considerable variation in social vulnerability between communities and measures to reduce vulnerability can be tailored for each community. Suggested measures to improve adaptive capacity and their potential to influence vulnerability are provided in Table 3.

Table 4: Possible Measures to increase Adaptive Capacity and their relative influence.

Component	Potential to influence	Possible management measures
Capacity to Change Livelihood	Low	Skills and capacity building
Access Credit	**High**	**Microcredit schemes, support for community savings**
Community Infrastructure	**High**	**Infrastructure development projects**
Fishing Gear Diversity	Low	Training, gear provision
Trust	Low	Eradication of corruption
Occupational multiplicity	Low	Support for economic growth
Wealth (MSL)	Low	Poverty alleviation plans and pro-poor policies
Recognition of Human Agency	Medium	Education and participation in research
Social Capital	**Medium**	**Support for community initiatives / organisations**

Adapted from Cinner et al. (2013)

The most important measures to implement for rural coastal communities in many less developed coral reef countries are likely to be: providing access to credit through microcredit schemes; building up and maintaining community infrastructure; increasing social capital within communities and social recognition of the 'bigger picture' through education and awareness initiatives. In addition, adaptive capacity can be increased by improving the health status of coastal populations over the long-term[210], but also in the short-term by providing sexual and reproductive health services as part of an integrated public health and environment (PHE) programme[211].

Implementing management measures to reduce social vulnerability can be undertaken by a combination of government and non-government organisations according to the type of measure to be implemented. For example improving local infrastructure is better suited to regional or national government while raising environmental awareness and providing microcredit could be undertaken by NGOs. Poverty is one of the main barriers to livelihood diversification. Providing public services such as reproductive health care in combination with building individual and collective assets can help to significantly address chronic poverty in communities and increase their ability to change livelihoods, thereby further increasing overall adaptive capacity.

[208] Ibid.
[209] Cinner, J, et al., 2013. Evaluating social and ecological vulnerability of coral reef fisheries to climate change. PLoS ONE 8: e74321. Doi: 10.1371/journal.pone.0074321
[210] Cinner, J, et al., 2012. Vulnerability of coastal communities to key impacts of climate change on coral reef fisheries. Global Environmental Change. Doi: 10.1016/j.glenvcha.2011.09.018
[211] Harris, A. et al., 2012. Integrating family planning service provision into community-based marine conservation. Oryx 46 (2): 179-186.

4. Planning proactively for climate-induced risks in combination with local stressors using an ecosystem-based approach to increase socio-ecological resilience through the application of integrated adaptation measures.

Management and planning efforts to minimize the effect of climate-induced stressors on coastal socio-ecological systems in coral reef regions require a combination of information on the current status and threat level to coastal ecosystems from local stressors and drivers, and the latest modelling predictions of expected impacts from global stressors. Projections of changes in socio-economic drivers should also be factored in if possible, particularly those for projected human population growth and associated effects on food security for coastal communities dependent on coral reef ecosystems.

Ideally, management and planning approaches should be part of outcome- and target-based management frameworks over the long-term (decades) that take into consideration actual and projected multiple stressors and cumulative impacts and the delivery of net benefits through the safeguarding of ecosystem goods and services. Within this overall management framework national action plans for coral reefs and interconnected ecosystems should be developed for shorter time periods (e.g. 5 – 10 years).

There has been a growing interest in the use of more integrated, ecosystem-based approaches to coastal and ocean management over the last decade[212]. Marine ecosystem-based management (EBM) approaches include place-based management strategies, ecosystem-based climate adaptation and restoration efforts, and interdisciplinary research that generates detailed biophysical and socioeconomic information needed to proactively manage coupled socio-ecological systems[213]. These ecosystem-based approaches recognise the importance of multiple forms of ecological diversity and connectivity in sustaining the resilience of socially desirable ecosystem conditions over varied spatial and temporal scales[214][215].

Ecosystem-based adaptation (EbA) is defined as 'Adaptation that integrates the use of biodiversity and ecosystem services into an overall strategy to help people adapt to the adverse impacts of climate change'[216]. EbA is an approach for planning and implementing climate change adaptation that considers ecosystem services and their uses by people. It can build resilience and reduce vulnerability to both climate and non-climate risks and provide multiple economic, social, environmental and cultural benefits, including, disaster risk reduction, livelihood sustenance and food security, biodiversity conservation, carbon sequestration and sustainable water management[217][218]. EbA is recognised as one of the ('soft') approaches to integrate planned adaptation strategies with ecosystem services in the face of change along with more conventional ('hard') approaches involving engineered, infrastructure-based solutions[219][220]. It has been suggested that EbA approaches are a

[212] Bernhardt, J.R. and Leslie, H.M. 2013. Resilience to climate change in coastal marine ecosystems. Ann. Rev. Mar. Sci. 5: 371-392.
[213] Ibid.
[214] Folke, C et al., 2004. Regime shifts, resilience, and biodiversity in ecosystem management. Ann. Rev. Ecol. Evol. Syst. 35: 557-581.
[215] Hughes T. et al., 2005. New paradigms for supporting the resilience of marine ecosystems. Trends Ecol. Evol. 20: 380-386.
[216] CBD. 2009. Report of the first meeting of the second Ad Hoc Technical Expert Group (AHTEG) on Biodiversity and Climate Change.
[217] Munang, R. et al., 2013. Climate change and Ecosystem-based Adaptation: a new pragmatic approach to buffering climate change impacts. Current Opinion in Environmental Sustainability. 5: 1-5
[218] UNEP 2012. Making the case for Ecosystem-based Adaptation: Building resilience to climate change. UNEP Policy Brief. 11 pp.
[219] Hills, T. et al., 2011. Pacific Island Biodiversity, Ecosystems and Climate Change Adaptation: Building on nature's resilience. SPREP, Apia, Samoa.
[220] Chatenoux, B. and Wolf, A. 2013. Ecosystem-based approaches for climate change adaptation in Caribbean SIDS. UNEP/GRID-Geneva and ZMT Leibniz Center for Tropical Marine Biology. 64 pp.

critical tool for use by adaptation planners and managers to reduce the effects of climate change and provide flexible and cost-effective alternatives to more conventional approaches[221].

Vulnerability assessments are an important tool that can help to design the most effective management measures for planned adaptation as part of an EbA approach. Planned adaptation involves societal intervention to manage systems based on the knowledge that conditions will change, and where actions are undertaken to reduce any risks that may arise from that change within vulnerable systems[222][223]. Where management is focussed on ecosystem state, function or services (e.g. for coral reef ecosystems) then the use of vulnerability assessment frameworks is regarded as the most appropriate framework for management rather than resilience or robustness[224]. It is likely that the management of socio-ecological systems will increasingly base decisions on the vulnerability of essential ecosystem services[225].

EBM approaches are being developed and implemented at a number of levels (local, provincial, national, regional and global) in tropical regions with coral reefs including the Coral Triangle, the Pacific Islands, the Western Indian Ocean and the Caribbean.

The United Nations Environment Programme (UNEP) is coordinating and implementing coral reef and ecosystem-based activities at the global, regional and national level. UNEP has an active and leading role in the development, implementation and coordination of activities to support the Regional Seas programmes as mechanisms for action towards the conservation and sustainable use of coral reefs. The purpose is to provide a support framework for national and regional actions to bring pressures on coral reefs and related ecosystems to a sustainable level. These activities, at the global level, support the exchange of best practice and lessons learned between regions and, where required, develop new tools and approaches for coral reef planning and management. At the regional level, approaches, tools and methods are adapted to address regional and national needs and their adoption by regional intergovernmental mechanisms will be facilitated by providing policy guidance and other forms of support. At the national level, uptake and implementation of ecosystem-based coral reef planning and management is supported through information access, capacity building and pilot or demonstration activities implemented with local, national, and international partners.

The partnership between UNEP and Regional Seas Programmes will enable and support an ecosystem approach to management of coral reefs and surrounding coastal and marine areas, under three programmatic themes:

1. Management for resilient coral reefs and related ecosystems in the face of climate change, ocean acidification and other anthropogenic stressors;
2. Sustaining coastal ecosystem services for communities, livelihoods and businesses; and
3. Knowledge for coastal policy.

Under theme 1 the partnership will focus on enhancing resilience indicators and planning and management tools for coral reef areas. Indicators and methods will be tested in coral reef management or adaptation planning, through integration with existing ecosystem-based decision support frameworks or processes (e.g. Marine Spatial Planning, EBA-Decision Support Framework). This will

[221] Munang, R. et al., 2013. Climate change and Ecosystem-based Adaptation: a new pragmatic approach to buffering climate change impacts. Current Opinion in Environmental Sustainability. 5: 1-5.
[222] Julius, S.H. and West, J.M. 2008. (eds.). Preliminary review of adaptation options for climate-sensitive ecosystems and resources: Final report, synthesis and assessment product 4.4: U.S. Environmental Protection Agency, Report by the U.S. Climate Change Science Program (CCSP) and the Subcommittee on Global Change Research, Washington.
[223] The two other types of adaptation, reactive and maladaptive, can lead to unintended consequences that may lower resilience.
[224] Mumby, P.J. et al., 2014. Ecological resilience, robustness and vulnerability: how do these concepts benefit ecosystem management? Current Opinion in Environmental Sustainability. 7: 22-27.
[225] Daily G.C. et al. 2009. Ecosystem services in decision making: time to deliver. Front. Ecol. Environ. 7: 21-28.

be supported through the pilot application of a guiding framework report[226], which is targeted at practitioners, that has two main objectives: to illustrate and describe the actual benefit and positive impact of considering reef resilience metrics in marine spatial planning (MSP); and provide guidance and information for bringing resilience metrics into MSP in a practical, robust and reliable manner.

Emerging issues in resilience-based coral reef planning and management will also be addressed through the development of technical guidance and policy briefs on specific priority/emerging issues. Recognizing that land-based sources of pollution drive considerable reef loss and also undermine ecosystem service provision, the project will explore how the GPA[227] priority source categories (sewage, nutrients, marine litter) can be addressed, in collaboration with the GPA coordination unit at UNEP as well as global partnerships on nutrients, wastewater and marine litter.

Under theme 2 activities focus on enabling an ecosystem service approach in decision-making, including development and testing of tools for policy-oriented coral reef ecosystem service valuation, use of economic instruments for coral reef management, and collaboration with key reef based industries to reduce impact and enhance investment in coral reefs as an industry asset. This will include particular focus on how coral reef resilience can secure ecosystem service provision in the intermediate to long term and under a changing climate, and how resilience variables can strengthen design and implementation of economic instruments for reef management.

Under theme 3 UNEP will continue to strengthen coral reef state of environment and outlook reporting that supports coral reef decision-making. Regional level comprehensive data compilation and analysis will be supported to provide a foundation for regional coral reef monitoring, including defining core indicators, and development of formats for regional level reporting on coral reef status and trends. Regional networking will be supported through the Regional Seas, to facilitate the uptake and use of indicators, methods and reporting formats and improve data availability for regional and national level planning. Activities will also enhance existing mechanisms for outreach on coral reef status and trends as well as emerging issues. This will include building on the global coral reef data layer hosted by UNEP-WCMC[228] as an online coral reef atlas, with improved habitat data that increasingly integrates with status, threat and resilience information.

The Coral Triangle Initiative (CTI) is developing a region-wide early action plan for climate change adaptation (REAP-CCA) that has two main objectives to: maintain marine and coastal ecosystem structure, function, and services critical to livelihoods and food security of coastal communities, and support diversification strategies that build coastal community resilience to climate change[229]. The REAP-CCA aims to meet the fourth goal of the CTI Regional Plan of Action (RPOA) that states that identified climate change adaptation measures will be achieved. The CTI RPOA commits the six Coral Triangle (CT) nations[230] to manage marine and coastal ecosystems and resources within an EBM framework, which if implemented effectively is thought to lead to long-term outcomes of biodiversity conservation, food security, socio-ecological resilience and sustainable livelihoods[231]. Development of the REAP-CCA required the identification of the most important and immediate adaptation measures both at the regional and national level for the CT nations. Many of these proposed measures are directly related to reducing local stressors on coral reef ecosystems,

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[226] Integrating coral reef resilience metrics into marine spatial planning: A guiding framework (in prep.) UNEP, IUCN and other contributing organizations.

[227] Global Programme of Action for the Protection of the Marine Environment from Land-based Activities (http://www.gpa.unep.org/)

[228] World Conservation Monitoring Centre

[229] CTI-CFF 2011. Region-wide Early Action Plan for Climate Change Adaptation for the Nearshore Marine and Coastal Environment (REAP-CCA). Coral Triangle Initiative on Coral Reefs, Fisheries and Food Security. CTI Interim Regional Secretariat, Jakarta, Indonesia.

[230] Indonesia, Malaysia, The Philippines, Papua New Guinea, Timor Leste and the Solomon Islands

[231] Flower K.R. et al., 2013. Toward ecosystem-based coastal area and fisheries management in the Coral Triangle: Integrated strategies and guidance. Jakarta, Indonesia: CTI Support Program for the U.S. Agency for International Development. 110 pp.

particularly addressing unsustainable fishing, sedimentation and land-based sources of pollution[232]. In addition conducting vulnerability assessments of coastal ecosystems and human populations, raising awareness and building capacity in relation to climate change threats and impacts were also commonly identified adaptation measures.

EbA approaches are becoming more established in adaptation planning processes in many Pacific Island nations[233] but are not specifically directed to address impacts on coral reef ecosystems. Rather, the benefits for coral reefs are secondary services generated by the EbA measures. For example, managing mangroves for coastal protection from storm surge effects and shoreline erosion can also trap nutrients and sediments, reducing their impact on adjacent coral reefs. Similarly managing slope vegetation to reduce the risk of landslides can also decrease sedimentation effects in inshore waters. Sedimentation and land-based sources of pollution, notably nutrients, are widely regarded, along with overfishing, as the local stressors with the greatest and most widespread impact on coral reef ecosystems. Effective watershed and wastewater management is therefore critical for increasing coral reef resilience to global stressors.

Ecosystem-based approaches are also included in current regional level plans for the Pacific. The Pacific Regional Environment Programme Strategic Plan (2011-2015) includes a target that calls for examples of EbA in PICTs while another target calls for efforts to mainstream adaptation, including ecosystem-based approaches, in development plans. Implementation of EbA approaches in the Pacific is likely to be constrained by a lack of stable technical capacity in government departments to advise on EbA opportunities[234]. Successful uptake of EbA was also related to two main factors: (1) demand from decision-makers for information on the full range of EbA and non-EbA solutions, and (2) the level of access to reliable data on the relative merits of alternative options according to the local climate context. The latter is usually limited by relative expertise, early-stage planning tools and associated financial resources for analysis, design, implementation and maintenance[235].

In Australia, the Great Barrier Reef Marine Park Authority (GBRMPA) is currently implementing the Climate Change Adaption Strategy and Action Plan 2012-2017[236]. This adaptation strategy builds on a comprehensive vulnerability assessment of the Great Barrier Reef (GBR) and the first climate change action plan implemented between 2007 and 2012. The current adaptation strategy adopts the key principles of EbA[237] within its six main objectives, each with a set of specific activities (Table 5) and time-based targets. The EbA principles of community involvement, multi-sector strategy development, and communicating and educating to build capacity and raise awareness are all clearly represented in the adaptation strategy for the GBR. Other key aspects of this strategy are the strong focus on science for management and the importance of instilling a durable sense of stewardship in all reef users. The GBR strategy is provided in some detail (Table 3) as it is regarded as a best-practise example of a comprehensive coral reef adaptation strategy that can be used as a model for developing similar strategies in other coral reef nations. GBRMPA have also developed a ‘Reef Health Incident Response System,’ which includes risk and impact assessment plans for coral bleaching, coral disease and tropical cyclones including flood plumes. A key aspect of the incident response system is the use of predictive and near real-time monitoring tools to provide an early warning system that highlights

[232] CTI-CFF 2011. Region-wide Early Action Plan for Climate Change Adaptation for the Nearshore Marine and Coastal Environment (REAP-CCA). Coral Triangle Initiative on Coral Reefs, Fisheries and Food Security. CTI Interim Regional Secretariat, Jakarta, Indonesia

[233] Hills, T. et al. 2013. A social and ecological imperative for ecosystem-based adaptation to climate change in the Pacific Islands. Sustain. Sci. 8: 455-467

[234] Ibid

[235] Ibid

[236] Great Barrier Reef Marine Park Authority. 2012. Great Barrier Reef Climate Change Adaptation Strategy and Action Plan 2012-2017. GBRMPA, Townsville.

[237] Colls, A. et al., 2009. Ecosystem-based Adaptation: a natural response to climate change. Gland, Switzerland: IUCN. 16 pp.

the likelihood of a major reef health incident at least a week (cyclones) or several months (coral bleaching, temperature-dependent disease outbreaks, and flood plumes) in advance[238].

Reef management for resilience over longer timeframes is accommodated within the Program Report[239], a strategic assessment of the GBR region, which is currently a draft for public comment. This management framework explicitly addresses impacts from ocean and climate change and outlines an approach to improve protection and management of the GBR over the next 25 years. The framework contains two important policies. Firstly a cumulative impact assessment policy will develop processes to improve how cumulative impacts are assessed and considered in planning and decision-making. This will involve identifying past, present and future impacts and the temporal and spatial scales at which direct and indirect impacts should be considered, whilst also selecting tools to assess cumulative impacts including multiple stressors and their interactive effects. The second is the ‘GBR net benefit policy’, which will establish a strategic framework to guide actions and manage funds to support ecosystem health and deliver net benefits to the GBR. Within this policy priority will be given to actions that restore ecosystem health and resilience including restoration of habitats and species and enhanced ecosystem protection to control incidents or protect vulnerable habitats.

The adaptation and management strategies and actions developed by the Australian Government for the GBR represent in some ways the best available and most comprehensive approach to coral reef planning and management, where funding or technical capacity are not limiting. However, many coral reef nations do not have a similar level of financial or technical resources available for coral reef management and will have to prioritise their actions to achieve the most beneficial and cost-effective outcomes according to the most pressing issues and stressors at the sub-national and national level.

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[238] Great Barrier Reef Marine Park Authority. 2013. Reef Health Incident Response System, Second Edition. GBRMPA, Townsville.

[239] Great Barrier Reef Marine Park Authority. 2013. Great Barrier Reef Region Strategic Assessment. Program Report, Draft for public comment. GBRMPA, Townsville.

Table 5: Objectives and Activities of the GBRMPA Climate Change Adaption Strategy and Action Plan 2012-2017.

Objectives	Main and Key Activities
A. A resilient (GBR) ecosystem: Improve the capacity of reef managers to build the resilience of the GBR ecosystem	**A.1. Reduce or offset risks to species and habitats from climate change** A.1.1. Identify and monitor species and habitats vulnerable to crossing resilience thresholds A.1.2. Develop and apply systems for assessing and reducing risks from potential management interventions A.1.3. Test, evaluate and refine management interventions for building resilience of vulnerable species and habitats **A.2. Provide tools and systems to support management decisions** A.2.1. Design and implement management strategy evaluation tools and processes to prioritise adaptation actions that will reduce climate risk to the reef A.2.2. Develop decision-support tools to evaluate interacting stresses and cumulative impacts including climate change pressures A.2.3. Develop a framework to evaluate climate change risks and identify strategic responses to improve spatial planning for protection of coastal ecosystems A.2.4. Develop a system for prioritising and evaluating offset strategies relating to development activities that will result in net improvement in reef resilience
B. Adaptation of industries and communities: Support adaptation of industries and communities so that they can continue to make wise use of the ecosystem and be active partners in building resilience	**B.1. Provide adaptation resources for reef-dependent industries and communities** B.1.1. Produce a climate adaptation guide and online resource centre to support reef stewardship and management in a changing climate B.1.2. Develop and implement tools and approaches for identifying and prioritising adaptation options for reef-dependent industries and communities B.1.3. Facilitate and otherwise support adaptation initiatives by reef-dependent industries and communities that contribute to ecosystem resilience
C. Action on climate change: Encourage action that reduces the rate and extent of climate change	**C.1. Inform national and international climate policy** C.1.1. Provide strategic information that enables key decision makers (individuals, corporate leaders, policymakers) to understand and incorporate the implications of climate change for the reef into their decisions C.1.2. Improve understanding of carbon sequestration potential of GBR habitats, such as mangroves, seagrasses and salt marshes (blue carbon) C.1.3. Facilitate and promote a program to recognise carbon offset projects that contribute to reef resilience
D. Strategic science:	**D.1. Address knowledge gaps that are limiting management response to climate change** D.1.1. Update and maintain the vulnerability assessment for the GBR D.1.2. Provide information on climate change implications to support major assessments and analyses such as strategic assessments and outlook reports

Targeted science that supports management decisions and adaptation planning	D.1.3. Establish formal collaborations with leading research organisations to develop and test new approaches to adaptation for complex ecosystems such as coral reefs D.1.4. Compile detailed knowledge of climate change implications and adaptation options for priority species, habitats and industry sectors as a basis for adaptation planning **D.2. Provide knowledge to support effective management of inshore areas of the GBR** D.2.1. Develop an integrated understanding of the inshore and coastal systems, addressing flows, linkages and barriers to support integrated responses to priority threats D.2.2. Improve knowledge of strategies for building resilience of priority species, habitats, processes and regions in the inshore coastal zone D.2.3. Identify strategies for protecting coastal processes and habitats critical to the resilience of inshore areas D.2.4. Develop adaptation plans to address key vulnerabilities in the inshore coastal zone and incorporate them into regional planning frameworks
E. Effective Communication: To support the implementation of the adaptation strategy	**E.1. Improved communication** E.1.1. Understand and monitor climate change awareness, attitudes and relevant behaviours among reef stakeholders E.1.2. Develop targeted communication materials and tools to support delivery of the climate change communications plan E.1.3. Design and implement a communications plan to build understanding among community and reef-based industries about climate change implications for the GBR and management responses, including contributions of partners and stakeholders E.1.4. Build and maintain knowledge and capacity among (GBRMPA) management staff and partners to support adaptation strategy delivery E.1.5. Build and maintain an online climate change adaptation resource centre to support the knowledge needs of all partners and stakeholders contributing to the delivery of the adaptation strategy.
F. Strong Stewardship: Among individuals and groups that interact with the reef ecosystem	**F.1. Build stewardship and increase compliance** F.1.1. Build stewardship and increase involvement of GBR stakeholders in reef management through participatory reef health monitoring and reporting F.1.2. Increase opportunities and capacity for stewardship among reef communities and industries through the ‘Reef Guardians’ programme and other initiatives F.1.3. Increase compliance with policies and regulations that build climate change resilience.

The use of EbA in the Caribbean has also recently been assessed by conducting a review of the coastal ecological assets of 14 Caribbean Community (CARICOM) countries, namely of mangroves, seagrass beds and coral reefs, and their potential to adapt to climate change[240]. The study recommended that five countries were most suitable for EbA projects based on the presence and extent of coastal ecosystems, their protection status and the ability of a country to successfully implement and sustain EbA approaches according to their previous involvement in ecosystem-based management programmes. It was suggested that the success of implementing EbA approaches will depend on identifying governmental departments or organisations in each country that will actively contribute to the advancement of project goals. Setting up a regional network that is led by the more proactive countries identified in the review could facilitate the provision of information and regular reporting required by regional adaptation projects.

At the community-based level (local or provincial) ecosystem-based approaches for adaptation planning have been developed within the Coral Triangle and Pacific regions in the form of a ridge-community-reef (RCR) adaptation framework which includes EbA[241] and a Vulnerability Assessment and Local Early Action Planning (LEAP) Guide[242]. Both these assessment and planning approaches have been trialled in the Solomon Islands where the National Government endorses Community-Based Resource Management (CBRM) and supports an integrated and holistic approach to climate change adaptation at the provincial level. The LEAP Guide sets out a site-based approach in a series of steps for planned adaptation that is designed to help government departments, NGOs and other groups working with communities identify adaptation actions to reduce the vulnerability of social, economic and natural resources that communities depend upon[243]. The four main steps are outlined below (Table 6). The RCR adaptation approach follows a similar process of working closely with communities within a collaborative partnership of development partners, government agencies and NGOs to identify vulnerabilities and adaptation options at both the community and provincial level. This coordinated approach in a targeted geographic area is thought to increase the likelihood of programme success, whilst also promoting optimal use of human and financial resources, minimising duplication and overlap, building on the strengths of multiple organisations and reducing the coordination burden on provincial or national government agencies[244]. The RCR and EbA approach was also assessed in terms of the provision of ecosystem services during the priority-setting phase of the process to enable direct comparison with more conventional adaptation solutions such as the use of hard infrastructure options. If RCR and EbA approaches compare favourably with more conventional adaptation options in terms of social acceptance and cost-effectiveness then the former should be the preferred choice for adaptation implementation[245].

Table 6. The LEAP Guide Steps for Planned Adaptation

No.	Step	Description	Output
1	Getting Organised for CCA Planning:	Development and implementation of a collaborative approach between multiple sectors bringing together technical expertise	An organised CCA Planning Team with roles and responsibilities that can support community-based assessment

[240] Chatenoux, B. and Wolf, A. 2013. Ecosystem-based approaches for climate change adaptation in Caribbean SIDS. UNEP/GRID-Geneva and ZMT Leibniz Center for Tropical Marine Biology. 64 pp.
[241] Mataki, M. et al., 2013. Choiseul Province climate change vulnerability and adaptation assessment report: securing the future of Lauru now. Secretariat of the Pacific Community, German Agency for International Cooperation and the Secretariat of the Pacific Regional Environmental Programme. Suva, Fiji. 65 pp.
[242] U.S. Coral Triangle Initiative Support Program 2013. Climate Change Adaptation for Coral Triangle Communities: Guide for Vulnerability Assessment and Local Early Action Planning (LEAP Guide). A publication to support the CTI-CFF. U.S. CTI Support Program Document No. 11-USCTI-13. 90 pp. + Appendicies.
[243] Ibid
[244] Mataki, M. et al., 2013. Choiseul Province climate change vulnerability and adaptation assessment report: securing the future of Lauru now. Secretariat of the Pacific Community, German Agency for International Cooperation and the Secretariat of the Pacific Regional Environmental Programme. Suva, Fiji. 65 pp.
[245] Ibid

		and local knowledge. Guidance provided for selecting a team who can lead the community through the LEAP process	and planning
2	Telling Your Climate Story	Helping communities understand climate change and its current and future implications. Combine traditional and local knowledge with the latest scientific knowledge to understand climate impacts and identify early actions for adaptation	A 'Climate Story' that summarises past, present and potential future climate conditions and the potential impacts on important natural resources
3	Conducting a Vulnerability Assessment	Building on the 'Climate Story' communities assess the vulnerability of both social and ecological resources. Activities are designed to help the community conduct a qualitative vulnerability assessment of social, economic, ecological and infrastructural resources	A Vulnerability Assessment that helps communities understand the causes of vulnerability and enables them to identify actions that will address impacts effectively.
4	Developing Your Local Early Action Plan	Activities to help the community identify and prioritise adaptation options, considering socio-ecological and governance benefits and potential implementation challenges. Guidance provided on: • prioritizing adaptation options based on effectiveness, cost/benefit, implementation feasibility; • the development of an implementation schedule; • the development of a monitoring and evaluation approach based on a benchmarking system provided.	Combine outputs from previous steps with completed activities in step 4 to produce a 'Local Early Action Plan' or LEAP for the community

A key stressor of shallow coral reef ecosystems is the use of unsustainable fishing practises, including the over-exploitation of fish and invertebrate populations and the use of destructive fishing methods. One tool that will be critical for successful EbA implementation at the local level is the use of locally managed marine areas (LMMAs). Although no-take or no-access MPAs are widely regarded as one of the best available tools to protect coral reef biodiversity and can also enable population recovery of exploited marine species from the effects of overfishing, there is a pervasive issue of effectiveness for MPAs in many coral reef nations due to a lack of enforcement and governance. A global assessment of coral reef MPA effectiveness indicated that almost half (47%) of MPAs assessed were ineffective in reducing overfishing and that the level of ineffectiveness was higher in some of the most threatened coral reef regions (e.g. 61% of MPAs in Southeast Asia)[246]. Much of the ineffectiveness is attributed to poor top-down management of MPAs by national government agencies as a result of insufficient technical and logistical capacity and funding to implement management plans properly. This is particularly the case for many LDCs and SIDs. In addition many coral reef nations often do not have the capacity or funds to manage their traditional or small-scale fisheries effectively resulting in unregulated inshore fisheries and continued over-exploitation of living marine resources.

Locally Managed Marine Areas

[246] Burke, L., Reytar, K., Spalding, M. and Perry, A. 2011. Reefs at Risk Revisited. World Resources Institute, Washington DC, USA. 114 pp.

Locally-based management initiatives such as LMMAs are one of the most cost-effective ways to manage inshore and coastal waters in developing countries that have limited institutional capacity and logistical resources, and especially for those with extensive or remote coastlines. The use of LMMAs has increased markedly over the last two decades, initially in Pacific Island Nations[247] and Southeast Asia but also more recently in the Western Indian Ocean (WIO) [248]. In the Pacific, there are currently 12000 km^2 of coastal and inshore waters managed by more than 500 communities in 15 countries, with 1000 km^2 of this designated as no-take areas with full protection[249]. A recent assessment of the WIO region indicates that LMMA coverage is just over 11000 km^2 with significantly greater management of inshore and coastal waters within LMMAs rather than MPAs for two countries (Tanzania and Madagascar)[250]. There is considerable scope to increase the use of LMMAs in all coral reef regions. For example LMMAs are currently present in only four nations in the WIO. Evaluation of LMMA initiatives[251], mainly in the Western Pacific, has identified a range of ecological, social and economic benefits that have resulted from community-based marine management or co-management projects (Table 7).

Table 7: Summary of benefits resulting from LMMA Initiatives (after Govan et al., 2009)

Factor	Benefits
Biodiversity conservation	Localized recovery or protection of vulnerable species such as large food fish or marine turtles
Fishery landings	Experiences from within the Pacific region and the Philippines show that, depending on species, catches may be sustained or increased
Governance	Communities may improve decision-making processes, links to other organizations and institutions, influence policy development, reduce internal conflicts and improve compliance and enforcement
Community organization	Simple resource planning and facilitation processes are being used to support community endeavours in other fields. Community institutions used for management may be used for other purposes or be adapted to handle other types of projects
Resilience and adaptation	Supporting local stewardship and promoting understanding of people's potential impact on resources provides a basis for response to new threats in the context of adaptive management and helps provide local security
Health	Improving or securing the supply of marine protein has a direct impact on community well-being aside from the potential to use the same planning process for other community priorities including health
Integrated resource management	Addressing a wide range of issues such as watersheds, waste management, community events, availability of building materials and erosion control
Cultural survival	The considered use of traditional management measures and knowledge may slow the loss of valuable aspects of culture and improve management success, for example the use of, and respect for, tabu areas or other traditional closures
Improved social	Knowledge, awareness and capacity for resource management and sustainable

[247] Govan, H. et al. 2009. Status and potential of locally-managed marine areas in the South Pacific: meeting nature conservation and sustainable livelihood targets through wide-spread implementation of LMMAs. SPREP/WWF/WorldFish-Reefbase/CRISP. 95pp + 5 annexes.
[248] Rocliffe, S. et al., (in press). Towards a network of locally managed marine areas (LMMAs) in the Western Indian Ocean.
[249] Govan, H. 2009. Achieving the potential of locally managed marine areas in the South Pacific. SPC Tradit. Mar. Resour. Manag. Knowl. Inf. Bull. 25: 16–25.
[250] Rocliffe, S. et al., (in press). Towards a network of locally managed marine areas (LMMAs) in the Western Indian Ocean.
[251] Govan, H. et al. 2009. Status and potential of locally-managed marine areas in the South Pacific: meeting nature conservation and sustainable livelihood targets through wide-spread implementation of LMMAs. SPREP/WWF/WorldFish-Reefbase/CRISP. 95pp + 5 annexes

and human capital	development in general may be increased as well as governance and other linkages;
Security of tenure	Community based management may be seen as a means of re-asserting traditional rights of ownership and access to resources which are vital to the livelihoods (and identity) of many coastal communities (e.g. on Pacific Islands) who perceive that these are being eroded.

A critical factor for the increase in the number and spatial coverage of LMMAs at the national or regional level has been the development of LMMA networks. The existing regional LMMA network supports 600 communities within eight countries in the Asia-Pacific region[252] although there have been calls for the setting up of a similar network in the Western Indian Ocean[253]. LMMA designation can be facilitated through the development and use of clear, well-designed communication and awareness raising resources that provides practical information on the need for management and on how to set up and manage locally managed areas. A recent example is a booklet produced by the Coral Triangle Initiative to help communities design individual or networks of LMMAs, or improve the effectiveness of existing managed areas[254]. This booklet is an abbreviated version of a companion facilitator's guide[255].

Marine Protected Areas

Although locally managed marine areas are likely to be a key tool in the future management of coral reefs in many countries there is still a great need for effective, well-designed MPA systems to protect biodiversity and the essential ecosystem services it supports. Decreases in species richness and abundance can threaten ecosystem services and reduce overall ecosystem stability and resilience[256]. In addition even ineffective sites offer a basis on which future, more effective management can be built[257]. MPAs can directly affect two main stressors – overfishing and nutrient and sediment pollution if they include a terrestrial component[258]. Existing healthy, resistant and resilient reefs need to be protected as no-take MPAs that have adaptive management arrangements to minimise local stressors such as unsustainable fishing and gleaning, but also land-based threats including pollution and sedimentation. These reefs are especially important as they serve as critical reference points as well as sources of recovery for surrounding areas. Effective MPAs are able to maintain or build resilient reef communities that can recover more quickly than non-protected sites from a variety of threats, including diseases and coral bleaching[259][260][261][262]. However, existing MPAs are not able to prevent the impact of global stressors on coral reef ecosystems such as warm temperature anomalies

[252] http://www.lmmanetwork.org/home
[253] Rocliffe, S. et al., (in press). Towards a network of locally managed marine areas (LMMAs) in the Western Indian Ocean.
[254] Gombos, M. et al., (Eds.) 2013. Designing effective locally managed areas in tropical marine environments: A booklet to help sustain community benefits through management of fisheries, ecosystems, and climate change. Jakarta, Indonesia. USAID Coral Triangle Support Partnership.
[255] Gombos, M. et al., (Eds.) 2013. Designing effective locally managed areas in tropical marine environments: A facilitator's guide to help sustain community benefits through management of fisheries, ecosystems, and climate change. Jakarta, Indonesia. USAID Coral Triangle Support Partnership
[256] Worm, B. et al., 2006. Impacts of biodiversity loss on ocean ecosystem services. Science 314: 787-790.
[257] Burke, L., Reytar, K., Spalding, M. and Perry, A. 2011. Reefs at Risk Revisited. World Resources Institute, Washington DC, USA. 114 pp.
[258] Selig, E.R. et al., 2012. Temperature-driven coral decline: the role of marine protected areas. Global Change Biology. doi: 10.1111/j.1365-2846.2012.02658x
[259] Mumby, P.J. and Harborne, A.R. 2010. Marine reserves enhance the recovery of corals on Caribbean reefs. PLoS ONE 5: e8657.
[260] Raymundo, L.J. et al., 2009. Functionally diverse reef-fish communities ameliorate coral disease. Proceedings of the National Academy of Sciences 106: 17067-17070.
[261] Grimsditch, G.D. and Salm, R.V. 2006. Coral reef resilience and resistance to bleaching. IUCN, Gland, Switzerland.
[262] Selig, E.R. and Bruno, J.F. 2010. A global analysis of the effectiveness of marine protected areas in preventing coral loss. PLoS ONE 5: e9278

and ocean acidification. A global analysis of thermal stress on corals in protected and unprotected reefs over a 20-year period (1985-2005) indicated that protection in MPAs did not reduce the rate of temperature driven coral loss[263]. The lack of an MPA effect was partly attributed to poor MPA design in that many protected areas were too small or in the wrong location to maximise resilience to warming incidents. MPAs can increase resilience to acute thermal stress if they are larger than areal extent of anomaly event in that there would be unaffected coral populations within the protected area[264]. In addition, field studies have shown that previous exposure to moderate levels of temperature variability can result in less future coral mortality[265266]. Locating MPAs in areas with a history of moderate temperature variability may therefore increase the efficacy of MPAs in mitigating coral decline[267]. A further issue in the aforementioned global study was that management at many of the protected sites may have been ineffective in preventing local stressors and these sites were therefore not actually more resilient than unprotected ones. It has been suggested that MPA measures proposed for managing reefs in the context of warming seas may also provide better conditions for corals to survive the early stages of ocean acidification[268]. Management actions that promote diversity, such as MPAs, may also in theory promote resilience to acidification-related species loss[269].

There have also been recent calls to protect mesophotic warm water coral reefs, which mainly occur between depths of 30 and 150 metres[270]. These reefs can cover large areal extents, are often unexplored, but are increasingly being assessed and mapped. For example mesophotic reefs and banks for the Great Barrier Reef are thought to represent 20 000 km2 of reef habitat, equivalent to all of the GBR's shallow reefs[271]. Many coral reef species have distributions that extend into from shallow waters to the upper mesophotic zone. Almost half of all Caribbean coral species occur down to 50-70 metres or more[272]. These reefs contain important biodiversity and are potential refugia, nursery habitats and sources or sinks for shallow water reef taxa[273]. Mesophotic reefs are less susceptible to bleaching as temperature and irradiance decrease with increasing depth. The influence of other stressors such as coral disease, storms, pollution, sedimentation and overfishing is also generally reduced for these deeper reef that are often located further from the coast[274]. However, the over-exploitation of marine resources in shallow waters often leads to a shift of fishing effort into deeper habitats. Pressure to over-exploit mesophotic reefs is also likely to grow as shallow reefs become more degraded through the impact of global and local stressors. Proactive management is therefore required to protect mesophotic reefs from potential future impacts, especially those from destructive practices.

Effective MPA networks are also critically important. These networks should include representation of all reef zones and habitats, to a reasonable extent whilst also protecting critical areas such as fish

[263] Selig, E.R. et al., 2012. Temperature-driven coral decline: the role of marine protected areas. Global Change Biology. doi: 10.1111/j.1365-2846.2012.02658x
[264] Ibid.
[265] McClanahan, T.R., et al., 2007. Effects of climate and seawater temperature variation on coral bleaching and mortality. Ecol. Monogr. 77: 503-525
[266] Ateweberhan, M. and McClanahan, T.R. 2010. Relationship between historical sea surface temperature variability and climate-induced coral mortality in the Western Indian Ocean. Mar. Poll. Bull. 60: 964-970.
[267] Selig, E.R. et al., 2012. Temperature-driven coral decline: the role of marine protected areas. Global Change Biology. doi: 10.1111/j.1365-2846.2012.02658x
[268] Burke, L., Reytar, K., Spalding, M. and Perry, A. 2011. Reefs at Risk Revisited. World Resources Institute, Washington DC, USA. 114 pp
[269] McLeod, E. et al., 2009. Designing marine protected area networks to address the impacts of climate change. Front. Ecol. Environ. 7: 362-370.
[270] Bridge, T.C.L. et al., 2013. Call to protect all coral reefs. Nature Climate Change 3: 528-530.
[271] Harris, P.T. et al., 2013. Submerged banks in the Great Barrier Reef, Australia, greatly increase available coral reef habitat. ICES Journal of Marine Science 70: 284-293.
[272] Bridge, T.C.L. et al., 2013. Call to protect all coral reefs. Nature Climate Change 3: 528-530.
[273] Slattery, M. and Lesser, M.P. 2012. Mesophotic coral reefs: a global model of community structure and function. Proceedings of the 12th International Coral Reef symposium, Cairns, Australia. 9C Ecology of mesophotic coral reefs.
[274] Slattery, M. et al., 2011. Connectivity and stability of mesophotic coral reefs. J. Exp. Mar. Biol. Ecol. 408: 32-41

spawning or nursery grounds and bleaching resistant areas[275]. Mesophotic reefs are currently under-represented in MPA networks and should be considered for incorporation into existing and new networks[276]. The use of well-designed, extensive and functionally connected networks of MPAs that are larger in spatial coverage than the temperature anomaly event may also ensure that some coral populations escape thermal stress. Designs of MPA network connectivity should also consider the effects of global stressors on the physiology of coral reef fauna at crucial life history stages. As mentioned previously (Section 1) global stressors have been shown to have detrimental thermal- and pH-induced effects on the planktonic larvae of reef fish and invertebrates which may decrease the duration of the larval phase and reduce recruitment success. This requires further investigation but should be considered when designing MPA networks in order to ensure larval supply between protected areas is maintained. A recent guide for MPA network design in tropical ecosystems provides fifteen design principles for integrating fisheries, biodiversity and climate change objectives into MPA networks[277]. The principles each contribute to five broad categories that are linked to resilient MPA network design: risk spreading, protecting critical areas, incorporating connectivity, threat reduction and sustainable use.

Consideration of the impacts of terrestrial activities, including protected area establishment, is important for the protection of marine biodiversity[278]. Ideally, to maximise coral reef resilience and biodiversity benefits, MPAs should be part of integrated land-sea planning and management approaches[279][280] which includes the coastal zone and watersheds to control coastal development, land use and pollution levels, particularly from wastewater treatment and agricultural runoff. However, there are very few practical examples of integrated land-sea planning on the ground[281] although conservation planning tools such as MARXAN are being used to produce a range of integrated planning options in some countries[282]. Management needs to be scaled up considerably over the next two decades to increase the spatial coverage of appropriately managed terrestrial and marine areas and either set strict ('reef-friendly') standards for water quality in the inshore zone, or enforce existing acceptable standards.

Fisheries Management

Overfishing and destructive fishing were recently ranked as the greatest local stressor for coral reefs globally[283]. Ecosystem-based management and adaptation approaches for coral reefs need to consider the sustainable management of fisheries outside of spatially managed areas (LMMAs and MPAs). This is especially required for small-scale fisheries targeting particular taxa or species for export markets such as sharks and rays for fins, holothurians, and other invertebrates including cephalopods, lobsters and gastropod molluscs. These targeted taxa can be important sources of livelihood for coastal communities but are in danger of fishery collapse in many tropical countries. Coral reef fisheries management is lacking or poor in many countries and these complex multi-species fisheries

[275] Burke, L., Reytar, K., Spalding, M. and Perry, A. 2011. Reefs at Risk Revisited. World Resources Institute, Washington DC, USA. 114 pp

[276] Bridge, T.C.L. et al., 2013. Call to protect all coral reefs. Nature Climate Change 3: 528-530.

[277] Green, A., White, A., Kilarski, S. (Eds.). 2013. Designing marine protected area networks to achieve fisheries, biodiversity, and climate change objectives in tropical ecosystems: a practitioners guide. The Nature Conservancy, and the USAID Coral Triangle Support Partnership, Cebu City, Philippines. 35 pp. + viii.

[278] Klein, C.J. et al., 2014. Evaluating the influence of candidate terrestrial protected areas on coral reef condition in Fiji. Marine Policy 44: 360-365.

[279] Richmond, R.H. et al., 2007. Watersheds and coral reefs: Conservation science, policy, and implementation. Bioscience 57: 598-607.

[280] Alvarez-Romero, J.G. et al., 2011. Integrated land-sea conservation planning: the missing links. Ann. Rev. Ecol. Evol. Syst. 42: 381-409.

[281] Game, E.T. et al., 2011. Informed opportunism for conservation planning in the Solomon Islands. Conserv. Lett. 4: 38-46.

[282] Klein, C.J. et al., 2014. Evaluating the influence of candidate terrestrial protected areas on coral reef condition in Fiji. Marine Policy 44: 360-365.

[283] Burke, L., Reytar, K., Spalding, M. and Perry, A. 2011. Reefs at Risk Revisited. World Resources Institute, Washington DC, USA. 114 pp.

are regarded as the most difficult to manage[284]. The management of herbivorous fish populations is particularly important on coral reefs as these grazers are key functional species that maintain essential ecosystem processes, and in combination with the management of nutrient pollution, can reduce the likelihood of a phase shift to algal-dominated ecosystems[285]. Ecosystem-based fisheries management (EBFM) is an important subset of overall ecosystem based management approaches (EBM / EbA) as it considers the impact fisheries have on all components of the broader marine environment, as well as the impact of other marine and coastal activities on fisheries[286]. EBFM applies an integrated approach to fisheries management within ecologically meaningful boundaries. Increasing coral reef resilience to climate-induced stressors requires effective fisheries management[287]. The integration of EBFM into existing fisheries management structures at the national and sub-national level for coral reef regions should be regarded as a priority. It will also be important to consider the drivers behind unsustainable fishing practises if EBFM is to be achieved.

Marine Spatial Planning

Marine Spatial Planning (MSP) is regarded as a key management strategy for the successful implementation of ecosystem-based approaches in the marine environment. MSP is a planning process for managing human activities that enables integrated, forward looking, and consistent decision-making on the use of the sea[288]. It is being increasingly used to develop marine zoning and allocation plans for both the protection of biodiversity[289] and the sustainable use of multiple marine resources[290] and can be applied over a wide range of spatial scales. MSP allows planners and managers to integrate information about ecosystem features, how human use affects them, and how they are connected to other ecosystems[291]. The take up of MSP internationally has been relatively slow[292] despite the availability of well-described methods[293][294][295] and an increasing range of tools to facilitate implementation[296]. MSP tools can be selected to suit a range of contexts including the use of participatory planning as part of community-based marine management at the low-tech end, to high-tech decision support tools such as MARXAN and GIS based multicriteria decision analysis[297] (GIS-MCDA).

For coral reef regions the rezoning of the Great Barrier Reef provides a best practise example of the use of MSP to develop and implement an ecosystem-based management framework for a large-scale

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[284] Fenner, D. 2012. Challenges for managing fisheries on diverse coral reefs. Diversity 4: 105-160.
[285] Mumby, P.J. et al., 2007. Thresholds and the resilience of Caribbean coral reefs. Nature 450: 98-102.
[286] Agardy, T. et al. 2011. Taking steps toward marine and coastal ecosystem-based management – An introductory guide. UNEP Regional Seas Reports and Studies No. 189. UNEP, Nairobi
[287] Mumby, P.J. and Steneck, R.S. 2008. Coral reef management and conservation in light of rapidly evolving ecological paradigms. Trends in Ecology and Evolution. doi: 10.1016/j.tree.2008.06.011
[288] Ehler, C. and Douvere, F. 2007. Visions for a Sea Change. Report of the First International Workshop on Marine Spatial Planning. Intergovernmental Oceanographic Commission and Man and Biosphere Programme. IOC Manual and Guides No. 48, IOCAM Dossier No. 4 UNESCO, Paris, p. 13.
[289] Fernandes, L. et al., 2005. Establishing representative no-take areas in the Great Barrier Reef: large-scale implementation of theory on marine protected areas. Conserv. Biol. 19: 1733-1744.
[290] Agostini, V.N. et al., 2010. Marine zoning in Saint Kitts and Nevis: A path towards sustainable management of marine resources. The Nature Conservancy.
[291] Agardy, T. et al. 2011. Taking steps toward marine and coastal ecosystem-based management – An introductory guide. UNEP Regional Seas Reports and Studies No. 189. UNEP, Nairobi.
[292] Alvarez-Romero, J.G. et al., 2013. Marine conservation planning in practise: lessons learned from the Gulf of California. Aquat. Conserv. Mar. Freshwater Ecosyst. 23: 483-505.
[293] Ehler, C. and Douvere, F. 2009. Marine Spatial Planning: A step-by-step approach toward ecosystem-based management. Intergovernmental Oceanographic Commission and Man and Biosphere Programme. IOC Manual and Guides No. 53, IOCAM Dossier No. 6. UNESCO, Paris.
[294] Gilliland, P.M. and Laffoley, D. 2008. Key elements and steps in the process of developing ecosystem based marine spatial planning. Mar. Policy 32: 787-796. The Role of Marine Spatial Planning in Implementing Ecosystem-based, Sea Use Management.
[295] Malczewski, J. 1999. GIS and Multicriteria Decision Analysis. John Wiley and Sons, Inc., Toronto.
[296] Ecosystem-Based Management Tools Network (EBM). 2010. Tools for marine spatial planning. Available at: http://www.ebmtools.org/msptools.html.
[297] Malczewski, J. 1999. GIS and Multicriteria Decision Analysis. John Wiley and Sons, Inc., Toronto.

reef system. The challenge is how to achieve effective, ecosystem-based MSP in the absence of such an 'iconic' socio-ecological system as the GBR[298]. MSP has recently been used in Kenya to address existing and potential user conflicts in the coastal zone and to facilitate the integration of divergent objectives into a decision-making framework[299]. This example and other MSP initiatives[300] have emphasised the critical importance of stakeholder participation in different stages of the MSP process as part of a strategy of effective engagement and communication with all stakeholders. This is especially important for marine and coastal resource users that depend on the marine environment for their livelihood, which is the case in many countries that contain coral reefs. It is also important to recognise that the MSP process can take some time to complete given the need for full stakeholder consultation and transparency. For example, re-zoning the GBR to increase no-take area coverage required extensive and intensive consultation over more than six years[301]. However, the length MSP process is likely to be related to the size of the area proposed for management, and the number of ecosystems and stakeholder groups present.

One of the stages of the planning process for MSP that is particularly relevant to the potential future impact of stressors on coral reef ecosystems is the 'defining and analysing future conditions'. This has been used to assess how future management actions will affect spatial conflicts[302] but could also be used to help define future resource use of coral reefs and associated ecosystems according to predicted changes in ecosystem status. For example the decreasing productivity of coral reefs may cause coastal fishers to switch their attention to mangroves and seagrass beds resulting in increased fishing pressure and potential conflict with existing users of these ecosystems. MSP combined with ecosystem modelling may provide a means of managing possible future issues according to a range of scenarios that manipulate stress levels on ecosystems caused by combinations of local and global stressors. The use of anticipatory planning and zoning to protect coral reef biodiversity from future impacts should be considered. Anticipatory planning is already occurring to protect marine biodiversity in some regions such as the Arctic and is regarded as an increasingly important governance tool in the face of climate change[303].

As mentioned previously, for coral reefs it is important to address land-based sources of stress as well as those in the marine environment. It would therefore be useful to consider terrestrial spatial planning for the coastal zone and catchment areas as well as MSP when setting up ecosystem-based management and adaptation plans that involve coral reef ecosystems.

Watershed Management

Runoff, sedimentation and land-based sources of pollution within adjacent watersheds are one of the greatest threats to coastal coral reefs surrounding high islands and along continental margins[304]. Effective watershed management to reduce the direct stressors of sedimentation and pollution is a key requirement in an integrated approach to improving the health and resilience of coral reefs and closely associated ecosystems. As well as addressing pollution from land use activities such as agriculture it is important to minimise sewage and wastewater pollution from rural and urban areas adjacent to coral

[298] Merrie, A. and Olsson, P. 2014. An innovation and agency perspective on the emergence and spread of Marine Spatial Planning. Marine Policy 44: 366-374.
[299] Tuda, A.O. et al., 2014. Resolving coastal conflicts using marine spatial planning. Journal of Environmental Management 133: 59-68.
[300] Gopnik, M. et al., 2012. Coming to the table: early stakeholder engagement in marine spatial planning. Mar. Policy 36: 1139-1149.
[301] Day, J. et al. 2003. RAP – an ecosystem level approach to biodiversity protection planning. In: Proceedings of the Second International Tropical Marine Ecosystems Management Symposium. GBRMPA, Townsville, Australia, pp. 251-265.
[302] Tuda, A.O. et al., 2014. Resolving coastal conflicts using marine spatial planning. Journal of Environmental Management 133: 59-68
[303] Craig, R. K. 2012. Marine Biodiversity, Climate Change, and Governance of the Oceans. Diversity 4: 224-238.
[304] Richmond, R.H. et al., 2007. Watersheds and coral reefs: Conservation science, policy, and implementation. Bioscience 57: 598-607.

reefs. Impacts on coral reefs from poorly treated wastewater are a cause for concern in a number of countries.

One of the most comprehensive programmes to manage watersheds adjacent to coral reefs is being undertaken for the Great Barrier Reef in Australia through collaborative efforts of government institutions and local universities. The 'Reef Plan' [305] was released by the national and state governments in 2003 with the overall aim to halt and reverse the decline in water quality entering the GBR within 10 years, strictly focussing on diffuse pollution from agriculture. The two main objectives of the plan were to: (1) reduce the load of pollutants from diffuse sources in the water entering the reef, and (2) rehabilitate and conserve areas of the reef catchment that have a role in removing water-borne pollutants. The plan was revised and updated in 2009 with better-defined targets and actions. In addition Reef Plan 2009 aimed to ensure that by 2020, the quality of water entering the GBR has no detrimental impact on the health and resilience of the GBR. The 2009 plan sets reduction targets for nitrogen, phosphorus and sediment loads and pesticide use plus a minimum level of groundcover on grazing land[306]. Active management across the whole catchment to reef continuum started in 2007 with incentive-based voluntary management initiatives (Reef Rescue) to improve water quality by increasing the adoption of a range of land management practises that reduce the run-off of nutrients, pesticides and sediments from agricultural land. A state regulatory approach[307] (Reef Protection Package) was introduced in 2009 and implemented in 2010-2011. The effectiveness of the 'Reef Plan' is being assessed by an integrated monitoring, assessment and reporting programme (Paddock to Reef Monitoring, Modelling and Reporting Programme 2008) that commenced in 2009, with the first report card released in 2011[308]. The considerable management interventions undertaken since 2007 have improved watershed management and agricultural practises for the GBR catchment areas, but measurable improvements in river and coastal water quality or ecosystem health may not be detected for up to several decades[309].

Collaborative watershed management at a more local level has been demonstrated in Micronesia where scientific research has informed traditional integrated 'ridge to reef' stewardship approaches that often consider legacy issues over the long-term[310]. Linkages between watersheds and adjacent coral reefs were studied on three Micronesian islands (Palau, Guam and Pohnpei) to identify the biological and physical parameters affecting coral reefs and the social aspects of policy development and implementation within the local communities, who were directly involved in the project design, the study and the application of research results[311]. In each case, local communities took ownership of and responsibility for the identified problems and alternative solutions. Local leaders were provided with clear analyses of the information collected by the researchers and then made their decisions within their own cultural context. In the case of Palau and Pohnpei, decisions by traditional leaders had the weight of legislation and could be implemented much more quickly than laws in more developed nations, with high compliance by community members in tradition-based island social systems. The success of the projects was attributed to an effective collaboration between researchers, community-based organisations and local leaders where traditional leadership and ownership of resources was still strong.

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[305] Queensland Department of the Premier and Cabinet, 2003. Reef Water Quality Protection Plan; for catchments adjacent to the Great Barrier Reef World Heritage Area. Queensland Department of the Premier and Cabinet, Brisbane.
[306] Brodie, J.E. et al., 2012. Terrestrial pollutant runoff to the Great Barrier Reef: An update of issues, priorities and management responses. Marine Pollution Bulletin 65: 81-100.
[307] Great Barrier Reef Protection Amendment Act 2009. Queensland Government.
[308] Carroll, C. et al., 2012. A paddock to reef monitoring and modelling framework for the Great Barrier Reef: paddock and catchment component. Marine Pollution Bulletin 65: 136-149.
[309] Darnell, R. et al., 2012. Statistical power of detecting trends in total suspended sediment loads to the Great Barrier Reef. Marine Pollution Bulletin 65: 203-209.
[310] Richmond, R.H. et al., 2007. Watersheds and coral reefs: Conservation science, policy, and implementation. Bioscience 57: 598-607.
[311] Ibid.

For social situations where traditional resource management systems are lacking or have declined a sense of local stewardship can be rebuilt through community-based initiatives facilitated by local government or non-governmental organisations that consider both land- and marine-based issues and solutions to reduce local stressors within an integrated ecosystem-based management approach. Examples are the locally managed marine area or integrated coastal management initiatives in different coral reef regions, although an increase in the remit of these local management approaches may be needed to fully integrate watershed linkages in some cases.

The scale and cost of managing watersheds can be rather daunting and impracticable for countries with limited resources. However, a strategic approach to identify and manage watershed 'hotspots' can be more cost-effective. Research in Hawaii has indicated that less than 5% of the land in a watershed produced most of the sediment, and only 1% was responsible for roughly half of the sediment[312]. It may therefore be possible to reduce sediment stress on reefs by focussing on these hotspots rather than restore entire watersheds[313]. Removal of vegetation by grazing can be a key factor. Studies in Australia indicate that a minimum level of groundcover of 75% is required to reduce erosion from a particular watershed[314].

Active Coral Reef Restoration and Rehabilitation

Active restoration of coral reefs through the use of *in* situ coral nurseries and transplantation has been suggested as a major conceptual and practical approach for restoring degraded reefs[315] given the continued and projected decline of coral reefs globally. However, it should be noted that there is still some debate whether artificial reefs and coral transplantation can be regarded as a practical and cost-effective activity for coral reef management [316] [317], although there have been considerable improvements in cost-effectiveness and transplant survival in recent years[318]. For example, the active restoration approach known as the 'gardening concept' involves rearing coral fragments in mid-water floating nurseries and then transplanting the farmed coral colonies onto degraded reef sites. This technique has been in development for almost two decades and tested in various coral reef regions including the Caribbean, Red Sea and parts of the Indo-Pacific[319]. Research has mainly concentrated on the nursery phase to improve nursery design, and the growth and survival of farmed corals to date. Mid-water floating nurseries have successfully reared 86 species of hard coral of various life forms (e.g. branching, massive or encrusting). The nurseries also recruit commensal and coral inhabiting species onto corals and can become 'larval dispersion hubs' if coral colonies become sexually mature *in situ*, which could have the potential to be developed into a management tool for enhancing larval supply[320] or for improving connectivity between distant coral populations. However, given the high natural mortality in the larval dispersal phase of many coral species it is not currently known whether larval dispersion hubs are capable of enhancing recruitment of juvenile corals. Coral nurseries could also be used as sanctuaries and propagation centres for endangered coral species. A range of methodologies have been tested for the transplantation phase and further research is required to

[312] Stock, J.D. et al., 2010. Sediment budget for a polluted Hawaiian reef using hillslope monitoring and process mapping. Abstract EP22A-01. 2010 Fall Meeting; AGU, San Francisco, CA, December 2010.
[313] Risk, M.J. 2014. Assessing the effects of sediments and nutrients on coral reefs. Curr. Opinion Environ. Sust. 7: 108-117.
[314] Bartley, R. et al., 2014. Relating sediment impacts on coral reefs to watershed sources, processes and management: a review. Sci. Tot. Environ. 468-469: 1138-1153.
[315] Rinkevich, B. 2008. Management of coral reefs: we have gone wrong when neglecting active reef restoration. Mar. Poll. Bull. 56: 1821-1824.
[316] ICRI Resolution on Artificial Coral Reef Restoration and Rehabilitation. 2005. http://www.icriforum.org/sites/default/files/ICRI_resolution_Restoration.pdf
[317] Mumby, P.J. and Steneck, R.S. 2008. Coral reef management and conservation in light of rapidly evolving ecological paradigms. Trends in Ecology and Evolution. doi: 10.1016/j.tree.2008.06.011
[318] Edwards, A.J. (ed.) 2010. Reef Rehabilitation Manual. Coral Reef targeted Research and Capacity Building for Management Program. St Lucia, Australia. ii + 166 pp.
[319] Rinkevich, B. 2014. Rebuilding coral reefs: does active reef restoration lead to sustainable reefs? Current Opinion in Environmental Sustainability. 7: 28-36
[320] Edwards, A.J. (ed.) 2010. Reef Rehabilitation Manual. Coral Reef targeted Research and Capacity Building for Management Program. St Lucia, Australia. ii + 166 pp (Chapter 4).

improve the success of the technique in terms of the survival of colonies and their ability to reproduce[321].

The 'gardening concept' has been suggested as a useful adaptive tool to combat climate change impacts in that restoration efforts should be more forward looking and select coral species or genotypes that are more tolerant of the anticipated environmental conditions according to climate and ocean changes[322]. This could lead to the formation of novel coral reef communities that are more robust to global stressors. There is also scope to combine restoration techniques such as the 'gardening concept' with the emerging research field of conservation physiology and the use of gene expression, particularly transcriptomics (quantifying changes in the cellular mRNA pool)[323]. Selection of corals with genotypes that are better adapted to future environmental conditions for growth in coral nurseries and subsequent transplantation or larval dispersal, could potentially help to develop reefs that are more resilient to global stressors. This is particularly relevant, as reef-building corals do not have the evolutionary capacity to acclimatise or adapt to the current rapid rate of climate change[324][325]. *In situ* coral farming or breeding protocols could be used to amplify genetic variation[326] and the proportion of more resilient genotypes in coral populations.

Any efforts to actively restore coral reefs need to go hand in hand with more conventional passive restoration activities to reduce or eliminate local stressors, otherwise any grown and transplanted colonies will be subject to the same local impacts and have less chance of surviving in the new locality. At sites where there is significant human impact, management for passive restoration needs to be in place before any attempt at active restoration is made[327]. If not then active interventions have a high risk of failure and will be a waste of resources. Passive restoration is usually the preferred and more cost-effective option for reef management rather than active techniques. Moreover, restoration[328] or rehabilitation [329] are long-term (decadal) processes to reverse reef decline while coral transplantation is an activity and one tool of a range of management measures available to improve reef health[330]. Detailed guidance on reef restoration and rehabilitation techniques involving coral nurseries, larval rearing and coral transplantation are available in a comprehensive reef rehabilitation manual[331].

Valuation of Ecosystem Services to support EbA

The case for incorporating an ecosystem-based approach to tropical coastal management and adaptation into adaptation planning frameworks can be supported by conducting ecosystem services valuation assessments to compare the cost effectiveness of a range of adaptation approaches. For example, a cost-benefit assessment of adaptation options for Lami Town in Fiji primarily to prevent

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[321] Ibid.

[322] Rinkevich, B. 2014. Rebuilding coral reefs: does active reef restoration lead to sustainable reefs? Current Opinion in Environmental Sustainability. 7: 28-36

[323] Evans, T.G. and Hoffman, G.E. 2012. Defining the limits of physiological plasticity: how gene expression can assess and predict the consequences of ocean change. Phil. Trans. R. Soc. B. 367. doi: 10.1098/rstb.2012.0019

[324] Hoegh-Guldberg, O. 2014. Coral reef sustainability through adaptation: glimmer of hope or persistent mirage? Current Opinion in Environmental Sustainability. 7: 127-133.

[325] Howells, E.J. et al., 2013. Historical thermal regimes define limits to coral acclimatization. Ecology 94: 1078-1088.

[326] Rinkevich, B. 2014. Rebuilding coral reefs: does active reef restoration lead to sustainable reefs? Current Opinion in Environmental Sustainability. 7: 28-36

[327] Edwards, A.J. (ed.) 2010. Reef Rehabilitation Manual. Coral Reef targeted Research and Capacity Building for Management Program. St Lucia, Australia. ii + 166 pp

[328] The act of bringing a degraded ecosystem back into, as nearly as possible, its original condition.

[329] The act of partially, or more rarely, fully replacing structural or functional characteristics of an ecosystem that have been diminished or lost, or the substitution of alternative qualities or characteristics than those originally present with the proviso that they have more social, economic or ecological value than existed in the disturbed or degraded state.

[330] Edwards, A.J. (ed.) 2010. Reef Rehabilitation Manual. Coral Reef targeted Research and Capacity Building for Management Program. St Lucia, Australia. ii + 166 pp.

[331] Ibid.

storm damage recommended that the integrated adaptation plan should focus on ecosystem-based options to protect and maintain coastal ecosystems (coral reefs, mangroves, seagrass beds, mud flats) whilst also including targeted engineering options such as sea walls to protect highly vulnerable built up areas[332]. Although the EbA solutions offered the highest benefit-to-cost ratios compared to engineering options the latter was assumed to provide the greatest avoidance of damage. However if an EbA option could be shown to provide a similar level of protection from damage as hard options then this would clearly make it the preferred option in terms of costs and benefits[333]. The benefits from the EbA option were also underestimated as not all of the ecosystem services provided could be quantified in this case.

Protecting and restoring mangrove ecosystems has particularly been shown to be a cost-effective adaptation solution with environmental and social benefits[334]. Cost-benefit analyses of mangrove restoration projects indicates that rehabilitation can provide net economic benefit even when only considering the direct use of products by local communities, with substantial additional value from shoreline protection[335]. In Vietnam the cost of planting 12000 hectares of mangroves was $1.1 million but was estimated to save $7.3 million annually in dyke maintenance[336]. In atoll-based nations such as the Maldives coral reefs provide an essential ecosystem service as a protective physical barrier against storms and erosion. If coral reefs were lost, the cost of replacing their coastal protective function by engineering solutions has been estimated to be $1.6-2.7 billion[337]. Conversely, an EbA option of preventing local stressors such as coral mining and overfishing through the establishment of MPAs was estimated to cost S34 million to set up and $47 million to maintain annually whilst potentially generating $10 billion per year in co-benefits in terms of tourism and sustainable fisheries[338].

On a more general note, greater economic valuation of climate-induced and local impacts on coral reef ecosystem goods and services can demonstrate the importance of healthy and resilient reefs for livelihoods, food security and coastal protection to a range of audiences (local communities, managers, and decision and policy makers). Although economic valuation methods and tools that can be used for tropical coastlines are well established, valuations do require considerable cost and effort to complete. Providing technical support for developing coral reef nations, especially SIDS and LDCs, to fully evaluate the goods and services provided by coral reefs and associated ecosystems (mangroves and seagrass beds) could help to support public and political momentum for policy action at multiple levels and facilitate the procurement of external funding and investment for coral reef and coastal management initiatives.

It is clear that any ecosystem-based approach to manage coral reefs needs to tackle key direct stressors such as overfishing and land-based sources of pollution using a suite of management strategies for fisheries and watersheds and a range of tools, including protected and managed areas, and spatial planning approaches. Of particular importance is the management of reef herbivore populations and nutrient pollution to strengthen ecosystem resilience against global stressors,

[332] Rao, N.S. et al., 2013. An economic analysis of ecosystem-based adaptation and engineering options for climate change adaptation in Lami Town, Republic of the Fiji Islands. A technical report by the Secretariat of the Pacific Regional Environmental Programme. Apia, Samoa. 62 pp.

[333] Ibid

[334] UNEP 2012. Making the case for Ecosystem-based Adaptation: Building resilience to climate change. UNEP Policy Brief. 11 pp.

[335] Badola, R. and Hussain, S.A. 2005. Valuing ecosystem functions: an empirical study on the storm protection function of Bhitarkanika mangrove ecosystem, India. Environmental Conservation 32: 85-92.

[336] Reid, H. and Huq, S. 2005. Climate change – biodiversity and livelihood impacts. Tropical forests and adaptation to climate change: in search of synergies. Adaptation to climate change, sustainable livelihoods and biological diversity, Turrialba, Costa Rica, March 2004. p. 57-70.

[337] Moberg, F. and Ronnback, P. 2003. Ecosystem services of the tropical seascape: interactions, substitutions and restoration. Ocean Coast. Manage. 2003. 46: 27-46.

[338] Emerton, L. et al., 2009. Valuing Biodiversity: The economic case for biodiversity conservation in the Maldives (AEC Project), Ministry of Housing. Maldives: Transport and Environment, Government of Maldives and UNDP.

especially ocean acidification[339][340]. There is a need to further develop EbA tools and indicators for use in coral reef regions, particularly for vulnerability assessments, and incorporate EbA principles and practises into the various types of management currently operating for coral reefs and associated ecosystems (i.e. community-based, co-management, top-down management). Greater understanding of the potential of EbA approaches is required by coastal communities, and local, provincial and national government departments, especially regarding cost-effectiveness. Non-governmental organisations can play an important role in increasing the awareness and understanding of EbA, and facilitating communication and collaboration between stakeholders and management bodies as part of a ridge to reef approach. The integration of ecosystem-based approaches for management and adaptation into development planning and legislative frameworks at different levels (e.g. local community-based and national laws) also needs to be considered. However, it is important to note than EbA is one of a number approaches to reducing vulnerability to climate change and may not be the best adaptation solution in all contexts[341].

Coral Reefs: Planning for the Future

Building ecological resilience through ecosystem-based management approaches may pay dividends in terms of reducing or delaying the effects of climate change on the marine environment[342]. For many coral reef ecosystems the key local stressors to address in order to improve or maintain resilience are overfishing and pollution, with effective management of herbivorous reef fish populations and water quality, particularly for nutrient and sediment pollution, regarded as critical objectives. However, there is also some concern that relying on conventional marine conservation strategies to maximise resilience and adaptation may not be sufficient in the time frame available given the continued increase in CO_2 emissions, the onset of global stressors and the local and large-scale pressures created by an increasing human population[343][344][345]. Conservation and management tools such as MPAs and fisheries management have the potential to increase coral reef resilience but are unable to protect corals from thermal stress, which suggests that they need to be complemented by additional and alternative strategies[346]. There will also be ecological limits to EbA, and activities to increase ecosystem resilience may only be effective for lower levels of climate change[347].

Overall a fundamental question that is being asked is:

'*If stabilization of atmospheric CO_2 at safe levels cannot or will not be achieved, and if critical marine species and ecosystems prove not to be resilient or able to adapt to elevated temperatures and*

[339] Folke, C. et al., 2004. Regime shifts, resilience, and biodiversity in ecosystem management. Annu. Rev. Ecol. Evol. Syst. 35: 557-581.
[340] McLeod, E. et al., 2013. Preparing to manage coral reefs for ocean acidification: lessons from coral bleaching. Front. Ecol. Envrion. 11: 20-27.
[341] Hills, T. et al., 2011. Pacific Island Biodiversity, Ecosystems and Climate Change Adaptation: Building on nature's resilience. SPREP, Apia, Samoa.
[342] Wong, P.P. et al 2014. Coastal Systems and Low Lying Areas. In: Climate Change 2014: Impacts, Adaptation, and Vulnerability. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. [Final Draft Report]
[343] Coté, I.M. and Darling, E.S. 2010. Rethinking ecosystem resilience in the face of climate change. PLoS Biol. 8: e1000438
[344] Rau, G.H. et al., 2012. The need for new ocean conservation strategies in a high-carbon dioxide world. Nature Climate Change. doi: 10.1038/NCLIMATE1555
[345] Reigl, B.M. and Purkis, S. 2011. Methods to preserve coral reef futures. Science (online comment). Available at http://www.sciencemag.org/content/333/6041/418/reply#sci_el_15719.
[346] Wong, P.P. et al 2014. Coastal Systems and Low Lying Areas. In: Climate Change 2014: Impacts, Adaptation, and Vulnerability. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. [Final Draft Report] (Box CC-CR. Coral Reefs)
[347] Colls, A. et al., 2009. Ecosystem-based Adaptation: a natural response to climate change. Gland, Switzerland: IUCN. 16 pp.

changing ocean chemistry, what are our options, if any, for protecting marine organisms and ecosystems?'[348].

This question is particularly relevant to coral reef ecosystems given their continued degradation and highly vulnerable status. There have been calls for more unconventional conservation strategies and methods for coral reefs and other marine ecosystems[349][350][351]. The proposed methods (Annex 3) are mainly at the concept or laboratory stage and many require considerable further research and assessment to determine whether they could be safe and cost-effective. Some are more focussed on reducing climate-induced stressors at a localised level, such as protecting a particular reef area from heat-stress events by solar shading to maintain tourism or fisheries for local livelihoods[352]. However, such actions may ultimately represent 'opportunities of last resort'[353]. Although it is vitally important for existing conventional efforts to protect coral reef biodiversity and manage ecosystem to continue and be rapidly scaled up, these unconventional approaches should also be taken into consideration according to local, national or regional contexts and the future success of conventional management strategies. Given the severity of the situation for coral reefs, all potential options for management deserve consideration.

The ongoing and projected global degradation of warm water coral reefs has also stimulated interest in the future characteristics of these ecosystems in terms of biodiversity, community structure and the provision of ecosystem services. In the most extreme cases, highly degraded reefs have undergone slow or fast transitions (phase shifts) to non-coral dominated systems in many places worldwide through the impacts of both chronic and episodic stressors[354]. This has resulted in often long-lasting shifts to assemblages dominated by macroalgae, bivalves, sponges, tunicates and zooanthids[355][356]. Less drastic alterations have also occurred leading to novel coral reef ecosystems that have changes in species configurations, interactions and functions, but are still regarded as calcifying coral-dominated reefs[357]. These ecosystems are becoming increasingly commonplace, which is attributed to three main mechanisms: introduced species, species range shifts and asymmetrical species responses to global and local stressors[358].

There are major gaps in the understanding of the types of novel coral reef ecosystems that are likely to occur in the future and how this will affect the provision of ecosystem services. To address these knowledge gaps, a number of critical research topics have been suggested (Table 8). Considerable research will be required to forecast coral reef compositions under different scenarios and in different biophysical and geographic locations[359]. Changes in ecosystem composition are also likely to alter the

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[348] Rau, G.H. et al., 2012. The need for new ocean conservation strategies in a high-carbon dioxide world. Nature Climate Change. doi: 10.1038/NCLIMATE1555

[349] Reigl, B.M. and Purkis, S. 2011. Methods to preserve coral reef futures. Science (online comment). Available at http://www.sciencemag.org/content/333/6041/418/reply#sci_el_15719.

[350] Rau, G.H. et al., 2012. The need for new ocean conservation strategies in a high-carbon dioxide world. Nature Climate Change. doi: 10.1038/NCLIMATE1555.

[351] Billé, R. et al., 2013. Taking action against ocean acidification: A review of management and policy options. Environmental Management 52: 761-779.

[352] Rau, G.H. et al., 2012. The need for new ocean conservation strategies in a high-carbon dioxide world. Nature Climate Change. doi: 10.1038/NCLIMATE1555.

[353] Ibid

[354] Hughes, T.P. et al., 2010. Rising to the challenge of sustaining coral reef resilience. Trends in Ecology and Evolution 25: 633-642.

[355] Done, T.J. 1992. Phase shifts in coral reef communities and their ecological significance. Hydrobiologia 247: 121-132.

[356] Norström, A.V. et al., 2009. Alternative states on coral reefs: beyond coral-macroalgal phase shifts. Mar. Ecol. Prog. Ser. 376:295-306.

[357] Graham, N.A.J. et al., 2014. Coral reefs as novel ecosystems: embracing new futures. Curr. Opin. Environ. Sustain. 7: 9-14.

[358] Ibid.

[359] Ibid

flow of ecosystem goods and services[360]. Therefore forecasts of the provision of ecosystem services (ES) will be important to feed into socio-ecological planning and management strategies as part of an ecosystem-based approach. Management approaches will need to be both adaptive and innovative to assess whether current approaches are suitable for altered ecosystems, whilst also developing new approaches that target ecosystem processes that are important for novel reefs[361]. New and innovative approaches could also consider using unconventional conservation strategies (Annex 3) as cost-effective and tested methods become available.

Table 8: Key Research Priorities and Potential Scientific Approaches to better understand novel coral reef futures. (adapted from Graham et al., 2014)

Research Priority	Scientific Approaches
Understand coral reef configurations possible under different future scenarios of stress levels, habitat types and biogeographic location for coral reef biota (corals, algae, fishes and mobile invertebrates	• Mesocosm experiments • Manipulative field experiments • Surveys of differentially impacted locations • Simulation modelling
Investigate how ecosystem processes are influenced by changing environmental conditions and species compositions with a focus on the changing importance of different processes, and identifying any overlooked important processes	• Manipulative field experiments, including bioassays • Surveys of differentially impacted locations
Assess management approaches to identify which will be most appropriate for novel coral reef futures (assessment of current approaches for effectiveness and trials of new options to manage altered but functional systems)	• Quantify response of species and processes to current management in differentially impacted locations • Adaptive management research in a range of locations • Assess ecological responses to innovative approaches (e.g. boosting important functions or importing thermally tolerant taxa)
Determine how ecosystem service generation is altered under different novel ecosystem scenarios, including how the organisms driving ecosystem services may change, and how the relative flow of different services may shift.	• Assess biological units contributing to a range of ES across differentially impacted locations • Valuation studies of ES in differentially impacted locations • Develop time series datasets of ES • Simulation modelling of ES under different scenarios
Better understand how human societies can adapt and respond to emerging novel coral reef ecosystems; Include all stakeholders, identify barriers to effective adaptation and examine policy associated with existing national and international environmental law.	• Comparative socio-economic and human motivation research across differentially impacted locations • Human preferences and behaviour research • Evaluations of barriers to adaptation in environmental law and policy

[360] Mooney, et al., 2009. Biodiversity, climate change, and ecosystem services. Curr. Opin. Environ. Sustain. 1: 46-54.
[361] Graham, N.A.J. et al., 2014. Coral reefs as novel ecosystems: embracing new futures. Curr. Opin. Environ. Sustain. 7: 9-14.

Estimating the goods and services that can be provided by non-coral dominated systems will also be important to assist in adaptation planning. A better understanding of the underlying processes that cause coral reef degradation and undesirable phase shifts, and whether they can be reversed has also been called for[362]. It has been suggested that management interventions should follow a resilience-based approach that aims to build an improved understanding of the dynamics of thresholds, reinforcing feedbacks, hysteresis and the reversibility of phase shifts[363][364]. Two types of interventions have been highlighted as critical for improving coral reef resilience[365]:

(1) reversing interacting slow drivers of degradation and change, particularly overfishing, pollution and greenhouse gas emissions, to avoid transgressing thresholds leading to phase shifts, and;

(2) promoting processes such as coral recruitment and herbivory that maintain the coral-dominated states of healthy reefs.

Resilience-based management of coral reefs has been regarded as a logical extension of current ecosystem-based management practises, but adopting a resilience-based approach will also require a major refocus of coral reef research[366]. Suggestions for future resilience related research[367] are:

- An improved understanding of the processes and mechanisms that build or erode resilience in order to predict and avoid undesirable phase shifts or regain a coral dominated phase – building the empirical evidence for feedbacks, thresholds and hysteresis is key;
- Increased use of meta-analyses of reef status to measure ecosystem responses to management interventions, with stronger links between monitoring and adaptive governance;
- The development of novel metrics for monitoring important processes such as rates of herbivory, coral recruitment and connectivity;
- An improved understanding of the scale of stock-recruitment relationships for important species and functional groups;
- Increased focus on the human dimension of coral reefs to better understand the importance of ecosystem services for stakeholders and society, and impacts of people on reef resilience, particularly;
- The influence of economic development, social capital, local history and culture on coral reef resource use and governance systems, and;
- Full integration of multiple disciplines (e.g. biology, social science and economics) to focus on the resilience of coral reefs as linked socio-ecological ecosystems.

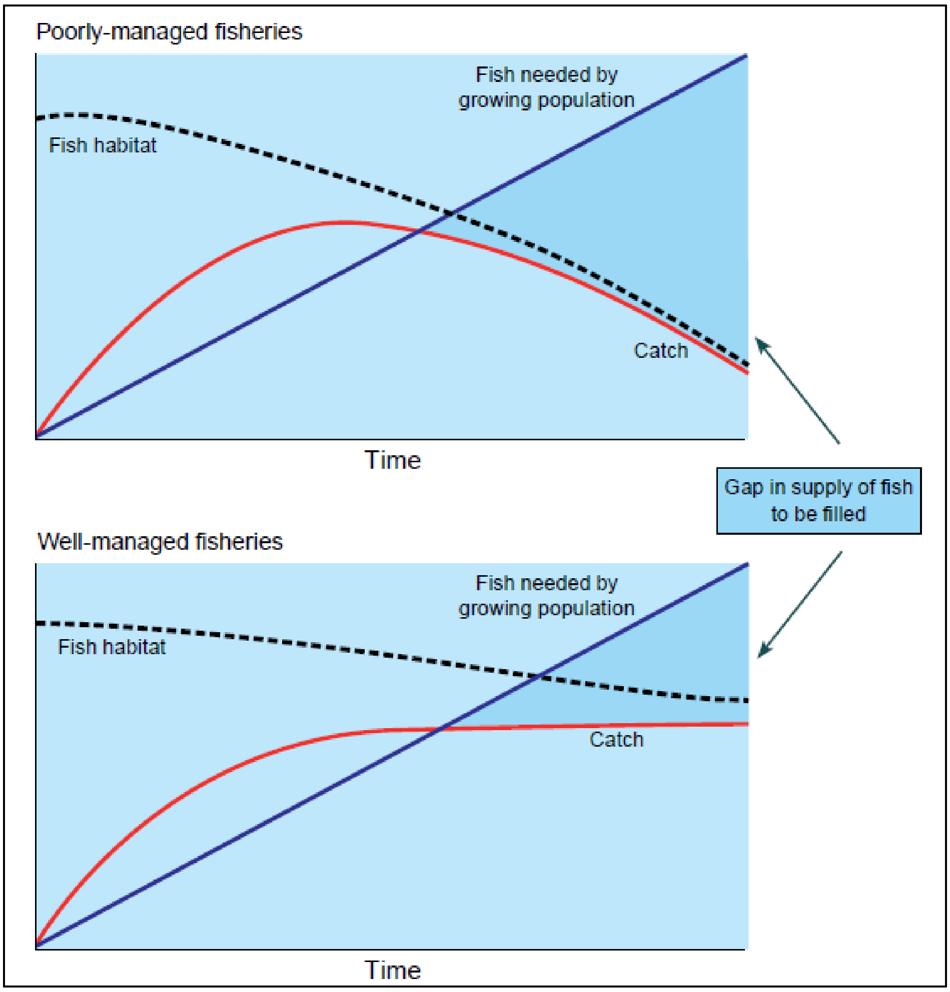
For the last point additional integration of the development sector to factor in issues such as human population, food security and public health will further improve the overall ecosystem-based management approach, which should also include terrestrial-based considerations.

The issue of rising human population with associated effects of increased impacts of local stressors, especially overfishing and pollution, is a critical factor in the future management of coral reef socio-ecological systems. Increased demographic pressure on coral reef ecosystems should be explicitly taken into account if management plans are to be realistic[368]. Recent projections for Pacific nations

[362] Hughes, T.P. et al., 2010. Rising to the challenge of sustaining coral reef resilience. Trends Ecol. Evol. 25: 633-642.
[363] Hughes, T.P. et al., 2005. New paradigms for supporting the resilience of marine ecosystems. Trends Ecol. Evol. 20:380-386.
[364] Mumby, P.J. et al., 2007. Thresholds and the resilience of Caribbean coral reefs. Nature 450: 98-101.
[365] Hughes, T.P. et al., 2010. Rising to the challenge of sustaining coral reef resilience. Trends Ecol. Evol. 25: 633-642.
[366] Ibid
[367] Ibid
[368] Reigl, B. and Tsounis, G. 2014. Editorial Overview: Environmental change issues: Coral reefs sustainability and its challenges. Curr. Opinion Environ. Sust. 7: iv-vii.

indicate that countries with rapidly growing human populations will have a substantial shortfall in meeting national nutritional needs from coastal fisheries, and that the size of this deficit is strongly related to the status of marine (and freshwater) ecosystems and how well they are managed[369] (Figure 4). For such countries, a combination of rapid population growth and limited areas of coral reef means that even well-managed coastal fisheries will not supply the recommended amount of fish per capita per year for good nutrition in the future[370]. In this case the effects of population growth on the availability of fish are profound and declines in coral reef fish production due to climate change are projected to increase the emerging gap only marginally[371]. The effects of rapid population growth on other factors such as coastal water quality may also be significant with associated increased impacts on coral reef ecosystems unless there is effective wastewater and watershed management in place.

Figure 4. The importance of managing habitats and marine resources well to minimise the gap between fish required by a rapidly growing population for food security and potential sustainable harvests from coastal fisheries (Source: Bell et al., 2011).



[369] Bell, J.D. et al., 2011. Implications of climate change for contributions by fisheries and aquaculture to Pacific Island economies and communities. In: Vulnerability of tropical Pacific fisheries and aquaculture to climate change. Bell, J.D. et al. (eds.). Secretariat of the Pacific Community. pp. 733-801.
[370] Bell, J.D. et al., 2013. Mixed responses of tropical Pacific fisheries and aquaculture to climate change. Nat. Clim. Change 3: 591-591.
[371] Bell, J.D. et al., 2013. Mixed responses of tropical Pacific fisheries and aquaculture to climate change. Nat. Clim. Change 3: 591-591. (Supplementary Table S5)

Improved fisheries management will increase the ability of tropical coastal and marine habitats to deliver their potential sustainable yields of biological resources[372] and make them more resilient to climate change impacts. A key issue for poorly managed coastal fisheries in many tropical countries will be to determine the sustainable fishing levels for each fishery and how these will change over time as global stressors have an increasing impact on marine and coastal habitats. There is a need to conduct detailed studies for coral reef countries in other regions, similar to the one completed for Pacific island nations[373], to estimate the potential for such a nutritional shortfall at subnational or national levels. Focussing efforts on improving the health and resilience of coral reefs and associated ecosystems will help to reduce any predicted deficit. Identifying alternatives sources of fish or protein in countries and their territorial waters and the scale of production required to meet any shortfall should be considered high priorities. Potential sources to consider are an increased reliance on pelagic fish stocks such as tuna and freshwater aquaculture, both as part of sustainable and ecosystem-based management approaches. Failure to manage coastal fisheries for projected but highly certain stressors is likely to result in greater degradation of coastal ecosystems utilised for living marine resources.

The current and future provision of ecosystem goods and services from ecosystems closely associated with coral reefs such as mangroves and seagrass beds should also be estimated. A recent economic evaluation of small-scale fisheries in south-west Madagascar revealed that mangroves provided 34% of the total catch, the second highest proportion after coral reefs[374]. With regards to coastal fisheries a decline in coral reef fish productivity may also lead to a shift in fishing effort to focus on adjacent ecosystems (seagrass beds or mangroves). The potential for such a transition should be anticipated and managed accordingly within an ecosystem-based integrated coastal zone management (ICZM) approach that also takes into account forecasts for change in these closely associated ecosystems. In the Pacific, large losses of mangroves and seagrass beds have been projected in relation to multiple climate-induced impacts such as sea level rise, storm surge, increased temperatures, increased turbidity, higher sediment and nutrient loads associated with greater rainfall and more intense tropical storms[375].

Given that the effects of elevated temperatures and ocean acidification on coral reefs are unavoidable, and the high level of risk to biodiversity and human society, it is critically important to strategically plan and act now in order to increase coral reef resilience over the next two decades, and minimise the loss of biodiversity and ecosystem services. As well as using a range of tools and strategies to improve coral reef condition and resilience, including spatial and temporal management (MPAs, LMMAs, seasonal closures, MSP), integrated coastal zone and watershed management, and fisheries management, as part of an overall ecosystem-based approach, it will be important to recognise the main social drivers of coral reef degradation. Drivers such a human population demographics, poverty, global demand for coral reef resources and unsustainable development should all be taken into consideration and the means to reduce these drivers identified and implemented. Understanding people’s livelihoods and motivations will help to influence behaviour in combination with informing communities through research and education. Specific measures to improve coral reef resilience must also address governance issues, and the levels of awareness and political will, as well as direct human pressures[376]. Building up coral reef resilience by addressing local stressors and drivers will enable reef ecosystems to respond better to future changes in temperature and ocean acidification, and also buy time for reef-dependent communities to adapt.

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[372] Bell, J.D. et al., 2011. Implications of climate change for contributions by fisheries and aquaculture to Pacific Island economies and communities. In: Vulnerability of tropical Pacific fisheries and aquaculture to climate change. Bell, J.D. et al. (eds.). Secretariat of the Pacific Community. pp. 733-801.

[373] Bell, J.D. et al., 2013. Mixed responses of tropical Pacific fisheries and aquaculture to climate change. Nat. Clim. Change 3: 591-591.

[374] Barnes-Mauthe, M., et al., 2013. The total economic value of small-scale fisheries with a characterization of post-landing trends: an application in Madagascar with global relevance. Fisheries Research 147. p. 175-185.

[375] Bell, J.D. et al. (eds.), 2011. Vulnerability of Tropical Pacific Fisheries and Aquaculture to Climate Change. Secretariat of the Pacific Community.

[376] Wilkinson, C. 2004. (ed.) Status of Coral Reefs of the World: 2004. Australian Institute of Marine Science, Townsville, Australia.

5. Conclusions and Main Recommendations for the Update

This section provides a set of preliminary recommendations to revise and update the work plan according to the latest understanding of the types of impacts that multiple stressors have on coral reefs and associated ecosystems. The need to manage coral reefs within an ecosystem- or resilience-based approach is stressed. A number of research priorities are suggested to improve the understanding of stressor effects on reef organisms and of the physical and chemical conditions that coral reefs are currently experiencing according to habitat and the relative inputs of various stressors such as ocean acidification and pollution. There is a need to better understand the future composition of coral reef ecosystems and the provision of ecosystem goods and services through forecasting and predictive modelling. Management of the tropical coastal and marine environment as part of an integrated ecosystem-based approach within EBM/EbA or resilience-based frameworks that equally include ecological and socioeconomic aspects of a coupled socio-ecological system is also required to improve coral reef resilience and socioeconomic adaptive capacity.

Firstly, it is important to update the work plan from one that primarily addresses mass coral bleaching events to an overall action plan for coral reef ecosystems that tackles multiple stressors and drivers not only for reef-building corals but also for other ecologically or economically important taxa such as reef fish and invertebrates, especially keystone species and functional groups.

In addition to the initial recommendations provided for the 16th meeting of SBSTTA in 2012[377] (Annex 4a) the main recommendations for updating the work plan are provided below. These recommendations are summarised as in Annex 5 as *Priority Actions to Achieve Aichi Biodiversity Target 10 for Coral Reefs and Closely Associated Ecosystems.* Specific recommendations and supporting information proposed by Parties or organisations in response to the recent notification[378] are provided in Annex 4b.

Coral Reef Resilience Assessment

Detection, monitoring and prediction of resilience, multiple stressors and their impacts

In addition to warming effects and mass coral bleaching events, the work plan should take into consideration the known and projected impacts of other significant global stressors of coral reef ecosystems, notably, the effects of ocean acidification (OA) but also the impact of altered weather patterns, extreme weather events, rising sea levels and changes to ocean currents. Determining the combinations of climate-induced stressors that can have interactive impacts on reef-building corals and other functionally important taxa is needed, particularly for interactions that are synergistic or additive. Identifying synergisms between stressors enables the prioritisation of management to mitigate the most severe interactions or take early preventative action to minimise the interactive impact. Antagonistic effects should also be identified and taken into consideration when prioritising management actions, in order to maximise efforts on reducing synergisms and not waste effort or limited resources on tackling antagonisms.

Evaluation of cumulative impacts of multiple stressors is regarded as critical to forecast future ecological change on coral reefs and effectively manage the combined impacts of multiple stressors. The cumulative effect of a series of global stressor impacts on coral reefs over time requires further assessment and modelling to predict the risk and likely impacts in the coming decades. The interaction between global and local stressors also requires further investigation. Although some combinations of global/local stressors have been investigated there is a lack of information on the effects of other combinations (e.g. ocean acidification in combination with local stressors such as nutrient pollution, sedimentation or overfishing).

Both direct and indirect effects of interactive stressors on coral reef organisms should be identified and quantified. In addition to reef-building corals, suggested research priorities of multiple stressor effects are ecologically or commercially important reef fish and invertebrate species, especially

[377] UNEP/CBD/SBSTTA/16/INF/11
[378] SCBD/SAM/DC/JL/JG/82124

effects on critical life history stages such as reproduction and recruitment. Further research on the thermal and pH tolerances of reef fish and invertebrates with key ecological functions should be a priority. There is also a need to further investigate multiple stressor effects on mangroves and seagrass beds and how these impacts alter ecosystem composition and functioning. It is important to develop processes and tools at the national level to assess cumulative impacts, multiple stressors and interactive effects on coral reefs and associated ecosystems.

The incidence of disease on coral reefs is also linked to elevated temperatures and bleaching events, nutrient levels, and interactions between stressors and requires considerable further investigation. A better understanding of the conditions required for disease outbreaks in corals and other taxa is needed to predict the onset of a disease event. Tools and approaches should be designed that can monitor and influence these particular conditions to minimise the impact on coral reefs.

There needs to be a greater understanding of the factors that confer coral reef resilience to multiple global stressors by identifying both naturally resilient or resistant areas and those that are particularly vulnerable. The biophysical characteristics of a coral reef and its surrounding environment that make it resilient to one or more stressors need to be determined (e.g. particular ecological characteristics or oceanographic properties). Research and actions that increase coral reef resilience at the species, population and community level, restore ecosystem health, deliver net benefits for coral reef ecosystems and maintain the provision of ecosystem goods and services should be prioritised.

Further development of methods and indicators for resilience assessment is required. These assessment techniques should be broadly applicable (e.g. practical and cost-effective), robust, and able to support common planning and decision making frameworks. Indicators should be developed according to criteria such as accuracy and precision, cost and ease of measurement, spatio-temporal resolution and scalability, and scientific basis. Indicators should also identify both intrinsic resilience of coral reefs and the degree of stressor effect on coral reef organisms and communities. Detection and ongoing monitoring of multiple stressors and their interactive impacts will be key to determining the full range of effects that a coral reef is experiencing and to help managers decide the most effective measures to mitigate impacts on coral reef organisms and habitats. Existing recognised reef resilience or stressor indicators, including bioindicators, should also be used where available and applicable, with new or revised indicators developed as required. The use of bioindicators should be scaled up, particularly simple, low cost techniques that can be used in remote locations or in countries with restricted capacity for the processing and analysis required for more complex procedures.

There is a need for continued emphasis on the long-term monitoring of both global and local stressors that affect coral reefs. Ongoing large-scale monitoring programmes to detect and measure bleaching events should be supported and developed whilst further methods and indicators should be devised for detecting other climate-induced stressors, particularly ocean acidification. Existing coral reef data-sets should also be collated and analysed to help identify critical factors controlling coral reef status and trends and provide recommendations for planning and management. Monitoring and reporting protocols at the national and regional level need to be further developed to include factors such as multiple stressor effects to feed into regional and global monitoring networks. The work plan should also encourage the development and implementation of reef health incident response systems to provide early warning system for major reef health incidents such as bleaching or disease events, tropical storms and flood plumes.

Specific attention is required to monitor ocean acidification and assess the effects of OA on coral reef ecosystems. There is a need for better and more cost-effective monitoring of water chemistry in coral reef areas to establish long-term monitoring programmes and detect natural cycles and patterns in coastal and inshore waters. Understanding the natural spatial and temporal variability of ocean carbon chemistry (i.e. CO_2, HCO_3^-, CO_3^{2-}, pH and aragonite) on coral reefs is important to assess the sensitivity of a reef community to future changes in ocean chemistry. Determining the sensitivity of species, habitats and communities within coral reefs to changes in ocean carbon chemistry will help to identify more resilient areas. A much greater understanding of how OA interacts with other stressors to affect coral reefs and other coastal ecosystems in terms of community structure and habitat condition or distribution is required. Further research is also needed to assess the potential for adaptation to OA in reef organisms and whether there are any existing biological or ecological mechanisms to cope with the impacts of high CO_2 or highly variable conditions in areas currently experiencing such conditions. Identification and development of management actions that could facilitate adaptation or buffer acidification effects are also needed.

The impact of global stressors on marine and coastal ecosystems that are closely associated with coral reefs, particularly seagrass beds and mangroves, should also be an ongoing research theme. Knowledge of the effects of mangrove or seagrass habitat degradation on coral reef ecosystems and on coastal communities that utilise one or more of the ecosystems will help managers to prioritise actions to minimise ongoing socio-ecological impacts.

Forecasting of future likely impacts of both global and local stressors and their interactive effects is also needed in combination with current and proposed management efforts. Further development of mapping tools that combine data on the current status of coral reefs, management efforts and their effectiveness with predictive modelling to generate future scenarios of reef condition and ecosystem service provision are required. Tools that can help predict or anticipate climate change effects and the implications of change at scales relevant to planning and management are needed. Predictable social drivers of coral reef degradation such as projected human population increase should also be taken into account in forecasts of coral reef status and ecosystem service provision in relation to climate-induced stressors to identify potential shortfalls in essential services such as nutrition provision from reef-based resources in coral reef nations or regions. Consideration of demographic changes and effects on local stressors needs to be a key aspect of coral reef management and planning.

Greater Consideration of Socio-economics Within a Socio-ecological System

Social and Ecological Vulnerability and Resilience

Measuring socio-economic and-ecological characteristics together as part of an integrated ecosystem-based approach to coral reef management should be promoted. Conducting vulnerability assessments can inform adaptation planning and management by identifying the most vulnerable sites in terms of high sensitivity and low adaptive capacity, as. The revised work plan should incorporate recognised socio-ecological techniques into assessments in coral reef regions and encourage the development of generic monitoring protocols for socio-ecological vulnerability assessments at the national or regional level that can be adapted to the local or sub-national context. Further research and methodological development is required to measure socio-ecological vulnerability for a range of stressors affecting a coral reef site. There is a need to further develop and test a range of ecological and socio-economic metrics for use in vulnerability assessments in coral reef regions, building on existing examples. The information collected should be used to develop current and projected socio-ecological vulnerability maps for coral reef locations at different scales to inform planning and management as part of an ecosystem-based approach

Identifying measures to improve the adaptive capacity of coral reef-based socio-ecological systems according to the local context should be prioritised. These should include measures to remove the main barriers preventing or limiting the improvement of adaptive capacity of reef-dependent communities, such as chronic poverty. Determining how livelihoods and coral reef-dependent industries affect reef resilience and how they are likely to be influenced by reef degradation will provide a better understanding of socio-economic linkages with the marine environment. Analysis of the various factors that enable resource users to adopt livelihood strategies that are not reef-dependent or do not negatively affect reef resilience is also key to reducing local pressure on coral reefs.

Economic valuation of coral reefs

Greater economic valuation of climate-induced and local impacts on coral reef ecosystem goods and services is needed to indicate to a range of audiences (local communities, managers, and decision and policy makers) of the importance of healthy and resilient reefs for livelihoods, food security and coastal protection. The valuation of ecosystem services for coral reefs and closely associated ecosystems can also provide managers and decision makers with up-to-date comparisons of a range of adaptation approaches including ecosystem-based (soft), engineering (hard) and hybrid approaches.

Economic valuation of coral reef ecosystems could be facilitated by broadening the financial basis for coral reef management through greater involvement of and support from the private sector. Providing support for SIDS and LDCs to fully evaluate the goods and services delivered by coral reefs and associated ecosystems (mangroves and seagrass beds) could help support public and political momentum for policy action at multiple levels and facilitate the procurement of external funding and investment for coral reef and coastal management initiatives.

A better understanding of the relationship between the status of coral reefs and closely associated ecosystems and the provision of ecosystem services is required. There is also a need to increase the understanding of current and future novel coral reef ecosystems and of the provision of ecosystem goods and services by them to inform socio-ecological planning and management. Knowledge of potential synergies and trade-offs between managing tropical coastal ecosystems for resilience in the face of climate change and ocean acidification and managing them for service provision will help coastal managers and decision-makers to plan more effectively for future change.

Managing Coral Reefs for Resilience

There is a need for robust, systematic and cost-effective approaches for resilience-based coral reef planning and management that are applicable to a range of geographic and institutional settings. In particular the continued development of management strategies that enhance recovery from damage by eliminating or significantly reducing one or more local stressors should be encouraged. These include spatial management approaches such as MPA networks, fisheries restrictions and multisectoral MSP frameworks. Existing healthy, resistant and resilient reefs need to be protected as no-take MPAs that have adaptive management arrangements to minimise local stressors, including land-based threats. These reefs are especially important as they serve as critical reference points as well as sources of recovery for surrounding areas. Further consideration is needed for designing MPA networks to cope with future physical and physiological effects of global stressors on coral reef ecosystems. Examples are reducing the distance between MPAs to compensate for the reduced larval phase duration of reef fauna, designing networks that are larger than the areal extent of the majority of thermal events in a region or locating MPAs in sites more resistant to OA effects or where water chemistry patterns are less affected by global effects.

Management of local stressors outside of MPAs is also critical to reduce overall ecosystem impacts and increase ecological resilience. Developing and implementing management strategies and plans to reduce fishing pressure to sustainable levels including destructive fishing practises, and reduce land-based sources of pollution including nutrients and sediments are especially required. The development and implementation of ecosystem-and resilience-based MSP should be supported to manage coral reef use, resolve potential user conflicts and anticipate future effects of multiple stressors, for both climate-induced and local impacts. There is also a need to consider terrestrial spatial planning and land use in catchments when developing management plans for the marine and coastal zone. Consideration of both marine and terrestrial conservation and management objectives as part of an integrated land-sea planning approach is a research area that should be supported.

It is extremely important to support the further development and use of a resilience-based approach for coral reef management is needed, that focuses on reversing drivers of degradation, avoiding thresholds that lead to phase shifts, and promoting ecological processes that maintain the coral-dominated states of reefs. Management approaches should also be both adaptive and innovative to adjust to the characteristics of novel coral reef ecosystems, noting that some existing management approaches may not be suitable for altered systems.

Support for the further development and implementation of practical cost-effective restoration programmes for coral reefs and closely associated ecosystems is also recommended. Reef restoration options should be explored that are based on existing science, guidance and ongoing efforts, which can, along with other management tools, improve the chances of reef recovery and adaptation.

Ideally, management and planning approaches should be part of outcome- and target-based management frameworks over the long-term (decades) that take into consideration actual and projected multiple stressors and the delivery of net benefits through the safeguarding of ecosystem goods and services. Within the overall management framework national action plans for coral reefs and interconnected ecosystems should be developed for shorter time periods (e.g. 5 – 10 years).

Facilitating community-based management and adaptation approaches

There is a need to scale up the use of locally managed marine areas (LMMAs) in tropical coastal regions and increase their spatial coverage so that it is sufficient to maintain or improve coral reef resilience and safeguard ecosystem goods and services. Locally-based management initiatives are regarded as the most cost-effective and practical way to manage inshore waters and the coastal zone in developing countries with limited institutional capacity and logistical resources, and especially for those with extensive coastlines or remote coastal regions. Community-based adaptation approaches to climate change are also being applied in coastal communities in coral reef nations and should be supported within the new work plan as an effective approach to achieve coral reef management goals. A strong sense of local stewardship of coral reef resources and strong leaderships are key factors required for the success of community-based management approaches. In addition management approaches need to be highly adaptive in order to cope with the anticipated rapid environmental changes as a result of climate-induced stressors such as warming and acidification.

The establishment of LMMA or other communication-based networks at the national and regional level should also be supported. There is a need to increase the understanding of the benefits of networks for management planning at multiple spatial scales (sub-national, national and regional). Sharing information or experiences through networks has particularly helped to increase the understanding and the coverage of LMMAs in a number of regions. Developing or expanding networks for a range of coral reef management aspects (e.g. local or national governance, public-private partnerships, education and outreach, predictive modelling, adaptation planning) at the national, regional and global level is required to maximise the exchange of information, knowledge and best practise. Networks between SIDs and LDCs should also be supported.

Ecosystem-based Management and Adaptation in coral reef regions

The work plan should also encourage the use of ecosystem-based management or adaptation approaches to climate change and local stressors for tropical coastal regions containing coral reef ecosystems, especially in LDCs or SIDs with limited capacity for infrastructure development. There is a need to further develop Ecosystem-based Adaptation (EbA) tools and indicators for use in coral reef regions and incorporate EbA principles and practises into the various types of management currently operating for coral reefs and associated ecosystems (i.e. community-based, co-management, top-down management). Developing and implementing coral reef adaptation strategies based on EbA principles, is especially required in LDCs and SIDs, which can be based on existing best practise examples, and designed for the local or national context.

At the national level it is important to identify and remove the major barriers to EbA/EBM implementation for tropical coastal areas such as lack of awareness of EbA options and their cost-effectiveness and lack of tools and capacity for each stage of an EbA planning and implementation process. At the local level the development and implementation of EbA and ridge-to-reef approaches to adaptation planning and management for coastal communities living adjacent to coral reef ecosystems should be encouraged. Greater understanding of the potential of EbA approaches is required by coastal communities, and local, provincial and national government departments, especially regarding cost-effectiveness. The integration of ecosystem-based approaches for management and adaptation into development planning and legislative frameworks at different levels (e.g. local community-based and national laws) also needs to be considered.

Consider all potential options

For coral reefs to persist as functional ecosystems, there needs to be effective action to address the main driver of the most damaging stressors for the ecosystem over the long-term i.e. reducing greenhouse gas (GHG) emissions through aggressive mitigation strategies. In recognition of the projected climate-induced global degradation of coral reef ecosystems, there needs to be due consideration of all potential approaches to improve the health and resilience of coral reef ecosystems to climate change. Existing conventional conservation strategies on their own will not be able to prevent extensive global degradation of coral reefs by warming and ocean acidification. With this in mind it is important to consider all possible options to reduce impacts of warming and acidification on coral reefs, both through passive conservation and management approaches that increase resilience, and by more active approaches such as additional and alternative conservation strategies. Further development and assessment of unconventional conservation strategies and methods, and their applicability and cost-effectiveness is required.

Further prioritise Capacity Building for monitoring and management of coral reefs

As highlighted in the 2012 background document[379] there is considerable variation in the capacity of coral reef nations to effectively manage the coastal and inshore waters to mitigate local anthropogenic impacts let alone global stressors. Capacity building programmes to improve management effectiveness, predominantly through community-based approaches and co-management arrangements, are urgently needed in coral reef nations with the highest vulnerability and lowest adaptive capacity to change.

Combining Recommendations

As well as referring to the initial recommendations for overcoming barriers to the implementation of the work plan summarised in 2012[380] the revised work plan should also include, as appropriate, high level policy recommendations provided in recent global frameworks and studies such as the ICRI Framework for Action[381], Reefs at Risk Revisited[382] and the GLOBE Action Plan for Coral Reefs[383]. A tabulated list of potential recommendations for consideration is provided as Annex 4c. A selection of these recommendations were combined with the main points identified in this report to produce an overall list of action points that contribute to the draft addendum to update the specific work plan on coral bleaching[384].

Other Recommendations and Considerations

The existing work plan should be renamed so that it better represents the need to address the full range of both global and local stressors that are having a negative impact on the structure and function of warm-water coral reef ecosystems and the goods and services they provide. Potential suggestions are a ‘Specific Work Plan on Coral Reefs’ or a ‘Specific Action Plan for Coral Reefs’.

The current work plan has been in place for ten years in which time there have been considerable changes in the understanding of global stressors and in the techniques and approaches to monitor and manage coral reefs. It is recommended that the work plan is updated at more regular intervals in future (e.g. every five years) to be more up to date with the latest scientific knowledge, monitoring techniques and tools, and management approaches.

The work plan could suggest the setting of clear and realistic outcomes and targets for national action plans for coral reefs over set time periods and consider the approach proposed by the GLOBE Action Plan for Coral Reefs[385], which is a ten year plan with actions split into two phases. Achievable goals and targets will vary between countries and regions, but could also be agreed at a regional level. The current deadline for Aichi Target 10[386] is 2015, meaning that the target is highly unlikely to be met. A realistic target to minimise anthropogenic impacts on coral reefs should be set that can be achieved

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[379] UNEP/CBD/SBSTTA/16/INF/11
[380] Ibid (Table 1)
[381] International Coral Reef Initiative Framework for Action 2013. ICRI 2013.
[382] Burke, L., Reytar, K., Spalding, M. and Perry, A. 2011. Reefs at Risk Revisited. World Resources Institute, Washington DC, USA. 114 pp.
[383] Harding, S., et al.. 2010. GLOBE Action Plan for Coral Reefs. GLOBE International Commission on Land-Use Change and Ecosystems.
[384] CBD code for addendum
[385] Harding, S., et al.. 2010. GLOBE Action Plan for Coral Reefs. GLOBE International Commission on Land-Use Change and Ecosystems.
[386] ‘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’.

using a phased approach before the predicted onset of severe impacts from global climate-induced stressors (mainly warming, bleaching and acidification), for example 2035.

Finally, the work plan has also focussed on low latitude shallow coral reefs to date. The development of an additional work plan or addendum to protect and manage cold- and deep-water coral reefs should be considered.

Annex 1 **Stressor-stressor interactions and direction of influence (↑ reinforcing, ↓ mitigating, ↔ mixed or no-effect).** The numbers in each cell indicate the number of studies reporting that finding. Empty cells indicate that no studies were found that investigated that particular interaction (Ban et al., 2014; Supplementary Table 4).

	Acidification	**CoTS**	**Fishing**	**Irradiance**	**Nutrients**	**Pollution**	**Salinity**	**Sedimentation**	**SLR**	**Storms**	**Temperature**	**UV**
CoTS			2↑ 1↔		1↑		1↑				2↔	
Fish Biomass/ Abundance	12↔					1↔		3↓ 1↔		1↓2↔	3↓6↔	
Irradiance								7↓		1↓		
Nutrients	1↔						17↑ 1↔	17↑		4↑		
Pathogen growth and virulence	2↑ 1↔		1↔	2↑	8↑	6↑ 1↔		1↑			18↑2↔	
Pollution								10↑				
Salinity										1↑		
Sedimentation					5↑1↔				2↑	22↑1↓ 1↔		
UV				1↑				2↓			4↑2↔	

Annex 2 **Effect of interacting stressors on response variables** (after Ban et al., 2014)

Bold text denotes a *deleterious* effect on individual corals or the overall amount of coral cover; unbolded entries are either neutral or potentially beneficial. The first number reflects how many studies were found reporting the corresponding effect, whether qualitatively or quantitatively. The number that follows in parentheses is the number of studies that quantitatively tested for an interaction. Arrows denotes the direction of the change in response variable associated with an increase in both of the stressor variables; sideways arrows indicate that the response is either complex (e.g., U-shaped) or dependent on some other factor. Columns and rows containing no studies were removed: for columns, sea level rise, storms and UV; for rows, acidification, crown of thorns outbreaks, and disease.

Stressor	Acidification	CoTS	Disease	Fishing	(Increased) Irradiance	(Increased) Nutrients	Pollution	(Reduced) Salinity	Sedimentation	(Increased) Temp.
Fishing			**1↑Algal cover (0)**							
Irradiance	**1↑ Bleaching (1)** 3↔Calcification (3) **1↓Calcification (1)** **1↓Zoox. Photosynthesis (1)** ↑Photosynthesis (1)[387]									
Nutrients	**3↓Calcification (0)** 1↔Calcification (1) **2↑Pathogen growth (1)** **1↔Zoox. Photosynthesis (0)**			**1↑Algal cover (1)** 1↑Corallimorphs (0) **1↓Herbivory (0)** 1↑Sea urchin grazing (0)	1↑Microalgal production (0) **1↓Calcification (0)** 2↔ Zoox. Photosynthesis (2) 1↑ Zoox. density (1) 1↔Pigmentation					

[387] This experiment compared sub-saturating irradiance with saturating irradiance; the effects of higher irradiances were not tested

					(1) 1↓Photosystem damage (1)					
Pollution				**1↓Reef condition(1)**	**2↑Bleaching (0)** **1↓ Zoox. Photosynthesis (1)**					
(Reduced) Salinity					1↑ Zoox. Photosynthesis (1)	**1↓Fertilization (1)** **1↑Mortality (0)**	**1↓Zoox primary production (1)**			
Sediment.				**1↓ Coral cover (0)** **1↔ Disease prevalence (0)** 1↔ Coral cover[388] (1)	1↓Coral mortality (1) **1↑UV penetration**	**2↓Coral cover (0)** **1↓Fert. (1)** **1↓Growth rate (0)** **1↑Macroalgal growth (0)** **2↑Mortality (0)** 1↔Mortality (1) **1↓ Photosynthesis (0)**		**1↓ Coral cover (0)** **1↓ Fertilization (1)** 1↔ Growth rate (0) **1↑Mortality (1)** **1↓Photosynthesis (1)**		**1↑Mortality (1)**
SLR					1↔ Photosynthesis (0)			**1↓Growth rate (0)**		
Storms		**1↓Recovery (0)** 1↑Larval settlement (0)		**1↑Physical damage (0)**		1↓ Algal cover (0) 1↑Fish abundance (0)				**1↑Disease (0)**
Temp.	**3↓Calcification (2)** 4↔ Calcification (4) **2↑Pathogenesis (2)**		**1↓Zoox density (1)**	1↔Zoox growth rate	1↔ Antioxidant enzyme activity (1) 1↔Bleaching (1) **7↑Bleaching(1)**	**1↑Bleaching (0)** 1↔ Calcification (0) **1↑Disease (0)**	**1↓Larval metamorphosis (1)** **2↓ Photosynthesis (2)**	**1↑Bleaching (0)** **1↓Photosynthesis (1)**	**1↑Bleaching (0)** 1↓Mortality (1) 1↓**Coral cover (0)** 1 ↔	

[388] Possibly confounded by poaching in ostensibly protected areas

	1↓Nutrient uptake (1) 1↓Aerobic scope of fish (1) 2↔ Photosynthesis (2) 1↔ Zoox density (1) **1↑Bioerosion (0)** 1↓Fertilization (1) 1↔Fertilization (1) 1↔Photosynthesis (1) 1↔Coral mortality (1) **1↑Coral mortality (1)**				1↑ Calcification (1) 1↔ Calcification (0) **3↑Coral mortality (2)** **4↑ Disease (4)** 1↔ Disease (1) 1↓ [Polyunsaturated FAs] (1) 2↑ [MAA] (0) **35↓ Photosynthesis (25)** 1↑ Photosynthesis (1) 5↔ Photosynthesis (4) 1↔ Symbiont clade (0)	1↔ Disease (0) 3↔ Photosynthesis (3) **1↓ Photosynthesis (1)**			Photosynthesis [389] (0)	
UV	**1↓ Calcification (1)** **1↓ Photosynthesis (1)**				**1↓Community productivity (0)** 1↔ Photosynthesis (0)		**1↑ Coral mortality (1)** **1↓ Photosynthesis (1)**			**1↑Bleaching (0)** **2↑ Coral mortality (2)** **1↓ Growth rate (0)** **7↓Photosynthesis (6)** 1↔Photosynthesis (1)

[389] This study was not unable to disentangle the effects of sedimentation from the effects of nutrient loading.

Annex 3. Unconventional conservation methods with potential application to coral reef ecosystems

(adapted from Rau et al., 2012, with input from Billé et al., 2013 and Reigl and Purkis, 2011)

Method Type	Conservation Method	Global Stressor Addressed			Notes
		Temperature	Acidity	CO_2	
Physical:	Solar shading: reduces heat stress effects on corals and extent of coral bleaching	X		(X)	Buoyant shade cloths applied on the GBR
	Global Solar Radiation management	X		(X)	Has significant risks and uncertainties
	Increased upwelling: use of wave or tidal power to bring cool, nutrient rich deep water to shallow habitats	X		(X)	Likely to be useful at small spatial scales
Biological	Actively assist biological resilience and adaptation by protective culturing, selective breeding or genetic engineering, for example: Select corals (symbionts and host) that are less sensitive to thermal stress Use selectively bred lines of thermal- or acidification- tolerant strains of target species for restoration efforts	X	X	(X)	May become a viable management strategy but little potential for scaling up. Feasibility and unforeseen consequences of introducing novel genotypes remains a major concern. Extensive research is needed to address issues of effectiveness and potential drawbacks
	Assisted migration of naturally heat-adapted corals with higher bleaching thresholds into bleaching-damaged areas.	X			Moving threatened Arabian Gulf corals into the tropical Indo-Pacific region
	Artificial preservation of genetic stock, creation of refugia and other *ex situ* techniques	X	X	(X)	Gene banks to prevent a permanent loss of genetic diversity and constructing refuges for impacted ecosystems
Chemical	Chemical, electrochemical or geochemical modification of seawater (alkalinity addition, pH elevation) to maintain or manage ambient ocean chemistry locally or regionally	(X)	X	X	Few techniques studied beyond the concept or laboratory stage. May not be feasible at scales to address the scope of the challenge
Hybrid and other approaches	Conversion of waste carbon dioxide to ocean alkalinity	(X)	X	X	Convert CO_2 from land-based waste streams into dissolved bicarbonates that could be added to the ocean to provide carbon sequestration and enhance ocean alkalinity
	Storage of land crop waste on the ocean floor	(X)	X	X	Increase carbon sequestration and reduce or eliminate carbon recycling in the atmosphere

	Ocean fertilisation to enhance CO_2 uptake by increased photosynthesis	(X)	X	X	Known impacts and uncertainties may outweigh the potential benefits – further research is needed. Currently forbidden by international law apart from necessary scientific research

Notes: X denotes direct effects; (X) indicates possible indirect effect. List is illustrative and not complete.

Annex 4: Summary Tables of Potential Recommendations to Update the Specific Work Plan on Coral Bleaching.

Annex 4a. Initial Recommendations Provided in 2012 to Overcome Barriers in the Implementation of the Work Plan

Barrier	Specific challenges	Responses and Suggestions to overcome Barriers
Information Limitations	Specific data collection (early warning systems, rapid response capability, climatic vulnerability) is often not prioritized due to limited capacity for basic monitoring and resource assessment. Lack of understanding of the effects of ocean acidification on coral reefs Limited research infrastructure (e.g. dedicated (and funded) marine research capabilities) in many countries; Data gaps in baseline information for shallow water ecosystems in many areas making MPA designation and resilience assessment more difficult Significant quantities of data are required and involve sophisticated processing to capture vulnerabilities of coral reef species and habitats to climate change;	Support coral bleaching studies evaluating and quantifying impacts and implications of repeated bleaching events both in ecological/biodiversity and socio-economic terms Support research on ocean acidification and the interaction with other stressors to increase the understanding of: • reef resilience in terms of acidification and multiple stressor effects • the implications of ocean acidification for coral reefs and dependent communities and potential management and mitigation strategies Increase scientific support for research and monitoring in countries lacking capacity through training and mentoring Use of research findings to provide guidance on management actions to reduce climate change impacts on reef ecosystems Ensure continued support to strengthen global initiatives to regularly and accurately document and report on coral reefs status and trends (e.g. GCRMN) and make

	Critical science and knowledge regarding resilience remains insufficient to enable the selection and design of MPAs and networks will high levels of confidence Resilience-based reef management and planning approaches contain many assumptions and uncertainties and require further testing and validation to improve their reliability and relevance The inter-relationship between reef responses to bleaching and the vulnerability and resilience of dependent communities and industries has not been awarded sufficient scientific and planning/management attention	information increasingly useful for national as well as global reporting and decision support Increase involvement of Parties, especially ones most vulnerable to reef loss, in regional partnerships and networks to support assessment and adaptation Catalyse interest among the science community to tackle essential knowledge gaps in practical resilience and ocean acidification science and put in place readily accessed sources of funding to support this Systematic testing and validation of resilience-based management and planning approaches Development of approaches for integrating ecological resilience into spatial conservation planning on coral reefs Development of tools and approaches for vulnerability mapping, ecosystem-based adaptation, and ecosystem-based marine and coastal resource management
Practical Management Strategies	Garnering community support and understanding for MPA goals and objectives is an on-going challenge and made more difficult by climate change; Generating support for resilience as a mechanism to combat climate change requires attitudinal shifts in management and stakeholder communities Ecosystem based and broad scale integrated management measures require significant institutional and staffing infrastructure (e.g. scaling up to MPA networks) which is often lacking and can delay single site-based management implementation Difficult for research agencies to catalyse action by management agencies across multiple countries which may translate into effective programs for Management Actions, Information Gathering, Capability Development and Policy Development Lack of appropriate mechanisms for tracking and monitoring of	Develop mechanisms to involve stakeholders and communities in marine resource management within and beyond MPAs boundaries Development of National Coral Reef (Action) Plans Support training and awareness programmes for communities, stakeholders and managers in resilience theory and practise and provide training in multiple languages Strengthen management of coral reefs to safeguard areas that are particularly resistant to bleaching, areas that exhibit high resilience or adaptive capacity, as well as areas that sustain coastal populations Strengthening of partnerships to improve guidance for managers on reef resilience indictors and methodologies to assess reef resilience, vulnerability assessment, and adaptation specific to coral reef ecosystems and dependent communities Further refinement of management and planning approaches based on research and critical review of past experiences, including ecosystem-based adaptation planning Implement mechanisms to evaluate the effectiveness of coral reef management

	management action during mass bleaching events Challenges of surveillance and enforcement in widely scattered remote reef systems coupled with poaching and weak governance	practices and to monitor management action during mass bleaching events
Capacity Challenges	Human and technical capacity for implementation remains limited, especially in developing countries and SIDS with vast geographic ranges, remote islands and atolls; Lack of scientific publications by developing nation authors on coral reef ecology and climate change Lack of coordination between the different coral reef actors involved in research, management and resource use and also within management agencies at the local and national level	Increase the number of regional or international action networks to support capacity building and ecosystem-based adaptation approaches Build capacity for incorporation of best practice into national and regional governance frameworks as well as reef management and coastal development planning Facilitate collaboration and coordination between agencies and levels through third parties (e.g. NGOs) and widely disseminate the specific work plan between the different actors involved in its implementation
Financial Limitations	Funding needs for long term monitoring are significant and are currently not well supported The complex funding environment makes it challenging to mobilize contingency funds quickly to respond to bleaching events; Continuation funding to support capacity development and training of reef managers is necessary in periods between bleaching events. Insufficient funding to run and manage research and monitoring programmes in all reef areas	Establish a rapid bleaching response contingency fund to enable increased reef monitoring and the review and revision of resilience principles in response to major bleaching events Increase financial support through multilateral agencies, particularly via climate funds, to implement activities relevant to the specific work plan but also to broader climate change impacts on coral reefs Development of National Climate Funds to fund relevant activities Enhance private sector engagement to support activities contributing to the specific work plan, including by identifying and replicating successful models

Annex 4b Recommendations and information provided by Parties and Organizations to update the Work Plan (Working Draft)

Respondent	Reasoning / Background	Proposal / Suggestion
Colombia	No specific suggestions to update the work plan. Information regarding Parque Nacional Natural Providencia provided.	Information regarding the update of the management plan of the Parque Nacional Natural Providencia, focused on monitoring of coral reefs in the context of identified trends and drivers,
European Commission	Half a billion people depend directly or indirectly on coral reefs for their livelihoods. The loss of coral reefs will have dramatic consequences worldwide	Visual computer simulations of "a world without coral reefs" may help to sensitise decision makers and the public worldwide that coral reefs are not just an issue for islands and coastal areas
	Means for coral reef conservation and restoration	Potential major source are climate change adaptation funds which are thought to be a key target for enhancing coral reef resilience and enabling social adaptation over the long-term
	Constraints to effective top-down management - five broad categories identified in the Caribbean: • non-compliance and a lack of effective enforcement; • lack of education and awareness among resource users; • lack of resources and capacity for reef management; • lack of political prioritisation of reef management issues; • lack of engagement of reef users in reef governance; and, • weaknesses in policy, legislation and regulations.	Possible areas for improvement that may lead to increased effectiveness of management: • Use of innovative approaches for reef management, including greater partnership between government and NGOs and sharing of expertise and resources across the region • Focus on stakeholder engagement and involvement in management programmes • Encourage and facilitate the collection of socio-economic data to inform management • Ensure effective communication and exchange of information to inform decision-making
ICRI - General		'The most efficient way to increase reef resilience, including to bleaching events, is to address direct anthropogenic threats in an integrated, adaptive, risk-based manner which takes into account the connectivity of land and sea influences and the cumulative impacts of anthropogenic uses and natural disturbances' The ICRI Framework for Action 2013 is designed to provide high-level guidance to governments and other stakeholders to implement management strategies and actions based

		on global best practices (see Annex 1c)
ICRI - GBRMPA	Plans and strategies for the Great Barrier Reef, Australia	• Currently implementing Climate Change Adaption Strategy and Action Plan 2012-2017. • Also developed a ‘Reef Health Incident Response System’ which includes risk and impact assessment plans for coral bleaching, coral disease and tropical cyclones • ‘Strategic Assessment’ and ‘Program Report’ currently open for public consultation. Latter outlines an approach to improve protection and management of the GBR for the next 25 years once endorsed, with a management framework to address impacts from climate and ocean change • Activities underway as part of the Australia-Caribbean Coral Reef Collaboration that address specific objectives of the current work plan. The Collaboration has six key components: 1. Regional plan of action to reduce coral reef vulnerability to CC 2. Framework for implementing marine biodiversity offsets 3. Monitoring multi-tool for coral reef managers 4. Primer on integrating social vulnerability into coral reef management 5. Outlook reporting for strategic management of coral reefs 6. Guidebook for building reef stewardship in local communities
ICRI - Cuba	Focus on tackling coral bleaching	Coral reef early warning monitoring network in Cuba – focus on bleaching assessment
ICRI - Japan	Specific editing suggestions for the current coral bleaching work plan	Track changes and comments provided for prioritisation of existing activities and actions listed in the current version of the coral bleaching work plan
ICRI – Ad Hoc Committee on Economic Valuation	Ocean acidification and fisheries / economics	Summary document provided for the second international workshop on the economics of ocean acidification (November 2012). Meeting focussed on assessing the economic impacts of OA on fisheries and aquaculture in six global regions. Recommendations provided: • Establish coastal monitoring networks for standardized measurement of OA • Support research on valuable finfish and invertebrates in high CO_2 conditions to enable socio-economic assessment of impacts in food security • Implement best practice and adaptive management of fisheries and aquaculture to increase ecological resilience of marine ecosystems • Increase the adaptive capacity of fishing communities through education, training and support for livelihood diversification • Improve multi-stakeholder exchange of information and communication between coastal

		communities, businesses, researchers, resource managers and policy makers
ICRI - IFRECOR	No specific suggestions to update the work plan. Information provided on reef monitoring programmes and CC adaptation planning in French Overseas Territories	Three main activities highlighted: 1. CC adaptation team – consider coral reef and coastal environments in adaptation plans and encourage overseas authorities to develop strategies for adapting to CC in the coastal zone 2. Creation of an online database to monitor the impacts of CC and anticipate future effects by integrating CC into management plans and long-term preventive measures to minimise CC impacts on ecosystems and coastal communities 3. Regular monitoring of coral reef status through a network of reference stations across the overseas territories.
India	Brief note on coral bleaching assessment in India	In favour of an ecosystem-based approach to coral reef management. Suggest the use of the resilience assessment methodology developed by the IUCN CC/CR working group
Israel	Provided a journal article and a list of relevant publications	Journal article provided: Fine, M., Gildor, H., and A. Genin. (2013). A coral reef refuge in the Red Sea. Global Change Biology (2013), doi: 10.1111/gcb.12356 List of relevant publications provided by expert from Yossi Loya Tel Aviv University
Mexico	Text suggestions for two specific sections of the current coral bleaching work plan	• For section 1. (a) (iii) include text about the development of *in situ* nurseries to raise genetically diverse corals that are resistant and/or resilient to identified multiple stressors • For section 2 (a) i. c. include coral disease as a synergistic stressor
Norway	No specific suggestions. Provided two information notes on cold water corals Emphasis of the principle of assessing cumulative environmental effects	Provided brief notes on the following: • Understanding *Lophelia pertusa* vulnerability to multiple stressors • Deep-water corals from AMAP Assessment 2013: Arctic Ocean Acidification
UK	Provided two documents: 1. report submitted by UK to ICRI meeting in Belize (October 2013) 2. report submitted by the Cayman Islands to ICRI meeting in Belize (October 2013)	No specific suggestions but a few examples of good practise provided for the Bahamas and the Cayman Islands Reports also include references and links to relevant academic papers produced recently on the topic of coral reef decline
UNEP	Detailed and specific suggestions on how to update the current coral bleaching work plan but also recognition	<u>*Predicting reef responses to CC and OA, measuring reef resilience, monitoring*</u> 1. Further development of methods and tools that generate predictive data on CC and OA

	of the many knowledge and management gaps that still currently exist, particularly with regard to the assessment and success of management efforts designed to enhance resilience	stress and impacts on coral reefs, at spatial and temporal scales that are relevant to coral reef management and planning. 2. Development a deeper understanding of factors that confer coral reef resilience to increasing sea surface temperatures, altered weather patterns and extreme events, ocean acidification, and possible cumulative impacts and feedbacks. Continued efforts to: a. Identify and quantify natural/biophysical characteristics that confer resilience (ecology of the coral reef including microbial ecology; temperature variability and anomalies; oceanography and bathymetry…) b. Identify naturally resistant or resilient areas, e.g. where natural conditions and stress regimes create lower vulnerability; c. Identify particularly vulnerable areas, e.g. where SST, OA and weather changes are likely to proceed at higher rates; d. Identify and quantify direct anthropogenic drivers of resilience (land- as well as sea-based) and how these interact with or reinforce CC and OA. 3. Development of indicators and methods for resilience assessment that are robust, broadly applicable and policy/management relevant, and lend themselves to use in common planning and decision support frameworks. These need to encompass consideration of intrinsic ecosystem properties as well as external forcing; a variety of data sources including field surveys, remotely sensed data and secondary data; use of time series data as well as one-off assessment; and issues related to spatial resolution and scaling. Indicators also need to be prioritized based on criteria including direct relevance to planning and management decisions; scientific basis; accuracy/precision; ease of measurement; availability and cost of data; and spatial and temporal resolution and scalability. 4. Continued emphasis needs to be placed on monitoring to track change over time, including impacts of direct anthropogenic stress and, as possible, impacts from CC and OA. This may require indicator as well as methodological development and could include: a. Collating existing long-term coral reef ecological data for comprehensive analysis, establishment of better baselines, identification of critical factors controlling coral reef status and trends, development of planning and management recommendations and further development of coral reef monitoring practices and state of the coral reef reporting through collaboration between the Global Coral Reef Monitoring Network (GCRMN), IUCN, UNEP and Regional Seas Conventions and Action Plans, following the method piloted in 2013 in the Caribbean by GCRMN; b. Based on detailed regional studies, development and integration of new variables in

		regional reef monitoring as needed, and strengthening regional coral reef status and outlook reporting utilizing regional intergovernmental mechanisms such as the RSCAP; c. Enhancing access to existing monitoring data for coral reef planning at multiple levels. 5. Develop interactive mapping tools on the state of coral reefs, including e.g. vulnerability, factors that confer resilience, and integration with data on management efforts including MPAs, management effectiveness data etc. 6. Specific priorities in relation to OA include: a. establishing better and more cost-effective long term monitoring in coral reef areas; b. finer scale predictions in coral reef areas and on the scale where coral reef ecological processes occur; c. more detailed understanding on how OA impacts interact with CC as well as direct anthropogenic stress, and their system-wide impacts, including potential shifts in coastal ecosystem composition, habitat distribution or extent etc.; d. understanding potential for adaptation to OA, rates and thresholds as well as potential to facilitate adaptation to or buffering of OA through management actions. *Managing reefs for ecological resilience and sustained ecosystem service provision* 7. Robust, systematic and cost-effective approaches for resilience-based coral reef planning and management are required that enhance prospects for recovery from damage and adaptation to CC, OA and other stress, and that can be applied in a variety of geographic and institutional settings. 8. Tools that help predict or anticipate change and implications of change (e.g. SST, OA, weather and extreme events and importantly their interaction) at scales that are relevant to planning and management (regional, national, subnational). 9. Increased focus on the relationship between coral reef ecosystem state and ecosystem service provision. Understanding possible synergies or tradeoffs between managing coral reefs for resilience in the face of CC and OA and managing them for service provision. 10. Continued development of management strategies that enhance recovery from damage, such as spatial approaches (MPA network planning, fishery refugia, multisectoral MSP); facilitating restoration through stress mitigation or appropriate reef restoration activities. This includes e.g. a. Ensuring healthy, resistant and resilient reefs are protected as no-take MPAs with adaptive management arrangements that minimise anthropogenic threats (including

		land-based threats). Such sites are critical reference points as well as sources of recovery of surrounding areas; b. Develop, adopt and implement management strategies and plans for coral reefs outside conservation areas that prevent degradation of reefs and promote resilience; c. Increase understanding of the implications of inter- and intra-regional connectivity for management planning; d. Based on existing science and guidance as well as ongoing efforts, explore through research and trials appropriate reef restoration options that can be used in combination with stress reduction and other management interventions to enhance prospects for recovery and adaptation. This must include coherent and reliable approaches to ensure efficacy and cost-effectiveness of restoration activities (see e.g. ICRI Resolution on Artificial Coral Reef Restoration and Rehabilitation, 2005). 11. Develop networks or communities of practice for coral reef management in the face of CC and OA, focusing on e.g. coral reef conservation, modelling, restoration, economic valuation, education and outreach, public-private partnerships, governance etc., where relevant building on the networks and committees of the International Coral Reef Initiative (ICRI) as well as regional entities such as the Coral Reef Task Forces or Regional Activity Centres of Regional Seas Conventions and Action Plans. 12. Further analysis of implications of CC and OA for the management of interconnected systems such as coral reefs, seagrass beds and mangroves, as well as economic and social impacts and implications for development planning. *<u>Social and economic considerations</u>* 13. Develop a better understanding of coral reef dependence and vulnerability of reef dependent people and industries, drawing on existing indicators and protocols for assessing social and economic vulnerability and adaptive capacity and ensuring they are appropriate in a coral reef context. This may include: a. Further analysis of how livelihood strategies as well as business sectors are supported by or influence coral reef resilience, and how they stand to be influenced by reef degradation; b. Further analysis of social resilience including the factors (environmental, human, financial, political…) that compel or enable adoption of new strategies that are not reef dependent or do not negatively influence reef resilience; c. Development of necessary analytical and planning tools for adaptation and development planning, as needed. 14. Strengthen economic valuation of the impacts of CC and OA on coral reefs, including in

		particular effects on livelihoods and food security among coastal communities. While economic valuation methods are well developed their application and use in coral reef areas to support decision-making in relation to development, adaptation or management planning as well as financing of reef management require considerable effort. This includes broadening of the financial basis for supporting coral reef protection, management, adaptation and development, beyond the public sector and traditional donors to also include the private sector and use of economic instruments. 15. Promote and support adaptation and development planning in coral reef areas that integrates sustainable use of coral reef ecosystem services and enhances reef health while building social resilience. This may include to: a. Identify and address improvement needs in existing vulnerability reduction and adaptation strategies in coral reef areas; b. Using available approaches to strengthening social and economic resilience of communities and business sectors in coral reef areas; c. Further strengthen use of ecosystem-based adaptation approaches, including through further development of tools and approaches, based on existing materials and ongoing efforts, capacity building and demonstration implementation, taking into consideration technical and financial capacities as well as governance and cultural context; d. Identify particularly vulnerable areas, communities and sectors (e.g. SIDS, reef fishery dependent people), and develop appropriate approaches for adaptation to or accommodation of CC and OA impacts.
USA	General and specific comments on the current work plan	1. Re-organise and simplify the document to cut down on redundant points 2. Recommendation to continue the funding of research programmes already in place to predict or observe bleaching – avoid re-direction of funding to new programmes to the detriment of existing ones 3. Recommendation of programmes to help reefs recover from coral loss after bleaching e.g. coral nurseries 4. A section on thermal stress and coral disease is needed in the background document
WWF	Series of resources commissioned and produced on behalf of the Coral Triangle Initiative on Coral Reefs, Fisheries and Food Security (CTI-CFF)	1. Climate Change Adaptation for Coral Triangle Communities: A Guide for Vulnerability Assessments and Local Early Action Planning (LEAP Guide) 2. Coral Triangle Initiative on Coral Reefs, Fisheries and Food Security Region Wide Early Action Plan for Climate Change Adaptation for the Nearshore Marine and Coastal Environment and Small Island Ecosystems (REAP-CCA) 3. Designing Effective Locally Managed Areas in Tropical Marine Environments - A

		Facilitators Guide to Help Sustain Community Benefits Through Management for Fisheries, Ecosystems and Climate Change 4. Designing Marine Protected Area Networks to Achieve Fisheries, Biodiversity and Climate Change Objectives in Tropical Ecosystems: A Practitioners Guide. 5. Coral Triangle MPA System Framework and Action Plan. 6. Full Report on the Biophysical Principles for Designing Resilient Networks of MPAs to Integrate Fisheries, Biodiversity and Climate Change Adaptation Objectives in the Coral Triangle 7. The CTI-CFF Regional Plan of Action 8. The CTI-CFF individual country National Plans of Action

Annex 4c. Existing Recommendations for consideration compiled from current global frameworks and recent reports

(ICRI Framework for Action 2013; Reefs at Risk Revisited (WRI, 2011); GLOBE Action Plan for Coral Reefs (GLOBE International, 2010)

Main Area	Recommendation	Source
Science and Monitoring	1. Encourage Governments, resource managers, scientists, the private sector and civil society to participate in initiatives such as GCRMN and SocMon as a way to strengthen monitoring efforts to document status and trends of coral reefs, dependent communities and sectors 2. Develop, share and promote best practice tools, protocols and methodologies for reef monitoring and encourage their adoption through regional intergovernmental mechanisms and uptake by governments as well as a wide range of stakeholders to broaden the spatial coverage on monitoring and strengthen regional data collection networks 3. Seek practical ways to integrate environmental, management and socioeconomic date to better understand the primary factors responsible for coral reef decline and how these stresses may be more effectively reduced 4. Encourage the development of a statistical framework that enables adequate analysis of heterogeneous, spatially disparate collections of short time series data to strengthen regional or global reporting of coral reef status and trends 5. Encourage research and monitoring of related ecosystems, particularly seagrass beds, mangroves and tidal wetlands 6. Disseminate information and results to coral reef and related ecosystem managers on a regular basis to help guide policy and actions 7. Promote the application of monitoring and evaluation activities for implemented management programmes to determine the effectiveness	ICRI Framework for Action 2013
Integrated Management	1. Encourage Governments to develop and implement legislation and integrated management programmes, including through Marine Spatial Planning approaches to ensure all known threats to coral reefs are systematically addressed 2. Encourage Governments to conduct ecosystem-based strategic assessments of pressures and impacts, including cumulative impacts and their effect on ecosystem service provision and value, and assessment of management to deal with impacts 3. Promote and replicate successes in integrated management, including new technologies 4. Encourage the mainstreaming of sustainable coral reef management into the activities of relevant international agencies, programmes and conventions, financial institutions and the donor community 5. Encourage effective regulation and management of trade in marine wildlife and products 6. Promote the review and reformulation of existing domestic legal instruments that support the sustainable management of coral reefs and their related ecosystems 7. Implement regular assessments of management effectiveness for all approaches to managing coral reefs and related ecosystems, including the assessment of all components of the management process 8. Engage all stakeholders in relevant elements of management effectiveness assessment and use the outcomes of these assessments to adapt and improve future management action	ICRI Framework for Action 2013

Management Coordination	1. Integrate national coral reef management plans into existing national mechanisms such as National Adaption Programmes of Action (NAPAs), National Biodiversity Strategies and Action Plans (NBSAPs) and broader national priorities such as poverty reduction and sustainable development strategies (including those for population and health, coastal development and food security). For example, NBSAPs should include coral reef plans with specific targets and be more legally binding; 2. Increase national representation and participation of coral reef countries in the UNEP Regional Seas Programme and in ICRI so that all nations are ICRI members and take an active role; 3. Ratify all relevant regional Conventions and Protocols related to the protection of the marine environment. For most coral reef regions there are a number of Conventions and Protocols related to environmental protection, pollution (including land-based sources), protected areas and wildlife; 4. Review fishery management plans, identify where shortfalls could be addressed and why fishery regulations are often ignored or poorly implemented; 5. Designate an organisation, initiative or new steering group to provide technical support to national focal points to integrate the work plan recommendations into existing or new national coral reef management plans as appropriate, and to provide global coordination support to manage and track progress; 6. Establish strong networks to share best practise at a range of scales between large-scale regional initiatives and between different disciplines in research, management and policy; 7. Develop a clustered approach to co-ordination for implementation and management involving governments, all relevant regional management bodies and main research and management organisations involved in coral reef conservation; 8. Provide sufficient support to ensure national, and later, regional coral reef task forces are in place and are maintained subsequently; 9. Establish national and regional reporting programmes, with accessible information storage mechanisms, for the exchange of coral reef datasets to encourage timely reporting to key global assessment processes supported by international conventions.	GLOBE Action Plan for Coral Reefs
Capacity Building	1. Support and facilitate technical collaboration and voluntary information sharing on all aspects of sustainable management of coral reefs and related ecosystems, including through all relevant national or regional networks and mechanisms 2. Encourage cooperation and collaboration amongst countries to set up networks of MPAs or LMMAs 3. Investigate, support and encourage transboundary management of large MPAs through bilateral or multilateral cooperation and pooling of resources 4. Improve access to training in financial, administrative and technological topics to enable improved collaboration, information sharing and management 5. Continue to encourage and support public awareness and education programmes, and awareness raising campaigns at multiple levels (subnational, national, regional, global) 6. Encourage reef stewardship through partnerships between Governments, communities and the private sector, and encourage community-based management approaches	ICRI Framework for Action 2013
Building Capacity for Effective	1. Synthesise existing knowledge to complete an assessment of current national capacity and the increase in logistical and technical capacity required for the level of management and enforcement needed to meet national or regional objectives; 2. Review existing national management structures for fisheries and conservation management to identify areas where management	GLOBE Action Plan

Management	could be improved; 3. Compile existing training manuals, guidance materials and other "how to" knowledge products addressing priority management issues through a 'one-stop shop' website for coral reef management agencies and disseminate hard copies to those without web access; 4. Initiate and support efforts to translate key coral reef management training literature into different languages to increase accessibility to local resource managers and government agencies; 5. Provide and increase support to existing national, regional and global networks and mechanisms for knowledge and information exchange for improved intra-national and trans-boundary cooperation 6. Implement an international training programme in priority management tools and interventions, incorporating existing regional or international initiatives, that will conduct regional workshops biannually in regional nodes and train enough local resource managers to meet the management and enforcement needs of each region; 7. Increase national technical capacity to manage coral reefs through degree level training in multidisciplinary studies (e.g., ecosystem-based management, marine and social sciences) and the recruitment of matriculated staff into management positions with on the job training; 8. Develop mechanisms to feed science into management including scientific advisory committees with accessible experts, identification of priority information needs for management, regular policy briefs with management recommendations and newsletters with the latest learning, facilitated discussions between scientists and decision makers; 9. Increase logistical capacity (monitoring and communication infrastructure, equipment, etc.) to meet national needs for required types of management and enforcement (top-down or bottom-up); 10. Scale up, support and build upon programmes of regional cross-visits for local resource managers and government agencies; 11. Facilitate the participation of resource and conservation managers in cross-discipline training at the local and national level; 12. Enable and increase levels of community-based management in areas with minimal capacity and infrastructure, backed by co-management agreements with local government and NGOs to set up community-led management and enforcement programmes with appropriate training and support	for Coral Reefs
Improving Governance	1. Implement effective enforcement systems for MPA and fisheries management locally, nationally and regionally with appropriate penalties to deter further infringements and full stakeholder involvement at the local level to ensure community support and ownership. Ensure all enforcement chain components are strong (detection, arrest, prosecution and sanctions), that there is a sound regulatory framework and sufficient stakeholder awareness efforts regarding regulations; 2. Establish international collaboration and regional agreements to reduce IUU fishing in the Exclusive Economic Zones of coral reef nations by: a. eliminating markets for illegally caught fish through strengthening market-based measures to effectively control the trans-boundary movement of products; b. coordinating MCS and enforcement activities including intelligence gathering on illegal fishers; 3. Establish personnel and review mechanisms within government agencies that have coral reef and fisheries specific mandates, in order to eliminate barriers to progression;	GLOBE Action Plan for Coral Reefs

	4. Hold local, provincial and national, governments or leaders accountable for commitments to local, regional and global initiatives; 5. Support the establishment of regional web-based monitoring and reporting systems to assess coral reef ecosystem health and make governance more accountable; 6. Increase devolution of management responsibility to local communities using existing or new local legislation, particularly for fisheries and MPAs, especially for remote regions and where capacity is low, within national guidelines and under national supervision. 7. Increase federal cohesion for fragmented nation states (politically and geographically) to facilitate the development of national management plans; 8. Establish regional commissions to support management of discrete but trans-boundary coral reef ecosystems; 9. Clarify legislation and responsibilities for management of marine resources and MPAs between different sectors and levels of government to avoid overlaps and inter-sectoral disputes.	
Threat Mitigation: Marine and Coastal Development	1. Protect coastal habitats (coral reefs, mangroves and seagrass beds) from dredging and landfilling activities 2. Establish and honour coastal development setbacks (restricting or limiting coastal development within a specified distance from the coast) 3. Develop coasts with nature in mind – ensure mitigation measures are in place and effective during construction, prevent landfilling near reefs and the extraction of corals or sand from or near reefs 4. Manage wastewater to maintain coastal water quality and reduce runoff of nutrients and other pollutants 5. Link terrestrial and marine protected areas to reduce multiple stressors such as overfishing, pollution and sedimentation 6. Implement sustainable tourism practices including following local regulations, managing marine recreation, sustainable sourcing, engaging local communities, educating tourists, following best practice and raising standards for environmental protection	Reefs at Risk Revisited (2011)
Threat Mitigation: Watershed-derived sedimentation and pollution	1. Manage watersheds to minimize nutrient and sediment delivery 2. Manage livestock waste to reduce nutrient and bacterial pollution of coastal waters 3. Control grazing intensity to manage erosion, particularly on remote islands with feral grazers 4. Retain and restore vegetation through the use of terrestrial protected areas 5. Control runoff from mining operations to minimize sediment and pollutants entering nearshore waters	Reefs at Risk Revisited (2011)
Threat Mitigation: Marine-based sources of pollution and damage	1. Improve waste management at ports and marinas by installing or expanding waste disposal and treatment facilities 2. Control ballast discharge at sea and in ports to minimise the uptake and establishment of invasive species 3. Designate safe shipping lanes and boating areas to minimise physical damage to reefs and protect critical habitats 4. Manage offshore oil and gas activities to prevent accidents and spillages through risk mitigation and adequate emergency response plans to minimise impacts 5. Use MPAs to protect reefs, related ecosystems and adjacent waters from shipping impacts	Reefs at Risk Revisited (2011)
Threat	Phase 1	

Mitigation: Unsustainable and destructive fishing	1. Increase enforcement capacity to implement existing bans on destructive fishing practices; 2. Implement national stock assessments of keystone species and key reef fish and invertebrate species targeted by commercial and artisanal fisheries, and by the aquarium and curio trades; 3. Remove harmful subsidies to fisheries and reduce fishing effort on over-exploited stocks; 4. Adopt and implement the FAO Code of Conduct for Responsible Fisheries at the national level; 5. Conduct socio-economic analyses to determine the value of commercial and artisanal reef fisheries and aquaculture to local economies and society as well as wider stakeholders; 6. Conduct vulnerability assessments to identify vulnerable groups and underlying social and economic drivers of overfishing. Phase 2 7. Identify viable and appropriate options for sustainable livelihood activities in reef dependent regions. 8. Ban all destructive fishing practices and ensure there is sufficient management capacity to effectively enforce bans through local and national legislation; 9. Revise existing or develop new regulations to implement sustainable ecosystem-based fisheries management plans locally (using community-based approaches) and nationally (following FAO guidelines) with effective enforcement; 10. Develop and implement regulations for threatened species of fishes and invertebrates and plan for their recovery using species-specific national action plans; 11. Adopt sustainable ecosystem-based management approaches, including setting targets and identifying indicators for sustainable fishery operations, and monitor these targets; 12. Implement programmes to diversify and enhance livelihoods in reef dependent regions, based on sustainable (ecologically, socially, economically) activities (both reef-based and other alternatives) supported through microfinance and capacity building; 13. Where necessary, implement policies to support local reef fish food security through market and trade measures.	GLOBE Action Plan for Coral Reefs Note: the GLOBE Action Plan was designed as a ten year plan with recommended activities undertaken in two main phases over that time period
Manage Watersheds, Water Quality and Reduce Pollution	Phase 1: 1. For all major watersheds linked to coral reefs identify the level of management required to draw up integrated watershed management policies; 2. Identify natural and legal watershed boundaries and determine what nations, sectors or communities have legal jurisdiction over these areas; 3. Identify the main point and diffuse sources of all pollutants on coral reefs; 4. Develop legislation to reduce the levels of all major pollutants by 50% over a 10 year period 5. Set up comprehensive national monitoring programmes for riverine and coastal water quality; 6. Redefine international shipping lanes to avoid coral reef areas and improve the monitoring of merchant vessels in national waters; 7. Develop national management strategies for large-scale marine pollution incidents such as oil leaks; 8. Support the establishment and implementation of polluter pays legislation for coral reefs; 9. Establish best practice standards for mariculture operations conducted in or adjacent to coral reefs; 10. Ratify and adopt robust implementing legislation for the Stockholm Convention on Persistent Organic Pollutants, the Global	GLOBE Action Plan for Coral Reefs

	Program of Action for the Protection of the Marine Environment from Land-based Activities (non-binding global agreement), and the International Convention for the Prevention of Marine Pollution from Ships (MARPOL); 11. Ratify regional Conventions and Protocols for the protection of the marine environment against land-based pollution. Phase 2: 12. Implement watershed management policies involving afforestation, runoff-reduction, sustainable agriculture methods, reduction of pesticide, herbicide, fertiliser and other agrochemical use; 13. Set up trans-boundary watershed management bodies; 14. Declare, through the International Maritime Organisation, coral reef regions of outstanding ecological value as Specially Sensitive Areas, prohibiting transport of hazardous cargo through these waters; 15. Encourage all coral reef states to ratify and implement the IMO Ballast Water Convention with support from the GloBallast Partnership; 16. Implement national management strategies for large-scale marine pollution incidents; 17. Implement best practice standards for mariculture operations conducted in coral reef or adjacent environments; 18. Ensure that water quality control and coastal zone building and industry regulation are integral parts of sustainable coastal planning legislation both locally and nationally that require Environmental Impact Assessments (EIAs) which are: a. Conducted for all coastal development with a full peer-review; b. Followed through so that all development projects identified by EIAs to have a negative impact on coral reefs are refused planning permission, relocated, or provide sufficient mitigation for any environmental damage caused.	
Increase MPA Coverage and Effectiveness	Phase 1 1. Conduct national and regional assessments of tropical MPA management effectiveness, coordinated through existing projects and in areas that are currently unmonitored; 2. Implement existing national legislation that support MPAs, including locally managed marine areas (LMMAs), and improve MPA management so that marine paper parks are converted into effective MPAs that meet their management and broader ecological objectives; 3. Identify the increase in MPA coverage required at the national level to meet specific targets; 4. Ratify regional Conventions and Protocols concerning protected areas and protection of marine natural resources; 5. Ensure existing legislation that supports MPAs is understood and supported by user communities and stakeholders. Phase 2: 6. Support collaboration between existing regional coral reef initiatives to help meet regional or global targets; 7. Implement national plans to increase no-take MPA coverage of coral reef area to a set target; 8. Ensure MPAs and MPA Networks protect biologically meaningful regions of known value to fisheries (such as spawning aggregation sites), conservation and communities; 9. Integrate ecological and social resilience factors into MPA network designation and management to help 'future proof' them against climate change effects;	GLOBE Action Plan for Coral Reefs

	10. Ensure that national legislative frameworks recognise the legitimacy of community-based marine protected areas and their management systems and devolve sufficient authority for effective community co-management of resources	
Environmental Education and Awareness	1. Identify and fill gaps in environmental educational materials - develop an international meta database of existing coral reef education materials and awareness raising material; 2. Assess local knowledge and levels of school attendance and completion prior to development of environmental education and awareness programmes; 3. Develop and implement teacher training programmes to ensure the delivery of the revised curricula; 4. Investigate ways to increase the uptake of national curricula for children of tropical coastal communities e.g. subsidising education for the poorest members of society. 5. Integrate information about coral reefs, environmental conservation and sustainable ecosystem-based management into existing curricula at all levels of national education systems; 6. Ensure universities and research institutes in coral reef nations offer undergraduate courses in tropical marine biology and conservation and fisheries management; 7. Establish national scholarships for students to pursue undergraduate degrees or shorter applied training courses in tropical marine biology, and conservation and fisheries management 8. Develop and implement targeted education and awareness campaigns for both children and adults on how communities and stakeholders can increase coral reef resilience by reducing direct threats	GLOBE Action Plan for Coral Reefs
Finance	1. Establish a cross-cutting working group involving government departments (including fisheries, environment, development and finance) to estimate the cost of a national coral reef action plan; 2. Ensure all coral reef states have the technical and logistical capacity to secure and maintain long-term sources of funding such as climate change adaptation funds; 3. Strongly support the implementation of comprehensive and diverse financing schemes for coral reefs. Explore opportunities for innovative financing such as the use of environmental bonds linked to Payment for Ecosystem Services (PES) initiatives, creation of trust funds, development of biodiversity offsets and compensation, green taxes and fees and new market mechanisms to ensure adequate annual cash flow to meet conservation needs effectively and maintain investments into the future; 4. Remove key bottlenecks and improve access to funding through capacity building and streamlining of funding processes; 5. Encourage smaller states to join forces in regional initiatives to seek funds and implement management projects; 6. Demonstrate the economic importance of coastal fisheries to communities and government and work towards encouraging countries to recognize the high value of their marine resources to the local economy and local population; 7. Improve the communications and management capability of government departments to ensure funding timelines are followed and deadlines are met.	GLOBE Action Plan for Coral Reefs

Annex 5. Priority Actions to Achieve Aichi Biodiversity Target 10 for Coral Reefs and Closely Associated Ecosystems[390]

1. Pursuant to decision XI/18 (paragraph 13 of Section A), this proposal on the following action items was prepared to update the specific work plan on coral bleaching (appendix 1 of annex I to decision VII/5) through an addendum to the work plan, taking into account the submissions[391] made by Parties, other Governments and relevant organizations in response to the notification 2013-108 (Ref No. SCBD/SAM/DC/JL/JG/82124, issued on 26 November 2013).

2. As such, it builds on the existing specific work plan (appendix 1 of annex I to decision VII/5) and is in line with operational objective 2.3 of the elaborated programme of work on marine and coastal biological diversity (annex I to decision VII/5) as well as the *Elements of a work plan on physical degradation and destruction of coral reefs, including cold water corals* (appendix 2 of annex I to decision VII/5).

3. It will contribute to the achievement of Aichi Biodiversity Target 10: *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*. It will also facilitate achieving Aichi Biodiversity Targets 6 and 11.

4. This proposal aims to address the urgent need to consolidate and further strengthen current efforts at local, national, regional and global levels to manage coral reefs as socio-ecological systems undergoing change due to the interactive effects of 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, land-based and sea-based pollution, coastal development, tourism and recreational use, etc). The proposal recognizes that increased sea temperature also increases risks to coral reefs from pathogens and that there are additional interactions, often synergistic, among all these stressors.

5. In particular, the proposal focuses on actions that will help:

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

(ii) Enhance the resilience of coral reefs and closely associated ecosystems through ecosystem-based adaptation to enable the continued provisioning of goods and services;

(iii) Maintain sustainable livelihoods and food security in reef-dependent coastal communities and provide for viable alternative livelihoods, where appropriate;

(iv) Increase the capability of local and national managers to forecast and plan proactively for climate risks and associated secondary effects, applying ecosystem-based adaptation measures; and

(v) Enhance international and regional cooperation in support of national implementation of priority actions, building upon existing international and regional initiatives and creating synergies with various relevant work within the Convention.

6. To this end, Parties should develop ***National Coral Reef Action Strategies,*** or equivalent policies, strategies, plans or programmes, consolidating existing national initiatives, as platforms to mobilize inter-agency and cross-sectoral partnerships, as well as close coordination among national and sub-national governments and local communities. National strategies should be complemented by

[390] Draft addendum to update the specific workplan on coral bleaching in the programme of work on marine and coastal biodiversity (appendix 1 of annex I to decision VII/5)
[391] Compilation of submissions is provided in the background document (UNEP/CBD/SBSTTA/18/INF/7)

regional strategies to address common stressors. National and regional strategies could include elements discussed in this proposal.

7. Recalling paragraph 4 of decision XI/20, Parties are also urged to advocate and contribute to effective CO_2 emission reductions, by reducing anthropogenic emissions by sources and by increasing removals by sinks of greenhouse gases under the United Nations Framework Convention on Climate Change, noting also the relevance of the Convention on Biological Diversity and other instruments[392].

Parties are encouraged to undertake the following actions:

8. Strengthen **existing sectoral and cross-sectoral management** to address local stressors, such as overfishing, destructive fishing practices, land- and sea-based pollution, coastal development, tourism and recreational use:

8.1 **Sustainably manage fisheries** for coral reefs and closely associated ecosystems

a. Conduct comprehensive national assessments, including retrospective analyses, of fisheries, including commercial fisheries as well as small-scale fisheries, to determine the level of unsustainable fishing practices;

b. Promote community-based measures to manage fisheries sustainably;

c. Introduce new, or strengthen existing, national regulations and management measures, including the application of the ecosystem approach to fisheries (EAF), to address unsustainable fishing practices, including overfishing, IUU fishing and destructive fishing practices, and ensure effective enforcement, using relevant FAO guidelines[393];

d. Identify and implement gear-based management measures for multispecies reef fisheries to reduce unsustainable fishing practices (e.g. fishing closures, marine reserves, marine and coastal protected areas, locally managed marine areas, etc);

e. Sustainably manage populations of key reef fish and invertebrate species targeted by export-driven fisheries or by the aquarium and curio trades, through measures including the setting of targets, identifying indicators for sustainable fishery operations, and establishing monitoring programmes to track fishery condition and management outcomes;

f. Prioritise the recovery and sustainable management of herbivorous reef fish populations, in particular species with key ecological functions.

8.2 **Manage land-based and sea-based sources of pollution**

a. Identify all sources of significant land-based and sea-based pollutants affecting coral reefs and set up comprehensive national/local water quality monitoring programmes;

b. Implement comprehensive watershed and coastal water quality management plans that reduce all major types of pollution, especially those causing eutrophication, sublethal effects on corals, lower seawater pH or other negative impacts;

c. Implement watershed management policies that address reforestation; erosion control; runoff-reduction; sustainable agriculture and mining; reduction of pesticides, herbicides, fertiliser and other agrochemical use, and waste-water management and treatment;

d. Prioritise the reduction of nutrient and sediment pollution from watersheds, and the management of pollution ‘hotspots’ (areas that produce the highest pollution loads);

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[392] http://www.cbd.int/doc/decisions/cop-11/cop-11-dec-20-en.pdf

[393] FAO Code of Conduct for Responsible Fisheries, FAO guidance and tools on Ecosystem Approach to Fisheries (EAF)

e. Implement best practice standards for mariculture, tourism or recreational operations conducted in coral reefs or adjacent environments;

8.3 **Increase spatial coverage and effectiveness of marine and coastal protected and managed areas** in coral reefs and closely associated ecosystems

a. Improve the management of existing areas protecting coral-reefs and related ecosystems, including mangrove and seagrass habitats, so that they meet their management and broader ecological objectives;

b. Prioritise the full protection of existing healthy, resilient and resistant coral reefs through the development and effective management of marine and coastal protected areas or as part of locally managed marine areas (LMMAs);

c. Integrate ecological and social resilience factors of coral-reefs and closely associated ecosystems into MPA network design and management;

d. Prioritize the enhancement of conservation and management measures for coral-reefs and closely associated ecosystems in areas described to meet the scientific criteria for ecologically or biologically significant marine areas (EBSAs)[394];

e. Improve the design of coral reef related MPA networks to improve the ability of coral reefs to cope with future climate and ocean change effects;

f. Encourage and support community-based marine managed areas, in line with national policies for marine and coastal management, national or legislative frameworks or other measures;

8.4 **Manage coastal development** to ensure that the health and resilience of coral reef ecosystems are not adversely impacted

a. Prioritize the protection of coral reef ecosystems in coastal development and land- and sea-use management in coastal areas, through the application of area-based management measures, such as marine and coastal protected areas and/or marine spatial planning;

b. Ensure that consideration of long-term climate related impacts are integrated into coastal development and land- and sea-use planning

c. Manage impacts from large-scale tourism development and its consequent habitat loss and alteration in coral reefs and closely associated ecosystems, and support sustainable tourism by providing socio-economic incentives and empowering coastal community for eco-tourism operation.

9. Identify and apply measures to **improve the adaptive capacity of coral reef-based socio-ecological systems within the local context**, which will ensure sustainable livelihoods of reef-dependent local communities and provide for viable alternative livelihoods:

a. Develop and apply socio-ecological vulnerability monitoring and assessment protocols in coral reef regions, including socio-ecological vulnerability maps and identify highly vulnerable areas for prioritizing management actions and to inform planning and management as part of a resilience- and ecosystem-based approach;

[394] In total, 88 of the areas described so far to meet the EBSA criteria address coral reefs by the regional workshops convened by the CBD Secretariat in the following regions: Western South Pacific (13 areas); Wider Caribbean and Western Mid-Atlantic (16 areas); Southern Indian Ocean (24 areas); Eastern Tropical and Temperate Pacific (5 areas); North Pacific (4 areas); South-Eastern Atlantic (11 areas); North-west Atlantic (3 areas); and Mediterranean (12 areas).

b. Prioritize poverty-reduction programmes for reef-dependent communities, to promote livelihood strategies that are socially and ecologically resilient and to reduce poverty-induced overexploitation of reef ecosystems

c. Develop and implement socio-economic incentives to encourage coastal communities to play a central role in conservation and sustainable use of coral reefs and closely associated ecosystems, including through, *inter alia,* the use of tax benefits or other economic incentives for sustainable fishing, conservation agreements that rewards users who forego unsustainable activities, and community-based conservation trust funds supported by fees from ecotourism and fines for unsustainable use;

d. Apply ecosystem-based adaptation (EbA) tools and indicators for use in coral reef regions and incorporate EbA principles and practices into coral reef management;

e. Incorporate social drivers of coral reef degradation such as projected human population increase and food security needs, into forecasts of multiple stressor impacts.

10. Establish or further enhance **integrated management and coordination mechanisms** to effectively address multiple stressors to coral reefs, including through the implementation of national coral reef action strategies/plans, as described above:

a. Integrate ecosystem-based approaches for management and adaptation, into development planning and legislative frameworks at the local, sub-national and national level, and identify and remove barriers to implementation;

b. Apply cross-sectoral, inter-agency area-based management tools, including watershed and marine spatial planning approaches, to effectively reduce local stressors from multiple sources and mitigate their impacts to coral-reefs and closely associated ecosystems;

c. Incorporate watershed-based management approaches into reef management through the application of an integrated land-sea planning approach;

d. Integrate national coral reef action strategies/plans into existing national mechanisms[395] and broader national priorities such as poverty reduction and sustainable development strategies (including those for population and health, coastal development and food security);

e. Set in place an inter-agency steering committee at national and/or subnational levels, as appropriate, to coordinate, support and monitor the implementation of national coral reef action strategies/plans;

f. Empower local communities in reef-management, particularly in remote regions or where capacity is low, by providing necessary resources and capacity building, and devolution of management responsibilities in line with national/subnational management guidelines

11. With the support of existing global (e.g. ICRI) and regional initiatives, and, as appropriate, the Executive Secretary, Parties should collaborate to strengthen international and regional cooperation in support of national implementation of priority actions, as described above, through facilitating **information exchange, knowledge sharing, awareness building, capacity building, sustainable financing, and research and monitoring:**

11.1 Education, awareness and capacity building

a. Develop or expand national and regional networks of coral reef managers of all types to promote the exchange of information, knowledge and best practices;

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[395] National Adaptation Programmes of Action (NAPAs), National Biodiversity Strategies and Action Plans (NBSAPs)

b. Develop a global coral reef portal linked to the CBD website and existing global and regional initiatives to facilitate technical collaboration and voluntary information sharing on all aspects of sustainable management of coral reefs and related ecosystems;

c. Facilitate wide implementation of existing training programmes on priority tools and approaches for coral reef management and develop additional training materials in support of implementing priority actions;

d. Integrate information about coral reefs, environmental conservation and ecosystem-based management into existing curricula at all levels of national education systems;

e. Develop and implement targeted education and awareness campaigns for diverse stakeholders on how communities and stakeholders can increase coral reef resilience by reducing the direct threats facing coral reefs;

f. Provide training and other capacity development opportunities in support of community-based management initiatives that increase socio-ecological resilience at the local or sub-national level.

11.2 Sustainable financing

a. Secure, through national sectoral budget systems (e.g. fisheries, environment, climate change adaptation fund, coastal development, tourism, etc.), the necessary financial resources to implement national coral reef action strategies;

b. Apply comprehensive and diverse financing schemes for coral reef management, and explore opportunities for innovative financing to support local implementation;

c. Remove key bottlenecks and improve access to funding through capacity building and streamlining of funding processes;

d. Demonstrate and increase awareness of the socio-economic importance of coral reefs and associated ecosystems to local and national economies.

11.3 Research and monitoring programmes

a. Research on multiple stressor interactions and effects on coral reefs at the species, population and ecosystem level to identify the most damaging local stressors affecting coral reefs ecosystems at the site-based level,;

b. Research to support a resilience-based approach to coral reef management that is embedded within an integrated ecosystem-based management framework;

c. Develop and implement early warning systems for major reef health incidents such as bleaching or disease events, tropical storms and flood plumes;

d. Develop water chemistry monitoring programmes for coastal and inshore waters to determine the natural spatial and temporal variability of ocean carbon chemistry, and detect trends;

e. Research on the sensitivity of species, habitats and communities within coral reefs to changes in ocean carbon chemistry and whether there is a potential for adaptation to ocean acidification in reef organisms;

f. Incorporate into the framework of management actions a set of broadly applicable and robust indicators for resilience and stressor assessment, and use these indicators to support regular assessments of management effectiveness;

g. Further develop ecological and socio-economic criteria and variables for use in vulnerability assessments in coral reef regions, building on existing work; and

h. Develop mapping tools that combine data on the current status of coral reefs, management efforts and their effectiveness with predictive modelling of stressor effects to generate future scenarios of reef condition and ecosystem service provision.
