OCEAN ACIDIFICATION IMPACTS ON CORAL REEFS
"From Sciences to Solutions"

CONCLUSIONS OF THE FOURTH INTERNATIONAL WORKSHOP ON THE ECONOMICS OF OCEAN ACIDIFICATION

Oceanographic Museum of Monaco - 15-17 October 2017

CREDIT: EMMA CAMP

HSH PRINCE ALBERT II - © PALAIS PRINCIER - ERIC MATHON

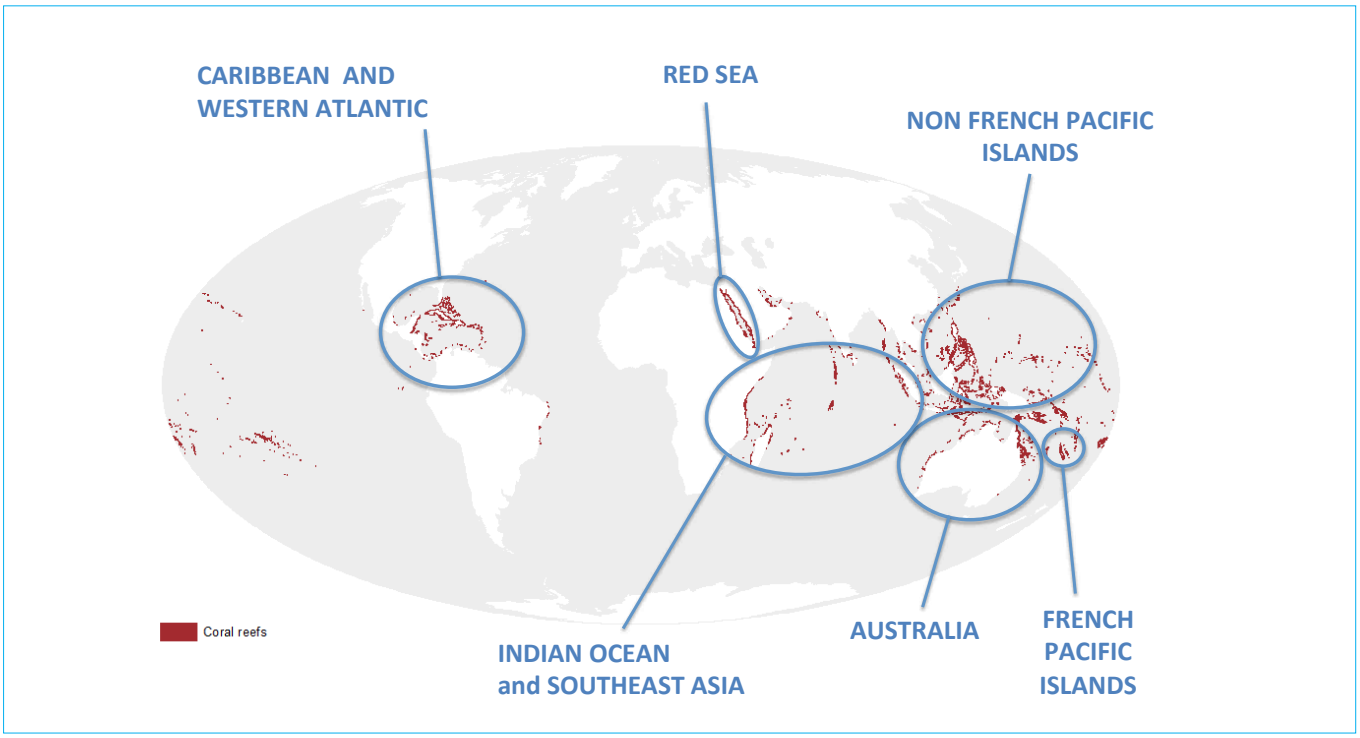
« Coral reefs are among the ocean's most important ecosystems in terms of their extraordinary biodiversity and their immense value for the human societies that depend upon them. Unfortunately these ecosystems are also among the ocean's most endangered, sustaining some of the clearest signs of damage that humans are inflicting on the planet. Despite these challenges, initiatives to preserve and restore coral reefs can be models for positive and effective action in marine conservation, particularly in the case of local approaches to ecosystem management.

The fourth edition of the workshop on the economics of ocean acidification was dedicated to science-based solutions that could improve the resilience of coral reefs threatened by Ocean Acidification and other global or local stressors. This workshop is timely, as numerous studies show the increasing rates of degradation of coral reefs, particularly by mass coral bleaching events. Following the *Coral reef life* declaration launched on October 2017 at the Our Ocean Conference in Malta by HRH Prince Charles and by My Foundation, the workshop is a contribution to the United Nations Sustainable Development Goal 14.

As the International Year of the Reefs 2018 begins, the present workshop conclusions are a call for action to reinforce the scientific knowledge of coral reefs through research and scientific expeditions like the Explorations of Monaco and Tara Pacific, both of which involve the Centre scientifique de Monaco.»

HSH Prince Albert II

The Fourth International Workshop on the Socio-Economic Impacts of Ocean Acidification gathered 62 experts from 22 countries. This inter-disciplinary workshop aimed to bring the global discussion from sciences to solutions, with a focus on coral reefs and the services they provide. The participants discussed both ecological and socio-economic risks and potential solutions for reefs in six different regions of the world.



This map was created using the Global Distribution of Coral Reefs (http://data.unep-wcmc.org/datasets/1) 2010 data layer.

CORAL FACTS

- Coral reefs cover only 0.16% of the sea surface but host about 30% of all known marine species: coral reefs are the biggest bioconstruction of the world.
- Coral reefs are essential to about 500 million people and have a conservative value of US$1 trillion which generates at least $300-400 billion each year in terms of food and livelihoods from tourism, fisheries, coastal protection and medicines.
- Coral reefs are the most endangered marine ecosystems to global change (global warming-induced bleaching and ocean acidification): about 30% of the world's coral reefs are already destroyed and 58% are potentially threatened.
- The extinction of coral reefs poses a critical threat for people in some of the world's developing countries.

COMMON SOLUTIONS FOR ALL REGIONS

- Reduce global CO_2 emissions.
- Implement controls on local land-based pollution.
- Promote marine conservation, e.g. through expanding Marine Protected Areas (MPAs).
- Create coral repositories to preserve particularly threatened species.
- Promote sustainable economies (tourism, fishing, agriculture, Blue Economy).
- Promote social resilience (e.g., stakeholder engagement, alternative incentive models).
- Invest in monitoring of coral reef health and scientific research, e.g. to identify resilient coral species.
- Invest in creative restoration / ecological engineering activities, e.g. selective harvesting or out-planting of more resilient coral species.
- Promote effective communication and increased awareness about the value of coral reefs and the risks they face.

AUSTRALIA – THE GREAT BARRIER REEF REGION

Specificities

The Great Barrier Reef (GBR) is the largest continuous reef system in the world, covering an area of more than 344,000 km^2, and 1,115,000 people live within the reef's catchment area. The GBR is the most famous and intensively managed marine park in the world. It became a national park in 1975 and was designated as a World Heritage Area (WHA) in 1981. The economic and social value of the GBR is estimated at $56 billion, owing to its vast biodiversity and assets related to commercial and recreational fisheries, shoreline protection, and reef-related tourism and recreation. Ocean acidification poses a significant risk to these ecological and socio-economic values and services, threatening not only the existence of the GBR but the livelihoods of reef-dependent sectors of society, and the enjoyment of millions of others.

Countries	Reef / Lagoon area (km^2)	Economic value	Population
Australia	344,000	$56 billion	1,115,000*

* For the catchment area

CREDIT: PETE WEST

Vulnerabilities and threats

The three major areas of socio-economic concern in the region are fisheries, shoreline protection, and reef-related tourism. For example, the annual net economic value from commercial fishery associated with the GBR is likely to be on the order of AU$40 million/year, suggesting potential important losses if reefs continue to decline. There are also potential socio-economic impacts on local residents that are culturally very connected to the GBR. Local residents are particularly attached to the lifestyle, biodiversity and aesthetic values within the region, and they possess significant pride in the World Heritage Area status of the GBR. It is possible that degradation of the GBR due to ocean acidification also threatens the WHA status of the region, and if the WHA status were to be removed, then the likely socio-economic impacts would be particularly significant.

The coastal areas within the GBR catchment area are already subject to erosion, but only a small proportion of the coast protected by the GBR is residential, potentially limiting impacts on populations. While losses to the tourism industry are likely to be large in the short-term, overall the economy would be expected to shift to other types of recreation.

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State of the reefs

Despite the history of environmental management in the area, the health of the GBR is in decline. As of 2011, crown of thorns starfish, cyclones, and bleaching had led to a ~50% loss in coral cover over the last three decades. Since then, the GBR has experienced back-to-back bleaching events that were more extensive and severe than anything previously experienced. Between March and November 2016, one third of the coral population along the entire GBR died due to warmer-than-average ocean temperatures.

Solution case study

Evaluation tool: Several local protective actions have been put into place since the creation of the marine park around the GBR (e.g. reduced fishing pressure and local pollution). In order to assess success of these and other measures, this working group identified 6 dimensions for addressing policy preparedness around ocean acidification adaptation, and a tool to evaluate performance against each:

- implementing climate protection measures
- bolstering adaptive capacity of reef-dependent sectors
- enhancing ocean acidification literacy
- enforcing area-based management
- investing in R&D, and
- committing to policy coherence

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RED SEA REGION

Specificities

Countries	Total area (km^2, reef + lagoon)	Total population (number of habitants, thousands)
Egypt	3800	98 671
Jordan	< 50	9 825
Israel	< 10	8 402
Saudi Arabia	6660	33 316
Sudan	2720	41 131
Eritrea	3260	8 141
Yemen	700	28 657
Djibouti	450	966

CREDIT: REBECCA WEEKS

• The Red Sea hosts some of the most productive and diverse coral reefs (mainly fringing reefs) while the surrounding land is mostly arid.

• Coral reefs of the Red Sea host diverse fish populations and are a source of food and income (mainly tourism) as well as a cultural asset to the people of the eight countries that share this sea.

CREDIT: STEPHANIE REYNAUD

• Even though the Red Sea reefs are unique, at present there is only a single UNESCO world heritage site in the Red Sea (Sudan).

• One of the longest continuous reef system in the world.

• The biodiversity of Red Sea reefs is important for a high latitude reef.

• High percentage of endemic species as well as deep reefs (mesophotic reefs).

• The northern part of the Red Sea is considered resilient to the effects of global warming and ocean acidification.

Vulnerabilities and threats

• Red Sea shoreline is getting highly urbanized in parts, with improved desalination techniques.

• Increased maritime transportation through the Suez Canal makes the coastal areas of the Red Sea economically attractive and larger ports are being developed.

• Mega-projects (Neom project, Dead Sea canal) and geopolitical transformation are likely to completely change the nature of coastal cities of the region, increasing environmental pressure on the marine environment.

• Local disturbances (pollution, eutrophication, physical destruction, light pollution) will compromise the unique coral reef refuge by increasing sensitivity of corals, the framework builders of reefs, to global factors (warming and acidification).

• Marine Protected Areas (MPAs) are not always adequately managed and regional management is lacking (except for the Regional Organization for the Conservation of the Environment of the Red Sea and the Gulf of Aden (PERSGA).

State of the reefs

• Millennia of scarce human population have left distinct reefs of the Red Sea in comparatively «pristine» condition (except for areas with high diving tourism and fishing pressure), but global climate change due to anthropogenic CO_2 emissions poses new threats.

• In contrast, the coral reefs in the northern Gulf of Aqaba/Eilat, which are of prime human interest, have been at the center of the economic development of the cities of Aqaba (Jordan) and Eilat (Israel). Consequently, these coral reefs are under severe threat and require immediate attention.

• The rate of sea surface temperature increase in the Red Sea greatly exceeds the tropical average with the northern part warming faster than southern sections. While temperatures in the northern Red Sea and Gulf of Aqaba have exceeded the expected bleaching threshold several times, no mass bleaching was ever recorded. This makes the northern part of the Red Sea a coral refuge from global warming, albeit within limits.

• To date there are no large-scale crown of thorns outbreaks, nor large scale coral disease outbreaks.

• The Red Sea is considered an «acidification-safe» sea as the total alkalinity and aragonite saturation state in the Red Sea is relatively high and pCO_2 is similar to pre-industrial levels.

Solution case study

• One of the largest programs of mooring buoys in the world put in place to avoid anchor damages has been implemented by Hurghada Environmental Protection and Conservation Association (over 1000 moorings installed and maintained throughout Hurghada, Safaga and the southern Red Sea). The presence and the continuous maintenance of the mooring system proved to be effective, as the number of coral colonies damaged by anchoring is significantly reduced.

CREDIT: ALEX MUSTARD

NON-FRENCH PACIFIC ISLANDS REGION

Specificities

Select countries	Reef (and/or lagoon) area (km^2)	Affected population	Economic valuation, in millions (USD)
American Samoa	296	55519	11
Federated States of Micronesia	5440	133100	---
Guam	238	164000	150
Hawaii	11057	1428557	455
Marshall Islands	11670	53158	---
Northern Mariana Islands - Saipan	579	53833	68
Palau	1661	20918	---
Ryukyu Islands Okinawa	--	1550161	---

The non-French Pacific Islands include over 20,000 islands crossing large latitudinal and longitudinal gradients, featuring tropical and subtropical climates, and supporting significant cultural diversity and biodiversity. These islands are further heterogeneous in their governance structures, level of development, and population density, presenting challenges to finding uniform solutions to ocean acidification across all sites. This socio-economic and ecological heterogeneity also presents an opportunity for regional testing. While every reef type is represented throughout the non-French Pacific Islands, the extent to which local economies depend on these ecosystem services varies between sites. Nonetheless, every island shares a similar vulnerability to climate change and sea level rise, a reliance on fisheries for local consumption and export earnings, and an economic and cultural reliance on coral reef ecosystem services such as coastal protection and recreational activities.

Vulnerabilities and threats

Each of the non-French Pacific Islands share similar threats to coral reef ecosystems, while the heterogeneity in reef type, local socio-economic conditions, and governance structures result in a different level of vulnerability to these threats. Key threats include local pollution, overfishing, overcrowding and tourism, and climate change. Climate change impacts entail warming, coral bleaching, sea level rise, and ocean acidification.

State of the reef

In general, the coral reefs of the Pacific are in better condition than other reef regions in the world; however, the diversity of reef types and local conditions across the region lead to variability in vulnerabilities and impacts. For example, the Hawaiian reef ecosystems have not been significantly stressed by climate change impacts but they suffer effects from other human activities such as overfishing and coastal development. The coral reefs of Palau and American Samoa are particularly vulnerable to ocean waves and storms, while the Marshall Islands must contend with sea level rise and coral bleaching. Although Okinawa and the Ryukyu archipelago are protected by an MPA, they have been significantly impacted by major bleaching events and soil erosion has impeded reef recovery.

Solution case study

In Hawaii, work is being conducted to harness basic science to develop corals with capacity to withstand climate change stress for use in restorations that build resilience on reefs. This involves identifying the most thermally resistant corals on the reef and increasing thermal performance through selective breeding; the manipulation of the coral symbioses (microbes); and, conditioning of corals with short exposures to warmer and more acidic waters that stimulate rapid adaptation processes. Early results suggest that both selective breeding and conditioning are feasible approaches that should be immediately applied to corals in other locations and scaled to improve the prognosis for reefs throughout the region through nursery propagation and use in reef restorations.

THE INDIAN OCEAN AND SOUTHEAST ASIA REGION

Specificities

Country	Reef area (km²)	(% of world total)
Indonesia	51020	17.9
Philippines	26000	8.8
Maldives	8920	3
India	5790	2
Malaysia	3600	1.3
Tanzania	3580	1.3
Madagascar	2230	<1
Thailand	2130	<1
Myanmar	1870	<1
Mozambique	1860	<1
Seychelles	1690	<1
Viet Nam	1270	<1
Taiwan	940	<1
Mauritius	870	<1
Somali	710	<1

CREDIT: STEPHANIE REYNAUD

Shallow water coral reefs are widespread in the Indian Ocean and Southeast Asia. These ecosystems are indispensable for food security, income and livelihoods. This region has the highest number of coral reef fishers with 3.35 million fishers in Southeast Asia and 1.5 million fishers in the Indian Ocean. Coral species richness peaks in the 'coral triangle' of Southeast Asia and declines gradually towards the west across the Indian Ocean. The coral triangle, which encompasses the waters of Malaysia, the Philippines, Indonesia and Papua New Guinea, has the highest marine biodiversity in the world due to the enormous range of reef-associated organisms. Coral reefs in the Indian Ocean also provide a wealth of goods and ecosystem services to the human population in this region, such as physical protection from storms, coastal erosion and important fisheries in the shallow-water coastal systems (including coral reefs, seagrass beds and mangroves). At a regional scale, Iles Eparses are largely preserved from anthropogenic impacts due to their geographical isolation and a historically very limited human occupation.

Vulnerabilities and threats

The coral reefs of the Indian Ocean and Southeast Asia are in steep decline because of multiple man-made stressors including pollution, sedimentation, overfishing and habitat destruction, such as coral mining and destructive fishing practices. On top of all that are the effects of CO_2 emissions which are causing surface waters to warm and acidify.

State of the reefs

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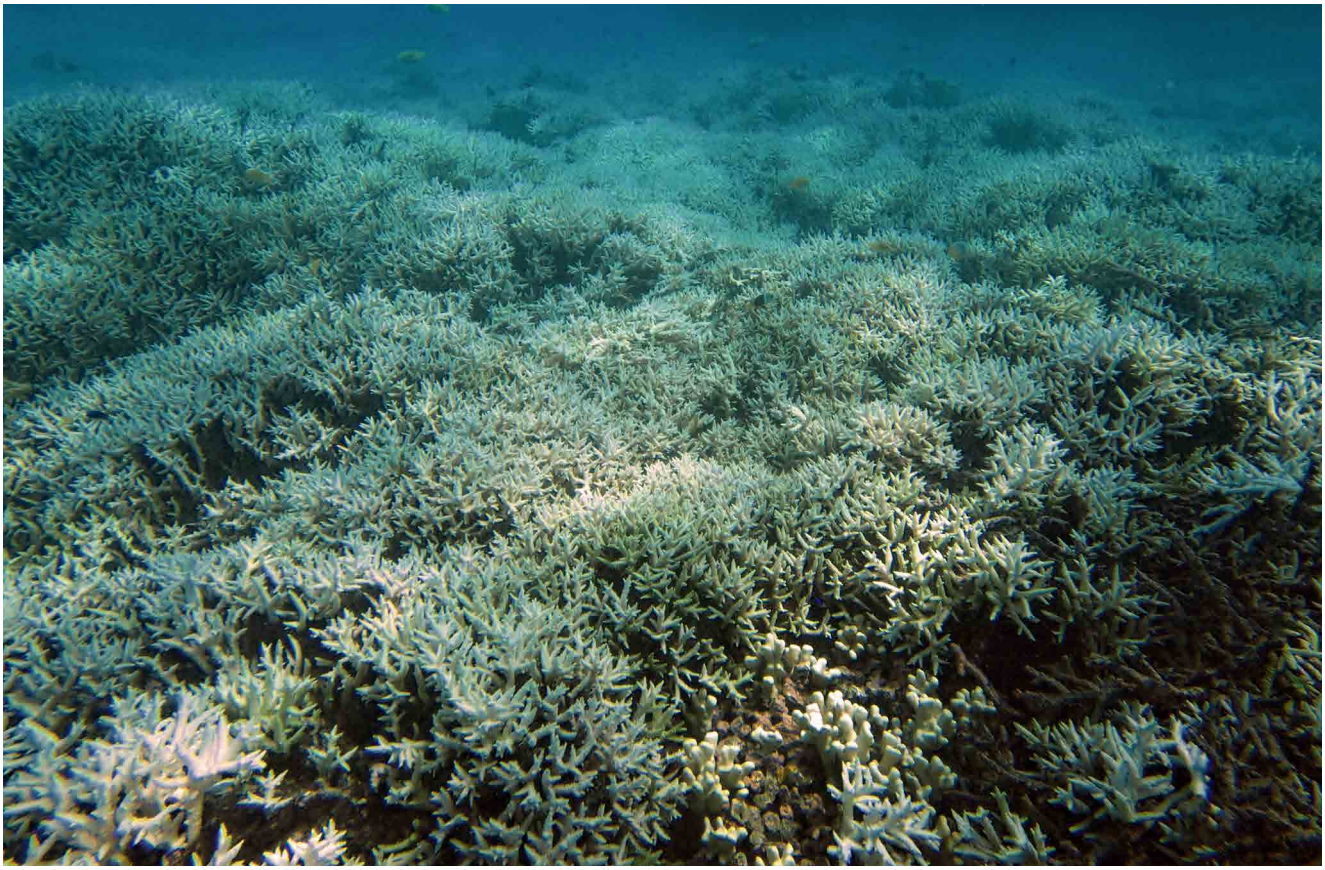
In the Indian Ocean, coral reefs experienced large-scale coral bleaching and mortality because of high temperatures in 1998 and 2005 and again in 2010. Previous studies showed that marine heat waves are now causing mass coral bleaching and subsequent mortality with increasing severity and frequency in the coral triangle in the past two decades. In the Pacific and Atlantic Oceans there is the hope that tropical coral reefs may be able to colonize higher latitudes but the northward movement of the coral reefs in the northern Indian Ocean is impossible due to the Asian land mass. Reefs in the coral triangle are projected to become continuously adversely impacted and become "marginal" within the period 2020 – 2050 unless CO_2 emissions are curbed.



CREDIT: EMMA CAMP

Solution case study

Among the various ecological solutions that have been discussed for the region during the workshop, “strengthen inter- and intra- national collaborations” was mentioned and this could happen through the restoration of the deteriorated coral reefs. Restoration becomes a major tool for reef rehabilitation in many countries particularly in Southeast Asian region. Although the long-term effectiveness of coral restoration on the ecological, socio-cultural and economic aspects still needs to be further explored, its short-term effectiveness on the growth and survival of coral reefs has been better studied. Many different coral reef restoration (rehabilitation) methods have been developed at the local, national and international levels with varying degrees of success. New scalable methods are emerging and being scientifically validated. One example of a successful program developed in Indonesia: the Mars Accelerated Coral Reef Rehabilitation System for coral reef restoration to improve the conditions of

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FRENCH PACIFIC ISLANDS REGION

Specificities

Region	Total area (km^2, reef + lagoon)	Total population (number of habitants)
New Caledonia	35 973	278,000
French Polynesia	15 047	281,674
Wallis and Futuna	932	15,289
Clipperton	11	0

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Globally, there is heterogeneity in biodiversity patterns, population density, latitude and longitude. Populations have a strong link to the lagoon and reefs, the lagoon is culturally considered an extension of the land. Any environmental change will reflect a change in the family and social structure. However, there is a strong cultural ability to adapt to changing environments (e.g., cyclones) with practices such as mobility of the populations. Populations are socially and culturally involved in reef protection with indigenous governance. There is a strong economic reliance of people on coral reefs and related lagoon services (tourism, fishing).

Vulnerabilities and threats

Climate change with ocean temperature increase and extreme climatic events (wave intensity) are threats at the global scale together with local threats such as pollution, sedimentation, mining, overfishing, salinization of aquifers, tourism. Ocean acidification is also an emerging threat.
Among these threats, some of them will affect reef health (coral massive bleaching, coral disease, crown-of-thorns starfish bloom) and others will lead to habitat destruction and loss of biodiversity. These changes could have important repercussions on the populations, likely causing social and cultural changes in knowledge and practices.

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State of the reef

In this region, based on the recent episodic stress events, coral reefs seem quite resilient, suggesting that they have not yet reached their upper threshold of tolerance.
Over 80% of coral reefs are healthy and far from local pollution sources. The range of anthropogenic pressure is less than in other coral reef areas globally.
Coral reefs show an important ability to recover after storms, crown starfish outbreaks and bleaching. Only two massive bleaching events have been observed in New Caledonia (1996 and 2016) with 90% of recovery. In French Polynesia events are more frequent but geographically sparse.
To date, the high degree of the ecosystem resilience and conservation avoided any social and economic catastrophe. However, future scenario could greatly affect the actual equilibrium.

Solution case study

Consideration of reef associated habitats is important when looking for regional solutions. Mangrove forests for example, are well known to play a fundamental role in coastal protection from erosion, decreased salinization of groundwater, CO_2 sequestration, refuge for marine and terrestrial biodiversity, as well as providing other social and economic benefits for humans. For these reasons, most of the mangroves in New Caledonia have been identified as heritage of national interest and are locally protected.

More recently it has been proposed that mangroves may provide refuge to corals threatened by climate change. Indeed, mangrove systems have dynamic temperature, pH and oxygen profiles, and as such, expose resident corals to very different physico-chemical conditions than neighbouring reefs. A French-Australian collaborative research expedition expanded this hypothesis, showing for at least one mangrove forest in New Caledonia, that coral reefs living near mangroves house corals thriving under conditions not expected for the open-ocean until beyond 2100. Specifically, regularly exposing more than 50 species of reef-building corals to pH as low as 7.3, temperature 1- 2°C higher than adjacent reefs, and oxygen levels below 3mg l^{-1}. Preliminary results show that at least some corals can thrive under conditions even more extreme than predicted under climate change. A consequence of this research in New Caledonia was that a consortium of scientists presented to the local institutions and to UNESCO a route map to protect, and valorise these special habitats which not only serve as reservoir of highly stress tolerant coral populations, but provides previously unrecognized ecosystem service value as a unique 'natural laboratory' to understand how coral reefs will respond to climate change.

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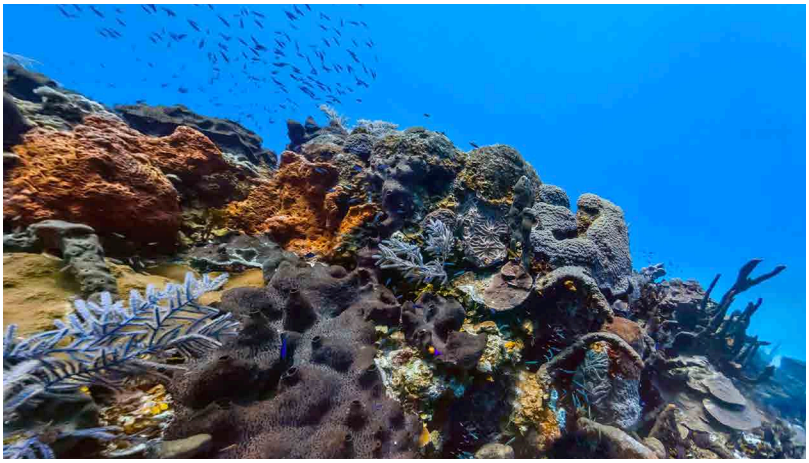
CARIBBEAN AND WESTERN ATLANTIC REGION

Specificities

The Caribbean and Western Atlantic is a highly diverse geopolitical region comprising 44 countries and territories, ranging in size from small island nations to large nations such as the U.S. There are large variations in coastal population densities and national GDP. Regardless of these differences, the marine environment and coral reefs are central to people's livelihoods in most Caribbean nations, which often depend on marine ecosystem services such as provision of food, support for tourist based economies, and physical protection from storm-driven waves. The Caribbean is the world's most isolated tropical sea, and therefore, has a unique biota that is distinct from the Indian and Pacific Oceans.

Region	Coral Reef Area (km^2)
US Caribbean	3040
North Caribbean	9800
Central America	4630
Lesser Antilles	1920
S. Tropical America	5120



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Vulnerabilities and threats

Compared to other regions, the Caribbean and Western Atlantic has low taxonomic diversity, meaning that the loss of a species or group can remove a vital link in the food web or other aspects of the ecosystem. This potentially heightens the vulnerability of the Caribbean to introduced pathogens and non-native species and reduces its capacity to recover from mortality events (e.g., caused by coral bleaching and disease outbreaks). At local scales, acute threats to Caribbean coral reefs include local water quality issues, disease and intensive fishing pressure. At the regional and global scale, Caribbean reefs also suffers from mass coral bleaching events (1998, 2005, 2010 and 2015-16) predicted to occur more frequently under climate change. In the Caribbean region, ocean acidification and associated changes in seawater chemistry are occurring at one of the fastest rates globally, likely posing an increasing threat to Caribbean reef recovery in the long term. In the short term, influxes of nutrients and/or organic matter (e.g. sewage) can result in localised seawater acidification.

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State of the reef

Since the 1970s, the Caribbean-wide region has lost 60-80% of its coral cover driven by a combination of disease, overfishing of herbivores and an additional range of pressures resulting from human activities. Disease has directly impacted major reef building corals (e.g. white band disease) and also important reef grazers, such as sea urchins. Coupled with overfishing of herbivorous fish, these threats have led to the overgrowth of many coral reefs by fleshy algae, leading to algal-dominated reefs. A Caribbean-wide study identified three current trajectories for Caribbean reefs in the last 50 years: 1) rapid loss of corals followed by little change 2) continuous loss of coral cover and 3) stability in coral cover with small changes.

Solution case study

In partnership with NOAA, The Nature Conservancy and partners have grown tens of thousands of staghorn and elkhorn corals in nurseries along the Florida Keys and in the U.S. Virgin Islands. Since 2004, a total of over 14,000 corals have been outplanted to sites in waters around Florida and the U.S. Virgin Islands as part of the largest restoration project of its kind. Initiatives such as this one in the Carribean provide best-practice for other regional locations that are having a growing need to undertake restoration activities.

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CARIBBEAN AND WESTERN ATLANTIC REGION

ECOLOGICAL SOLUTIONS

• Manage land-based and near-shore water fluxes and quality by: 1) reducing the point sources and inputs of pollution (e.g., sediment, nutrients); 2) introducing natural barriers or filters (e.g. mangroves) between the land-based sources of pollution and the reef; 3) redirecting pollutants away from reef ecosystems toward industrial or natural treatment facilities.
• Reduce unsustainable fishing practices by: 1) developing a hierarchy of fishing rights for stakeholders; 2) removing destructive practices that negatively impact reef accretion; 3) replicating successful MMA/MPA management practices; 4) promoting fish stocks by the protection of juveniles, apex predators, keystone and foundation species, and spawning and nursery areas.
• Apply and develop new ecological engineering approaches by 1) using selective harvesting approaches to enhance coral settlement and resilience, and 2) applying contemporary reef restoration techniques, such as out-planting corals tolerant to low seawater pH and/or high temperature that have been selected from coral nurseries and/or local extreme environments.

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SOCIO-ECONOMIC AND POLICY SOLUTIONS

• Increase regional communication and potential to leverage resources through the establishment of a regional reef secretariat. The secretariat's goal would be to increase communication and coordination amongst international governmental, non-governmental, and other funding organizations with the aim to manage, protect, and restore coral reefs of the wider-Caribbean region.
• Adapt Blue Economy Principles to coral reef economic sectors that incorporate increased investment in reef management. The goal would be to support reef function and health to provide long-term ecosystem services and economic dividends from reefs long-term through pro-active planning and management.
• Initiate a reef label or certification program that provides positive rewards for corporations becoming partners in reef restoration and sustaining their overall long-term health in the region.

THE INDIAN OCEAN AND SOUTHEAST ASIA REGION

ECOLOGICAL SOLUTIONS

• Establish a network of effectively locally-managed Marine Protected Areas (MPAs) for protecting the coral reefs, for example, marine park of Glorieuses in Iles Eprases, established in 2011.
• Strengthen inter- and intra- national collaborations to adopt science based best practices for monitoring ocean acidification and coral condition, while taking into account the local and national interests, e.g. food provision and coastal defense
• Adopt coral reef restoration program for restoring the deteriorated coral reefs.
• Promote non-destructive use of marine resources to reduce the stress of coral reefs and hence increase their resilience to the impact of ocean acidification.

SOCIO-ECONOMIC AND POLICY SOLUTIONS

• All countries to commit to reducing carbon dioxide emissions, for example, reducing demand for emission-intensive goods and services and encouraging lower-carbon technological use of power, heat and transport sector.
• Implement a proper cost benefit analysis to make sure that the cost of proposed alternatives are lower than the cost of inaction.
• Increase public and political awareness on the value of coral reefs' services and its risk under ocean acidification by determining and promoting the value of the goods and services provided by the coral reefs and also the risk of ocean acidification to these goods and services to the general public and also the politicians.

• Education program needs to incorporate the knowledge on sustainable use of marine resources, for example, marine renewables, low carbon food production and sustainable fishing practices.

• Involve communities in the policy decision process on the use of their marine resources can help to manage the coral reef habitats in a more sustainable way.

FRENCH PACIFIC ISLANDS REGION

• Identify climate refuges and establish MPA networks to protect climate change-resistant hotspots,
• Select and breed of locally resistant corals (coral gardens is a local option but not scalable),
• Restore and protect native vegetation (mangroves and vegetation on atolls) for CO_2 sequestration, decrease salinization of groundwater,
• Promote Pacific Islanders as guardians of the oceans, using French Pacific island territories as champions of climate change solutions (incl., research, management actions, renewable energy, etc.),
• Promote traditional coastal management practices for sustainable use of marine resources,
• Plan and potentially relocate/develop activities according to projected climate change impacts

ALL SOLUTIONS NEED TO ACCOUNT FOR LOCAL SOCIAL, ECONOMIC AND ECOLOGICAL CONTEXT:

• Local worldviews and values, local social organizations involvement are important to ensure sustainability of solutions
• Need long term monitoring to track trends in ecological, socio-economic and cultural sub-systems, in a context where French Polynesia and New Caledonia could be a model of coral reef resilience.
• Traditional and scientific knowledge systems must be integrated at the regional scale (monitoring, fundamental research, etc.)
• Research, participatory approaches, citizen science are important for communication.

RED SEA REGION

ECOLOGICAL

• Close knowledge gap on coral resilience: the Red Sea harbors some of the most thermotolerant corals and we have to better understand what is the mechanism for this resilience.
• Control of pollution into reef systems: while the Red Sea hosts some of the most resilient reefs to global stress (ocean warming and acidification), they are not safe from local anthropogenic impacts, and require measures to be implemented to prevent pollution of the Red Sea.
• Protect reef resilience: reef resilience can be enhanced by employing traditional conservation acts to increase the numbers and sizes of MPAs, and reducing anthropogenic adverse impact.
• Regulate fishing: artisanal overfishing is widespread throughout the Red Sea. Regulations need to be put in place that monitor and control the catch.
• Create coral repositories: consider coral nurseries to preserve essential local genotypes and local coral species (primarily rare species and endangered species).
• Coral reef restoration: Target coral reefs that are poorly protected, highly degraded, and exposed to multiple threats. It will be advisable to prepare the coral restoration toolbox for cases and the time it is needed.
• Apply ecological engineering: employment of ecological engineering approaches may enhance the acclimation and adaptation mechanisms of impacted corals.

POLITICAL

• Build regional collaboration and concerted efforts: As coral reefs worldwide are under threat from global and local stress, the Northern Red Sea coral reef refuge deserves special protection measures.
• Develop MPAs: even though the Red Sea reefs are unique, at present there is only a single UNESCO world heritage site in the Red Sea (Sudan).
• Support cross national research and regulations: regional management is lacking (except for PERSGA which doesn't include all 8 countries) and not any Red Sea country has yet signed the new Malta agreement. Therefore, it is important to strengthen regional monitoring, to accelerate distribution of knowledge, and for the neighboring countries and the international community to endorse collaborative research and protection of this remarkable natural resource.

SOCIO-ECONOMIC

• Manage Tourist and hospitality industry: the northern Red Sea is a hub of tourism. As such, it is in the interest of the bordering nations to sustainably develop the region.
• Collect and build a socio-economic dataset/ database: A centralized coordination center is required to allow better monitoring and implementation of conservation policies in the region.
• Educate local stakeholders: efforts should be put to educate the local people about the value of coral reef ecosystems with regard to their cultural, economic, and ecological value, and also with regard to actions that can be done by single individuals.
• Build Capacity: while countries bordering the Red Sea rely on many of its services, opportunities should be created that incentivize individuals that choose a career track in Marine Science.
• Create citizen science: invested efforts are needed in participatory monitoring and participatory action research of the public in the Red Sea coral reefs' affairs.
• Explore business opportunities on reef resources (blue technology): identify and develop sustainable use of Red Sea bioactive materials from reef organisms.

AUSTRALIA - THE GREAT BARRIER REEF REGION

• Rapid decrease of man-made CO_2 emissions.
An extensive program of management actions has been implemented since the creation of the Great Barrier Reef Marine Park in 1975, which encompasses most of the Great Barrier Reef region.

Existing measures relevant to building resilience to ocean acidification include:

- Regulations to ensure fishing is ecologically sustainable
- Comprehensive tourism permitting arrangements
- Controls on wastewater discharge
- Programs to reduce land-based sources of pollution (especially from agriculture).

• Actions that would complement this long history of management to increase the region's preparedness for ocean acidification. These include:

- Enhancing measures to build resilience to climate change, for example through implementing an effective climate policy that addresses ocean acidification, including targets for emissions level,development of emissions, renewable energies, and efficiency.
- Supporting the adaptive capacity of reef-dependent sectors, for example by developing an understanding of the vulnerability of these sectors and communities, identifying adaptation options, and developing sectoral strategies for responding to risks from climate change and ocean acidification (e.g. action plans, milestones, measurable outcome indicators).
- Enhancing ocean acidification literacy among the public and decision-makers, including accountability for climate dedicated government infrastructure (e.g. dedicated departments, technical assistance, education and outreach) and the incorporation of curriculum material on ocean acidification (e.g. within high school teaching schedules).
- Increasing compliance with area-based management, especially for locations found to be ocean acidification refuges, including through the establishment of management plans that explicitly support resilience to ocean acidification and programs in place to measure and report on the effectiveness of management.
- Additional investment in R&D relating to ocean acidification impacts and responses, including building capacity through training programs and international partnerships.
- Improving policy alignment and coherence across jurisdictions and sectors, including commitment to evidence-based decision-making that is consistent within and between governmental departments. It is important that policies aiming to deal with the issue of ocean acidification are not offset against other policies that might render a response to ocean acidification ineffective.

NON FRENCH PACIFIC REGION

ECOLOGICAL

Two categories of ecological solutions are proposed for the region: mitigation (atmospheric and ocean CO_2 reduction) and adaptation (resilience of coral reefs):
• Mitigation of pollution and greenhouse gas emissions (e.g., land-based sources of pollution, sediment).
• Bigger and more effective marine protected areas (MPAs).
• Development of innovative solutions, better baseline information, and greater capacity for real-time monitoring to better understand how ocean acidification is affecting these ecosystems and how vulnerability differs across sites.

SOCIO-ECONOMIC

• Education and communication at all levels to build an informed community that has the capacity to implement solutions efficiently and effectively, as well as promote stakeholder buy-in of proposed solutions
• Financial commitment for research and development to build capacity for effective protection of ecosystems.
• Regional collaborations and networking between developed and developing nations with the desired goal to develop solutions in one part of the region and implement in another.
• Ecologically sustainable agriculture, industry, and services.
• Effective implementation and enforcement of laws and regulations.
• Alternative incentive models (offsets/ quotas/taxes, tourism, military, fisheries).

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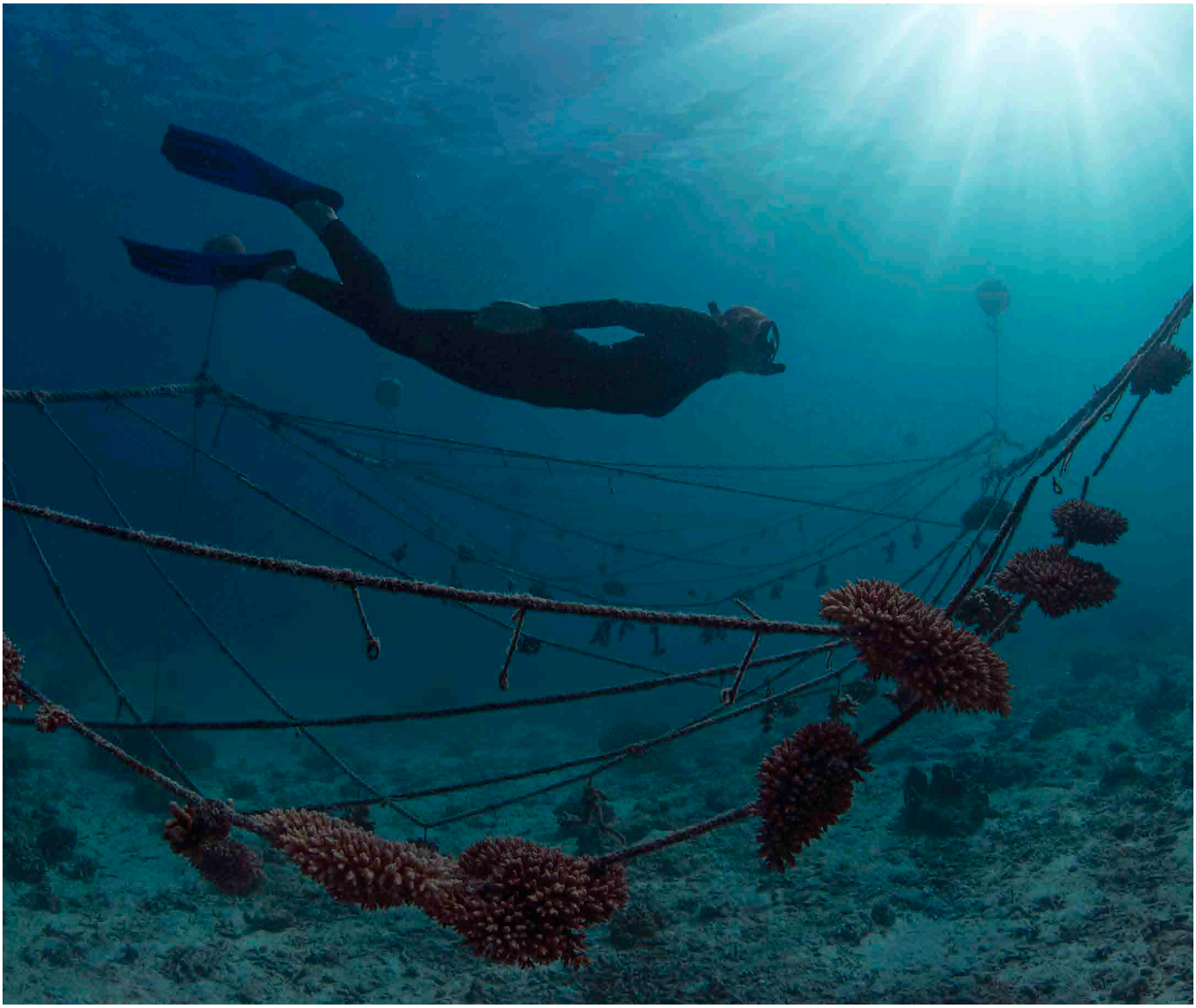

CREDIT: THE OCEAN AGENCY

Suggested citation : Hilmi N, Allemand D, Claudel-Rusin A, Gazeau F, Gaziello M, Hansson L, Metian M, Mondielli P, Osborn D, Reynaud S, Swarzenski P, Tambutté S, Venn A (2018) Fourth International Workshop on the Economics of Ocean acidification: Bridging the Gap between Ocean Acidification Impacts and Economic Valuation "From Sciences to Solutions: Ocean acidification impacts on ecosystem services- Case studies on coral reefs", Oceanographic Museum of Monaco, Principality of Monaco, 15-17 October 2017.

The workshop was organized by the Centre Scientifique de Monaco (CSM) and the Ocean Acidification International Coordination Centre (OA-ICC) of the International Atomic Energy Agency (IAEA), with the support of:

PRINCE ALBERT II OF MONACO FOUNDATION

Gouvernement Princier PRINCIPAUTÉ DE MONACO

Ministère de l'Écologie, du Développement durable et de l'Énergie

ICRI International Coral Reef Initiative

IAEA Ocean Acidification International Coordination Centre OA-ICC

Institut océanographique Fondation Albert Ier, Prince de Monaco

CCMI Central Caribbean Marine Institute

AMAO

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