Evidence of Climate Change Damage to Coral Reefs

- Mass coral bleaching was unknown in the long oral history of many countries such as the Maldives and Palau, before their reefs were devastated in 1998. About 16% of the world's corals bleached and died in 1998;
- In that year, 500 to 1000 year old corals died in Vietnam, in the Indian Ocean and Western Pacific;
- Coral bleaching was only recorded as minor local incidents before the first large-scale bleaching was observed in 1983.
- The hottest years on record in the tropical oceans were in 1997/98, 2003, 2004 and 2005; the major bleaching years for Caribbean corals were in 1998 and 2005.
- Records for hurricanes in the wider Caribbean were broken in 2005.
- The bottom cover of corals on Caribbean reefs has dropped by more than 80% since 1977, with much of this decline due to disease, coral bleaching or coral disease following bleaching. Any coral recovery was often reversed by other human pressures or more bleaching and disease.

Bleaching in 1998 destroyed this reef in the Seychelles; subsequent stress killed this lone recovering colony.

Bleaching in the Caribbean in 2005 did not affect all corals indicating that some colonies have more resistance.

- Between 50 and 90% of corals died from bleaching on many reefs in the Indian Ocean in 1998. This caused major losses in tourism incomes and reductions fish habitats.
- The first major bleaching event on the Great Barrier Reef was in 1998; since then there has been major bleaching in 2002 and 2006.
- The growth rate of some corals species has declined by 14% on the Great Barrier Reef since 1990, either due to temperature stress or ocean acidification or both. Other reef areas report similar results.
- Ocean temperatures have risen in all oceans in the last 40 years as seen in satellite and other measures over 135 years from the National Oceanic and Atmospheric Administration of USA.
- Coral bleaching and death has reduced tourism incomes in countries like the Maldives, Palau and throughout the Caribbean.
- Sea level rise has already decreased the habitability of some coral island countries, such as Kiribati, Tuvalu, Marshall Islands and Maldives, and many counties are threatened with inundation, erosion, loss of agriculture and displacement of people and cultures.

This brochure was produced for the International Coral Reef Initiative by Clive Wilkinson of the Global Coral Reef Monitoring Network (clive.wilkinson@rrrc.org.au), with input from Andrew Bauman, Leah Bunce-Karrer, Lauretta Burke, Christine Dawson, Mark Eakin, Dwight Gledhill, Stefan Hain, Ellycia Harrould-Kolieb, Scott Heron, Gregor Hodgson, Maria Hood, Joan Kleypas, Judith Lang, Christy Loper, Janice Lough, Carl Lundin, Paul Marshall, Bernard Salvat, Francis Staub, Al Strong, Jerker Tamelander, John Veron, Anne-Marie Wilson. ICRI is a unique public-private partnership of governments, international organizations, scientific entities, and NGOs committed to reversing the global degradation of coral reefs and related ecosystems, including mangroves and seagrasses, by promoting conservation and sustainable use of these resources for future generations. ICRI & GCRMN are partnerships that seek to improve management practices, increase capacity and political support, and share information on the health of these fragile ecosystems. More information can be found in www.icriforum.org, www.gcrmn.org, www.reefbase.org, www.reefcheck.org, www.coralreefwatch.noaa.gov. Scientific documents supporting this brochure are available on www.ICRIForum.org/climatepapers or the other sites; inquiries to secretariat@icriforum.org

Images and graphs from: Ray Berkelmans, AIMS Townsville; Simon Donner, University of British Columbia; Mark Eakin & Richard Feely NOAA, USA; Louise Goggin; Ove Hoegh-Guldberg, University of Queensland; Scott Heron, NOAA Coral Reef Watch; Charles Sheppard, University of Warwick; Jerker Tamelander IUCN; http://wallpaper-s.org/15.

Conclusions and Recommendations

Global climate change seriously threatens the immediate future of coral reefs:

- Global climate change damage to coral reefs will threaten the livelihoods of 500 million people around the world and seriously reduce the $100 billion that reefs provide the global economy.
- Global climate change has already damaged many of the world's coral reefs; more greenhouse gases in the atmosphere will exacerbate this and threaten mass extinctions on coral reefs, including deep cold water corals.
- About 19% of the world's coral reefs have been effectively destroyed by human activities (over-fishing and destructive fishing, sediment and nutrient pollution, and habitat loss) as well as by climate change.
- Global average temperatures are predicted to increase by 2^{o}C or more if CO_2 concentrations reach 450 ppm and cause severe damage with massive losses of coral cover from bleaching, extinctions of corals and other species, more fragile skeletons, and losses from more damaging tropical storms.
- Loss or reduced growth of coral reefs will expose coastal communities to greater storm and tsunami damage, erosion and loss of life.
- This damage and the probable sea level rise of 0.8 to 1.2 m by 2100 with ice shelf melting included will be disastrous for low lying countries such as Kiribati, Maldives, Marshall Islands and Tuvalu which will be flooded and may cease to 'exist'.
- More than 3000 scientists at the 2008 International Coral Reef Symposium recommended that major reductions in greenhouse gas emissions must occur in the next 8 to 10 years in order to conserve reef resources. This was based on strong field and experimental evidence showing climate change as the greatest threat to coral reefs.

To avoid permanent damage to coral reefs and support people in the tropics, it is recommended that:

- The world community tackles global climate change urgently through major reductions in greenhouse gas emissions and the development of effective mechanisms to permanently sequester existing CO_2.
- Damaging human activities (unsustainable fishing, nutrient pollution and poor land use) be controlled to improve the resilience of coral reefs to resist and recover from climate change threats.
- Assistance is provided to developing countries and communities to:
  - reduce population pressures on coral reef resources;
  - develop alternative livelihoods that take pressures off reefs;
  - improve local catchment and coastal management practices;
  - develop strategies to cope with climate change damage; and
  - improve national capacity for better management, monitoring and enforcement of regulations.
- Include more coral reefs in marine protected areas (MPAs), including many remote and uninhabited reefs still in good condition to act as future biodiversity reservoirs.

Current scientific predictions are that the world's coral reefs could be the first ecosystem casualty of climate change and may become functionally extinct if CO_2 concentrations reach 450 ppm. This will occur in 20 years time if we continue with 'business as usual'. Scientists at the Royal Society meeting stated that atmospheric CO_2 concentrations must not reach 450 ppm and stabilize below 350 ppm for the world's coral reefs to thrive and provide valuable goods and services to millions of people. We know that the world is at a 'tipping point' for coral reefs now; urgent action is required to save them.

"We cannot wait for ever; somebody has to dive first if we want to save the oceans and coral reefs".

GCRMN Global Coral Reef Monitoring Network

ICRI International Coral Reef Initiative

2010 International Year of Biodiversity

Climate Change and Coral Reefs

Consequences of inaction

The world could lose most if its coral reefs unless urgent action is taken now to reverse the rate of climate change.

Already reefs are suffering catastrophic damage and threatening the livelihoods and food security of millions of people.

The world's coral reefs were probably the first ecosystem to show major damage from climate change. Reefs will suffer catastrophic collapse from climate change within the next few decades unless there are major and immediate reductions in greenhouse gas emissions.

Global climate change will cause irreparable damage to coral reefs in our lifetimes when:

- Increasing sea surface temperatures cause more coral bleaching and mortality during summer. The abundance of many coral species will be reduced and some species may go extinct;
- Ocean temperatures increase beyond the current maximum of natural variability making bleaching a frequent, or eventually an annual, event;
- Increasing ocean acidification reduces calcification in corals and other calcifying organisms resulting in slower growth, weaker skeletons and eventual dissolution;
- A predicted increase in severe tropical storms (category 4 and 5 cyclones, typhoons and hurricanes) results in destroyed corals and eroded coastlines; and
- Rising sea levels result in damaging flood events on low lying tropical islands and coasts, and make them uninhabitable. Some nations will be totally submerged and whole populations may be displaced.

Already 19% of the world's coral reefs have effectively been lost; and 35% more are seriously threatened with destruction, mostly due to direct human threats. Climate change will cause even more dramatic losses; we are just determining that climate change will cause serious damage to deep, cold water coral reefs.

Climate Change and People

About 500 million people depend on coral reefs for some food, coastal protection, building materials and income from tourism. Among these, about 30 million people are dependent on coral reefs to provide their livelihoods, build up their land and support their cultures. Global climate change threatens these predominantly poor people, with many living in 80 small developing countries.

Human wellbeing will be reduced for many people in rapidly growing tropical countries; 50% of the world's population are predicted to live on coasts by 2015. This growth is putting unsustainable pressures on coastal resources. In 2009, the United Nations Environment Programme estimated that the coral reef area of 284,300 km^2 provides the world with more than US$100 billion per annum in goods and services. Even moderate climate change will seriously deplete that value.

"The threat from climate change is serious, it is urgent, and it is growing .. We know that our planet's future depends on a global commitment to permanently reduce greenhouse gas pollution."

Barack Obama, President United States of America September 2009

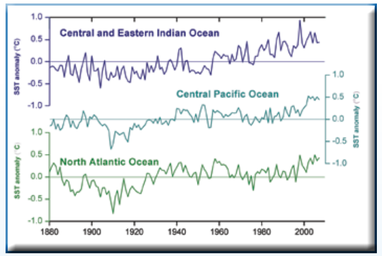
Warmer Waters Cause Coral Bleaching and Death

The most dramatic recent damage to coral reefs occurred in 1998 when global-scale coral bleaching and subsequent mortality devastated reefs around the world. It was followed in 2005 by unprecedented levels of bleaching-related mortality in parts of the Caribbean. Such events have become increasingly common since the early 1980s when atmospheric CO_2 concentrations reached 320 parts per million (ppm); it is now more than 385 ppm and is predicted to reach 450 ppm by 2030 to 2040.

In 1997/98, massive El Niño and La Niña climate oscillations resulted in raised sea surface temperatures (SSTs) throughout the Indian Ocean, the wider Caribbean and Pacific Ocean. About 16% of the world's coral reefs were effectively destroyed in just 9 months. For example, more than 90% of the corals on many reefs in the Maldives and Palau were lost. Since then, some reefs have recovered, but many have not because sediment and nutrient pollution, over-fishing, mining of sand and rock and coastal development have inhibited recovery.

Then in 2005, severe ocean warming resulted in coral bleaching and mortality that was far more damaging than anything previously experienced in the Northeastern and Eastern Caribbean. Some reefs lost more than 50% of their live coral cover; 2005 also broke storm records in the wider Caribbean region.

Sea surface temperatures just 1–2^{o}C above the normal summer maximum for a few weeks under clear tropical skies will cause corals to bleach; they will die if these conditions persist. The higher temperatures and solar radiation disrupt photosynthesis in the coral's symbiotic algae (*zooxanthellae*) and result in the production of toxic free oxygen radicals that cause the corals to eject the algae. These stressed corals have lost their major source of energy and are effectively starving. Some corals can regain their algae and recover; but the increased stress often results in lethal coral diseases or reduced coral reproduction and growth during the next year.



Ocean temperatures show distinct warming in all oceans over the last 50 years as measured by the National Oceanic and Atmospheric Administration of USA

Global temperatures are steadily rising and have increased by 0.74^{o}C over the lands and oceans since 1900. Tropical reef-building corals are now about 1^{o}C closer to their upper thermal tolerance limits than they were 100 years ago. Bleaching could become an annual event in 20 years with predicted CO_2 concentration of around 450 ppm. The consensus of leading scientists assembled by the UK Royal Society in 2009 was that atmospheric CO_2 concentrations need to be "significantly below 350 ppm" for the long-term viability of coral reefs.

Prevention of coral bleaching and death is needed to sustain local food sources and economies in coral-reef dependent states such as Palau, Bonaire, and Seychelles; Palau experienced a 5-10% decrease in tourism income after the bleaching in 1998.

Rising CO_2 in Seawater will Reduce Coral Calcification

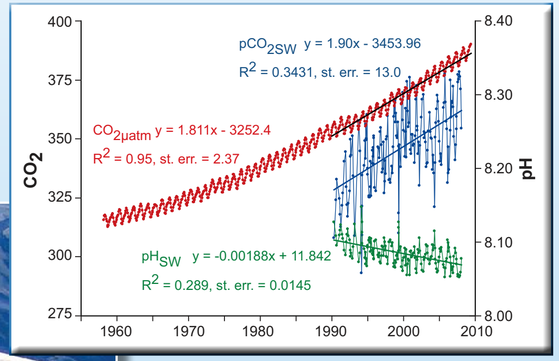
Another major impact of increasing CO_2 emissions is ocean acidification. This is a well known chemical reaction when CO_2 dissolves in seawater to make a weak acid or marine 'soda water'. The oceans absorb 25% to 33% of all the CO_2 added to the atmosphere each year, leading to the formation of carbonic acid and an increase in acid ions, which have already increased by 30%.

The average pH in the upper layers of the ocean (where most ocean life thrives) has dropped from approximately 8.21 to 8.10 units since the industrial period. The acid ion concentration in the surface layers of the ocean is already the strongest in 800,000 years, and probably 20 million years; if atmospheric CO_2 concentrations continue to increase to 800 ppm, surface ocean pH will decrease further by 0.3 - 0.4 pH units and severely disrupt calcification.

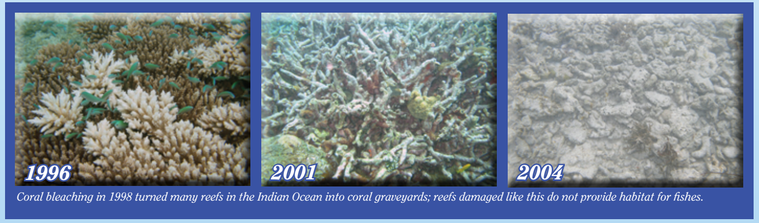
Ocean acidification causes a suite of chemical changes in seawater, some of which have been shown to affect marine life. Of special concern to coral reefs is the decrease in the carbonate ion concentration, because this reduces the capacity of corals and many other calcifying organisms to make strong calcium carbonate skeletons. Reefs growing in naturally lower pH environments are more fragile because they have less of the 'cement' that binds reefs together.

In experiments simulating pH conditions for the year 2050 (550 ppm or double the CO_2 in pre-industrial times), coral skeletal growth decreases by 20–50%. Weakened corals will crumble in the face of storm waves, thereby destroying much of the habitat for other reef biodiversity, including food fish. Under more extreme acid conditions, some corals could completely lose their skeletons. Coral calcification has probably already decreased by 15%, due to increasing ocean acidification and more heat stress and bleaching. Ocean acidification also may increase the susceptibility of corals to bleaching due to warmer temperatures.

Crustose coralline algae are also important reef-builders as they 'cement' coral reef rubble together; these are particularly vulnerable to ocean acidification because they secrete a more soluble form of calcium carbonate. At 450 ppm, these coralline algae will not calcify and the reduced calcification rates will shift most reefs from net growth to net dissolution by 2050. The combined effects of ocean acidification and bleaching will be devastating for all the other animals and plants that depend on coral reefs for a habitat. Moreover this will be particularly disastrous for people living on low lying coral islands.



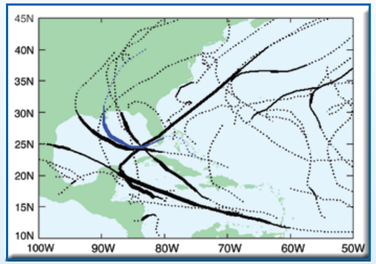
As CO_2 (red) increases in the atmosphere, more will dissolve in the oceans (blue) and lower the pH (green = more acidity) thereby reducing calcification for corals and other biota.



Coral bleaching in 1998 turned many reefs in the Indian Ocean into coral graveyards; reefs damaged like this do not provide habitat for fishes.

Storms, Currents and Sea Level Rise

Rises in global temperatures increase the energy in the oceans and atmosphere that can generate tropical storms (hurricanes, cyclones, typhoons). Present predictions do not suggest a major increase in the number of storms, but predict an increase in the strength of storms with more category 4 and 5 severe cyclones. These will wreak havoc on coral reefs and islands, for example, severe cyclone Hamish smashed 70% of the corals along a 500 km strip of the southern Great Barrier Reef in 2009.



The 26 named tropical storms in the wider Caribbean between July and November, 2005, included Hurricane Katrina (blue line) that devastated New Orleans among the 13 hurricanes (thick lines). But there were no hurricanes in the Lesser Antilles where coral bleaching was most extreme.

Sea level rise will be devastating for the many tropical coral islands that are only 1 to 3 metres above sea level. Any rises will increase erosion, and seawater will contaminate fresh groundwater especially during storm surges and destroy agriculture. These low lying countries must either build up the land by dredging sand from nearby reefs (causing much local damage) or abandon these lands. The seas rose by 17 cm during the last century, and the Intergovernmental Panel on Climate Change (IPCC) predicts there will be a further 20 to 60 cm rise in this century; without considering the predicted melting of the Greenland and Antarctic ice shelves.

Sea level rise, however, will pose no significant problems for corals and other organisms on a coral reef except for increases in sediments from coastal erosion; any rise may be temporarily beneficial for corals growing on reef flats by presenting them with more space to grow upwards. But reduced calcification will make these corals more fragile and less able to protect fragile shorelines.

Changeable weather may result in damage to coral reefs, especially through the predicted variations in rainfall. The IPCC predicts that local severe weather events will become more variable with more frequent bursts of heavy rainfall. This will increase sediment pollution on coral reefs and reduce coral growth.

Large and small scale tropical ocean currents will probably shift as the oceans try to redistribute the extra heat; such current disruptions will affect the distribution of larvae and juveniles of reef species.

Sea level rise threatens the existence of low lying island countries; this is Kiribati during a storm in 2005.

$$CO_2\ (gas) \longleftrightarrow CO_2\ (dissolved) + H_2O \longleftrightarrow H_2CO_3 \longleftrightarrow HCO_3^- + H^+ \longleftrightarrow CO_3^{2-} + 2H^+$$