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The Greenhouse Effect, Global Warming and Implications for Coral Reefs

by Lennart Nyman

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The Greenhouse Effect, Global Warming and Implications for Coral Reefs

by Lennart Nyman PhD

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The Greenhouse Effect

The Earth absorbes energy from the sun, some of which is retained and heats up both land and water surfaces. Greenhouse gases like carbon dioxide and methane trap heat in the atmosphere which makes the earth warmer. These gases trap heat in our atmosphere through a process called the Greenhouse Effect. Carbon dioxide and methane account for some 75% of all greenhouse gases emitted by human activities, and carbon dioxide alone accounts for almost two thirds of those gases (IPCC, 2014). On the other hand, some greenhouse gases remain in the atmosphere for only a short pertiod of time, whereas others may remain in the atmosphere for millennia and affect Earth´s climate. The longterm increase of carbon dioxide has been measured continuously by Charles Keeling and his son Ralph since 1958 in the clean air almost on top of Mauna Loa in Hawaii. This increase in atmospheric CO_2 is due to the combustion of fossil fuels. Mean historic CO_2 concentration has been between 275 and 285 ppmv during the Holocene epoch (9,000 BC and onwards) but started rising sharply at the beginning of the nineteenth century. In 2013 the concentration reached 400 ppm which is higher than it has been for at least a million years (IPCC, 2013 – Fig 1). In 2015 the Keeling Curve (see reference) was designated a National Historic Chemical Landmark by the American Chemical Society.

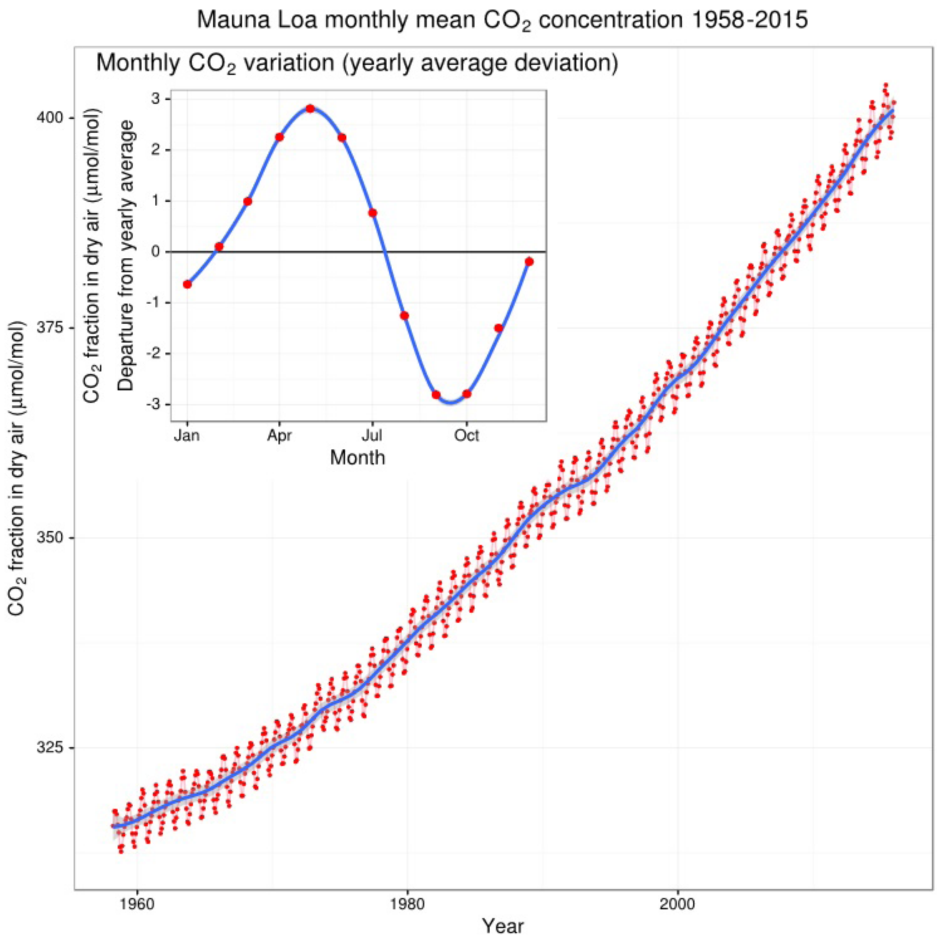

Fig. 1: The Keeling Curve showing atmospheric carbon dioxide (CO_2) concentrations from 1958-2015 (Wikipedia 2016).

The only solution to curb this negative trend is to rapidly stop carbon pollution by burning coal and oil, and stop irreversible forest destruction, and other related human activities.

Global warming and climate change

The Paris Agreement on climate change in December 2015 aims to keep global temperature rise "well below" the 2 degree level previously agreed, but available scientific knowledge on how to achieve this level is still based on controversial and still-untested technologies including carbon capture and storage. Even though we aim to limit warming to below 1.5 degrees C there is still such great uncertainty in the climate response that we could end up by more than a 2 degree increase by the end of this century. At either temperature level mentioned there will be increasing temperature rises in the Earth´s oceans.

Coral reefs

Coral reefs are marine structures of limestone built from the coral animals´ skeletons, and it has taken millions of years to build the reefs we see today. A nearby example is the island of Gotland which was once a coral reef, which is why the soil and bedrock there is so rich in lime.

Coral reefs occur in at least two types. Barrier reefs are extended along coasts. The most wellknown example is the Great Barrier Reef off the east coast of Australia, which is the world´s largest coral reef (see more below). Coastal reefs form an addition to an island or a coast. Corals prefer such shallow areas where they eventually reach the water surface and create a kind of platform.

There are also two types of coral reefs depending on water temperature and depth of occurrence. The most wellknown and studied ones are the shallow-water coral reefs of tropical and subtropical waters, the other type occurs in northern temperate areas in much colder water and at great depth. Most of this overview is focused on the tropical reefs, because they are already heavily impacted by global warming. Fig. 2 shows the global distribution of warm-water coral reefs (NOAA, 2014).

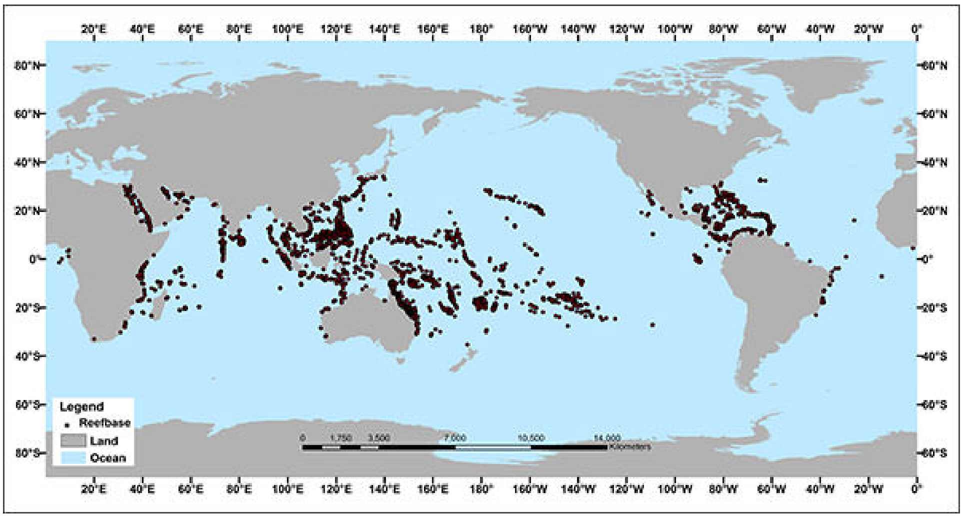

Fig. 2: Global distribution of warm-water coral reefs (NOAA´s National Ocean Service, revised November 19, 2014).

The projected water temperature increase will greatly affect the most biodiversity rich ecosystems of the oceans – the tropical coral reefs – which harbor some 25 per cent of all marine species on an area covering less than 0.1 per cent of the oceans´ surface area (Spalding et al. 2001). Another side effect of global warming is the increased content of carbon dioxide in the atmosphere. The liming processes in the corals are disturbed by increasing carbon dioxide.

Tropical coral reefs are found in more than 100 countries. This figure refers to the warm-water coral reefs, which are by far the most wellknown, because they occur in very shallow water and even at the present sea water level.

Much less known are the stone corals of temperate waters which may occur at depths from 40 to 3,000 meters and at temperatures ranging from 4 to 13 degrees (Corcoran et al., 2006). These reefs have so far been found in 41 countries and their total area is estimated to be as great or even greater than the tropical coral reefs (Corcoran et al., 2006). Cold-water corals provide structural habitat for diverse species communities. About 70% of the presently known cold-water corals are expected to be exposed to corrosive waters by the end of this century due to ocean acidification (Büscher et al. 2017). At the same time, these corals will experience a steady warming of their environment. Studies on the sensitivity of cold-water corals to climate change mainly concentrated on single stressors in short-term approaches, not accounting for long-term acclimatisation and interactive effects of multiple stressors. In the North Atlantic cold-water reefs are mainly built up by eyes corals (Lophelia pertusa), which also occur e. g. off the Swedish West Coast (www.marbipp.se - 2016). In the study of Büscher et al (2017) a multifactorial long-term experiment on the eyes corals was performed. For the first time multiple ocean change impacts were tested with regard to growth, fitness and survival. The results indicated that an increased food supply did not compensate for adverse effects of ocean acidification and stresses the importance of considering the nutritional status in studies on organism responses under environmental changes.

The largest cold-water coral reef of eyes corals yet discovered is found off the Lofoten archipelago in Norway, which appears to cover an area of close to 100 km^2 (Fosså et al., 2003). The global distribution of cold-water coral reefs is shown in Fig. 3 (Freiwald et al., 2004). The high density of reefs shown in the North Atlantic most probably reflects the intensity of research in this region and further discoveries are expected mainly in the deeper waters of tropical and subtropical regions.

The global oceans regulate our climate and weather conditions, like rainfall and floods. The oceans also absorb roughly one third of all carbon dioxide emitted through human activities, and has also absorbed some 90% of the extra heat trapped by the rising concentrations of greenhouse gases (Gattuso et al., 2015). The temperature rises so far experienced have caused that three-quarters of the world´s coral reefs are currently threatened (Burke et al., 2011).

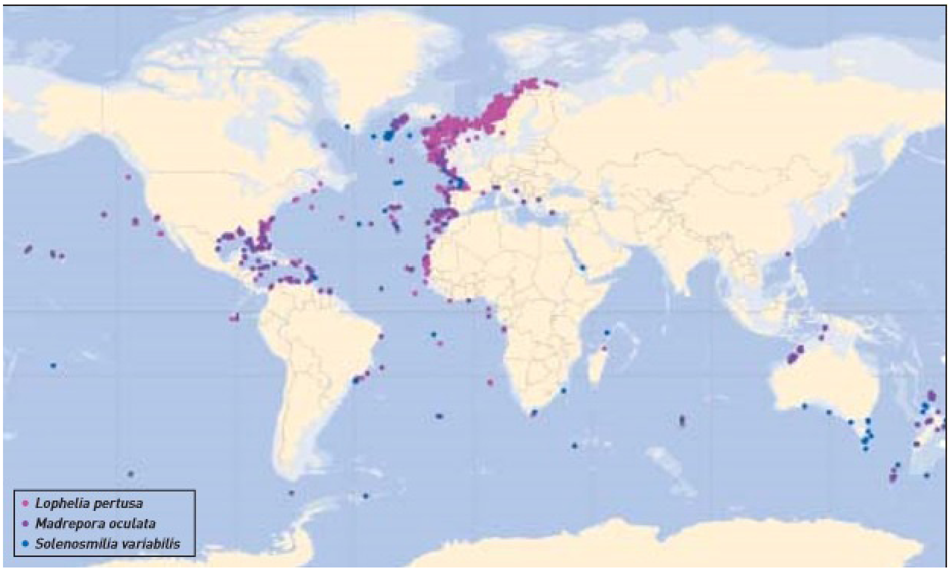

Fig. 3: Global distribution of cold-water coral reefs (Freiwald et al., 2004)

Coral bleaching

Above I have mentioned that among marine ecosystems tropical coral reefs probably are among the least resilient and also first victims of global warming. These reefs occur in shallow water, where temperature rarely is less than 20 degrees and salinity is around 3.5 per cent. I have emphasized (see below) that the number of fish species has declined significantly, but the most destructive effect on the well-being of a coral reef ecosystem is the effect on the reef itself. This process is termed coral bleaching. Corals are adapted to live within a narrow temperature regime. A temperature increase above the corals´ threshold level by as little as 1-2 degrees (C) during 5-10 weeks can lead to coral bleaching (Lang, 2002-2014), and eventually to extinction.

Coral bleaching occurs when stressful conditions result in the expulsion of the algal partner from the coral. Before human interference with climate, such events were relatively rare, allowing for full recovery of the reef between events. Tropical coral reef systems are now transitioning to a state in which the interval between recurrent cases of coral bleaching are too short for a full recovery of mature assemblages (Hughes et al. 2018). Median return time between pairs of severe bleaching events has diminished steadily since 1980 and is now only 6 years. In the near future coral bleaching will occur more frequently, increasing the likelyhood of annual bleaching in coming decades.

Coral bleaching indicates that the corals lose their coloration and the underlying white calcium skeleton becomes visible. What happens is that the corals´ endosymbionts, called zooxanthels, lose their photosynthesizing pigments. When coral bleaching occurs some 60-90 per cent of the zooxanthels are lost and in addition individaul zooxanthels can lose as many as 50-80 per cent of their photosynthezising pigments (Lang, 2002-2014). Some corals, however, may also have additional fluorescent pigments that are not associated with the zooxanthels and these corals may not lose all their colors. Bleached corals grow much more slowly than healthy ones, but under extreme conditions like prolonged temperature increase above what is normally tolerated by the corals, mass mortality can occur which may require decades to recover. Thus, mass coral bleaching events are projected to increase in frequency and intensity, and even preserving more than 10 per cent of present coral reefs would require limiting warming to below 1,5 per cent (Frieler et al., 2013).

In the period 1997-98 warm-water coral reefs all over the world suffered from massive bleaching. The major impact was noted in the coral reefs of the Central Indian Ocean, where some 90 per cent of all corals in an area covering several thousand km^2 died, including most corals in the Maldives, the Chagos Archipelago and the Seychelles (Lang, 2002-2014). Other coral reefs, e g off the coasts of Thailand and Vietnam were also badly damaged but they harbored more robust coral species that allowed the reefs to recover. Even parts of the Great Barrier Reef (see more below), Indonesia, the Philippines and the Caribbean area were also damaged but with a lower mortality of some 20-50 per cent (Lang, 2002-2014). These events were attributed to a combination of two weather scenarios, ENSO (El Nino-Southern Oscillation) and La Nina. The combination of those two weather phenomena probably caused the warmest water temperatures that "modern" corals have been subjected to, and it seems likely that some of the most severely damaged reefs may require years or even decades to recover. Even if most coral reefs will slowly recover there is a chance that local extinction of coral species may occur, which will lead to reduced biodiversity and, at worst, to less resilience to future accidents. Even worse, in the years 2015-2016 record temperatures triggered an additional global-scale event of coral bleaching, the third since mass bleaching was first documented in the 1980s (Hughes et al., 2017). This worst case scenario may in future occur annually as a consequence of continued temperature increase, i.e. cause local or even regional destruction of entire coral reef ecosystems. At current projected levels of temperature increase it has been suggested that tropical coral reefs could be lost altogether already by 2050 (Hoegh-Guldberg et al., 2015) and, in fact, fluctuating and rising ocean temperatures caused by global warming presents the largest primary threat to coral reefs.

The Great Barrier Reef

The Great Barrier Reef off eastern Australia har lost more than half its coral cover in the past 30 years, and the Marine Park Authority sees climate change as the most serious threat to the reef (GBRMPA, 2014). Almost half of this loss is attributed to foraging by the crown-of-thorns starfish, which are possibly triggered by nutrient-rich run-off from farms (De´ath et al., 2012). Implementation of new practices to reduce run-off and erosion and improve farm productivity are tested. The cuts to pollution needed for the reef´s survival need to be scaled up and include all catchments running into the reef´s waters, encompassing millions of hectares. The major threat to this objective is the plan to build industrial developments along the entire coastline, which will allow some 100 million tonnes of dredge spoil to be dumped into the shallow coastal waters. However, public support has recently resulted in a ban on dumping the spoil, but increased shipping traffic, dredging, dumping for port maintenance and other causes to coastal habitat destruction are still significant problems. Distinctive geographic footprints of recurrent bleaching on the Great Barrier Reef in 1998, 2002 and 2016 were determined by the spatial pattern of sea temperatures in each year. It was found that water quality and fishing pressure had minimal effect on the unprecedented bleaching in 2016, suggesting that local protection of reefs had afforded little or no resistence to the extreme heat (Hughes et al. 2017).

The Mesoamerican Barrier Reef (Belize Coral Reef)

This coral reef system is the second largest in the world and the largest in the Northern Hemisphere. It was listed as a World Heritage Site by UNESCO in 1996. It contains more than 100 species of corals. Its most widespread reef is the one off Belize, but both the coasts of the Greater and Lesser Antilles and the waters off Florida include coral reefs. Although lesser affected by the extreme weather conditions in 1997-98 (see above) some coral species were almost eradicated locally in 1998/99 (Aronson et al., 2002).

The Florida Coral Reef

This is the third largest barrier reef system in the world and the only coral barrier reef in the continental United States. This reef consists of two ridges separated by the Hawk Channel. More than 40 species of coral live on this reef and species diversity is comparable to that of the reefs in the Caribbean Sea even though it extends close to the northern limit for tropical corals (U. S. Geological Survey, 2010). The first recorded bleaching incident on the Florida reefs was in 1973, and in recent decades incidents of bleaching have become more frequent (Precht and Miller, 2008). Numerous other possible causes of the losses of coral in this area are also enumerated by Precht and Miller (2008).

The Coral Triangle

The co called Coral Triangle covers an area of ocean including the states and islands of Indonesia, Malaysia, the Philippines, New Guinea, Solomon islands and Timor (Fig. 4). This area is probably the richest area in the world in marine resources. More than 120 million people depend on these resources for their income and livelihood, and fish is of course the major source of protein in local diets (ADB, 2014). Fisheries exports, including more than a fourth of the global tuna catch and coral reef fish, amount to some US$ 1 billion annually (Muldoon, unpublished 2015). In addition to this lucrative trade income some parts of the region attracts tens of millions of visitors annually, and this nature-based tourism is estimated to be worth at least ten times as much as the income from fisheries (Pet-Soede et al., 2011).

Fig. 4: Map of the Coral Triangle (The Coral Triangle Atlas; UNEP-WCMC, WorldFish Centre, WRI, TNC 2010.

In 2009 the six coral triangle countries established an initiative of cooperation to sustainably manage their natural marine sources for future generations. Some of the major key areas of focus are shown in Fig. 5, and to address all these factors ecosystem-based fisheries management will be applied, theatened marine species will be protected and climate change matters will be addressed.

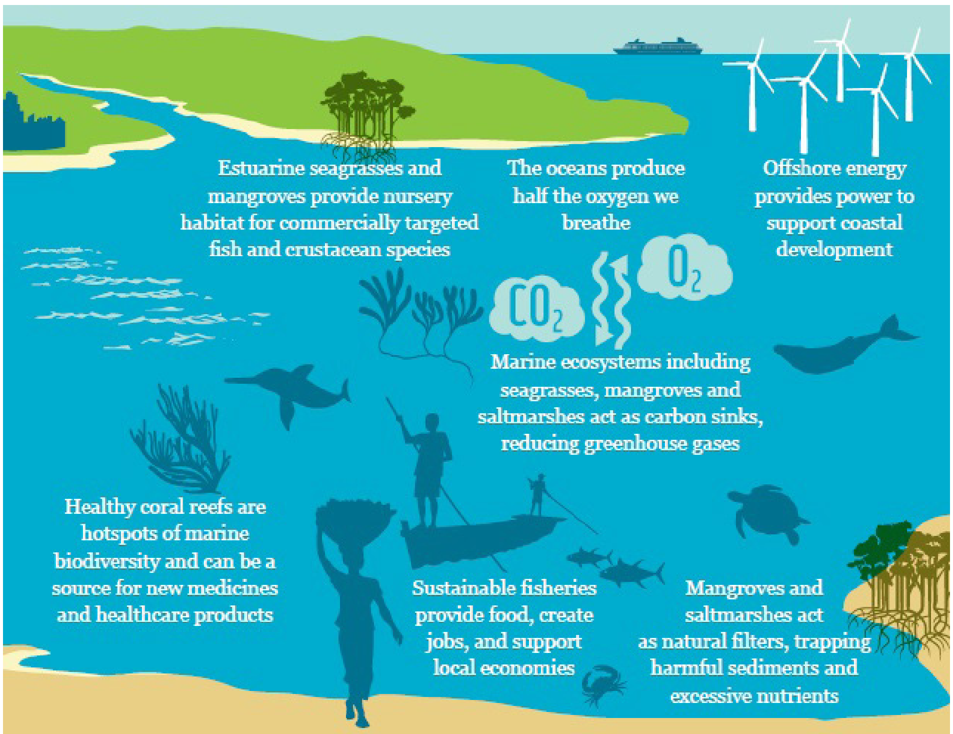

Fig. 5: The way forward to protect and increase sustainability of marine natural resources within the Coral Triangle countries. WWF-ZSL, 2015.

Some of the basic activities addressed will be to enlarge current small protected areas and stimulate development of community-based natural resource management, thus conserving and sustainably using marine resources.

The so called cold-water stone corals that build deep-water reefs in temperate waters lack the symbiosis with zooxanthels, which is why they can occur at greater depths. Obviously, there is still no indication of coral bleaching among those corals. On the other hand, deep-water trawl fishing may cause mechanical damage to the cold-water reefs, so human activities are already affecting the reef structures in northern waters.

Additional threats to coral reefs

There are also biological threats to coral reefs. A starfish called the crown-of-thorns has recently been found to eat coral polyps leaving only the skeleton behind. It is not known why this aggressive behavior has increased. Another human activity causing destruction of coral reefs is by dynamite fishing and collection of corals to sell to tourists, and also tourism itself may cause severe mechanical damage to the reefs.

Coastal agriculture, development and shipping, deforestation and increased unsustainable fishing, are all important vectors in this degradation of the coral reefs.

Some 850 million people in the tropical regions around the globe benefit directly from the social and economic services provided by coral reefs (Burke et al., 2011). The degradation projected will obviously affect both the reefs and the communities they sustain.

Another way of measuring effects on coral reefs is by refering to the Living Planet Index database (WWF, 2015) which covers 930 fish species 352 of which are classified as reef associated. This index has declined 34 per cent between 1979 and 2010 (Fig. 6). While overexploitation is listed as the primary threat, climate change is also identified as a significant threat.

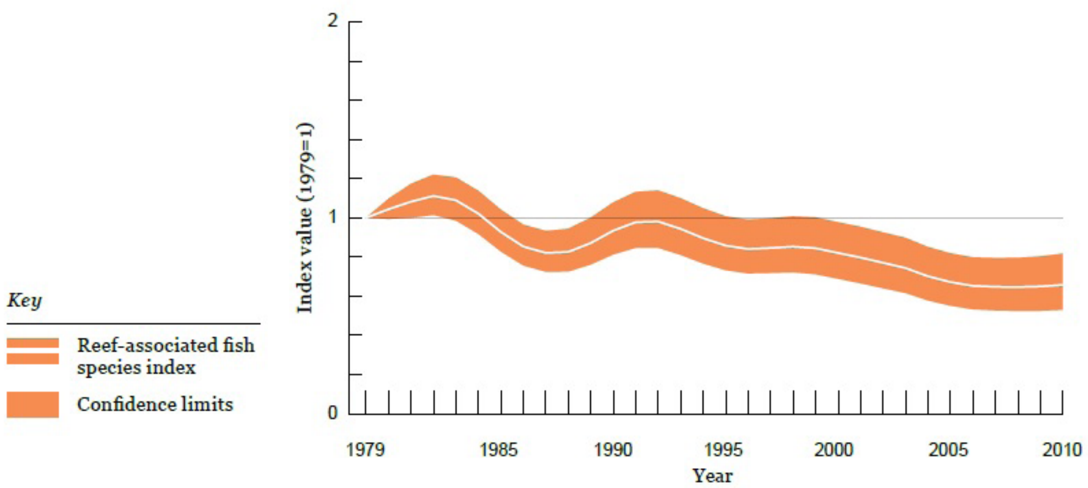

Fig. 6: The reef-associated fish species index declined 34 per cent between 1979 and 2010 (WWF, 2015).

It is fair to say that the Coral Triangle is the world´s center of marine life, but in the last decades more than 40 per cent of the region´s coral reefs and mangroves have been destroyed (Hoegh-Guldberg et al., 2009). The reasons for these threats are population growth, economic development, pollution and damage from agriculture, shipping installations and unsustainable fishing.

These basic threats are compounded by increasing ocean temperatures. Consequently, immediate global action to curb future warming is essential to secure a future for coral reefs world wide.

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