recent study by the World Resources Institute in the "Reefs at Risk Revisited" report (Burke et al., 2011a) calculated that more than 60 per cent of the world's coral reefs are under immediate threat. Indeed the latest Intergovernmental Panel on Climate Change (IPCC (2014)) report suggests that "coral reefs are one of the most vulnerable ecosystem on Earth" and will be functionally extinct by 2050, without adaptation (worst case scenario), or by 2100 with biological adaptation of the whole ecosystem. Presently the level of threats varies considerably in different geographical regions; reefs of the Pacific Ocean are least threatened, but those throughout Asia and the wider Caribbean and Atlantic regions are under greater threats.

Coral reefs developed throughout millions of years under a wide range of "natural" stresses, such as storms, variations in sea level, volcanic and tectonic plate activity. However recent anthropogenic stresses are overwhelming the natural reef resistance/resilience and recovery mechanisms, resulting in major losses and declines in the reefs and their biological resources in many regions. The major threats are: overfishing and destructive fishing practices; pollution and increased sedimentation; h

Reefs and mangrove forests provide coastal protection for land resources and human infrastructure, especially where large areas of shallow reef flats are adjacent to the shore and reefs have a distinct crest. This is a continual service, which is especially important during storms and cyclones. This service also includes some attenuation of tsunami waves, as was the case during the 2004 Indian Ocean tsunami (Wilkinson et al., 2006). Coastal protection provided by coral reefs is valued at 10.7 billion dollars (Table 1), which can be considered as a natural alternative to the cost of building seawalls along coasts that are otherwise protected from ocean swell and storm waves by offshore barrier reef systems.

Table 1. Annual net global benefits from coral reef-related ecosystem services in dollars assessed in 2010, with two important States included for emphasis. Values are expressed in millions of United States dollars as net benefits, including costs (from Burke et al., 2011b).

Global 29 000	11 500	6 800	10 700

the main island of the Maldives, Malé, was so seriously mined over centuries that the shoreline protection was virtually lost, such that in 1987 storm waves penetrated throughout the city causing massive saltwater damage, including contamination of the groundwater system. Replacement concrete tetrapod seawalls cost more than 10 million dollars per km in the 1990s; the cost would be much higher now (Talbot and Wilkinson, 2001). Such problems create economic dilemmas for governments, as it may be cheaper to mine fringing reefs and sand flats, rather than take the material from land or remote coral structures. This will be exacerbated with climate change-related sea-level rise. Mining also occurs at deeper areas. Large-scale mining projects are predicted for eastern Brazil to

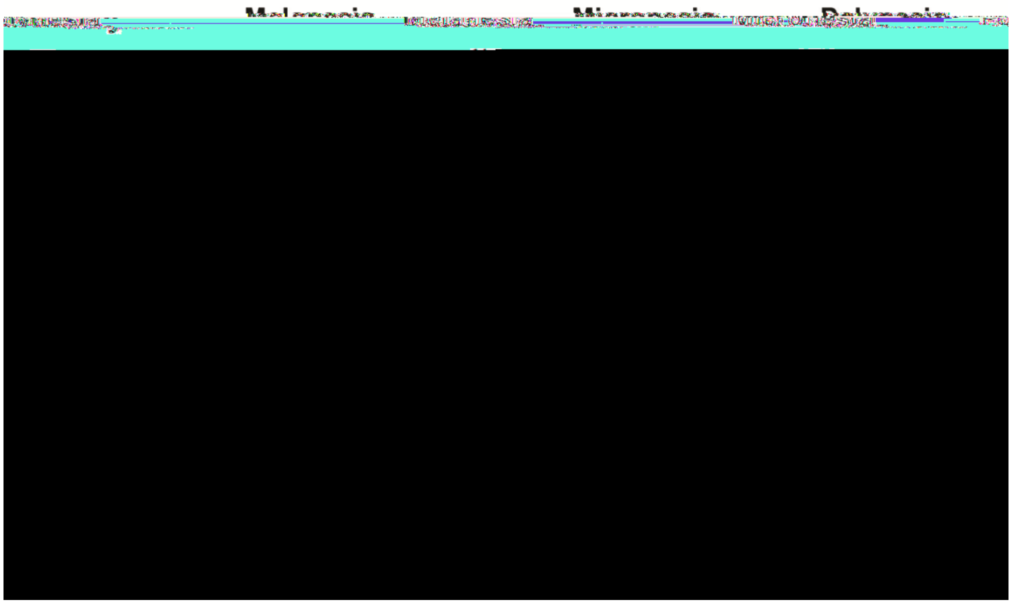
The boundaries and names shown and the designations used on this map do not imply official endorsement or acceptance by the United Nations.

Figure 1. The diversity of hard coral species is

these resources. The major threats include extractive activities, pollution, sedimentation, physical destruction, and the effects of anthropogenic climate change. Such stressors often interact synergistically with natural stressors, such as storms (Table 2). Carpenter and 38 other authors (Carpenter

iii. Poor political will and poor oceans governance	Political ignorance, indifference, inertia; corruption and low transparency in governance at global and regional levels all impede decision-making and waste resources.
iv. Uncoordinated global and regional conservation arrangementsBT-0.005 T	Inadequate coordination among multJETQ77Tm[(iv)-0.8(.)-6.7(U)-4.8(n)-2.3(coor)0.8(d)-2.4(

with reef fish taken largely



from mining in New Caledonia (France), while contamination by persistent organic pollutants (POPs) occurs across the whole lagoon region (Briand et al., 2014). Millions of mirror agricultural use in the catchments adjacent to the GBR (Kennedy et al., 2012; Lewis et al., 2009) and on reefs of French Polynesia (France) (Salvat et al., 2012).

Herbicides that inhibit photosystem II in plants are highly persistent in marine environments and are regularly detected in coral reef systems (Schaffelke et al., 2013); with concentrations of herbicides periodically exceeding regulatory guidelines for the GBR during flood plume events (Lewis et al., 2012). These concentrations are known to deleteriously affect corals (Jones and Kerswell, 2003; Negri et al., 2005), microalgae (Bengtson Nash et al., 2005; Magnusson et al., 2008), crustose coralline algae (Negri et al., 2011), foraminifera (van Dam et al., 2012), and seagrass (Haynes et al., 2000; Gao et al., 2011).

The sensitivity of a coral reef to po)) se 2.N063 a1(p)-4(o)82i Td1(5)()TjTd()BTf(0)8((it.9(o Tc St.]TJ0.0 7.6

world’s coral reefs and at least 10 identified coral diseases (~30 per cent of known coral diseases; Willis et al., 2004). It is unclear whether coral disease will have the same impact on Indo-Pacific reefs as it has in the Caribbean due to fundamental differences in their coral reef communities (Wilson et al., 2014). A higher level of diversity and functional redundancy in herbivorous fishes and coral communities, slower macroalgal growth, and less dependence on fragmentation as a reproductive mode, may protect Indomajor outbreaks have occurred simultaneously with mass coral bleaching in 2005 and 2006.

Four widely supported but not mutually exclusive theories to explain COTS outbreaks are: (a) fluctuations in COTS populations are a natural phenomenon; (b) removal of natural predators (such as large molluscs and some fishes) of the COTS has allowed populations to expand; (c) human-induced increases in the nutrients flowing to the sea have resulted in an increase in planktonic food for larvae of the COTS which leads to an increase in the number of adult starfish causing outbreaks (Fabricius et al., 2010); and (d) increased COTS larval survival as ocean temperatures increase (Uthicke et al., 2014).

Although many reefs lie outside the zone of frequent tropical cyclones and hurricanes (approximately between 7^{o}N and 7^{o}S latitude), storms regularly damage coral reefs outside this latitudinal zone (Figure 3). Storm damage is exacerbated by storm surge and both reduce the ability of coral reefs to return to their mean pre-disturbance state or condition by slowing coral recruitment, growth, and reducing fitness (Nyström et al., 2000). The combination of tropical storms with other stressors has caused successive and substantial losses of corals worldwide (Harmelin-Vivien, 1994; Done, 1992; Miller et al., 2002; Fabricius et al., 2008; Williams et al., 2008a). However, tropical storms also benefit reefs when the storms are sufficiently distant to not inflict damage, but close enough to cool waters through enhanced wave-induced vertical mixing and to reduce bleaching risk (Szmant and Miller, 2005; Manzello et al., 2007; Carrigan and Puotinen, 2014). A recent modelling study predicted that Caribbean coral reefs with intact herbivore fish and urchin populations would likely maintain their community structure and function under any expected level of tropical cyclone activity, as long as other stressors,

The boundaries and names shown and the designations used on this map do not imply official endorsement or acceptance by the United Nations.

Figure 3: These plots of tropical cyclones (and typhoons) over the past 100 years illustrate that damaging storms are rare within a band between 7^{o} North and South of the Equator, such that a large proportion of the high biodiversity reefs in Indo-Pacific are rarely damaged by damaging storms (courtesy of NASA, USA, 2008). There are predictions that under increasing climate change, the damaging strength of cyclones will increase with more category 4 and 5 storms, but the number of storms may not change (Wilkinson and Souter, 2008).

The first detailed prediction of the potential for increasing ocean acidification to damage coral reefs was made in 1992 at the 7th International Coral Reef Symposium (Buddemeier 1993). Experimental studies confirmed these predictions of damage to coral calcification in the 1990s (Gattuso et al., 1998; Gattuso et al., 1999). The IPCC (2014) report determined that under medium- to high-emission scenarios (RCP4.5, 6.0 and 8.5), ocean acidification poses substantial risks to coral reefs through its effects on the physiology, behaviour, and population dynamics of individual species from phytoplankton to animals (to , IPCC, 2014). Also the lowering of pH will favour the dissolution of the calcareous matrix of coral reefs.0(t)-4(h)-1.

synergistic with da magefrom rising s -surface temperatures. Further e

increased concentrations of CO_2 in seater have shown decreased calcification rates by corals and other calcium carbonatesecreting organisms (Ber and Elderfield, 2002; Doney et al., 2009;iebesell et al., 2000;eeo Chapter 7). A doubling of current atmospheric CO_2 concentrations reed calcification .ty 11 per cepitR.9(s)2+rb4.1(a-0.001 Tw -35.26 -1.36

However, some corals show either olimited

Economic valuation of coral reefs is a relatively recent process (Cesar, 1996; Cesar et al., 2003) to demonstrate the importance of reef ecosystem services and encourage greater conservation efforts. However, there is a potential critical error in that high-value, short-term economic gains that result from development activities can occur at the expense of longer-term benefits. Economic valuation provides more complete information on the economic consequences of decisions that lead to degradation and loss of natural resources, as well as the short- and long-term costs and benefits of environmental protection. Many studies have assessed the value of ecosystem services provided by coral reefs, at local to global scales. The focus is predominantly on tourism and reef-related fisheries; because these are widely studied and direct-use data are more readily available. It is more difficult to estimate indirect-use values, such as shoreline protection, and most difficult with controversial methods to estimate non-use values, such as cultural, biodiversity and heritage values. The annual net global benefits from coral reefs have been estimated at 29 billion dollars

(11.5 billion dollars tourism; 6.8 billion dollars fisheries;olbest dificurt di.9( )]TJg5yielbe[(fvdse)03 Tw.0

Phoenix Islands Protected Area	Kiribati	2008	408,250
Papahānaumokuākea (	United States	2006	362,100
Great Barrier Reef Marine Park	Australia	1975	344,400

Those areas face major logistical and economic challenges of implementing, managing and monitoring (Leehardt et al., 2103).

Emslie et al. (2015) showed that expanding NTMR networks had clear benefits for fishery target, but not non-target, species. During the study, a cyclone caused widespread degradation, but target species biomass was retained within NTMRs, with great-4(e)-1(di-4(re)-0.9(aE12 -0 0 12 90 648.360 12 90 648.360 12 90 64.486(it-0.001 (a)10(d)-4(d)6(e)-1(g

During the first half of 1998, the most severe El Niño event ever recorded resulted in the loss of more than 90 per cent of live coral cover throughout large parts of the Indian Ocean. Damage was particularly severe in the Maldives, Chagos Archipelago, Seychelles and Kenya. Prior to 1998, reefs adjacent to large human populations along the coast of East Africa, India and Sri Lanka had already suffered serious damage from excessive and destructive fishing, nutrient pollution, increased sediment input from land and direct development over the reefs, including coral mining.

Reefs on remote islands and in the Red Sea were generally in good health prior to 1998. Since 1998, coral recovery has been minimal in the Persian Gulf and Gulf of Oman, with recovery often reversed by more bleaching. Throughout the Arabian Peninsula region, massive coastal development and dredging to create oil industrial sites and residential and tourist complexes has occurred. Many reefs in the Red Sea continue to be healthy, although COTS (crown-of-thorns starfish) have caused damage, and expanding tourism in the Northern Red Sea is accelerating some coral losses.

Along the coastline of Eastern Africa, a mix of reef recovery and reef degradation is observed as management efforts are directed at controlling the effects of rapidly growing populations and at involving local communities in coastal management. All States are increasing their networks of marine protected areas and States are improving management capacity and legislation.

Reefs of the southwestern islands in the Indian Ocean continue to recover after devastation in 1998. Some reefs of the Seychelles and Comoros have regained about half or more of their lost coral cover but recovery has been poor on reefs damaged by human activities. Recovery rates in the Seychelles varied, in part, due to factors that have now been shown to increase reef resilience – depth and structural complexity (Graham et al., 2015).

The reef decline in South Asia continues, as large human populations further impact coral reefs, adding to the damage that occurred in 1998. Recovery has been observed in the reefs of the western Maldives, Chagos Archipelago, the Lakshadweep Islands (India) and off northwest Sri Lanka, with seemingly locally extinct corals making major recoveries, e.g., some reefs have gone from less than five per cent coral cover to 70 per cent in 10 years. The 2004 Indian Ocean earthquake and tsunami caused significant reef damage at some sites, but many are recovering. In Sri Lanka, bleaching was reported in 2010, fisheries continue to be the biggest chronic impact, and pollution has increased sedimentation and urban and industrial pollution from rapid economic development are accelerating reef degradation and more than 50 per cent of the region's mangroves have been lost.

Coral reefs in Northeast Asia have shown an overall decline since 2004; most reefs are coming under significant levels of human pressures, as well as bleaching and COTS stress. In China, coastal development and overfishing has destroyed 80 per cent of coral cover over the past 30 years (Hughes et al., 2013). A few reefs with high coral cover remain, such as Dongsha Atoll between Taiwan Province of China and the mainland of China. Increased coral reef monitoring and research, including the establishment of a regional database, is occurring in Japan; Hong Kong, China; Taiwan Province of China; and Hainan Island (China), and the region is stimulating more awareness and cooperation by having held the Asia Pacific Coral Reef Symposium in 2006, 2010 and 2014. Awareness of the need for coral reef conservation is rising rapidly in most countries.

Australian reefs continue to be relatively stable due to several management measures. Since 2004, no major bleaching events have occurred, although two significant cyclones have resulted in major damage to some reefs. Particular features are the effective partnerships between coral reef science and management. The future outlook for the GBR is regarded as poor, especially in the southern half of the area, where anthropogenic stresses are strongest. Climate-change impacts are considered to be the greatest long-term threat to the whole GBR system (GBRMPA 2014).

In Papua New Guinea, capacity-building for reef management is being conducted via large NGOs working with local communities. Papua New Guinea still has vast areas of healthy and biologically diverse coral reefs, but human pressures are increasing.

The coral reefs of the Pacific remain the most healthy and intact, compared to reefs

distribution and even their existence are unknown in most reef provinces. For this reason, deeper reefs have been underestimated in analyses of the available area of coral habitat and are not included in assessments for conservation measures, despite recent evidence that these areas may be significant (Locker et al., 2010; Bridge et al., 2013). A recent study suggests that the area of submerged reefs in the GBR may be equal to that of near-surface reefs (Harris et al., 2013). Understanding the extent of submerged reefs is therefore important, because they can support large and diverse coral communities (Bridge et al., 2012) and hence may provide vital refugia for corals and associated species from a range of environmental disturbances (Riegl and Piller, 2003; Bongaerts et al., 2010).

The scientific consensus is that threats associated with climate change (bleaching, ocean acidification, stronger storms etc.) pose the greatest threat to the medium- to long-term existence of coral reefs around the world. What is unknown is whether reefs can and will respond to these threats with greater resilience. Reefs contain very high biodiversity and have progressed through major climate change events in the geological past; how will they be able to respond in the next decades to rapid climate changes? There are early indications that some corals can adapt to warmer temperatures and grow in more acidic water, but it is predicted that many corals and other reef organisms do not have that capacity. The adaptation potentials of coral reef organisms are areas for more targeted research which will significantly increase our ability to reliably predict how reefs will fare into the future.

(iii) The pollution of coastal waters by harmful substances (heavy metals and persistent organic pollutants) is prevented, and amounts of inputs of sediment and nutrients are kept at levels that do not damage the reefs (see chapter 20);

(iv) Any development in coastal areas is kept to levels and forms that are consistent

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