Changes to coral reef communities: more than just fish and corals

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ABSTRACT

Worldwide coral reefs are declining in health due to anthropogenic impacts including widespread bleaching or corals which often leads to death of the coral colony. Not only are we witnessing impacts on the cover of live coral and fish populations, but also we are losing the tremendous diversity of other animals which are dependent on live corals. To date these losses of the other invertebrates (non corals) have been largely neglected and this paper attempts to rectify this and also to highlight the impact of these. However other groups of organisms responsible for bioerosion of coral substrates initially benefit from an increase in dead coral substrate available. So with climate change and other anthropogenic impacts there are winners and losers, but the long term outlook for coral reefs as we know them today is depressing and will have major impacts on the economy of many developing countries in the tropics which rely heavily on reefs for food, coastal protection and tourism.

Key words: coral reefs, climate change, marine invertebrates, coral bleaching

Introduction

A recent vulnerability assessment report of the Great Barrier Reef (Johnson and Marshall 2007), provided a good synthesis of the physical and chemical factors which are changing as a result of global warming through the emissions of greenhouse gasses, and which are all likely to impact on the reef and all its component biota. These include rising air and sea temperatures, rising sealevels, increasing incidence of UV light, acidification of water, and intensity of storms resulting in increasing run off and increases in turbidity of coastal waters, and changing oceanographic patterns. However the changes are not consistent either across or down the reef, with some areas being more affected by certain components than others. In addition they vary between seasons and years. So while there are levels of uncertainty in the magnitude of these changes there is already very good evidence that changes are occurring to reefs worldwide including the Great Barrier Reef. The Great Barrier Reef Marine Park Authority invited a series of researchers to review the likely impact of these physical and chemical factors on each of the major biological components of the reef and inter-reefal areas. I was asked to co-ordinate an assessment of the vulnerability of reefal invertebrates (excluding corals) to these changes (Hutchings *et al.* 2007).

One of the most visible signs of increasing water temperature especially during the summer months and when weather patterns are such that for many consecutive days the seas are calm, allowing surface water temperatures to increase, is coral bleaching (Marshall and Baird 2000) (Fig.1). However some serious impacts of climate change of non coral invertebrates can be quantified and the rest of this paper is devoted to these groups which have tended to be ignored compared to fish and corals the groups which have been relatively well studied in comparison (Bellwood *et al.* 2006, Coker at al. 2009, Pratchett *et al.* 2008). While one can make some predictions as to how these individual components of change may affect marine invertebrates on both the reef and inter-reefal areas, in reality most of these will act synergystically (Przeslawski *et al.* 2008). Another compounding factor is that impacts vary throughout the year, for example if a major storm (cyclone) hits an area which increases rates of runoff and turbidity at exactly the same time as species are spawning, this may seriously impact on rates of fertilisation and subsequent recruitment patterns, whereas such a storm a few weeks later or earlier may have far less impact. This makes quantifying the impact of climate change difficult and this is also compounded by variations along and across the reef. In addition it highlights the complexity of climate change and the synergystic effects, for example it may reduce fecundity, levels of recruitment or change growth patterns, and all these subliminal impacts may gradually reduce populations and finally lead to local extinctions. So we may see immediate death of reefal invertebrates after a major storm or bleaching event as well as a slow death as a variety of subliminal effects impact on individuals and populations.

Often the general public think of corals reefs as being dominated by corals and fish, yet in reality the bulk of the coral reef diversity in terms of both numbers of species and individuals is provided by the diverse invertebrate fauna (excluding corals) which lives on the reef, often within the reefal framework or in amongst the live coral. This fauna, often small, is largely hidden so as to minimise predation but some may be seen at night when they emerge to feed. Another diverse fauna is found in amongst the reefal sediments and such intereefal habitats constitute a significant component of the reefal ecosystem. While few attempts have been made to document the diversity of intereefal sediments, a survey of epifaunal communities

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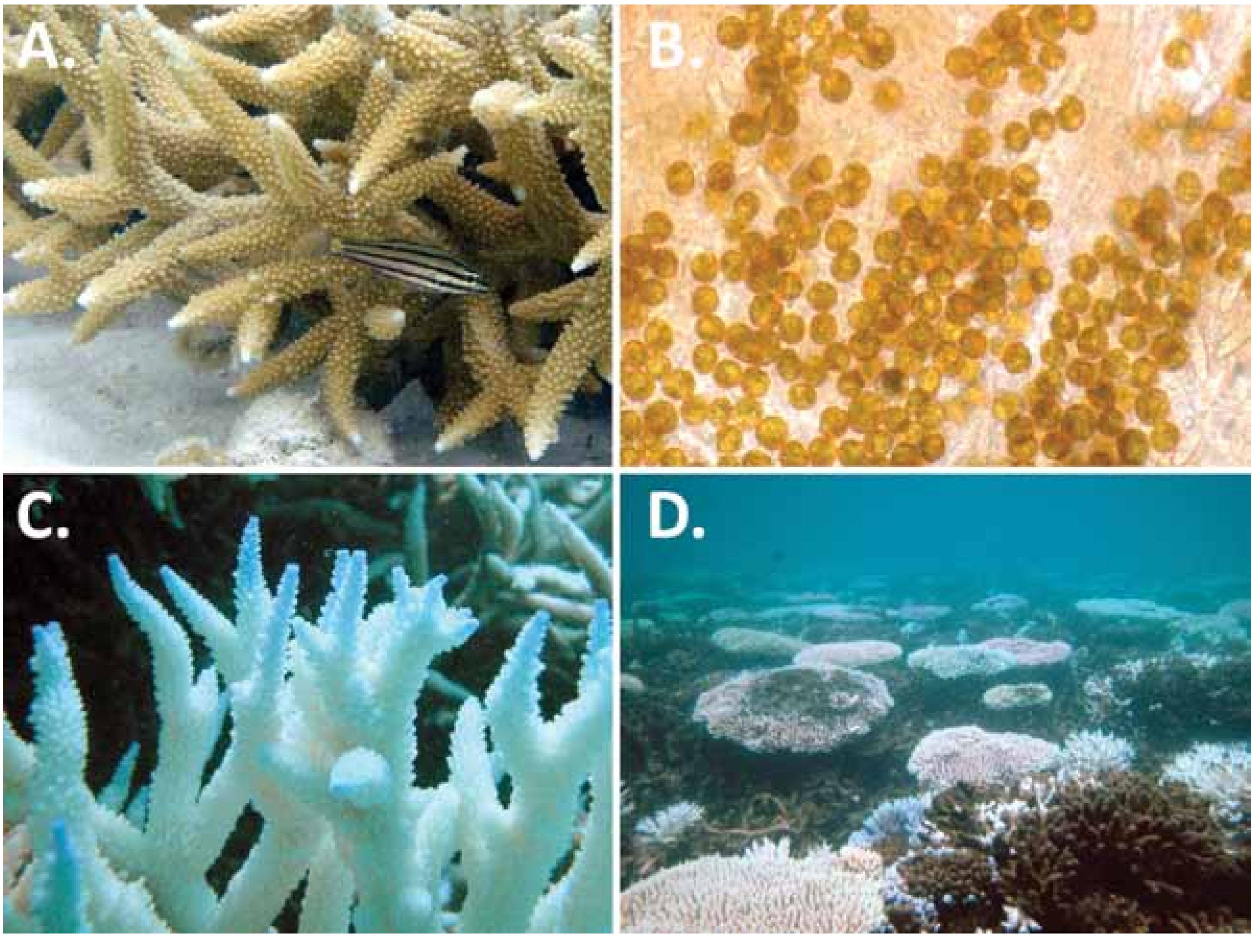

Figure 1. Rising seawater temperatures cause bleaching of corals, which may or may be lethal. A. Healthy reef building coral with dinoflagellates. B. Shows healthy dinoflagellates which are responsible for the colour of the coral, and which are ejected when water temperatures rise. C. *Acropora* spp. which has been bleached due the ejection of the z dinoflagellates. D. Reef at Great Keppel Island after a bleaching event in 2006. All photos by Ove Hoegh-Guldberg (From Hutchings *et al.* 2008)

on the surface of these sediments has shown them to be very diverse although poorly known taxonomically (Pitcher *et al.* 2007). In contrast more is known about the invertebrates which are associated with live scleractinian corals. Stella *et al.* (2011) found 869 invertebrate species representing 108 different families belonging to eight phyla; Arthropoda, Mollusca, Echinodermata, Annelida, Porifera, Platyhelminthes, Sipuncula and Hemichordata. Of these 869 invertebrates, 56% (487) were found to be obligate coral associates. This means that if the health of the coral declines or the coral dies then it is unlikely that these animals will survive as they need to live in amongst live coral. These invertebrates are using the live coral in a variety of ways, for some it represents a protective habitat in which to live, others feed exclusively on live coral polyps, some seek refuge within the coral branches from predation and others mate exclusively within the branches (for more details see Stella *et al.* 2011). This illustrates how important the health of the coral is for a large suite of diverse organisms. In addition to the invertebrates there are many fish which have a similar dependence on live coral (Pratchett *et al.* 2008).

So when mass coral bleaching is reported on the Great Barrier Reef, Australia as occurred in 1983, 1987, 1991, 2002, 2006, it is not just the corals which are affected but all the associated organisms which in amongst the live coral. Bleaching occurs when corals expel their zooxanthellae as a result of increased water temperatures and while potentially they can recover if water temperatures drop, often the bleached colonies die (Hoegh-Guldberg 1999). While corals in shallow water are most vulnerable, in 2006 some sites experienced 90% mortality of live coral colonies to 30 m (Fig. 1). Another massive bleaching was averted during 2010, because while water temperatures were very warm, strong winds during the hottest periods reduced water temperatures in the surface as they became agitated and reduced the temperature (Maynard *et al.* 2009), but obviously this does not always occur. Exactly when the associated fauna of live corals are impacted by coral bleaching is unknown and probably varies between groups, and almost certainly those which feed on the live coral polyps are impacted first. Most of this fauna is relative sedentary and so it is dificult for them to move to nearby unbleached colonies without being predated upon. Also during a mass bleaching event most colonies in an area will be impacted especially the branched corals an important habitat for many of these coral dependent species. If the coral recovers from bleaching, recolonisation by these coral dependent invertebrates may occur through larval recruitment as many of these species have pelagic larvae. However this will depend on the presence of non bleached areas where breeding populations of these invertebrates still exist. No studies to date have been undertaken to monitor the rate of recolonisation by these invertebrates as the corals recover from bleaching, but suspect it will be highly variable between groups. Another factor which is likely to be very important is the frequency of bleaching, sites where regular bleaching occurs will almost certainly have lower levels of associated fauna.

If bleaching events lead to coral death then there will be localised extinctions of coral dependent invertebrates. Whethor or not coral recruitment occurs in the area depends on a variety of factors including water quality and having reasonable populations of herbivorous fish to graze on the filamentous algae which rapidly colonise the newly killed coral colonies. However if water quality is poor this may encourage the growth of macroalgae which if not grazed by the herbivorous fish will smother the reef substrate and prevent any subsequent recruitment of corals and associated coral dependent invertebrates. In place like the Great Barrier Reef where considerable effort is being made to improve water quality and reduce overfishing it is hoped that these strategies will facilitate the succesful recruitment of coral and with it their associated fauna (Maynard *et al.* 2009). However the increasing frequency of bleaching events will only make this more unlikely and we are likely to see algal dominated reefs as already common in many parts of the world (Wilkinson 2008, Harris *et al.* 2010). Even on the Great Barrier Reef some inshore reefs are becoming degraded (Fabricius *et al.* 2005) as a result of a variety of events such as bleaching, Crown of Thorns, declining water quality and increasing turbidity (Brodie *et al.* 2005).

Rising sea water temperatures also impact on various aspects of the physiology of reefal invertebrates, including rates of growth, feeding and life spans and may affect the time of breeding which may result in larvae being dispersed into the water column out of synchrony with phytoplankton blooms for exampled. The thermal tolerances of most reefal invertebrates are unknown but it is suspected that intertidal species may be most impacted as they will be subjected to both increases in water and and air temperatures.

As well as rising seawater temperature we are seeing an increase in ocean acidification as anthropogenic produced CO_2, dissolves in seawater. To date, the pH of the ocean has dropped by 0.1 of a pH unit; as this is a logarithmic scale, this is a significant change. This represents a 30% increase in the concentration of carbon dioxide in the sea. Future changes in pH depend on the rate at which carbon dioxide is emitted as the century continues, but most projections have the pH decreasing by 0.3 – 0.4 units by the end of the century (Raven *et al.* 2005). This change makes carbonate ions less available to make calcium carbonate, which is used by corals to build the reef framework (Anthony *et al.* 2008), shells of molluscs, and the skeletons of echinoderms for example (Wood *et al.* 2008, Byrne 2011) and leads to less dense skeletons or thinner shells. Organisms with thinner shells or skeletons may be more vulnerable to predation (Irie & Iwasa 2005) and larvae may be less likely to settle successfully (Dupont *et al.* 2008). These declines in pH also leads to increasing rates of dissolution of calcium carbonate substrates, by chemical dissolution and less dense substrates are more susceptible to increase rates of bioerosion or reef destruction.

So with increasing bleaching events and subsequent death of coral colonies and associated invertebrates there will be significant increases in the amount of dead coral substrate available for colonisation by boring organisms. For while live coral colonies are bored by some animals the majority of boring organism only infest dead coral substrates (Hutchings 1986). Similarly most grazing organisms feed on the epilithic or algae just living below the surface of dead coral, which will increase rates of bioerosion across the reef. Bioerosion is a process which occurs on all "healthy" reefs and is normally balanced by coral growth (Hutchings 1986, 2011) but when coral growth declines bioerosion becomes the dominant process affecting coral reefs. A suite of organisms are adapted to bore into dead coral and create a three dimensional habitat which can then be used by non borers (Hutchings 2011). Bioerosion consists of erosion of calcareous substrate by grazing and boring and this is complemented by physical and chemical erosion of substrate. Rates of bioerosion will increase with climate change but also may be accentuated by other anthropogenic impacts. For example, while river run off from Daintree River in North Queensland has always occurrred during the wet season, the amount of erosion of topsoil has increased since European settlement and is accentutated by such agricultural practises as overstocking land upstream with beef cattle, and the removal of riperian vegetations downstream. Such vegetation can reduce the amount of sediment flowing down the river and out in the Great Barrier Reef lagoon and as most rivers flowing into the Great Barrier Reef lagoon have been substantially cleared (Brodie *et al.* 2003), there are major programmes being implemented by various catchment management authorities to restore riparian vegetation (Brodie *et al.* 2001). A transect across the reef from the entrance to the Daintree to out into the Coral Sea showed how the rates and agents of bioerosion changed along its length (Hutchings *et al.* 2005, Osorno *et al.* 2005). Inshore sites were covered with fine silt which inhibited the development of a good endolithic algal population and hence reduced grazing by scarids but allowed internal boring communities to thrive. In contrast, offshore sites had well developed endolithic algal populations which increased rates of fish grazing and loss of calcium carbonate. In addition the macro boring communities were also significantly different along the transect.

In cases when runoff is also eutrophic with increased levels of nutrients from sewage or pig farms as occurs at Faaa a suburb of Papeete, Tahiti, much higher rates of bioerosion occur. This situation is also exacerbated by intense levels of overfishing to such an extent that virtually no fish are present. The highly eutrophic waters encourage the development of both endolithic algae but also fleshy algae growing over dead coral substrates which are heavily grazed by dense populations of echinoids which remove large amounts of the algae as well as dead coral substrate. The epilithic algae prevent new coral recruits from settling and with no fish to eat the echinoids, substantial losses of reef substrate occurred (Pari *et al.* 1998) (Fig. 2).

Figure 2. Experimental blocks of *Porites* attached to the reef substrate after 6 months of exposure to grazing sea urchins *Echinometra mathaei* in eutrophic waters at Faaa, Papeete, Tahiti. Photos M. Peyrot-Clausade (after Hutchings *et al.* 2008)

With increasing ocean acidification we are witnessing a decline in the density of coral skeletons (Kleypas *et al.*, 2005) which then makes them more vulnerable to bioerosion as less dense substrates will initially favour borers and the nestlers which occupy the burrows created by the borers, however such weaker substrates will also be more vulnerable to physical and chemical erosion and results in loss of substrate and associated invertebrates especially during storm events. An alternative hypothesis is that as increasing ocean acidification is normally associated with increasing temperatures, and this might actually stimulate increased calcification through enhancement of the physiological processes involved, potentially ameliorating the effect of acidification (McNeil *et al.* 2004). So the predicted combined impacts of ocean acidification and sea warming on coral reef invertebrates remains controversial and open to debate (McNeil *et al.* 2004, Kleypas *et al.* 2005, Matear & McNeil 2006, Wood *et al.* 2008). It also highlights the synergistic effects of the various components making definitive predictions difficult. Experimental studies are about to commence in which levels of acidification will be controlled and rates and agents of bioerosion measured over time (Hutchings, pers. comm). It is anticipated that changes to rates and agents of bioerosion will occur.

So while invertebrates dependent on live coral will be severely impacted as coral reefs change to algal dominated reefs and the organisms which depend on live coral will become extinct at least locally, others will flourish such as borers and algal grazers but only as long as the reef framework is retained. Thus there will be winners and losers.

A question often asked is if conditions are so adverse to corals and their associated suite of dependent organisms why don't the corals or their progeny just move further south into cooler water? In some cases this may be possible but often reefs are surrounded by deep water like the southern edge of the Great Barrier Reef which falls away into deep water so there is no suitable substrate in shallow water on which new recruits could settle. If bleached colonies are surrounded by unbleached colonies then recruitment of corals and associated invertebrates is possible. If an entire reef is killed, factors such as the distance from "healthy reefs" is critical together with local currents which may transport propagules of both corals and other invertebrates (Levin 2006). Evidence is accumulating that currents along the Great Barrier Reef are changing but not in consistent patterns across or along the reef (Steinberg 2007). An example of the tyranny of distance is the slow recovery of coral reefs and their associated invertebrates of some of the remote atolls of French Polynesia which during the early 1980's were severely impacted by Crown of Thorns, cyclones and very low tides during the middle of the day leading to extensive mortality of these reefs. Ten to 15 years later these reefs still had not recovered (pers. observations) and this was largely due to many 100's of kilometres separating reefs and probably unfavourable ocean currents. In contrast, reefs at North Head at Lizard Island on the Great Barrier Reef were subjected to Crown of Thorns plagues around the same time recovered within 3-5 years as there was an abundance of healthy reefs nearby and favourable ocean currents for dispersal of larvae (pers. observations).

So while the location of coral reefs has changed over geological time, it is the rate of temperature sea level changes which are occurring which is the problem, and is not comparable in any way with changes which have occurred in previous geological times. In addition in geological times when temperatures have changed there were not the other anthropogenic factors operating such as increased sedimentation, declining water quality and overfishing all of which impact on reefs and their associated biota.

So what is the future for the Great Barrier Reef? Certainly we are already witnessing a change in the reef with inshore reefs becoming more algal dominated. The recent cyclone along northern Queensland coast will have had serious impacts on the inshore shallow water reefs, whether they will recover will to some extent depend on how long before the next cyclone hits the area again as well as water quality issues. Reefs can recover from such storm events but they need decades to. Therefore we must reduce emissions as well as other management options, as even if we reduce emissions now, there is a considerable time lag before conditions stabilise, so not looking very hopeful for reefs even areas like the Great Barrier Reef which are well managed. We are already seeing heavily damaged reefs in many other parts of the world (Wilkinson 2008).

So while this paper has concentrated on the impacts of coral loss on much of the reefal biodiversity, there are other factors to consider. Coral reefs are restricted to tropical areas and many are managed by developing countries often with limited funding and expertise available. Reefs are also critical to many of these countries for coastal protection against storms especially for low lying coral atolls. In addition they are also critical as a source of protein for local populations with regards to fish and several commercially important invertebrates which live associated with live coral. Many of these countries rely upon tourism as a major source of income to these communities. So loss of coral reefs has major ecological and economic consequences for many countries. In Australia the Great Barrier Reef is one of Australia's major tourist attraction as well as sustaining important fisheries and has often been quoted at AUD$5 billion per year (Access Economics 2008). A better value based on the principle of true cost-benefit (Oxford Economics 2009) have recently estimated the Total Economic Value (TEV) of the Great Barrier Reef (excluding indigenous values) as $51.4bn which is an order of magnitude greater than previous estimates. So there are sound economic reasons as well as a need to conserve reef biodiversity to manage our reefs and this must include more than just the corals and fish, although if the corals stay healthy so will the diverse invertebrate populations associated with coral reefs.

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