Chapter 11
Synthesis: Coral Bleaching - Patterns, Processes, Causes and Consequences

M.J.H. van Oppen and J.M. Lough

Global climate is changing as a result of human activities. As we enter a rapidly warming world, "coral bleaching" has entered the lexicon of early climate change impacts. Breakdown, due to thermal stress, of the special relationship between two organisms, coral and algae, has consequences for ongoing maintenance of the structurally complex, biologically diverse, charasmatic and both economically and socially important ecosystems that make up tropical coral reefs. This volume brings together various perspectives on the coral bleaching phenomenon, how it is measured (Chap. 5) and what its consequences are, ranging from deep geological time through to possible future scenarios for tropical coral reef ecosystems.

There is no doubt that sea water temperatures have increased over the past century (Chap. 4) and climate models predict that further temperature rises and greater fluctuations are to be expected (Chap. 10). Many scientific publications state that the frequency and severity of bleaching events have also increased, but a detailed analysis of bleaching reports suggests that there is an insufficient amount of data to support or refute the hypothesis that major bleaching events are increasing in frequency (Chap. 3). The same analysis reports a lack of evidence for an increase in bleaching intensity, despite an increase in thermal stress. One possible explanation is that corals have acclimatised to elevated water temperatures (Chap. 7), through shuffling of their algal symbionts (Chap. 6) or as a result of phenotypic plasticity in other traits. A recent study has shown that algal shuffling can lead to increased thermal tolerance in a natural and non-manipulated coral population (Jones et al. 2008), but it is unlikely that all coral species have this ability to shuffle their symbionts. Alternatively, selection may already have removed the colonies most sensitive to bleaching. The potential for corals to adapt to further increases in sea water temperatures by genetic changes at the level of populations is unknown, but estimates (of heritability) are underway for a range of traits that are relevant to the bleaching tolerance of the coral host and their algal endosymbionts (Csaszar et al., unpublished data).

Modelling efforts show that most corals populations will have to adapt to survive future temperature increases (Chap. 10). If individual coral species are unable to adapt, then large changes in coral community composition (Chap. 8) and loss of diversity (Chap. 2) are likely to result, which will have major down-stream consequences for motile reef organisms (Chap. 9). In the short term, it is important for

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managers to understand which reefs are most resistant to bleaching and how quickly coral reefs can recover from bleaching events, especially those that cause mass coral mortality. The spatial patchiness in thermal stress and responses to thermal stress indicates that "climate change refuges" may exist (Chap. 8). Such refuges are likely to be located either in areas with stable cool water or in those that show historically large fluctuations in sea surface temperatures (McClanahan et al. 2007). Degraded reefs may be reseeded from "climate change refuges" and it is therefore crucial to understand the dispersal potential of corals and other coral reef organisms over ecological time scales (van Oppen and Gates 2006; Hellberg 2007). The direction and distances of recent dispersal events can be measured using genetic approaches (Underwood et al. 2007) or with stable isotope labelling of fish larvae (Almany et al. 2007).

In summary, coral bleaching is a biological response to changes in the physical environment of present-day coral reefs. Several mass coral bleaching events in recent years, most notably 1997–1998, have prompted enhanced research efforts into many aspects of this phenomenon. We now know much more about the causes and consequences of coral bleaching than we did only a decade ago. However, there is still much more to learn and, unfortunately, many of the experiments are happening in real time in the real world. Changes in the physical environment, in particular warming of the tropical oceans, are, without drastic greenhouse gas mitigation strategies, set to continue into the foreseeable future. Continued warming of the tropical oceans, along with other climate change and ocean acidification impacts on coral reefs, is an added human-induced burden on what, in many parts of the world, are already seriously compromised ecosystems due to direct local and regional stresses. In combination, this panoply of human-induced pressures does not bode well for the maintenance of the world's coral reefs into the future.

References

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