

## SESSION 2

# Pressures and effects on the Great Barrier Reef lagoon

# Macroalgal distributions on the Great Barrier Reef: a review of patterns and causes

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## ABSTRACT

Despite the long recognised importance of algae on both healthy and degraded coral reefs, there has been a lack of information about algal distributions on the Great Barrier Reef. This paper reviews research on the patterns and causes of macroalgal distributions on the Great Barrier Reef, including both published studies and current research. There is little previous work on distribution patterns, but a recent series of surveys provides a background description of distribution patterns. Hard data on the causes of Great Barrier Reef algal distributions are only just emerging. Recent work includes manipulative experiments with *Sargassum*, and ecological and physiological tests of nutrient effects on a range of algae. Despite this emerging body of data, we argue that there is still a critical lack of information on the roles and significance of Great Barrier Reef algae, especially in the context of reef degradation. In particular, despite claims to the contrary, we argue that there is a lack of data on the history and causes of abundant algae on inshore fringing reefs of the Great Barrier Reef. Both the emerging picture of algal distributions and the uncertainty remaining have important implications for reef managers and stakeholders.

## INTRODUCTION

Benthic algae are crucial elements of both healthy and degraded coral reef communities. They are major contributors to reef growth and development and to primary production and nitrogen fixation (reviews by Hatcher 1988, 1990; Cribb 1990). Reef degradation due to eutrophication or reduced herbivory commonly involves replacement of hard corals by macroalgae (seaweeds: Smith et al. 1981; Maragos et al. 1985; Kinsey 1988; LaPointe 1989; LaPointe and O'Connell 1989; Carpenter 1990; Hughes 1994).

Despite their importance to reef status and ecology, there is a critical lack of information on algal distributions and ecology on the Great Barrier Reef. Survey of the published literature shows that algae have received far less research effort on the Great Barrier Reef than fish or corals (McCook and Price, in press). We review here the available information on the patterns and causes of benthic algal distributions on the Great Barrier Reef, including work currently underway. We then assess the available evidence for temporal shifts in macroalgal abundance, especially on inshore fringing reefs. We argue that the baseline information needed to recognise an unnatural bloom of benthic algae on the Great Barrier Reef is only just emerging. The ability to predict, interpret and manage changes in reef biota will depend on increased understanding of patterns and causes of algal distributions.

### Distribution patterns

The macroalgal flora of the Great Barrier Reef region is low in endemism, but high in diversity, reflecting the exceptional latitudinal extent of the Great Barrier Reef, the diversity of reef and substrate types and water conditions, and the consequent habitat diversity. We have estimated that there are 400–500 species of macroalgae on the Great Barrier Reef, although an accurate estimate will require much more survey and taxonomic work. There are few published accounts of algal distributions with any degree of taxonomic resolution and these are largely restricted to intertidal or shallow subtidal zones of a few, isolated islands (often research stations; review by McCook and Price, in press, table 1). This contrasts with the situation in the Caribbean, where taxonomic and composition data have been available for many years.

In order to redress the lack of adequate baseline information on algal distributions, we have surveyed 583 sites on 77 reefs in the Cairns and Central Sections, estimating abundance for around 125 taxa of macroalgae, as well as community and environmental parameters. The most detailed data are for 12 Central Section reefs, including data for 3 times of year, for two cross-shelf series of reefs, surveying 3 zones (slope, crest and flat) for each of three sites on the south-eastern side of each reef. These data will provide descriptions of large-scale variation, both across the shelf and between series (north-south), and variation between and within reefs, between zones, and critically, between seasons.

Only a brief overview of the results can be presented here. Most importantly perhaps, the surveys showed that turf algae, blue-green algae (Cyanophyta), nongeniculate crustose coralline algae and *Halimeda* were widespread and abundant (McCook et al., in press). Cross-shelf differences are dramatic quantitatively but not simple or easy to define in terms of individual species. The brown algae (Phaeophyta) are more diverse and abundant (especially *Sargassum*) inshore whereas the flora of offshore reefs is dominated by green algae (Chlorophyta, especially *Caulerpa*, *Chlorodesmis* and *Halimeda*) and red algae (Rhodophyta, especially crustose corallines). However, red algae are also common inshore and some brown algae also occur offshore. The cross-shelf patterns are also confounded by within-reef zonation, latitudinal and other large-scale variations and occasional distributional outliers (such as individuals of *Sargassum* or *Padina* on outer-shelf reef fronts). On offshore reefs, contrary to the widespread perception, fleshy seaweeds, especially red algae, are commonly dominant on reef flats, and surprisingly common and diverse on reef fronts. Moreover, inshore reefs with abundant *Sargassum* and turbid water may also have high cover of healthy hermatypic corals, again in contrast to widespread perception.

There are strong seasonal changes in composition and abundance of algal vegetation, in contrast to dominant benthic fauna such as corals. Not only is *Sargassum* highly seasonal in abundance on inshore reefs, but on mid- and outer-shelf reef flats, the abundance of blue-green algae, red algae such as *Spyridia filamentosa*, *Laurencia* spp., *Galaxaura* spp. and *Liagora* spp., and green algae such as *Boodlea* spp., also varied greatly with season.

By distinguishing between macroalgal abundances and taxa expected in different reef areas at different seasons, multivariate analyses of these data should allow classification of reefs based on algal composition. The only other large-scale data on reef algal distributions and abundance comes from long-term monitoring studies (LTM) (e.g. Oliver et al. 1995), but these data have little taxonomic resolution (McCook and Price, in press). There is potential to use our survey descriptions to significantly enhance the power of the LTM surveys to detect and interpret changes in algal abundances. For example, if low resolution LTM surveys indicated increased algal abundance on an offshore reef, a simple sampling procedure could allow comparison with expected compositions for different reef types, based on our surveys.

Large-scale descriptions of inter-reefal flora are also emerging from recent surveys of vegetation in deep water, soft-bottom areas of the northern Great Barrier Reef, using towed video cameras (R. Coles and W. Lee Long, QDPI Cairns, pers. comm.). Although these surveys show that rhizoid-anchored macroalgae are very abundant in these areas, the surveys focus on seagrasses and currently lack the resources to quantify macroalgae with any degree of taxonomic resolution (Coles and Lee Long, pers. comm.).

The surveys described above can only provide preliminary descriptions of algal distributions on the Great Barrier Reef, given limitations on spatial and seasonal coverage, and especially given limitations on field identification of algae. We have summarised the resources available for identifying Great Barrier Reef algae (McCook and Price, in press, table 2), and noted a critical lack of both expert taxonomic floras and field identification guides. The lack of field identification guides has been ameliorated with the recent publication of a naturalists guide to seaweeds of Queensland (Cribb 1996). However, this work is not comprehensive, and does not allow unequivocal identifications. Although Phillips and Price (in review) have recently completed a critical compilation of the brown algal species recorded for Queensland, there remain no comprehensive taxonomic treatments for the brown, green and blue green algae, for non-turfing species or for the central and northern regions of the Great Barrier Reef.

## Causes of macroalgal distributions

There is also little published information on the processes which determine the patterns of algal distribution on the Great Barrier Reef, at any scales, although there are a number of relevant studies currently underway. Factors which influence the distribution of marine species, especially of algae, include resource availability (e.g. nutrients, light, substrate); stress gradients and disturbance regimes (e.g. wave exposure, temperature, emergence, cyclones, freshwater); recruitment and dispersal; and species interactions, including competition and herbivory (e.g. Underwood and Denley 1984; Chapman 1986). Table 1 summarises publications and studies underway which address the roles of these different factors. Attention has focused on possible effects of water quality (primarily sediments and the nutrients nitrogen and phosphorus) and herbivory, since work in other reef areas has demonstrated that increases in sediment or nutrient inputs or reductions in herbivory can lead to shifts from coral to algal dominance (references in Introduction).

On the Great Barrier Reef, recruitment, productivity and abundance of algal turfs (as 'epilithic algal community') have been shown to depend strongly on herbivory (Hatcher and Larkum 1983; Sammarco 1983; Wilkinson and Sammarco 1983; Scott and Russ 1987; Klumpp and McKinnon 1989, 1992) and to some degree on nutrients (Hatcher and Larkum 1983; Russ, unpubl. data). Of these studies, only Russ's work addresses the causes of large-scale distributions, suggesting roles for both herbivory (Scott and Russ 1987) and water quality (unpubl. data) in the cross-shelf differences in turf algal vegetation. Other work has focused on chemical mediation of competition (de Nys et al. 1991) and herbivory (Steinberg et al. 1991).

More recently, several studies have indicated that herbivory has a stronger direct impact on the distribution of larger macroalgae than does water quality. Transplant experiments demonstrate that fish herbivory significantly reduces the survival of *Sargassum* both on offshore reefs and on inshore reef slopes, whereas differences in water quality had no direct effect on survival or on tissue nutrient levels. It appears that the absence of *Sargassum* on most mid-shelf reefs and on many inshore reef slopes is due to an interaction between herbivory and low dispersal, and not due to any nutrient limitations (McCook 1996, in press). Several other experiments have addressed the direct impacts of sediments or nutrients on *Sargassum*. Manipulation of sediments on a fringing reef showed that *Sargassum* was directly inhibited by sediment deposition, despite being generally more abundant on reefs with greater sediment loads (Umar et al., unpubl. data). Preliminary experiments in large aquaria suggested that *Sargassum* growth and recruitment were directly inhibited by long-term, high level nutrient enhancement, perhaps due to overgrowth by epiphytes (McCook et al., in press). However, more detailed experiments show *Sargassum* growth in isolation to be stimulated by moderate nutrient enhancement but inhibited at higher levels. Importantly, *Sargassum* shows rapid uptake and growth in response to pulsed delivery of nutrients. This could allow the alga to grow in areas which experience only brief periods of high nutrient supply, such as resuspension during storms (Schaffelke and Klumpp, in press; similarly Russ, unpubl. data, for turfs).

Nutrient effects on reef biota have also been recently examined in the collaborative ENCORE experiment, which used a factorial combination of nitrogen and phosphorus supplements in small microatolls at One Tree Island. Neither algal turfs nor coralline algal rhodoliths showed strong direct effects of enhanced nutrient input (Larkum et al., in press; Larkum and Koop, in press). Dennison et al. (unpubl. data) used the ENCORE experiment to compare ( $^{15}\text{N}$ ) ammonium uptake among various macroalgal and coral species. Interestingly, uptake rates were highest in the red alga *Laurencia intricata*, which has very wide cross-shelf distribution patterns (e.g. McCook and Price, unpubl. data).

It is important to note that the available data form a very incomplete picture, and by no means preclude effects of nutrients or sediments on algal distributions. Direct nutrient effects are likely to be complex and species-specific and to depend on period and intensity of enhancement, epiphyte growth etc. Water quality is also likely to have major indirect effects on algal distributions, perhaps by affecting herbivorous fish abundances or substrate availability through coral mortality. Further, interactions between different factors are likely. By trapping sediments, algae may render a site less suitable for coral recruitment. Finally, several studies have shown that chronically stressed reefs may show little degradation due to eutrophication or herbivore depletion until damaged by natural disturbances, such as storms

or freshwater floods (e.g. Hughes 1994; Kinsey 1988). The critical impact of the chronic stress may be in preventing recovery from natural disturbance, allowing algae to persist and inhibiting coral recovery. Thus natural disturbance which normally leads to a successional sequence from algae to coral may be blocked, resulting in a long-term phase shift and degradation.

**Table 1.** Summary of ecological research, published or underway, relevant to the causes of macroalgal distributions on the Great Barrier Reef. Descriptions of work currently under way is based on information requested from the various authors ('in prep.' November 1996; black dots indicate study directly addresses the factor; asterisks indicate study has related information). Data on distribution patterns or taxonomy are not included, but are tabulated in McCook and Price (in press).

Author	Scale and/or Area	Approach or Technique	Taxa	Herbivory	Nutrients	Sediments	Recruitment/ Dispersal	Competition
Scott and Russ 1987	Cross-shelf	Settlement plates and cages	Algae esp. turfs	•	*	*	•	
McCook et al. , in press, unpubl.	Cross-shelf - >between zones, seasons	Surveys; correlations; chemistry	Algae	*	*	*	*	
McCook and Price, in prep.	Among fringing reefs; 50 km	Settlement plates	Algae				•	
Russ, in prep.	Cross-shelf	Settlement plates, cages, cyclone	Algae esp. turfs	•	*	*	•	
Coles and Lee Long, in prep.	Large scale: 100s km, deep water inter-reefal	Towed video surveys	Soft-bottom taxa (Chlorophyta)		*	*		
Elmetri and Bell in prog.	Cross-shelf; Laboratory	Correlations with growth rates, phosphatase	Macroalgae		•			
Hatcher and Larkum 1983	Offshore reef $\mu$ atolls	Cages and nutrient enhancements	Turfs	•	•			
Sammarco 1983, Wilkinson and Sammarco 1983	Damselfish territories	Settlement plates, cages, nitrogen fixation measurements	Turfs, Cyanophyta	•	*		*	
Klumpp and McKinnon 1989, 1992 etc.	Within mid-shelf zones, damselfish territories	Trophodynamics	Turfs etc	*	•			
Larkum and Koop, in press	Offshore reef $\mu$ atolls	Nutrient manipulation: ENCORE	Turfs		•		*	
Purcell, in prep.	Within mid-shelf reef	Correlations	Turfs	*		•		
Fugelli and Johnson in prog.	Offshore reefs	Nutrient manipulation, surveys, physiological ecology	Turfs	•	•		•	*
Steinberg et al. 1991	Cross-shelf	Transplants; Chemistry	Sargassum; other browns	•				

Author	Scale and/or Area	Approach or Technique	Taxa	Herbivory	Nutrients	Sediments	Recruitment/ Dispersal	Competition
McCook 1996	Cross-shelf; 50 km	Cages; transplants	Sargassum	•	*	*		
McCook et al., in press	Aquaria	Nutrient manipulations	Sargassum; Padina		•		•	
Schaffelke and Klumpp, in press, in prep.	Culture, aquaria, fringing reef flats	Nutrient manipulations; physiological ecology	Sargassum		•			
McCook, in press	Within fringing reefs; 50 m	Cages; transplants	Sargassum	•	*	*	•	
Umar et al., in prep.	Fringing reef flats	Sediment manipulations	Sargassum			•	•	
McCook in prog.	Among and within fringing reefs	Canopy removal	Sargassum / other benthos				•	•
Drew 1983	Cross-shelf	Physiological ecology	Halimeda	*	*			
Wolanski et al. 1988	Offshore reefs, medium scale	Oceanography, correlation	Halimeda		*			
de Nys et al. 1991	Fringing reefs, small scale	Chemistry, transplants	Plocamnum (Rhodophyta)					•
Costanzo and Dennison, in prep.	Inshore, Whitsundays, Moreton Bay	Physiological ecology	Gracilaria (Rhodophyta)		•			
Dennison, Drew and Stewart, in prep.	Offshore,	Nutrient manipulations	Laurencia (Rhodophyta)		•			
Chisholm 1988	Within mid-shelf reef	Physiology	Crust. corallines (non geniculate)					*
Larkum et al., in press	Offshore reef atolls	Nutrient manipulation: ENCORE	Crust. corallines (non geniculate)		•			
Ringeltaube and Johnson, in prep.	Within Heron Reef	Surveys, settlement plates, grazer and algal removals, transplants, shading	Crust. corallines (non geniculate)	•			•	•

### Long-term changes in abundance of macroalgae on inshore reefs: what is the evidence?

The abundance and composition of macroalgal vegetation on inshore reefs has been suggested as a symptom of widespread decline of those reefs (e.g. Endean 1976; Bell and Elmetri 1995), apparently in response to large increases in anthropogenic inputs of sediments and nutrients (Moss et al. 1992; Pulseford 1991; Brodie 1995). However, given the proximity of these reefs to natural terrestrial inputs, it is likely that they always had different flora from the offshore reefs. We here review the evidence for and against recent increases or shifts in status of inshore reefs, with emphasis on the macroalgae. Evidence either for or against widespread shifts in reef biota is very limited and equivocal. As there is even less data specifically for macroalgae, we conclude that there is no clear indication whether the abundance of algae on fringing reefs is natural or anthropogenic.

The Great Barrier Reef Expedition of 1928–29 collected quantitative transect data, photographs and descriptions of reef flats at Low Islets, including the only detailed survey of algal composition prior to 1960 (Stephenson et al. 1931; McCook and Price, in press). Resurvey of these sites led Bell and colleagues to suggest a long-term decline in coral cover, with a concomitant increase in macroalgae and other non-reef builders (e.g. Bell and Elmetri 1995). However, these data refer to only a limited area on a single reef flat, and provide no indication of intervening dynamics. Photographs of other reef flat areas at Low Islets indicate that at least part of these reefs are in good condition (Wachenfeld, in press). Even where changes in coral cover have occurred, assessment of algal changes awaits detailed resurvey of algal composition (currently under way by J. Phillips, Univ. Qld, pers. comm.).

Historical descriptions and photographs of Green Island, Dunk Island, Magnetic Island, and reefs in the Whitsunday region, as well as Low Islets, led to suggestions of widespread declines in inshore reefs over the last 50 to 100 years (Endean 1976; Bell and Elmetri 1995). However, photographic comparisons by Wachenfeld (in press) of 14 reefs, including Green Island, Magnetic Island, and the Whitsunday Islands suggest that such declines are not prevalent. These photographic comparisons are problematic, as they do not necessarily represent general dynamics (Wachenfeld, in press). Although more reliable quantitative data are available for the last two decades, their significance is also equivocal. At Brampton Island, comparison of data from 1986 (Van Woesik 1992) and 1995 (Burns et al. 1995), along with anecdotal reports from resort staff, suggest a decline in coral cover and increased abundance of algae such as *Sargassum*. Similarly, environmental assessments at Magnetic Island from 1989–1995 suggest an increase in macroalgae, although these results are confounded by differences in sites, seasons and survey techniques (Sinclair Knight Merz 1995). On Pandora Reef, near Townsville, Done (in press) found that although macroalgae dominated in 1980, corals have actually displaced *Sargassum* over the following 15 years. Ayling (in press) presented quantitative data for changes in cover for 7 fringing reefs from Cape Flattery to the Keppel Islands for 4 to 10 years. Although reef flats were typically dominated by macroalgae, with low coral cover, he recorded high (> 50%) coral cover on reef slopes, with no evidence of decreases, even at Magnetic Island between 1989 and 1993 (cf. Sinclair Knight Merz 1995).

Detection and interpretation of widespread and long-term changes in algal composition are limited not only by the paucity of quantitative data, but also by several confounding factors. Comparisons of single before and after points on a time series give no indication of intervening dynamics, and may give false impressions of long-term change or lack of changes (e.g. Underwood 1991). Shifts from coral to algal abundance may be a natural phase of reef dynamics, in which damage to corals results in temporary dominance by macroalgae, followed by recovery of corals. If reef degradation involves failure to recover after disturbances, then widespread decline in response to anthropogenic factors may be expressed piecemeal, and so be difficult to detect and interpret. Further, it cannot be assumed that evidence of decreases in coral cover necessarily means increased macroalgal cover. Cover of corals and *Sargassum* are not simply negatively correlated on fringing reef flats (McCook, unpubl. data).

Finally, evidence that reef biota are currently stable in the short-term does not preclude past (or future) shifts. Terrestrial inputs have probably increased throughout the last hundred years (Pulseford 1991), and there is very little information on the rates of terrestrial input likely to cause changes at different reef sites. Thus, shifts could conceivably have occurred and stabilized long before most of the data reviewed above were collected. We conclude that, in the absence of high quality historical ('pre-impact') surveys of sufficient coverage, definitive description of 'natural' inshore algal flora is not possible.

### **Implications for reef science, management and development**

Even this brief review of the available information on Great Barrier Reef algal distributions has a number of significant implications for reef scientists, managers and tourist operators. Given the importance of macroalgae on both healthy and degraded reefs, it is imperative that we improve our ability to distinguish between the two states.

The description of algal species distributions and abundances emerging from our surveys (McCook et al., in press) should allow the identification of an multivariate, inshore species

'suite'. Whether the composition of inshore algal vegetation is anthropogenic or natural, the appearance of similar vegetation on offshore reefs would most likely represent degradation. The surveys show that individual species distributions are not simple or clearcut, suggesting that individual species would be poor indicators of reef status. In contrast, an 'inshore species suite' or region of multivariate space, based on quantitative abundance of a wide range of taxa at a range of seasons, should provide a much more robust measure of reef status. Although such surveys require some expertise in field identification of algae, they are relatively fast and technically simple, and so should be feasible and cost-effective as management tools. Since algal vegetation may change more rapidly than corals, algal surveys may allow more rapid detection of changes in benthos.

Although knowledge of the detailed causes of algal distributions remain far from complete, the emerging results have several significant implications. The importance of herbivory is consistent with results from other reef regions and highlights the importance of protecting herbivorous fish populations on all reefs (e.g. Hughes 1994; McCook 1996). The management implications are less clearcut for the lack of nutrient effects in the field, especially given the strong effects in physiological studies. The ability of *Sargassum* to obtain sufficient nutrients on offshore reefs indicates that nutrient levels on offshore reefs are already sufficiently elevated, naturally or anthropogenically, for *Sargassum* growth. If natural, this might imply that nutrient effects on algal distributions are not a management concern. If offshore nutrient levels are anthropogenic, macroalgal invasion of offshore reefs may be an imminent possibility, perhaps in response to disturbances or declines in coral or herbivore populations.

Similarly, although the emerging picture suggests that large fleshy algae such as *Sargassum* may rarely invade reefs without prior disturbance to corals, we still have little information on the impact and community dynamics of macroalgal beds once established. Even where macroalgal abundance is not the direct cause, but the consequence of coral decline, we need more information on the factors which may lead to stable maintenance of algal dominance, or to the successional re-establishment of abundant corals.

Probably most critical to reef management is the still considerable lack of knowledge about Great Barrier Reef algal distributions. Whilst work is underway in a number of significant areas, there are still many issues which are not being addressed. This lack of information is compounded by the complexity of spatial and temporal patterns and scales, taxonomic diversity and uncertainty, and the likelihood of indirect effects and of interactions between natural and anthropogenic factors. It is likely that simple, definitive answers are not feasible for some issues (e.g. identifying natural algal flora for inshore reefs). Definitive interpretation of patterns of algal distribution as natural or anthropogenic is thus difficult and unwise, and easily discredited. Rather, an approach which attempts to assess the risks and consequences, of different interpretations and management responses, should provide a better direction for science, management and publicity. Given the increasing reports of abundant macroalgae on degraded reefs world-wide, the lack of strong evidence for degradation does not justify assuming that reefs are pristine.

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