The state of the algae of the Great Barrier Reef: what do we know?

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Introduction

Lack of information about the distribution, abundance and ecological roles of the benthic algae constitutes a major gap in our knowledge of the state of the Great Barrier Reef. Benthic algae are major contributors to reef growth and geomorphology, as sediments and cements (Borowitzka 1983; Davies 1983; Marshall 1983; Smith 1983; Cribb 1990). They contribute major proportions of reef primary production and nitrogen fixation (Wiebe et al. 1975; Larkum 1983; Larkum et al. 1988; Hatcher 1988; 1990; Cribb 1990, Klumpp and McKinnon 1989, 1992). Reef degradation due to eutrophication or herbivore reduction 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). Possible reef degradation due to eutrophication is currently attracting considerable attention and funding in the Great Barrier Reef region (Bell 1992; Baldwin 1992; Brodie 1995), yet there is so little extant information on the distribution patterns of macroalgae on the Great Barrier Reef that even a major shift in these patterns would be difficult to identify.

We here review the state of knowledge of the large-scale distribution and abundance of benthic macroalgae on the Great Barrier Reef. We summarise first the available information and the work in progress on the patterns of distribution and abundance of algae on the Great Barrier Reef, then provide a brief review of studies addressing the causes of those patterns. Finally, we review the resources available to scientists and managers for identifying Great Barrier Reef algae. We use the term macroalgae to refer to species whose individuals are visible to the naked eye, thus including filamentous and turf species.

State of knowledge of the benthic algae of the Great Barrier Reef

Despite the apparent acceptance of algae as crucial elements of reef communities, there is very little information published on the benthic algae of the Great Barrier Reef. Literature searches suggest that algae receive far less research effort than corals or fish, and this is reflected in the distribution of research funding from both scientific and management sources. Searching the Aquatic Sciences and Fisheries Abstracts for the years 1978 to June 1995, using the search terms 'Great Barrier Reef' and 'algae' or 'macroalgae', recovered 121 references. Of these, only about 80 were relevant to benthic algae and probably less than 40 had benthic algae as a focus of the work. In contrast, there were 248 references recovered using 'fish' and 'Great Barrier Reef' and 765 using 'coral' and 'Great Barrier Reef'. In particular, there is very little information on algal distributions, although the geographic distributions of corals, fish and other taxa have been documented for some time (Done 1982; Williams 1982; Williams and Hatcher 1983; Dinesen 1983; Russ 1984; Wilkinson and Cheshire 1988). Similarly, population and community level studies have attempted to explain distributions and roles of fish and corals (e.g. Done 1988, 1992; Williams 1991), but very few studies have addressed the causes of algal distributions (see below).

Distribution and abundance of macroalgae of the Great Barrier Reef

The Great Barrier Reef region has a diverse macroalgal flora, reflecting the exceptional latitudinal extent, the diversity of reef and substrate types and water conditions, and the consequent habitat diversity. Endemism is low, as most Great Barrier Reef species are relatively widespread throughout the Indo-West Pacific biogeographical region. The uniqueness of the algal flora stems from the extent of the Great Barrier Reef as a single, relatively contiguous system of reefs, in both geographic/ecological and management terms. We estimate there are 400-500 species of macroalgae on the Great Barrier Reef, although an accurate estimate will require considerably more survey and taxonomic work. Cribb (1973) reported 230 species from the Capricorn-Bunker group, based on relatively intensive, but exclusively intertidal, sampling over several years. On this basis he extrapolated a figure of 330 species for the Great Barrier Reef as a whole, but this figure apparently excluded both mainland and subtidal areas. Womersley (1990) estimated that 400 species occurred in Queensland, and Lewis (1984, 1985, 1987) listed almost 800 taxa of benthic macroalgae (excluding blue-green algae) for all of northern Australia, based on synthesis of published records. The flora is dominated by red algae (Rhodophyta), with about twice the number of brown (Phaeophyta) or green (Chlorophyta) algal species. However, the taxonomy of most groups is so poorly studied that these figures remain very approximate.

Do we have the baseline information to recognise an unnatural bloom of benthic algae on the Great Barrier Reef? Almost certainly not, given that, to the authors' knowledge, there has been no large-scale survey of benthic algal distributions for the Great Barrier Reef. Table 1 summarises the published data on floristic composition for Great Barrier Reef algae. There are only a few accounts with any degree of taxonomic resolution, and those are largely restricted to a few, isolated islands (often research stations), to the intertidal or shallow subtidal (several workers did not SCUBA dive or even snorkel). Cribb's (1990) review of the algal vegetation of the Great Barrier Reef is based on work in the Capricorn-Bunker group, and is restricted to small-scale (within reef) intertidal zonation. Morrissey (1980) provides a detailed description of zonation within a single fringing reef at Magnetic Island, but again the survey is restricted to intertidal zones. Few of these studies provide data on seasonality or longer term changes. I. R. Price is currently collaborating with Dr J. Phillips (University of Queensland and Queensland Herbarium) to integrate these various taxonomic records into up-to-date check-lists of Queensland macroalgae. A report on the Phaeophyta (brown algae) is nearly complete (Phillips and Price in prep.).

There are a number of large scale surveys and monitoring studies (e.g. AIMS 1985-6; AIMS 1986-7; Oliver et al. 1995; Kaly et al. 1994) which quantify abundance of macroalgae on reefs as part of general benthos, but they have little taxonomic and seasonal resolution (as dictated by the scale and focus of the surveys). These surveys generally assess benthic algal cover in broad categories, such as 'Macroalgae', 'Turfs' or '(Crustose) Coralline Algae'. *Sargassum* or *Halimeda* may be distinguished from 'Other Macroalgae'. In contrast, most of these surveys assess hard corals and often fish with considerable taxonomic resolution.

These large scale surveys (AIMS 1985-6; AIMS 1986-7; Oliver et al. 1995) probably provide the best information presently available for detecting any gross changes in benthic algae (such as massive blooms), since they cover the length and breadth of the reef. However, they are obviously very limited as algal surveys. Many focus on coral dominated zones, such as reef fronts and crests, in which algae are rare or cryptic, and ignore back reefs and reef flats, zones which currently often have large areas dominated by algae (unpubl. data). Lack of taxonomic resolution severely limits the resolution of any comparisons between reefs or sampling dates. 'Other Macroalgae' can often include brown algae or taxa indicative of poor reef state, or species of red and green algae which are common on healthy reefs. Even lumping apparently

similar groups may prevent detection of important differences or changes. For example, most species of *Sargassum* are restricted to inshore reefs, whereas species of the related and morphologically similar *Turbinaria* are currently widespread on offshore reef flats (unpubl. data). Recording the two genera together as 'Macroalgae', rather than separately, could mean that surveys would fail to detect an invasion of offshore reefs by *Sargassum.* Similarly, lack of seasonal information could lead to false rejection or false detection of shifts in algal abundance (e.g. Kaly et al. 1994), since both inshore and offshore reef zones have seasonally highly variable abundance of several algal communities (see below).

Table 1. Published information on the floristic composition and distribution of macroalgae in the Great Barrier Reef (GBR) region

Geographic location	Source	Taxonomic data	Ecological data
Thursday I. area	Cribb 1961	annotated species list; intertidal only	
Lizard I.	Price et al. 1976	annotated species list; intertidal and subtidal	
Low Isles	Stephenson et al. 1931	species lists; intertidal only	descriptive; intertidal only
Central GBR	Drew 1983	species list; intertidal and subtidal	*Halimeda* ecology; intertidal and subtidal
Central GBR; shelf reefs	Scott and Russ 1987	species list; subtidal	
Central GBR	Price and Scott 1992	turf algal monograph (Rhodophyta); intertidal and subtidal	
Central GBR; rocky shores, fringing reef, mid-shelf reef	Price 1989	species records; intertidal and subtidal	Seaweed phenology; intertidal and subtidal
Townsville rocky shores	Ngan and Price 1979	annotated species list; intertidal only	
	Ngan and Price 1980		distribution; intertidal only
Magnetic I., fringing reefs	Morrissey 1980	species list; intertidal only	zonation; intertidal only
	Vuki and Price 1994		*Sargassum* phenology; intertidal only
	Martin-Smith 1993		*Sargassum* phenology: subtidal
Heron I. reef flat	Cribb 1966	species list; intertidal only	distribution; intertidal only
One Tree I.	Borowitzka et al. 1978	species list	colonisation, succession, productivity, seasonality
Capricorn Section	Cribb 1984	species list; intertidal only	
Swains	Saenger 1979	annotated species list; subtidal	

In order to redress this lack of baseline information on algal distributions, we are currently undertaking a series of large scale surveys of algal distributions and abundance. Surveys have been made at nearly 300 sites at over 55 reefs in the Central and Cairns Sections (38 reefs between Cairns and Lizard Island). In the Central Section, 15 reefs in two cross-shelf transects north of Townsville have now been surveyed in three seasons (June, October/November and March), estimating abundance of all macroalgal taxa for reef slope, crest and flat at three sites

per reef. The surveys are hampered by the limited background taxonomic work, which necessitated compromises between taxonomic resolution and coverage.

The results have not yet been analysed in detail, but several important points have emerged. It appears that simple patterns in algal distribution will be difficult to extract from the overall complexity. Cross-shelf differences are dramatic quantitatively but not simple, clearcut or easy to define. Inshore reefs usually have abundant brown algae (Phaeophyta), especially fucaleans such as *Sargassum*, whereas several groups of red algae (Rhodophyta) are more abundant offshore. The patterns are confounded by within-reef zonations, latitudinal differences and occasional distributional outliers (such as individuals of *Sargassum* or *Padina* on outer reef fronts). The fucalean brown alga *Turbinaria* is often common on mid- and outer shelf reef flats. Dominance by non-turf forming macroalgae is seasonally common on offshore reef flats. Even outer shelf reef fronts commonly have a surprisingly large number and abundance of erect seaweed species, especially red algae (Rhodophyta). These are often quite cryptic, occurring in underhangs and caves and at the base of reef slopes.

In contrast to dominant benthic fauna such as corals, many reef algae are strongly seasonal in abundance, and sampling at different times of the year is essential. Not only is the abundant *Sargassum* of inshore reefs highly seasonal in abundance, but it appears that on mid- and outer shelf reef flats, there is a highly seasonal abundance of blue-green algae (Cyanophyta), red algae such as *Spyridia* sp., *Laurencia* spp., *Galaxaura* spp. and *Liagora* spp., and green algae (Chlorophyta) such as *Boodlea.* As indicated earlier, this seasonality has major implications for the ability of surveys and monitoring programs to detect changes in the benthos. This is important not just in large scale surveys, but particularly for environmental impact assessments (e.g. Kaly et al. 1994). In combination with the high taxonomic and geographic/spatial diversity which also complicate assessments of other reef biota, the seasonal variations in the algae make comparisons between sites or sampling dates especially complex.

Our surveys can only provide preliminary rather than definitive descriptions, given the limitations of spatial and seasonal coverage and field identifications. Indeed, their most valuable outcome may be a solid basis for optimising taxonomic resolution in general benthic surveys.

Other current work includes the recent large scale surveys of vegetation in deep water, soft-bottom inter-reefal areas, using towed video cameras (R. Coles and W. Lee Long, Queensland Department of Primary Industries, Cairns, pers. comm.). Although these surveys show that rhizoid-anchored macroalgae are very abundant in these areas, the surveys focus on seagrasses and lack the resources to quantify macroalgae with any degree of taxonomic resolution (Coles and Lee Long pers. comm.).

Causes of macroalgal distribution on the Great Barrier Reef

There is also a lack of published information on the processes which cause the patterns of algal distribution on the Great Barrier Reef, at all scales, although there are a number of studies currently underway. Attention has focused on possible effects of water quality (primarily sediments and the nutrients nitrogen and phosphorus) and herbivory, since work in other areas has demonstrated that increases in sediment or nutrient inputs or reductions in herbivory can lead to shifts from coral to algal dominance (see Introduction, more detailed review by McCook in press). On the Great Barrier Reef, recruitment, productivity and abundance of algal turfs (as epilithic algal community) have been shown to depend 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' 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 algae. Other work has focussed on chemical mediation of competition (de Nys et al. 1991) and herbivory (Steinberg et al. 1991).

More recently, several studies have suggested that herbivory has a stronger direct impact on the distribution of larger macroalgae than does water quality. Transplant experiments have shown that fish herbivory significantly reduces the survival of *Sargassum* both on offshore reefs (McCook in press) and on inshore reef slopes (McCook in review), whereas differences in water quality had no direct effect on survival. Manipulation of sediments on a fringing reef showed that *Sargassum* was directly inhibited by sediments, despite being generally more abundant on reefs with greater sediment loads (Umar et al. in review). Similarly, preliminary experiments in large aquaria suggested that *Sargassum* growth and recruitment were directly inhibited by long-term, high level nutrient enhancement (McCook and Klumpp unpubl. data). Culture experiments show *Sargassum* growth in isolation to be stimulated by moderate nutrient enhancement but inhibited at higher levels (B. Schaffelke, Australian Institute of Marine Science (AIMS) unpubl. data). It is important to note, however, that these results form a very incomplete picture. Water quality is very likely to have major indirect effects on algal distributions, perhaps partly by affecting fish abundances.

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 (Steven and Larkum 1993; Larkum and Steven 1994). Interestingly, preliminary results suggest that, as with *Sargassum*, algal turfs did not show strong direct effects of enhanced nutrient input (Steven pers. comm.).

Reference resources for the identification of Great Barrier Reef macroalgae

Both descriptive and experimental ecology are severely hampered by the lack of taxonomic resources. There is a need both for expert taxonomic floras, and for identification guides suited for field researchers. Currently available reference materials are very limited in scope (Table 2), and these in turn are severely limited by the lack of basic taxonomic accounts and research. Even widely studied and abundant taxa, such as *Sargassum*, have not been yet resolved taxonomically (work on *Sargassum* is underway by K. Edyvane, Sth. Aust. Research and Development Institute; I. R. Price has recently completed a taxonomic revision of *Caulerpa*).

A small proportion of the species included in *The marine benthic flora of southern Australia* (Womersley 1984, 1987, 1994) also occur in Great Barrier Reef waters.

There are only two taxonomic monographs relevant to Great Barrier Reef macroalgae, both restricted in coverage (Table 2). Cribb (1983) covers red algae only, the southern Great Barrier Reef only and is largely limited to intertidal species. Price and Scott (1992) is restricted to red turf algae. Thus the brown, green and blue-green algae, non-turfing species and the central and northern Great Barrier Reef still lack comprehensive monographs. The various field guides are also very limited in scope, and the descriptions are often insufficient for unequivocal identifications. One reference includes a photograph labelled 'Unidentified algae, probably a filamentous blue-green', a description which is of limited use even to casual natural historians.

Given the paucity of reference material, two cautionary notes need to be made about the degree of taxonomic resolution used in studies of reef algae. Firstly, researchers should avoid the trap of identifying algae to species (or higher) level, without an adequate basis for that degree of taxonomic resolution. To illustrate this point, several of the guides in Table 2 describe species with no indication of similar species, particularly congenerics (e.g. *Padina*, *Sargassum*, crustose corallines). We have seen several accounts which identify *Padina australis* to species

level, apparently based on field identification. It is not possible to identify *Padina* to species without microscopic examination of fertile material. Secondly, the lack of taxonomic resources suggests that the identities of species in published studies should be treated with caution, if that identity affects the interpretation of the results.

Table 2. Sources for identifying species of macroalgae in the Great Barrier Reef region

Source	Coverage	Format
Cribb 1983	southern Great Barrier Reef (mainly Capricorn-Bunker group) **intertidal only**	detailed, comprehensive, illustrated taxonomic monograph of red seaweeds (Rhodophyta only)
Price and Scott 1992	entire Great Barrier Reef region Intertidal and subtidal	detailed, comprehensive, illustrated taxonomic monograph of turf algae (Rhodophyta only)
Cribb and Cribb 1985 **out of print**	Great Barrier Reef region **intertidal only**	68 species, coloured photographs and brief descriptions; selected common and distinctive species of Cyanophyta, Rhodophyta, Phaeophyta and Chlorophyta
Cribb 1993	Great Barrier Reef **intertidal only**	line diagrams and brief notes; common species of Rhodophyta, Phaeophyta and Chlorophyta
Saenger 1977 **out of print**	Great Barrier Reef intertidal and subtidal	line diagrams and brief notes; common species of Rhodophyta, Phaeophyta and Chlorophyta
Allen and Steene 1994	Indo-Pacific reefs intertidal and subtidal	Field guide with coloured photographs only, some misleading or unclear; 39 common taxa of Rhodophyta, Phaeophyta, Chlorophyta and Cyanophyta
Fuhrer et al. 1981	Australia **intertidal only**	Coloured photographs and brief notes: about 15 reef Rhodophyta, Phaeophyta and Chlorophyta included
Lewis 1984, 1985, 1987	Northern Australia	Comprehensive checklist and bibliography only of taxa recorded for northern Australia. No descriptions include

We hope to address the lack of taxonomic references with two specific contributions: a reliable and easy-to-use 'field guide' to the more common and distinctive seaweeds of the Great Barrier Reef; and completion of the Turf Algal Flora of the Great Barrier Reef (Part II: Phaeophyta and Chlorophyta, to complement Price and Scott's Part I: Rhodophyta). The field guide could be produced as part of a computer-based identification system. Commitment to such algal reference works is essential if reef studies are to resolve the ecological roles of this major component of reef benthos and provide an adequate foundation for sustainable management of the Great Barrier Reef.

Summary

The ecology of macroalgae warrants particular attention from researchers concerned with the sustainable management of the Great Barrier Reef, especially given that water quality is a major concern on the Great Barrier Reef, and that benthic algal blooms are a common consequence of eutrophication. In order to detect changes in reef biota, there is a need for (i) improved baseline descriptions of macroalgal species distributions and abundances; (ii) improved knowledge of the processes which lead to those distributions etc; and (iii) improved taxonomic descriptions and identification resources as necessary tools for obtaining better information about algal distributions.

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