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An evaluation of the role of macroalgae in mangrove dieback at Whyte Island, Moreton Bay, subtropical eastern Australia

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ABSTRACT

The macroalgal/cyanobacterial assemblages of the Whyte Island mangal on the subtropical east Australian coast were investigated to determine if these assemblages had either contributed to, or had resulted from, mangrove dieback on the landward margin of the community. Habitat disturbance in the area is indicated by: lowered abundances of species of the red algal genera *Bostrychia*, *Caloglossa*, *Catenella* and *Murrayella*; the presence of green algal species under the mangal canopy; and a well developed microbial mat in the ponded area. None of these features are characteristic of healthy mangals in the Moreton Bay region. Impacts at Whyte Island from the ponding of water, discharge of sewage effluent, onshore algal blooms, and drifts from offshore blooms are discussed as possible causal factors for mangrove dieback. Algae and cyanobacteria respond quickly to environmental disturbance by showing a shift in species composition and abundance thereby providing a useful and much needed tool in assessing, understanding and dealing with perturbations in marine ecosystems. ❑ *mangrove dieback, tidal inundation, macroalgae, microbial mats, Microcoleus chthonoplastes*

Mangrove communities (mangals) typically occur on unconsolidated substrata (mud, sand, rubble) in the mid to high intertidal zone on sheltered tropical to warm temperate coasts worldwide (Chapman 1977; Hutchings & Saenger 1987; Saenger 2002). Only a relatively small number of terrestrial flowering plants have successfully colonised the harsh environment of the land/sea interface. Eighty-four species of mangroves (Saenger 2002) have evolved adaptations to overcome salt toxicity, physiological inaccessibility of water, anaerobic waterlogged soils and problems associated with dispersal and germination of reproductive propagules in the marine environment (Hutchings & Saenger 1987; Saenger 2002).

Mangals are amongst the most threatened ecological systems (Hutchings & Saenger 1987; Hyland & Butler 1988; Field 1999; Bridgewater & Cresswell 1999; Alongi 2002; Saenger 2002). In the last 50 years, approximately one-third of the world's mangals have been destroyed by the activities of an ever increasing human population. Large areas of mangals have either been reduced to a degraded state or cleared for urban development, aquaculture and timber. Mangals are an invaluable ecological and economic asset, providing breeding and nursery habitats for a variety of animals including those contributing to the fishing industry, accumulation sites for nutrients and sediments, a renewable source of wood and protection against coastal erosion. Devising appropriate management strategies for these ecologically important ecosystems are crucial for both conservation and sustainable

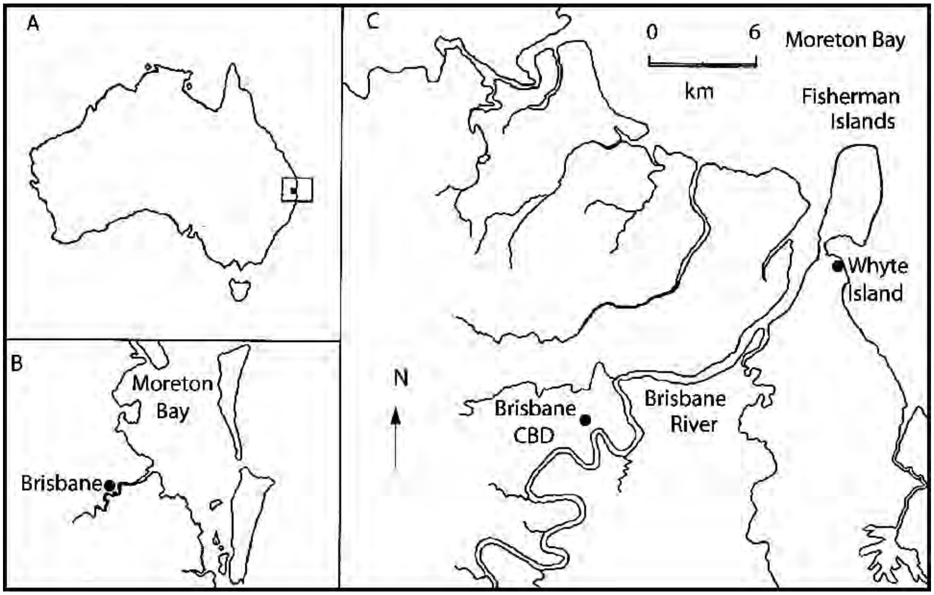

FIG. 1: Location of Whyte Island in Australia (A), the Moreton Bay region (B) and the mouth of the Brisbane River (C).

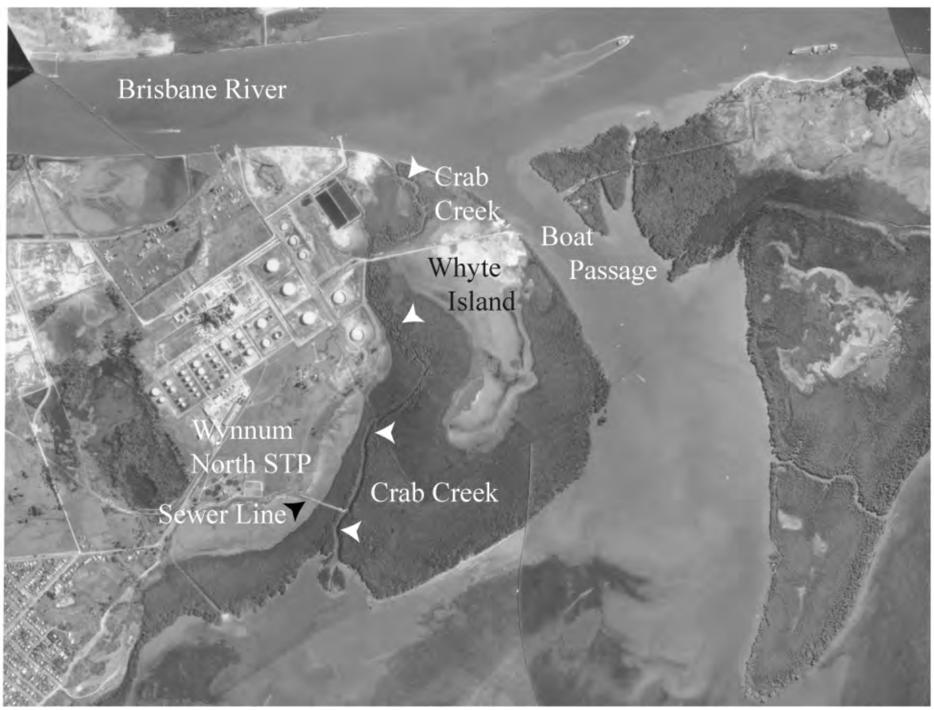

FIG. 2: Before the construction of Port Drive from 1972–1978, Whyte Island was surrounded by an extensive mangal. Crab Creek (white arrowheads) flowed from the Brisbane River between Whyte Island and the mainland coast and into Moreton Bay. The Wynnum North Sewage Treatment Plant (STP) discharged effluent via a sewer line into Crab Creek (black arrowhead).

use — the two key objectives of the Convention of Biological Diversity.

Seven species of mangroves occur in the extensive mangals on the sheltered shores of subtropical Moreton Bay, with three species being widely distributed. *Avicennia marina* is the most common and widespread species, growing along rivers and coastlines. *Rhizophora stylosa* occurs behind the *Avicennia marina* zone in the bay as well as in sheltered inlets and creeks. *Aegicerus corniculatum* is most common along the lower reaches of rivers and creeks (Dowling 1986; Hyland & Butler 1988).

Macroalgae are common components of healthy mangals, often growing on the trunks and aerial roots (pneumatophores, cone roots, stilt roots, knee roots, buttresses) of mangrove trees, and on any other firm substrata (rocks, mollusc shells, wood) on the mangal floor. Species of the red algal genera *Bostrychia*, *Caloglossa*, *Catenella* and *Murrayella* form the typical epiphytic algal community of mangals, commonly referred to as the *Bostrychia*/ *Caloglossa* association or the Bostrychietum (Post 1937; King & Puttock 1994; Phillips *et al.* 1994; Laursen & King 2000).

The macroalgae of Queensland mangals have been little studied. Cribb (1979) provided a general descriptive account of the macroalgae of Moreton Bay mangals. Atherton & Dyne (1977) collected quantitative data on macroalgal species along transects in the Serpentine Creek area, near the mouth of the Brisbane River. One of the authors (J.A.P.) has undertaken a systematic ecological survey along sea-to-land transects through a number of mangals in Moreton Bay to gather quantitative data on macroalgal species composition, abundance and distribution (Phillips, in prep.).

Considerable development along the mainland coast of Moreton Bay has caused the large scale loss of mangals either through direct removal of trees or indirectly from environmental disturb-

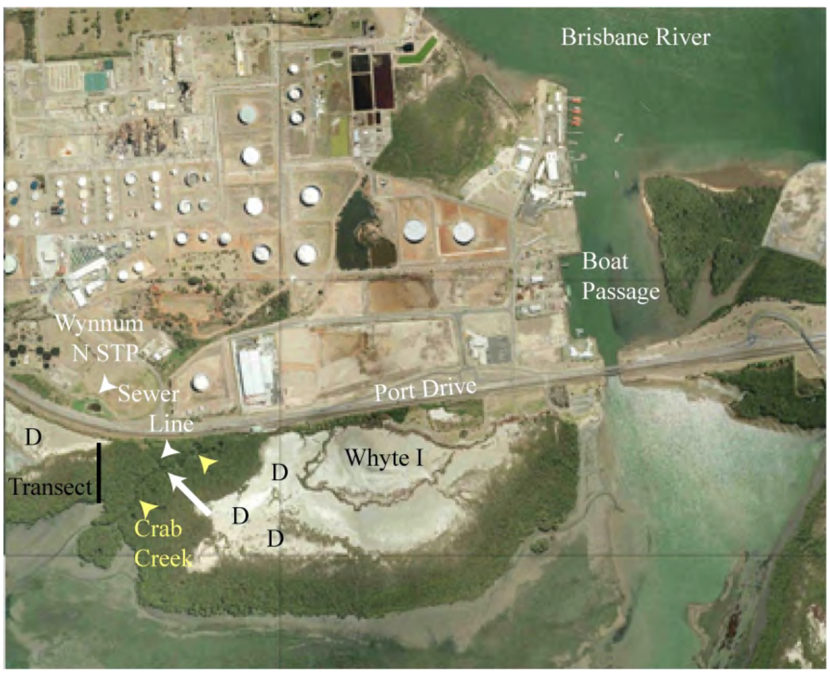

FIG. 3: Mangrove dieback at Whyte Island observed in September 2004. Crab Creek (yellow arrowheads) is truncated by Port Drive. The Wynnum North Sewage Treatment Plant (STP) discharges effluent via a sewer line (white arrowheads) and outfall (white arrow) into Crab Creek. The transect (black line) surveyed by the present study stretches from the seaward edge of the mangal to the smaller of the two dieback (D) areas.

ance. The progressive loss of mangal on Whyte Island near the mouth of the Brisbane River since the 1970s is a good example (Fig. 1). The island now has two large treeless areas between Port Drive and a narrowing seaward fringe of *Avicennia marina* (WBM 2002). This paper investigates the species composition and abundance of macroalgal/cyanobacterial species inhabiting the Whyte Island mangal to determine if blooms or drifts of macroalgal/ cyanobacterial species are a consequence of, or have contributed to, the death of large numbers of *Avicennia marina* trees in the area.

Table 1. Survey of algal/cyanobacterial vegetation in the Whyte Island mangal on the 24th Feb 2005 and 19th July 2005. (+ = surveyed, – = not surveyed).

Quadrat No.	Distance from sea (m)	Feb. Survey	July Survey
1–3	0	–	+
4–6	15	+	+
7–9	40	–	+
10–12	80	+	+
13–15	140	–	+
16–18	145	+	+
19–21	145	–	+
22–24	150	+	+

MATERIALS AND METHODS

STUDY SITE

Prior to the 1970s, Whyte Island was largely covered by an *Avicennia marina*/*Rhizophora stylosa* mangal and separated from the mainland coast by Crab Creek (WBM 2002: Fig. 2). Between 1972 and 1978, a road (Port Drive) connecting Fisherman Islands to the mainland was constructed through the Whyte Island mangal and across Crab Creek which, together with subsequent industrial development to the west of the road, was responsible for the loss of 45 ha of mangal in the area. A large section of Crab Creek was infilled, leaving only a 50 m stretch of the creek to the east of Port Drive (WBM 2002). A sewer outfall discharges secondarily-treated effluent via a culvert directly into the remaining portions of Crab Creek.

Table 2. Survey of 24th Feb 2005.

Distance from Sea (m)	Quadrat No.	Pneumatophore No.	% Canopy Cover	Low Tide Depth (cm)	Seedling No. (2–6 leaves)
Under mangrove canopy (15 m)	4	60	70	1	0
	5	80	80	2	0
	6	80	80	0	0
	Ave.	**73.3**	**76.6**	**1**	**0**
Under mangrove canopy (40 m)	7	50	70	1	5
	8	60	80	0.5	4
	9	35	70	1	4
	Ave.	**48.3**	**73.3**	**0.8**	**5.3**
Edge of dieback area (145m)	13	90	50	1	0
	14	80	60	1	0
	15	90	50	1	0
	Ave.	**86.6**	**53.3**	**1**	**0**
Dieback (ponded) area (150m)	19	8	0	5	0
	20	2	0	5	0
	21	1	0	5	0
	Ave.	**3.67**	**0**	**5**	**0**

Table 3. Survey of 19th July 2005.

Distance from Sea (m)	Quadrat No.	Pneumat-ophore No.	% Canopy Cover	Low Tide Depth (cm)	Seedling No. (2–6 leaves)
Sea edge (0m)	1	25	70–80	0	0
	2	40	70–80	0	0
	3	70	70–80	0	0
	Ave.	**45**	**70–80**	**0**	**0**
Under mangrove canopy (15m)	4	80	70–80	0	0
	5	80	70–80	0	0
	6	90	70–80	0	0
	Ave.	**83.3**	**70–80**	**0**	**0**
Under mangrove canopy (40m)	7	60	50	0	7
	8	80	60	0	6
	9	70	50	0	2
	Ave.	**70**	**53.3**	**0**	**5**
Under mangrove canopy (80m)	10	90	30	0	7
	11	60	50	0	8
	12	70	60	0	11
	Ave.	**73.3**	**46.6**	**0**	**8.6**
Under mangrove canopy (140m)	13	80	50	0	0
	14	80	55	0	0
	15	80	80	0	0
	Ave.	**80**	**61.6**	**0**	**0**
Edge of dieback area (145m)	16	0	20	0	0
	17	1	0	0	0
	18	18	0	0	0
	Ave.	**6.3**	**6.6**	**0**	**0**
Dieback (ponded) area (150m)	19	20	0	0	0
	20	5	0	0	0
	21	19	0	0	0
	Ave.	**14.6**	**0**	**0**	**0**

The volume discharged has increased significantly in recent years in response to an increasing population in the bayside area.

A preliminary survey of the Whyte Island mangal was undertaken during a 0.52 m tide on the 24th February 2005 to assess both algal/cyanobacterial populations and mangrove dieback. A more detailed survey was undertaken during a 0.31 m tide on the 19th July 2005 when algal/cyanobacterial populations are more abundant and floating algal drifts are known to occur (R. Morton, pers. com).

RECORDING VEGETATION

Vegetation was recorded along a transect through the mangal extending from the sea-ward edge, approximately 10 m south of the

Table 4. Macroalgal species recorded from the Whyte Island mangal.

Cyanobacteria
Lyngbya majuscula (Dillwyn) Harvey
Microcoleus chthonoplastes (Mertens) Zanardini
Chlorophyta (green algae)
Cladophora socialis Kützing
Rhizoclonium riparum (Roth) Harvey
Ulva compressa L. (= *Enteromorpha compressa* (L.) Nees)[1]
Ulva flexuosa Wulfen (= *Enteromorpha flexuosa* (Wulfen) J.*Ag.*)[1]
Ulva lactuca Linnaeus
Ulva ralfsii LeJolis (= *Enteromorpha ralfsii* Harvey)[1]
Rhodophyta (red algae)
Bostrychia moritiziana (Sonder ex Kützing) J. Agardh[2]
Bostrychia radicans (Montagne) Montagne[2]
Bostrychia simpliciuscula Harvey ex J. Agardh (=*B. tenuissima* R.J. King & Puttock)[3]
Bostrychia tenella (Lamouroux) J. Agardh
Caloglossa adhaerens King and Puttock
Caloglossa ogasawaraensis Okamura
Caloglossa viellardii (Kützing) Setchell[4]
Catenella nipae Zanardini
Gracilaria sp.
Murrayella periclados (C. Agardh) Schmitz
Polysiphonia infestans Harvey
Polysiphonia sp.
Sarcomena filiforme (Sonder) Kylin (drift)

[1]Based on DNA sequencing, the genus *Enteromorpha,* often a signature genus in disturbed areas, has been reduced to a synonym of the genus *Ulva* (Hayden *et al.* 2003).

[2]Zuccarello & West (2003) treated *Bostrychia radicans/B. moritziana* as a species complex.

[3]Zuccarello & West (2006) treated *Bostrychia tenuissima* as a synonym of *Bostrychia simpliciuscula*

[4]Kamiya *et al.* (2003) treated most Eastern Australian *Caloglossa leprieurii* as *Caloglossa viellardii.*

mouth of Crab Creek, to an area of mangrove dieback at the landward edge (Fig. 3). The algal/cyanobacterial vegetation was recorded from 0.25 m^2 replicate quadrats systematically placed on the transect, and at a 5 m interval to each side. Each recording station was selected when changes in the algal vegetation were detected. For each quadrat, quantitative estimates of individual algal/cyanobacterial species abundance were made using the 5 point ordinal scale of Hult-Serander-Du Rietz based on percentage vegetation cover (1: <6.25%; 2: 6.25–12.5%; 3: 12.5–25%; 4: 25–50 %; 5: 50–100%; Du Rietz 1921). For the purposes of species identification, samples of the algal/cyanobacterial vegetation were collected for light microscopy examination ranging in magnification from X10 to X400. Pneumatophore number, water depth, overhead mangrove canopy cover, mangrove seedling number and any drift algal/cyanobacterial material were also recorded for each quadrat. Three replicate quadrats were surveyed at 4 stations/vegetation types on the 24th Feb 2005 and at 8 stations/vegetation types on 19th July 2005 (Table 1).

RESULTS

Loss of mangal was apparent in two large areas flanking the east side of Port Drive at the landward side of the mangal. Even under the mangal canopy adjacent to the dieback areas, there were many dead mangrove trunks and branches scattered over the mangal floor. Pneumatophore numbers were greater under the mangrove canopy than in the dieback area (Tables 2, 3) and, in February, under the canopy peripheral to the dieback area (Table 2). The seaward fringe (to 15 m) had greater canopy cover (70–80%) than other areas of the mangal. Ponding of water in the dieback area contrasted with only a slight covering of water (generally up to 1 cm depth) under the mangrove canopy during the higher low tide of the February survey. Recruitment of mangrove seedlings was only recorded under the mangrove canopy 40–80 m away from the seaward edge (Tables 2, 3). No seedling recruitment was recorded in the dieback areas. There was very little algal/seagrass drift observed during the surveys. Some detached thalli of the red alga *Sarcomena filiforme* were

Table 5. Cover of algal species in the Whyte Island mangal, 24th Feb 2005. (**1** = <6.25%; **2** = 6.25–12.5%; **3** = 12.5–25%; **4** = 25–50 %; **5** = 50–100% cover). (shaded quadrats not sampled). Canopy cover at 'Edge of Dieback' varied from 0–60% (see Tables 2 and 3).

Canopy present (C)	**Yes**			**Yes**			**Yes**			**Yes**			**Yes**			**Yes**			**Edge of dieback**			**No**		
Distance from Sea (m)	**0**			**15**			**40**			**80**			**140**			**145**			**150**			**150**		
Species/Quadrat No.	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**23**	**24**
Bostrychia tenella				1	1	1	1		1															
Bostrychia moritiziana					1																			
Caloglossa adhaerens				1																				
Caloglossa ogasawaraensis				1			1	1	1				1	1	1									
Catenella nipae				2	2																			
Gracilaria sp.				1	1	1																		
Microcoleus chthonoplastes																			5	5	5			
Murrayella periclados				1																				
Ulva lactuca				2		2	2		2															

trapped among pneumatophores on the seaward side of the mangal and small amounts of dead seagrass leaves were caught on some mangrove branches.

A total of 19 algal (6 species of Chlorophyta and 13 species of Rhodophyta) and 2 cyanobacterial species were recorded from the Whyte Island mangal over the 2 surveys (Table 4). Many species grew on the *Avicennia marina* pneumatophores although some (e.g. *Gracilaria*) were found growing on the mud. Lower species richness and abundance were recorded during the February survey compared with the July survey (Tables 5, 6). *Caloglossa adhaerens*, recorded in the February survey, is rare in mangals of Moreton Bay.

Two vegetation types were identified along the transects: a benthic microbial mat (and in July unattached *Ulva compr*essa) in, and near, the dieback area and an assemblage of red and green algal species under the mangal canopy (Tables 5, 6). The microbial mats were dominated by the filamentous cyanobacterium *Microcoleus chthonoplastes* which, although restricted in distribution to the ponded area, was the most abundant of all the species recorded along the transects in both February and July. Large free-floating thalli of the green alga *Ulva compressa* were often tangled around pneumatophores on the edges of the ponded area in July. In February, the macroalgal community under the mangal canopy was characterised by widespread low cover of *Caloglossa ogasawaraensis* and to a slightly lesser extent *Bostrychia tenella,* and a more restricted distribution but greater cover of *Catenella nipae* and *Ulva lactuca* (Table 5). More species were common under the canopy in July when species of the red algal genera *Bostrychia*, *Caloglossa*, *Catenella*, *Gracilaria* and *Murrayella* were well represented while species of the green algal genera *Ulva, Rhizoclonium* and *Cladophora* were less abundant (Table 6).

DISCUSSION

The 21 macroalgal/cyanobacterial species recorded from the Whyte Island mangal is less than the 35 marine macroalgal species previously reported for mangals throughout Moreton Bay (Cribb 1979), but is similar to the total

Table 6. Cover of algal species in the Whyte Island mangal, 19th July 2005. (**1** = <6.25%; **2** = 6.25–12.5%; **3** = 12.5–25%; **4** = 25–50%; **5** = 50– 100% cover). Canopy cover at 'Edge of Dieback' varied from 0–60% (see Tables 2 and 3).

Canopy present (C)	**Yes**			**Yes**			**Yes**			**Yes**			**Yes**			**Yes**			**Edge of dieback**			**No**		
Distance from Sea (m)	**0**			**15**			**40**			**80**			**140**			**145**			**150**			**150**		
Species/Quadrat No.	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**23**	**24**
Bostrychia tenella							1	1		1	1	1	1	1	1									
Bostrychia moritiziana			1	1			1	1		1		1												
Bostrychia radicans				1				1																
Bostrychia simpliciuscula				1	1	1	1	1		1	1	1												
Caloglossa ogasawaraensis	1	1	1	1	1	1	1	1		2		1	1	1	2									
Caloglossa viellardii						1		2			1		1											
Catenella nipae							2	2	2															
Cladophora socialis			1	1	1																			
Gracilaria sp.							3	2	3	1	1	1												
Lyngbya majuscula					1																			
Microcoleus chthonoplastes																5	5	5	5	5	5			
Murrayella periclados			1		1		1	1		1		1												
Polysiphonia sp.						1				1		1												
Polysiphonia infestans			1																					
Rhizoclonium riparum				1	1		1					1	1	1										
Sarcomena filiforme	5	3	1			5																		
Ulva compressa																			2	2	1	4	3	5
Ulva flexuosa										1														
Ulva lactuca	1				1		1	1						1										
Ulva ralfsii					1			1			1													

number of macroalgal/cyanobacterial species recorded for the mangals of nearby Serpentine Creek (Atherton & Dyne 1977). However, each of the four seasonally sampled Serpentine Creek transects recorded between 9 to 13 species, a species richness consistent with the February survey for Whyte Island but considerably lower than that reported for the July survey. The reason for the lower species richness at the Serpentine Creek sites is not known, although mangals lining creeks may support fewer macroalgal/ cyanobacterial species than mangals directly under a fully marine influence, as has been reported previously for southern Australian mangals (Davey & Woerlkerling 1980). Sewage from the Luggage Point outfall may also have had an impact on macroalgal species diversity at Serpentine Creek. Cribb (1979) also reported 13 cyanobacterial species from saltmarshes and mangals of Moreton Bay, but gave no ecological distribution data except to report that *Lyngbya majuscula* (as *Microcoleus lyngbyaceus*) and *Schizothrix* spp. were common on mud substrata between salt marshes and mangals, an area of the shore only wetted by spring tides. Like other mangals in Australia and around the world, species of the red algal genera *Bostrychia*, *Caloglossa*, *Catenella*, *Gracilaria* and *Murrayella* were present under the canopy at Whyte Island (King & Puttock 1994; Phillips *et al.* 1994; Laursen & King 2000). The presence of *Caloglossa adhaerens*, a rare species in Moreton Bay, together with differing distribution patterns of the mangal macroalgae at various sites in Moreton Bay highlights the pressing need to collect quantitative data on these species for the purposes of documenting biodiversity and for developing strategies for macroalgal conservation. Further, it is imperative that the data collected incorporates recent taxonomic revisions of mangrove species (see footnotes in Table 4).

Shifts in macroalgal species composition and abundance are considered invaluable tools for assessing the responses of marine communities to natural and anthropogenic-mediated disturbances (Middelboe *et al.* 1997, 1998; Middelboe & Sand-Jensen 2000; Pedersen & Snoeijs 2001; Eriksson *et al.* 2002). Lower abundances of red algal species, the presence of green algal species under the mangal canopy and of the benthic *Microcoleus chthonoplastes* mat in the ponded area are features which separate the macroalgal/ cyanobacterial vegetation of Whyte Island from other mangals in the Moreton Bay region (J. Phillips, pers. observ.). Large ponded areas are usually not found in the mangals of Moreton Bay, the landward edge of which usually grades either into salt marsh, also previously reported by Cribb (1979), or grassland in residential areas or directly into industrial sites (J. Phillips, pers. observ.).

Species of the red algal genera *Bostrychia*, *Caloglossa*, *Catenella*, *Gracilaria* and *Murrayell*a generally account for < 10% cover in most quadrats in the Whyte Island mangal, contrasting markedly to healthy mangals in Moreton Bay where red algal cover frequently exceeds 20% (J. Phillips, pers. observ.). *Catenella nipae* and *Bostrychia tenella* are often dominant species which are conspicuous, identifiable in the field, and festoon pneumatophores on the seaward edge and from the middle to the landward edge of the mangals respectively (J. Phillips, pers. observ.). The lower abundances of red algal species at Whyte Island are probably related to the altered environmental conditions of the incomplete canopy. These red algal species are well adapted to the tidally-driven immersion-emersion cycles of the mid to upper intertidal zone, but they are still dependent on the shading effects of the canopy to ameliorate the higher light intensities, temperature, desiccation and osmotic stress associated with long periods of emersion (Davison & Pearson 1996). These environmental stressors are considerably less under intact canopies than for areas outside or under breaks in the canopy (Clarke & Hamon 1969; Hutchings & Saenger 1987; Pena *et al.* 1999). Mangal red algal species are typical 'shade plants' with low light adaptations for the saturation of photosynthesis and low light compensation points (below 17 μmol photons m^{-2} s^{-1}) (Karsten & Kirst 1989; Karsten *et al.* 1993; Pena *et al.* 1999). Consequently mangrove red algae are prone to photoinhibition and photodamage at ambient irradiances as low as 200 μmol photons m^{-2} s^{-1} (~ 10% sunlight) (Pena *et al.* 1999). Consistent with this are the lower species richness and abundance of mangal red algae recorded in February at Whyte Island which in part would be due to the higher light intensities of summer.

Species of the green algal genera *Ulva*, *Cladophora* and *Rhizoclonium*, found under the canopy within the Whyte Island mangal, have not been observed under the canopy inside other mangals in the Moreton Bay region (J. Phillips, pers. observ.). Green algal species are usually common on the outside edges of mangals (Atherton & Dyne 1977; Cribb 1979; Hutchings & Saenger 1987), but are rare within mangals, presumably limited by the low light intensities under an intact canopy. The higher light intensities under the breaks in the canopy and in the ponded area as well as the elevated nutrient levels from the sewage discharge would favour rapid-recruiting, opportunistic, stress-tolerant species of *Ulva*, *Cladophora* and *Rhizoclonium* (Brown *et al.* 1990; Duarte 1995; Morand & Briand 1996; Hernandez *et al.* 1997; Raffaelli *et al.* 1998; Taylor *et al.* 2001) over less tolerant species, and may explain the higher abundance of stress tolerant species inside the Whyte Island mangal. Elevated nutrient levels from effluent discharge have undoubtedly contributed to the shift in macroalgal species composition at the disturbed sites within the Whyte Island mangal.

The presence of the benthic microbial mat dominated by the cyanobacterium *Microcoleus chthonoplastes* is indicative of the harsh environmental conditions prevailing in the ponded area. Loss of the mangrove canopy, which would have a moderating effect on the physical environment, would result in higher light intensities and temperatures in the ponded area, favouring tolerant cyanobacterial species (Sage & Sullivan 1978; Golubic 1994; Potts 1999; Bhaya *et al.* 2000; Golubic *et al.* 2000; de Lomas *et al.* 2005). *Microcoleus chthonoplastes* often dominates intertidal and lagoonal microbial mats in temperate to tropical marine habitats worldwide (Potts 1980, 1999; Prufert-Bebout & Garcia-Pichel 1994; Stal 2000). This species is desiccation tolerant, surviving prolonged periods of emersion (Hershkovitz *et al.* 1991; Potts 1999), due to the production of a water-retentive mucilaginous sheaths (Stewart 1977; Hussain & Khoja 1993; DeWinder *et al.* 1999; Stolz 2000) and the ability to move to deeper mat layers, where the species is also shaded from the damaging effects of high light intensity and UV radiation (Stewart 1977; Ramsing & Prufert-Bebout 1994; Bebout & Garcia-Pichel 1995; Stal 2000).

McLeod (1969) recorded *Microcoleus chthonoplastes* as a minor component of southern Queensland salt marshes but the species has not previously been recorded from mangals in the Moreton Bay region. This again reflects the paucity of knowledge of the ecology of this region, and in this instance of cyanobacterial diversity. *Microcoleus chthonoplastes* has been recorded from tropical Queensland (Phillips 1997, 2002), from mangals in the Sydney region (Karsten 1996) and in mangals worldwide (Fogg 1973; Tanaka & Chihara 1984; Lambert *et al.* 1989; Hussain & Khoja 1993; Phillips *et al.* 1994), occuring either as an inconspicuous component on aerial roots (Phillips *et al.* 1994) or conspicuously on mud and aerial roots (Fogg 1973; Lambert *et al.* 1989) or in microbial mats (Potts 1980; Stal *et al.* 1985; Hussain & Khoja 1993).

POSSIBLE CAUSES OF MANGROVE DIEBACK

It is apparent from this survey and the WBM (2002) report that the Whyte Island mangal is under threat. While the loss of *Avicennia marina* trees from and the occurrence of large areas of *Microcoleus chthonoplastes* mats in the ponded area are obvious features of the environmental stress, the mangroves and macroalgae at the landward edge of the existing Whyte Island mangal are also showing signs of stress. This is evident from the large gaps in the canopy, restricted recruitment of mangrove seedlings (which never exceeded the 6 leaf stage), epicormic shoots on *Avicennia marina* trunks, the reduced biomass of the Bostrychia/Caloglossa association on pneumatophores and the presence of green algae under the mangrove canopy.

It is probable that interactions of multiple stressors may have contributed to the mangal dieback over the last three decades at Whyte Island. Mangroves live in saline, waterlogged, anaerobic soils and already are hard pressed to cope with salt toxicity, absorption of water against an osmotic gradient (desalination), high light regimes, high temperatures and anaerobiosis (Clough *et al.* 1982; Hutchings & Saenger 1987; Saenger 2002). Any disturbance will interfere with the finely-tuned balance between the mangroves and the environment that supports them, often resulting in a loss of trees and a decline in the mangal. It makes good sense to start by examining some of the more obvious potential causes of the Whyte Island dieback: 1) the large scale ponding of seawater within the area formerly occupied by the mangal; 2) discharge of sewage into Crab Creek; and 3) the potential for onshore algal blooms or drifts from offshore blooms to smother *Avicennia* pneumatophores and/or contribute to, or cause, seawater ponding.

Ponding of water. Mangroves do not survive in habitats which are flooded for prolonged periods, and for this reason are ecologically restricted to the upper intertidal zone (mid to high tide mark), an area where the substratum should be drained at every low tide. Mangal soils are typically anaerobic, the mangrove roots obtaining oxygen for respiration from the atmosphere via aerial roots. Diffusion of air during low tide through air pores (lenticels and horizontal structures) on *Avicennia marina* pneumatophores is sufficient to aerate the extensive aerenchyma (air filled tissue) throughout the pneumatophore/subterranean cable root system in order to supply oxygen for root respiration during tidal inundation (Curran 1985; Curran *et al.* 1986; Skeleton & Allaway 1996). Root respiration, required for the energetically-expensive uptake of water against the osmotic gradient (desalination), is dependent on oxygen stored in root aerenchyma, as there is little oxygen in the surrounding anaerobic muddy substratum. Oxygen is rapidly consumed by *Avicennia marina* roots, with only c. 0.1 atmospheric oxygen concentration remaining in the root aerenchyma 22 hrs after the onset of the continuous flooding (Skeleton & Allaway 1996). Continuous immersion of aerial roots was considered responsible for the death of mangroves at Wallum Creek, North Stradbroke I., following the construction of a 70 m long bund wall which retained water in the mangal (Quinn & Beumer 1984). Waterlogged mangroves behind bund walls generally die within six weeks of inundation (Hutchings & Saenger 1987; Saenger 2002). Death of mangroves also followed the unintended ponding of seawater from roads constructed through mangals in northern Western Australia (Gordon 1987), New Guinea (Saenger 2002), Puerto Rico (Patterson-Zucca 1982) and Colombia (Elster *et al.* 1999).

Sewage discharge. Several studies have investigated the discharge of secondarily-treated sewage into mangals, reporting that mangroves have the ability to absorb high levels of nutrients found in sewage without any discernible harmful effects (Nedwell 1975; Clough *et al.* 1983; Corredor & Morell 1994; Tam & Wong 1995; Wong *et al.* 1995; Saenger 2002). However, sewage sludges may be contaminated with heavy metals which can be mobilised and released from mangal sediments (Montgomery & Price 1979; Tam & Wong 1997). Heavy metals may be accumulated by mangrove species (Clark *et al.* 1997, Lacerda 1998), although detrimental effects to mangrove species, which are generally considered to have a high tolerance to heavy metal exposure and accumulation, have not been observed even after exposing seedlings to sediment concentrations of Cu, Zn, Pb, Ca and Hg to approximately 500 $\mu g\ g^{-1}$ (for discussion see Saenger 2002). The sediments at Whyte Island have heavy metal concentrations well below 100 $\mu g\ g^{-1}$ (WBM 2002).

While nutrients and heavy metals appear not to have any discernible effect on mangroves, sewage effluent may also be the source of anionic surfactants (found in detergents), plasticizers and other toxicants such as phenol, toluene and chlorine. These components may be delivered in pulses of high, potentially-damaging concentrations, may act synergistically with other components to either enhance\reduce toxicity (Kevekordes 2001) or may interact with the physical environment, such as the sediments, resulting in the development of adverse environmental conditions (e.g. the production of acid sulphate soils due to the oxidation of sulphides bound to heavy metals (Clark *et al.* 1997)).

Algal blooms and drifts. Marine macroalgal blooms and drifts are often a consequence of environmental disturbance caused by elevated nutrient levels delivered, in the case of Whyte Island, from sewage effluent. Effluent from the Wynnum North Sewage Treatment Plant is discharged directly into Crab Creek and under favourable environmental conditions could potentially result in on-site blooms. Effluent is also discharged from Luggage Point and from rivers feeding into Moreton Bay. These more distant sources may result in offshore blooms drifting into the Whyte Island mangal. However, these were not observed during the present study. The small amount of macroalgal biomass recorded under the canopy at Whyte Island would not be sufficient to form floating blooms. Nor are there any reports in the scientific literature of the very common *Microcoleus chthonoplastes* forming floating mats, although the benthic mat formed by this species in the ponded area could prevent or further exacerbate poor seawater drainage at low tide, due to the ensheathing mucilage around the cyanobacterial filaments (Golubic 1973).

Algal/cyanobacterial blooms and drifts were not observed during the current study at Whyte Island, but monitoring would be required to detect these episodic events. Large drifts of *Ulva* are known to occur at Whyte Island during the winter (R. Morton, pers. com.) and drifting algal mats have been reported to block drainage channels and cause the ponding of water at Luggage Point (WBM 2002). Atherton & Dyne (1977) reported extensive floating algal masses at low tide, dominated by *Gracilaria sp.* and *Ulva clathrata* and to a lesser extent *Caulerpa fastigiata* during summer near thin stands of stunted mangroves at Serpentine Creek. They also reported vast tracts of floating cyanobacterial mats comprising *Lyngbya majuscula*, *Scytonema* and *Chroococcus* caught on pneumatophores further landward of the floating macroalgal masses. Any impact the drift may have had on the mangroves was not described, and the authors found it difficult to assess whether algal mat growth had been stimulated by mangrove thinning, also reported in their study.

There is little evidence on the effects that algal/cyanobacterial/seagrass drifts may have on mangrove survival. Bird & Barson (1982) reported that accumulations of dead *Zostera* were thought to contribute to mangrove dieback in Westernport Bay, Victoria. Loss of mangroves in the St Kilda-Port Gawler area of South Australia was attributed to large drifts of *Ulva* and dead seagrass retarding recruitment of *Avicennia marina* seedlings and smothering pneumatophores (Edyvane 1995).

RECOMMENDATIONS FOR FURTHER STUDY

While a number of factors may potentially interact to cause mangrove dieback, the long periods of seawater inundation (several days to weeks) of the Whyte Island mangroves would itself be sufficient to cause mangrove death. Thus investigations should initially focus on the ponding of water. Gaining an understanding of the environment in the ponded area is necessary for devising a rehabilitation plan. Restoring vegetation on the tidal landward fringe is challenging because of natural environmental stresses and anthropogenic disturbances. The impact of strandings of large masses of algae or cyanobacteria, that may contribute both to water ponding and to pneumatophore smothering, also needs investigation.

The following research is suggested:

1. The ponded area should be studied in regard to physico-chemical parameters, the periodicity of inundation from the sea, freshwater inputs, water depth, the biology of the *Microcoleus chthonoplastes*, and mangrove recruitment (if any). The study should be undertaken throughout the year to detect seasonal effects and tidal variation (both lunar and solar cycles).

2. Possible impacts of algal/cyanobacterial blooms/drift on mangrove survival at Whyte Island need to be investigated and monitored (in particular the occurrence, periodicity, origin (inside versus outside mangal), species composition, and possible causes). Identifying the species composition of any blooms/drifts is crucial for identifying the possible origin of the bloom species. This in turn will determine appropriate management strategies. In our opinion, blooms that may impact on the Whyte Island mangal will be unlikely to originate from within this mangal. Similarly a variety of species also form 'algal/cyanobacterial mats', and the likelihood that *Microcoleus chthonoplastes* mats may become pelagic also needs to be investigated.

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LITERATURE CITED

Alongi, D.M. 2002. Present state and future of the world's mangrove forests. *Environmental Conservation* **29**: 331–349.

Atherton, G. & Dyne, G. 1977. Survey of the algal flora of the Serpentine Creek area. Pp. 83–109. *In*, Brisbane Airport Development Project Environmental Study. Volume 4. Marine Study Reports. (Australian Government Printing Service: Canberra).

Behout, B.M. & Garcia-Pichel, F. 1995. UV-induced vertical migration of cyanobacteria in a microbial mat. *Applied and Environmental Microbiology* **61**: 4215–4222.

Bhaya, D., Schwartz, R. & Grossman, A.R. 2000. Molecular responses to environmental stress. Pp. 397–442. *In*, Whitton, B.A. & Potts, M. (Eds). *The Ecology of Cyanobacteria*. (Kluwer: Dordrecht).

Bird, E.C.F. & Barson, M.M. 1982. Stability of mangrove systems. Pp. 265–274. *In*, Clough, B.F. (Ed.), *Mangrove Ecosystems in Australia: Structure, Function and Management*. (ANU Press: Canberra).

Bridgewater, P.B. & Cresswell, I.D. 1999. Biogeography of mangrove and saltmarsh vegetation: implications for conservation and management in Australia. *Mangroves and Salt Marshes* **3**: 117–125.

Brown, V.B., Davies, S.A. & Synnot, R.N. 1990. Long-term monitoring of the effects of treated sewage effluent on the intertidal macroalgal community near Cape Schanck, Victoria, Australia. *Botanica Marina* **33**: 85–98.

Chapman, V. 1977. *Ecosystems of the World. Wet Coastal Ecosystems*. (Elsevier: Amsterdam).

Clarke, L.D. & Hamon, N.J. 1969. The mangrove swamp and salt marsh communities of the Sydney district. II. The holocoenotic complex with particular reference to physiography. *Journal of Ecology* **57**: 213–234.

Clarke, M.W., McConchie, D., Saenger, P. & Pillsworth, M. 1997. Hydrological controls on copper, cadmium, lead and zinc concentrations in an anthropogenically polluted mangrove ecosystem, Wynnum, Brisbane, Australia. *Journal of Coastal Research* **13**: 1150–1158.

Clough, B.F., Andrews, T.J. & Cowan, I.R. 1982. Physiological processes in mangroves. Pp. 193–200. *In*, Clough, B.F. (Ed.), *Mangrove Ecosystems in Australia: Structure, Function and Management*. (ANU Press: Canberra).

Clough, B.F., Boto, K.G. & Attiwell, P.M. 1983. Mangroves and sewage: a re-evaluation. Pp. 151–161. *In*, Teas, H.J. (Ed.), *Biology and Ecology of Mangroves*. (Dr W. Junk: The Hague).

Corredor, J.E. & Morel, J.M. 1994. Nitrate depuration of secondary sewage effluents in mangrove sediments. *Estuaries* **17**: 295–300.

Cribb A.B. 1979. Algae associated with mangroves in Moreton Bay, Queensland. Pp. 63–69. *In*, Bailey, A. & Stevens, N.C. (Eds), *Northern Moreton Bay Symposium*. (Royal Society of Queensland: Brisbane).

Curran, M. 1985. Gas movements in the roots of *Avicennia marina* (Forsk.) Vierh. *Australian Journal of Plant Physiology* **12**: 97–108.

Curran, M., Cole, M. & Allaway, W.G. 1986. Root aeration and respiration in young mangrove plants (*Avicennia marina* (Forsk.) Vierh). *Journal of Experimental Botany* **37**: 1225–1233.

Davey, A. & Woelkerling, Wm. J. 1980. Studies on the Australian mangrove algae. I. Victorian communities: composition and geographic distribution. *Proceedings of the Royal Society of Victoria* **91**: 53–66.

Davison, I.R. & Pearson, A.G. 1996. Stress tolerance in intertidal seaweeds. *Journal of Phycology* **32**: 197–211.

De Lomas, J.G., Corzo, A., Garcia, C.M. & Van Bergeijk, S.A. 2005. Microbenthos in a hypersaline tidal lagoon: factors affecting microhabitat, community structure and mass exchange at the sediment water interface. *Aquatic Microbial Ecology* **38**: 53–69.

De Winder, B., Staats, N., Stahl, L.J. & Paterson, D.M. 1999. Carbohydrate secretion of phototrophic communities in tidal sediments. *Journal of Sea Research* **42**: 131–146.

Dowling, R. 1986. The Mangrove Vegetation of Moreton Bay. Dept Primary Industries Botany Bulletin No. 6. (Queensland Government: Brisbane).

Duarte, C. 1995. Submerged aquatic vegetation in relation to different nutrient regimes. *Ophelia* **41**: 87–112.

Du Rietz, G.E. 1921. *Zur metodologischen Grundlage der modernen Pflantzensoziologie*. (Holhausen: Vienna).

Edvyane, K.S. 1995. *Where Forests Meet the Sea. Mangroves of South Australia*. (SARDI: Adelaide).

Elster, C., Perdomo, L. & Schnetter, M.-L. 1999. Impact of ecological factors on the regeneration of mangroves in the Cienaga Grande de Santa Marta, Colombia. *Hydrobiologia* **41**: 35–46.

Eriksson, B.K., Johansson, G. & Snoeijs, P. 2002. Long-term changes in the sublittoral zonation of brown algae in the southern Bothnian Sea. *European Journal of Phycology* **33**: 241–249.

Field, C.D. 1999. Rehabilitation of mangrove ecosystems: an overview. *Marine Pollution Bulletin* **37**: 383–392.

Fogg, G.E. 1973. Physiology and ecology of marine blue-green algae. Pp. 368–378. *In*, Carr, N.G. & Whitton, B.A. (Eds), *The Biology of Blue-Green Algae*. (Blackwell: Oxford).

Golubic, S. 1973. The relationship between blue-green algae and carbonate deposits. Pp. 434–472. *In*, Carr, N.G. & Whitton, B.A. (Eds), *The Biology of Blue-Green Algae*. (Blackwell: Oxford).

1994. The continuing importance of cyanobacteria. Pp. 334–340. *In*, Bengtson, S. (Ed.), *Early life On Earth*. (Columbia University Press: New York).

Golubic, S., Seong-Joo, L. & Browne, K.M. 2000. Cyanobacteria: Architects of sedimentary structures. Pp. 57–67. *In*, Riding, R.E. & Awramik, S.M. (Eds), *Microbial Sediments*. (Springer-Verlag: Berlin).

Gordon, D.M. 1987. Disturbance to mangroves in tropical-arid Western Australia: hypersalinity and restricted tidal exchange as factors leading to mortality. Technical Series No 12. (Environmental Protection Authority: Perth, Western Australia).

Hayden, H.S., Blomster, J., Maggs, C.A., Silva, P.C., Stanhope, M.J. & Waaland, J.R. 2003. Linnaeus was right all along: *Ulva* and *Enteromorpha* are not distinct genera. *European Journal of Phycology* **38**: 277–294.

Hernandez, I., Peralta, G., Perez-Llorens, J.L., Vergara, J.J. & Niell, F.X. 1997. Biomass and dynamics of *Ulva* species in the Palmones River Estuary. *Journal of Phycology* **33**: 764–772.

Hershkovitz, N., Oren, A. & Cohen, Y. 1991. Accumulation of trehalose and sucrose in cyanobacteria exposed to matric water stress. *Applied and Environmental Microbiology* **57**: 645–648.

Hussian, M.I. & Khoja, T.M. 1993. Intertidal and subtidal blue-green algal mats of open and mangrove areas in the Farasan Archipelago (Saudi Arabia), Red Sea. *Botanica Marina*: **36**: 377–388.

Hutching, P. & Saenger, P. 1987. *Ecology of Mangroves*. (University of Queensland Press: St Lucia).

Hyland, S.J., & Bulter, C.T. 1988. The distribution and modification of mangroves and saltmarsh-claypans in southern Queensland. Information Series Q189004. (Department of Primary Industries, Queensland Government: Brisbane).

Kamiya, M., Zuccarello, G.C. & West, J.A. 2003. Evolutionary relationships of the genus *Caloglossa* (Delesseriaceae, Rhodophyta) inferred from large-subunit ribosomal RNA gene sequences, morphological evidence and reproductive compatibility, with description of a new species from Guatemala. *Phycologia* **42**: 478–497.

Karsten, U. 1996. Growth and organic osmolytes of geographically different isolates of *Microcoleus chthonoplastes* (Cyanobacteria) from benthic microbial mats: response to salinity change. *Journal of Phycology* **32**: 501–506.

Karsten, U. & Kirst, G.O. 1989. The effect of salinity on growth, photosynthesis and respiration in the estuarine red alga *Bostrychia radicans* Mont. *Helogolander Meeresuntersuchungen* **43**: 61–66.

Karsten, U., West, J.A. & Ganesan, E.K. 1993. Comparative physiological ecology of *Bostrychia moritziana* (Ceramiales, Rhodophyta) from freshwater and marine habitats. *Phycologia* **32**: 401–409.

Kevekordes, K. 2001. Toxicity testing using developmental stages of *Hormosira banksii* (Phaeophyta) identify ammonium as the damaging component of secondary treated sewage effluent discharged into Bass Strait, Victoria, Australia. *Marine Ecology Progress Series* **219**: 139–148.

King, R.J. & Puttock, C. 1994. Macroalgae associated with mangroves in Australia: Rhodophyta. *Botanica Marina* **37**: 181–191.

Lacerda, L.D. 1998. Biogeochemistry of trace metals and diffuse pollution in mangrove ecosystems. *ISME Mangrove Ecosystems Occasional Papers* **2**: 1–65.

Lambert, G., Steinke, T.D. & Naidoo, Y. 1989. Algae associated with mangroves in South African estuaries: Cyanophyceae. *South African Journal of Botany* **55**: 476–491.

Laursen, W.J. & King, R.J. 2000. The distribution and abundance of mangrove macroalgae in Woolooware Bay, New South Wales, Australia. *Botanica Marina* **43**: 377–384.

McLeod, J. 1969. Tidal Marshes of south-eastern Queensland and their associated algal flora. MSc Thesis, (University of Queensland: Brisbane).

Middelboe, A.L. & Sand-Jensen, K. 2000. Long-term changes in macroalgal communities in a Danish estuary. *Phycologia* **39**: 245–257.

Middelboe, A.L., Sand-Jensen, K. & Brodersen, K. 1997. Patterns of macroalgal distribution in the Kattegat-Baltic region. *Phycologia* **36**: 208–219.

Middelboe, A.L., Sand-Jensen, K. & Krause-Jensen, D. 1998. Patterns of macroalgal species diversity in Danish estuaries. *Journal of Phycology* **34**: 457–466.

Montgomery, J.R. & Price, M.T. 1979. Release of trace metals by sewage sludge and the subsequent uptake by members of a turtle grass mangrove ecosystem. *Environmental Science and Technology* **13**: 546–549.

Morand, P. & Briand, X. 1996. Excessive growth of macroalgae: a symptom of environmental disturbance. *Botanica Marina* **39**: 491–516.

Nedwell, D.R. 1975. Inorganic nitrogen metabolism in an eutrophicated tropical estuary. *Water Research* **9**: 222–231.

Patterson-Zucca, C. 1982. The effects of road construction on a mangrove ecosystem. *Tropical Ecology* **23**: 105–124.

Pedersen, M. & Snoeijs, P. 2001. Patterns of macroalgal diversity, community composition and long-term changes along the Swedish Coast. *Hydrobiologia* **459**: 83–102.

Pena, E.J., Zingmark, R. & Nietch, C. 1999. Comparative photosynthesis of two species of intertidal epiphytic macroalgae on mangrove roots during submersion and emersion. *Journal of Phycology* **35**: 1206–1214.

Phillips, A., Lambert, G., Granger, J.E. & Steinke, T.D. 1994. Horizontal zonation of epiphytic algae associated with *Avicennia marina* (Forssk.) Vierh. pneumatophores at Beachwood Mangrove Nature Reserve, Durban, South Africa. *Botanica Marina* **37**: 567–576.

Phillips, J.A. 1997. Bacillariophyceae, Chlorophyceae, Chrysophyceae, Cyanophyceae, Euglenophyceae, Phaeophyceae, Rhodophyceae, Xanthophyceae. Pp. 223–240. *In*, Henderson, R.J.F. (Ed), *Queensland Plants: Names and Distribution* (Department of Environment: Brisbane).

2002. Protista- Algae. Pp 228–245. *In*, Henderson, R.J.F. (Ed), *Names and Distributions of Queensland Plants, Algae and Lichens*. (Environment Protection Agency: Brisbane).

Post, E. 1937. Weitere Daten zur Verbreitung des Bostrychietum. I. *Hedwigia* **77**: 11–14.

Potts, M. 1980. Blue-green algae (Cyanophyta) in marine coastal environments of the Sinai Peninsula; distribution, zonation, stratification and taxonomic diversity. *Phycologia* **19**: 60–73.

1999. Mechanism of desiccation tolerance in cyanobacteria. *European Journal of Phycology* **34**: 319–328.

Prufert-Bebout, L. & Garcia-Pichel, F. 1994. Field and cultivated *Microcoleus chthonoplastes*: the search for clues to its prevalence in marine microbial mats. Pp. 111–123. *In*, Stal, L.J. & Caumette, P. (Eds), *Microbial Mats. Structure, Development and Environment Significance* (Springer-Verlag: Berlin).

Quinn, R.H. & Beumer, J.P. 1984. Wallum Creek — a study of the regeneration of mangroves. Pp. 238–249. *In*, Coleman, R.J., Covacevich, J. & Davie, P. (Eds), *Focus on Stradbroke*. (Boolarong Publications: Brisbane).

Raffaelli, D.G., Raven, J.A. & Poole, L.J. 1998. Ecological impact of green macroalgal blooms. *Oceanography and Marine Biology, Annual Review* **36**: 97–125.

Ramsing, N.B. & Prufert-Bebout, L. 1994. Motility of *Microcoleus chthonoplastes* subjected to different light intensities quantified by digital image analysis. Pp. 183–192. *In*, Stal, L.J. & Caumette, P. (Eds), *Microbial Mats. Structure, Development and Environment Significance*. (Springer-Verlag: Berlin).

Saenger, P. 2002. *Mangrove Ecology, Silviculture and Conservation*. (Kluwer Academic Publishers: Dordrecht).

Sage, W.W. & Sullivan, M.J. 1978. Distribution of blue green algae in a Mississippi Gulf coast salt marsh. *Journal of Phycology* **14**: 333–337.

Skelton, N. J. & Allaway, W.G. 1996. Oxygen and pressure changes measured in situ during flooding in roots of the grey mangrove *Avicennia marina* (Forssk.) Vierh. *Aquatic Botany* **54**: 165–175.

Stal, L.J. 2000. Cyanobacterial mats and stromatolites. Pp. 61–120. *In*, Whitton, B.A. & Potts, M. (Eds), *The Ecology of Cyanobacteria*. (Kluwer: Dordrecht).

Stal, L.J., Van Gemerden, H. & Krumbein, W.E. 1985. Structure and development of benthic marine microbial mat. *FEMS Microbiology Ecology* **31**: 111–125.

Stewart, W.D.P. 1977. Blue Green Algae. Pp. 63–123. *In*, Hardy, R.W & Silver, W.S. (Eds), *A Treatise on Dinitrogen Fixation*. (John Wiley & Sons: New York).

Stolz, J.F. 2000. Structure of microbial mats and biofilms. Pp. 1–8. *In*, Riding, R.E. & Awramik, S.M. (Eds), *Microbial Sediments*. (Springer-Verlag: Berlin).

Tam, N.F.Y. & Wong, Y.S. 1995. Spatial & temporal variations of heavy metal contamination in sediments of a mangrove swamp in Hong Kong. *Marine Pollution Bulletin* **31**: 254–261.

Tanaka, J. & Chihara, M. 1987. Species composition and vertical distribution of macroalgae in brackish waters of Japanese mangrove forests. *Bulletin of the National Science Museum, Tokyo. Ser. B.* **13**: 141–150.

Taylor, R., Fletcher, R.L. & Raven, J.A. 2001. Preliminary studies on the growth of selected ‘green tides’ algae in laboratory culture: effects of irradiance, temperature, salinity and nutrients on growth rate. *Botanica Marina* **44**: 327–336.

WBM Oceanics Australia 2002. Assessment of the health and viability of the mangrove communities at Whyte Island. (Brisbane: Australia).

Wong, Y.S., Lan, C.Y., Chen, G.Z., Li., S.H., Chen, Z.P. & Tam, N.F.Y. 1995. Effect of wastewater discharge on nutrient contamination in mangrove soils and plants. *Hydrobiologia* **295**: 243–254.

Zuccarello, G.C. & West, J.A. 2003. Multiple cryptic species: molecular diversity and reproductive isolation in the *Bostrychia radicans/B. moritziana* complex (Rhodomelaceae, Rhodophyta) with focus on North American isolates. *Journal of Phycology* **39**: 948–959.

2006. Molecular phylogeny of the subfamily Bostrychioideae (Ceramiales, Rhodophyta): Subsuming *Stictosiphonia* and highlighting polyphyly in species of *Bostrychia*. *Phycologia* **45**: 24–36.