Algae associated with mangroves in southern African estuaries: Cyanophyceae

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This paper describes taxa of the Class Cyanophyceae which are inconspicuous within a turf-like Bostrychietum that coats plant, mud and rock in the mangrove-associated estuaries of southern Africa. The pneumatophores of the white mangrove *Avicennia marina*, support the richest flora. Of the 27 taxa recorded *Microcoleus chthonoplastes* has the widest biogeographical range and was common on most substrata. Non-heterocystous were more prevalent than heterocystous Cyanophyceae and four other taxa occurred epiphytic only on the dominant macroalgal species of *Bostrychia, Caloglossa, Enteromorpha* and *Rhizoclonium*. Preliminary explanations, based on related studies, are offered on the recycling of nitrogen by Cyanophyceae within the mangrove ecosystem.

Hierdie artikel beskryf die taksons van die klas Cyanophyceae wat onopvallend is en aangetref word in die turfagtige Bostrychietum wat plante, modder en rotse in die manglietgeassosieerde strandmere van Suidelike-Afrika, bedek. Die pneumatofore van die wit-mangliet *Avicennia marina* huisves die rykste flora. Van die 27 taksons wat aangeteken is, besit *Microcoleus chthonoplastes* die wydste biografiese verspreiding en word algemeen op meeste substrate aangetref. Nie-heterositiese verteenwoordiges was meer algemeen as heterosistiese Cyanophyceae en vier ander taksons kom alleenlik epifities voor op die dominante makro-alg *Bostrychia, Caloglossa, Enteromorpha,* en *Rhizoclonium*. Voorlopige verklarings wat op soortegelyke ondersoeke gebaseer is, word aangebied met betrekking tot die hersirkulering van stikstof deur Cyanophyceae, binne die manglietekosisteem.

Keywords: Cyanophyceae, mangroves, southern Africa

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Introduction

Millard & Broekhuysen (1970) is the only reference that lists blue-green algae (Class Cyanophyceae) associated with mangroves in estuaries along the south-east African coastline; namely, *Lyngbya confervoides* and *Microcoleus chthonoplastes* from the southern lake and estuary of Lake St Lucia (Figure 1).

Lambert *et al.* (1987) discussed the status of 19 of the 41 mangrove-associated estuaries along this coastline and described in some detail the rhodophycean component of the Bostrychietum (Post 1936). This is the conspicuous maroon turf-like algal covering on mainly plant substrata. Certainly the species content varied between estuaries and it was emphasized that these algae very likely play a significant role in the ecosystem. Selected species have now been studied and the vertical zonation of *Bostrychia radicans* (Mont.) Mont. and *Caloglossa leprieurii* (Mont.) J. Ag. up pneumatophores of *Avicennia marina* can be explained by their physiological response rates to varying environmental conditions (Mann 1987; Mann & Steinke 1988).

This paper chronicles the taxa in brown, purple, dark blue-green and bright green mats or turfs, that are inconspicuous within the Bostrychietum or distinctive upon a variety of plant and sedimentary surfaces. The associated Chlorophyceae and Phaeophyceae are not discussed as further studies are required therein.

Materials and Methods

Nineteen mangrove-associated estuaries were surveyed for algae (Figure 1). Further details are available in Lambert *et al.* (1987). Most sampling was carried out during low spring tide and six substrata were found to support these plants.

1. Pneumatophores of *Avicennia marina* (Forrsk.) Vierh.
2. Stem base and prop roots of *Rhizophora mucronata* Lam.
3. Stem base, knee and buttress roots of *Bruguiera gymnorrhiza* (L.)Lam.
4. Stem base of *Ceriops tagal* (Perr.) C.B. Robinson
5. Mud
6. Rock

No algae were recorded epiphytic on *Lumnitzera racemosa* Willd. For the remainder of the text 'pneumatophores', 'prop roots', 'knee roots', 'stem base', 'mud' and 'rock' will refer to substrata 1 to 6 respectively.

Sampling other mangrove substrata

Towards the lower tidal limit, pneumatophores were usually largest, more numerous and supported the greatest biomass of epiphytic algae than elsewhere. There was a decrease in size and number of pneumatophores, and also abundance of algae, towards the upper tidal limit. To overcome these difficulties, sampling was carried out

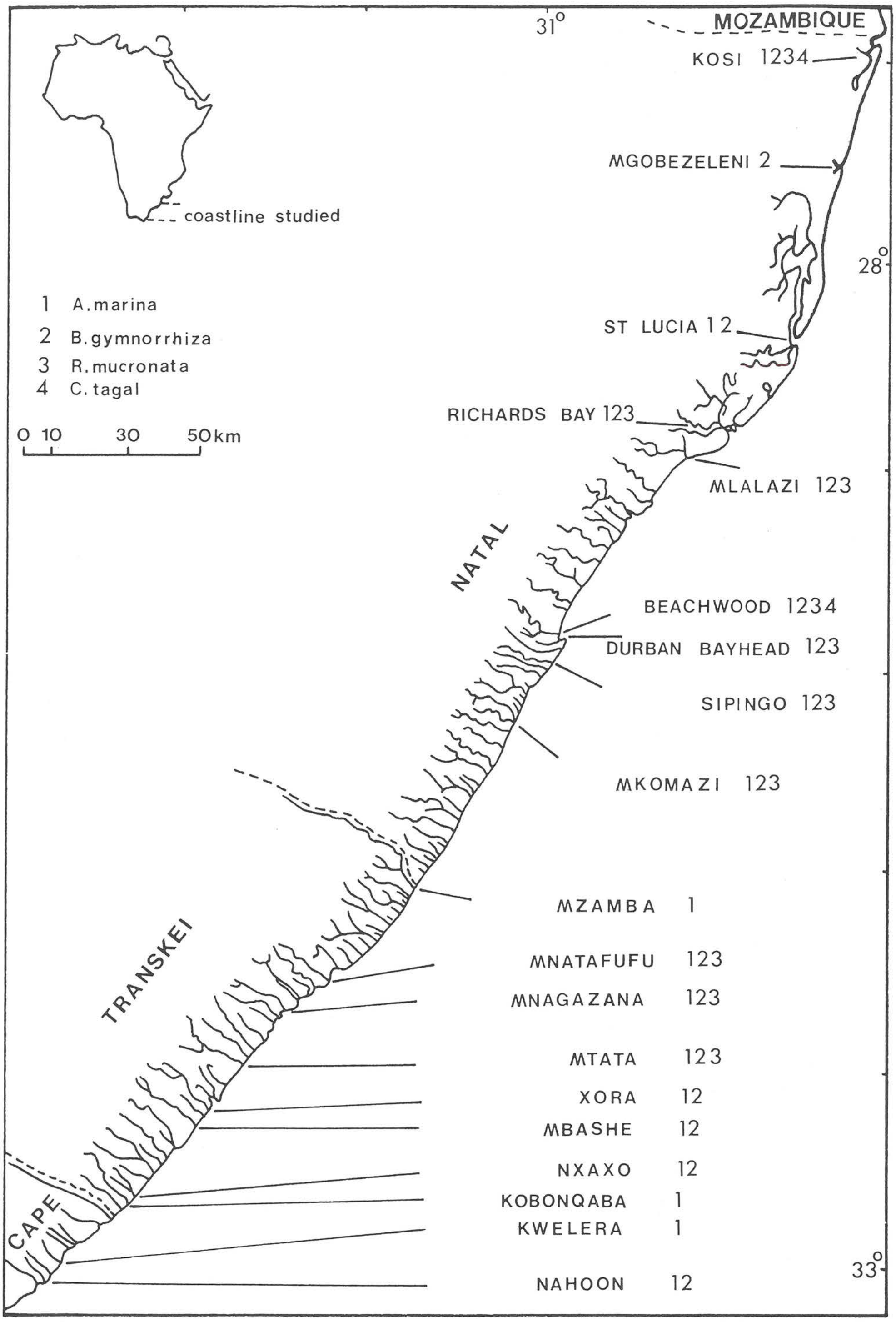


Figure 1 Map of southern African mangrove-associated estuaries studied.

using a modified proportionate stratified random technique. Initially samples were collected from a transect along the water's edge and each sample was obtained by cutting a pneumatophore at the sediment surface. Submerged pneumatophores were sampled likewise. Subsequent parallel transects were then sampled in the same way to the landward limit of the pneumatophores. Distance between transects was about 1 m, but where pneumatophores were sparse a wider spacing was employed. Following systematic sampling, the area was searched once again to reduce the chance that any algal material had been missed.

All other mangrove substrata

From the roots and stem bases of *Bruguiera gymnorrhiza, Ceriops tagal* and *Rhizophora mucronata* algal-covered bark was scraped off. These trees were not sampled as intensively as the pneumatophores because of their sparse distribution in most estuaries and they supported less algal growth.

Mud and rock substrata

Samples were collected from dry, moist and wet sectors of the swamp wherever visible patches of algae were observed on mud or rock.

Frequency of sampling

Monthly samples were collected from St Lucia estuary and the Beachwood Mangrove Nature Reserve (Beachwood) at the Mgeni estuary (Figure 1). Quarterly collections were made at Kobonqaba and Nxaxo. The remaining estuaries were rather inaccessible so they were not sampled regularly, but collections were made overall to achieve quarterly data. Quarterly refers to intervals January to March, April to June, July to September and October to December which were coincident with ambient and sea temperature regimes for the Natal and Transkei coastal weather patterns (Schulze 1974).

Preservation and processing

All samples were preserved in 4% formaldehyde in estuarine water. In the laboratory they were removed from their substrata, cleaned free of mud and separated into species. For each estuary, taxonomically useful specimens were prepared for light microscopy and mounted in glycerine jelly, 25% corn syrup (Johansen 1940), or 50% Hoyer's medium (Anderson 1954) containing the stains safranin or eosin.

Voucher specimens are housed in the Botany Department, University of Durban-Westville. Habitat information has been stored on discs using a data template derived from a Visidex programme for an Apple computer. In this text and that of Lambert *et al.* (1987) locality details were taken from 1:250 000 maps (Table 1).

Taxonomy

The blue-greens have not been designated herein as cyanobacteria (Stainer *et al.* 1971, 1978; Whitton & Carr 1973; Stanier & Cohen-Bazire 1977) but as algae, since their chlorophyll a differs from bacteriochlorophyll, oxygen is released during photosynthesis and the organisms are thalloid (Bold & Wynne 1978; Lee 1980; Sze 1986). Consequently the authors did not feel it necessary to study their physiology and biochemistry according to Bergey *et al.* (1957), Stanier *et al.* (1971), Kenyon *et al.* (1972), Buchanan & Gibbons (1974), Sprent (1979) and Potts & Whitton (1980). In addition, it was impractical to culture so many samples axenically which would take many years of experimentation to survey. The classical method of classification adapted in this study followed Geitler (1932) and Desikachary (1959) and considered cell, trichome and sheath characteristics. Their schemes were preferred to Drouet (1968, 1973, 1978), Drouet & Daily (1952, 1956), Humm & Wicks (1980) and Lawson & John (1982) because morphological differences could be studied within and between different localities.

Staining

Thalli of the Family Oscillatoriaceae were stained to determine the presence or absence of a sheath, with grams-iodine, potassium dichromate–sulphuric acid, chloro-zinc-iodide or methylene blue (Desikachary 1959; Mann 1987). A sheath appears to be stain-specific, so the use of more than one stain is recommended for a study. Sheath characteristics described by Geitler (1932) and Desikachary (1959) were closely followed, though the authors were aware of other opinions. The contentious genus was *Oscillatoria*. Geitler (1932) and Desikachary (1959) claimed *Oscillatoria* lacked a sheath. Drouet (1962, 1968) and Humm & Wicks (1980) acknowledged the presence of a sheath but did not use it as a diagnostic criterion, and Fogg *et al.* (1973, Figure 2.3) described the genus as having a very watery, faint sheath yet their illustration lacked this feature. Staining by Mann (1987) lead the authors herein to conclude that *Oscillatoria* lacked a sheath, *Phormidium* had a sheath with a soft, collapsible appearance and *Lyngbya* had a firm, thick sheath, which might be pigmented.

Results

Key to the Class Cyanophyceae

1a Thallus unicellular or colonial **2**

1b Thallus filamentous **13**

2a Thallus of one cell (unicellular).............................. **3**

2b Thallus of 2 or more cells (colonial) **6**

3a Cells spherical of 2.0 µm diameter or less bounded by a thick sheath, epiphytic .... ***Hydrococcus rivularis***

3b Cell oval or spherical greater than 3.0 µm diameter and bounded by a thick sheath..................................... **4**

4a Cell bright blue-green, 15.0 µm – 18.0 µm diameter, bounded by a thick conspicuous sheath .... ***Chroococcus turgidus***

4b Cell 3.0 µm – 6.0 µm diameter bounded by a distinct sheath, protoplasm pale blue-green, yellow or purplish... .... **5**

5a Cell distinctly spherical, embedded in a thick translucent sheath. Protoplasm pale blue-green to purplish, epiphytic .... ***Xenococcus acervatus***

5b Cell distinctly oval, attached to substratum by short, translucent mucilaginous stalk. Protoplasm yellow to blue-green, epiphytic.................. ***Dermocarpa olivacea***

6a Colony spheroidal to subspheroidal of many cells......... **7**

6b Colony of 2 or more cells in clusters of definite numbers in regular or irregular pattern **8**

7a Spheroidal colony of varying diameter containing many grey to blue-green cells, 0.5 µm to 2.0 µm diameter .... ***Aphanocapsa elachista* var *conferta***

7b Spheroidal to subspheroidal colonies containing many blue-green cells, 2.5 µm to 4.0 µm diameter .... ***Aphanocapsa montana***

8a Cells more or less in pairs, juxtaposing walls always planar **9**

8b Cells never in pairs, but clustered in discoid or amorphous form **10**

9a Cells about 10 µm diameter in definite clusters of four enclosed by common mucilage to form dense amorphous colonies. Protoplasm reddish to violet-blue .... ***Chroococcus hansgirgii***

9b Bright blue-green colonies of 1, 2, 4 or 8 cells, 15.0 µm to 18.0 µm diameter enclosed by a thick sheath. Cells distinctly hemispherical with juxtaposing cell walls clearly parallel after fission.......... ***Chroococcus turgidus***

10a Cells form tight amorphous clusters, thickly epiphytic on macroalgae.. **11**

10b Discoid colony, with cells more or less radial. Colony appears to be planar **12**

11a Spherical cells, each enclosed by a thick sheath but never attached by a mucilaginous stalk. Cells remain rounded even when densely clustered in a colony, epiphytic .... ***Xenococcus acervatus***

11b Ovoid cells each enclosed by a sheath which is attached to a substratum by a short mucilaginous stalk. Cells ovoid to polygonal due to adpressure in colony, epiphytic .... ***Dermocarpa olivacea***

12a Colony develops from a single cell enclosed in a mucilaginous sheath. Thallus enlarges by fission into one or two layers of cells and then into an adpressed disc with cells more or less radiating from the centre. Thallus free or more commonly epiphytic on macroalgae .... ***Xenococcus kerneri***

12b Solitary cells spherical, enclosed in a thick mucilaginous sheath. Mature colonies adhere to the host substratum forming a discoid arrangement of more or less radiating cell clusters. Medullary cells spherical to quadrate, peripheral cells elongated and/or lobed, epiphytic .... ***Hydrococcus rivularis***

13a Filaments without a sheath after staining................. **14**

13b Filaments with a sheath after staining...................... **17**

14a Trichome regularly, spirally coiled (sheath not apparent)......................................***Spirulina subsalsa***

14b Trichome not regularly spirally coiled **15**

15a Cells of trichome about as long as wide **16**

15b Cells of trichome much wider than long **24**

16a Trichome straight or coiled with the apical cell offset obliquely from the axis. Cells 3.0 μm – 4.0 μm diameter and 3.0 μm – 5.0 μm long.. ....***Oscillatoria chlorina***

16b Trichomes conspicuously hooked and attenuating over several cells. Cells 3.0 μm – 5.0 μm diameter and 2.0 μm – 3.0 μum long, with marginal optical aberrations ....***Oscillatoria schultzii***

17a Trichomes with heterocysts and akinetes, no hormogonia **28**

17b Trichomes without heterocysts and akinetes, with hormogonia.. **18**

18a More than one trichome within a common sheath **19**

18b One trichome within one sheath **20**

19a Many trichomes within the sheath forming a dark and dense blue-green rope-like habit. Cells 2 μm – 3 μm diameter and 4 μm – 5 μm long ....***Microcoleus chthonoplastes***

19b Several trichomes within the sheath, some interwoven, many free. Cells 2 μm – 3 μm diameter and 5 μm – 7 μm long....................................***Schizothrix arenaria***

20a Sheath mucilaginous, thin, cells about two times broader than long, protoplasm uniformly blue-green containing one or two hyaline bodies ....***Phormidium ambiguum***

20b Sheath firm, cells about three times broader than long, protoplasm with or without distinct granules **21**

21a Sheath 20.0 μm – 30.0 μm diameter.......................... ....***Lyngbya cinerescens***

21b Sheath less than 20.0 μm diameter **22**

22a Sheath 12.0 μm – 18.0 μm diameter, cells distinct, 6.0 μm – 20.0 μm diameter. Protoplasm granular.......... **23**

22b Sheath 4.0 μm – 6.0 μm diameter, cells indistinct, 3.0 μm – 5.0 μm diameter protoplasm slightly granular....... ....***Lyngbya lutea***

23a Sheath 12.0 μm – 18.0 μm diameter, cells distinct and protoplasm granular. Granules may concentrate at septa. Cells 6.0 μm – 8.0 μm diameter, never epiphytic or attached .... ***Lyngbya confervoides***

23b Sheath 12.0 μm diameter, cells distinct, slightly granulated, 9.0 μm diameter, 2.0 μm – 3.0 μm long; epiphytic, always attached at mid-length .... ***Lyngbya baculum***

24a Cells slightly wider than long, apical cell hemispherical with terminal chaetae or thick wall, apex slightly attenuated ....***Oscillatoria corallinae***

24b Cells at least three times wider than long, apical cell of similar or smaller diameter to intercalary cells, may or may not be attenuating....................................... **25**

25a Trichome distinctly attenuated through several cells, terminal cell of much smaller diameter than intercalary cells. Latter 12.0 μm – 15.0 μm diameter, 3,0 μm long.................................... ***Oscillatoria proboscidea***

25b Trichome slightly or not attenuated apically, terminal cell distinctly hemispherical of same or only slightly smaller diameter than intercalary cells **26**

26a Cells not constricted at the septa, protoplasm not distinctly granular, cell diameter 6.0 μm – 10.0 μm (can reach 15.0 μm), cell length 1.0 μm – 3.0 μm ....***Oscillatoria subbrevis***

26b Cells constricted at the septa, protoplasm distinctly granular, cell diameter 10.0 μm – 15.0 μm, cell length 2.0 μm – 3.0 μm **27**

27a Granules never concentrated at the septa, necridia distinct, apical cell of slightly smaller diameter than intercalary cells. Cell diameter 10.0 μm – 15.0 μm, cell length 2.0 μm – 3.0 μm diameter .... ***Oscillatoria nigroviridus***

27b Granules very distinctly concentrated at the septa, necridia not evident, apical cell of the same diameter as intercalary cells with thickened terminal wall. Cell diameter 12.0 μm – 15.0 μm, cell length 3.0 μm.................. .... ***Oscillatoria limosa***

28a Heterocysts always terminal, single or multiple trichomes per sheath, trichomes may or may not taper to a hair **29**

28b Heterocysts always intercalary, one trichome per sheath, trichomes of uniform diameter throughout. False branching evident .... ***Scytonema hofmannii***

29a Very distorted cells and trichomes embedded in a common mucilaginous sheath, trichomes curved upon themselves and taper to a fine hair .... ***Rivularia bullata***

29b Cells generally uniform and not distorted. Trichomes may or may not taper to a fine hair **30**

30a Trichomes attached by basal heterocysts to hard substrata, or mangrove bark, never epiphytic on algae. Trichome tapers to a long hyaline hair .... ***Calothrix contarenii***

30b Trichomes attached by basal heterocyst to macroalgae, rest of trichome can be very long and always of the same diameter .... ***Calothrix scopulorum***

Class Cyanophyceae
Order Chroococcales
Family Chroococcaceae
Genus *Aphanocapsa* Nageli 1849

Characteristics

Numerous oval cells densely arranged in a spheroidal to subspheroidal gelatinous matrix.

Distribution

Epipelic *Anacystis marina* was recorded by Saenger *et al.* (1977) in mangrove swamps of SE Queensland; and as a littoral species in West Africa by Lawson & John (1982).

1. Aphanocapsa elachista *var.* **conferta** *W. et G.S. West* 1912: 432; Geitler 1932: 157; Desikachary 1959: 133; Humm & Wicks 1980: 56 (= *Anacystis marina* Drouet & Daily).

Spheroidal colony of varying diameter, embedded in algal mucilage, rarely epiphytic (Figure 2). Cells grey to blue-green, 0.5 μm to 2.0 μm diameter, densely clustered. Sheath conspicuous and colourless.

The species was identified in Kosi, Durban Bayhead, Nxaxo and Nahoon estuaries (Tables 1 & 2). It is distinguished from *Aphanocapsa montana* by having much smaller cells with paler blue-green protoplasm, and occurred within algal mucilage on pneumatophores and knee roots (Table 3).

2. Aphanocapsa montana *Cramer* 1862, refer Desikachary 1959: 135; Humm & Wicks 1980: 56 (= *Anacystic montana* (Lightfoot) Drouet & Daily forma *montana* Drouet & Daily).

Small spheroidal colonies, 15.0 μm to 60.0 μm diameter, with an obvious colourless translucent sheath (Figure 3). Larger colonies subspheroidal, rarely amorphous. Cells closely compacted, spherical to ovoid, 2.5 μm to 4.0 μm diameter.

Aphanocapsa montana has the same geographical distribution as *Aphanocapsa elachista* var. *conferta* but occurred in Kosi, Mgobezeleni, St Lucia, Durban Bayhead, Mzamba, Mnagazana, Xora, Nxaxo and Nahoon estuaries (Tables 1 & 2). It is distinguished from *Aphanocapsa elachista* var. *conferta* by having larger cells and a darker blue-green thallus; and occurred in algal mucilage epiphytic on pneumatophores, knee roots and on rock (Table 3).

Genus *Chroococcus* Nageli 1849

Characteristics

Cells spherical to ovoid, or hemispherical after cell division, form a colony of rarely 1, more commonly 2, 4, 8 or more cells; each cell enclosed by thick, translucent sheath. Adjacent daughter cell walls generally flattened after recent cell division.

Distribution

Chroococcus turgidus was identified as an epipelic mangrove associate in Queensland (Saenger *et al.* 1977), and *Anacystis dimidiata* occurred within floating algal scum in lagoons and brackish water pools in West Africa (Lawson & John 1982).

1. Chroococcus hansgirgii *Schmidle* 1900: 78; Desikachary 1959: 105.

Four-celled colonies of 25.0 μm diameter, each enclosed

Table 1 Location of estuaries studied as denoted on 1:250 000 maps and '¼' grid system

Estuary	1:250 000	'¼' grid system
Kosi	2632 DD (Kosi Bay)	2632 (Bela Vista) DD
Mgobezeleni	2732 DA (Sodwana Bay)	2732 (Ubombo) DA
St Lucia	2832 AD (St Lucia)	2832 (Mtubatuba) AD
Richards Bay Sanctuary	2832 CC (Richards Bay)	2832 (Mtubatuba) CC
Mlalazi	2831 DD (Felixton)	2831 (Nkandla) DD
Beachwood Nature Reserve	2931 CC (Durban)	2931 (Stanger) CC
Durban Bayhead	2931 CC (Durban)	2931 (Stanger) CC
Sipingo Lagoon	2931 CC (Durban)	2931 (Stanger) CC
Mkomazi	3030 BB (Umkomaas)	3030 (Port Shepstone)BB
Mzamba	3130 AA (Port Edward)	3130 (Port Edward) AA
Mntafufu	3129 DA (Port St Johns)	3129 (Port St Johns) DA
Mngazana	3129 CB (Tombo)	3129 (Port St Johns) CB
Mtata	3129 CC (Coffee Bay)	3129 (Port St Johns) CC
Xora	3228 BB (The Haven)	3228 (Butterworth) BB
Mbashe	3228 BB (The Haven)	3228 (Butterworth) BB
Nxaxo	3228 DA (Cebe)	3228 (Butterworth) DA
Kobonqaba	3228 CB (Kei Mouth)	3228 (Kei Mouth) CB
Kwelera	3228 CC (Gonubie)	3228 (Kei Mouth) CC
Nahoon	3327 BB (East London)	3327 (Peddie) BB

Table 2 Geographical distribution of algae in 19 southern African mangrove-associated estuaries

	Zululand						Natal			Transkei									
Taxon	Kosi Bay	Mgobezeleni	St Lucia	Richards Bay	Mlazi	Beachwood*	Durban Bayhead	Sipingo Lagoon	Mkomazi	Mzamba	Mntafufu	Mngazana	Mtata	Xora	Mbashe	Nxaxo	Kobonqaba	Kwelera	Nahoon
Aphanocapsa elachista var. *conferta*	x						x									x			x
A. montana	x	x	x				x			x		x		x		x			x
Chroococcus hansgirgii	x					x								x		x		x	x
C. turgidus	x					x													
Hydrococcus rivularis	x			x	x	x				x	x	x	x	x	x	x	x	x	x
Xenococcus acervatus	x		x	x	x	x	x			x	x	x	x	x	x	x	x	x	x
X. kerneri	x		x	x	x	x	x		x			x	x	x			x		
Dermocarpa olivacea	x											x	x	x		x	x		x
Lynbya baculum			x										x						
L. cinerescens						x						x		x	x	x			
L. confervoides		x	x			x	x						x	x	x		x		x
L. lutea						x				x			x		x	x		x	
Microcoleus chthonoplastes	x	x	x	x	x	x	x			x	x	x	x	x	x	x	x	x	x
Oscillatoria chlorina	x															x			
O. corallinae		x	x	x	x														
O. limosa	x	x						x							x				
O. nigroviridus			x	x		x	x				x	x	x	x		x	x		
O. proboscidea										x									x
O. schultzii							x						x			x			
O. subbrevis		x	x	x	x	x				x	x	x				x			
Phormidium ambiguum	x		x																
Schizothrix arenaria													x			x			
Spirulina subsalsa	x	x				x													
Calothrix contarenii	x	x								x					x	x		x	x
C. scopulorum	x									x	x			x	x	x			
Rivularia bullata	x																		
Scytonema hofmannii	x					x				x						x			

*Beachwood Mangrove Nature Reserve

by common mucilage (Figure 4). Cell division in 3 planes such that juxtaposing walls are planar. Cells 10.0 μm diameter with red to violet-purple protoplasm.

Chroococcus hansgirgii was recorded at Kosi, Beachwood, Xora, Nxaxo and Kwelera estuaries and was most common at Nahoon estuary (Tables 1 & 2). This species occurred in algal mucilage and formed thick, dense colonies on pneumatophores and knee roots (Table 3).

2. Chroococcus turgidus *(Kütz.)* Nageli 1849: 46; Geitler 1932: 228; Desikachary 1959: 101; Humm & Wicks 1980: 57; Lawson & John 1982: 356 [= *Anacystis dimidiata* (Kütz.) Drouet & Daily].

Thallus 1, 2, 4 or 8-celled colony of 10.0 μm to 45.0 μm diameter (Figure 5). Cells distinctly hemispherical, embedded in a thick sheath, 15.0 μm to 18.0 μm wide. Adjacent cell walls flattened after cell division, enclosing bright blue-green protoplasm.

The protoplasm was quite distinct from the reddish cells of *Chroococcus hansgirgii. Chroococcus turgidus* occurred in Kosi and Beachwood (Tables 1 & 2) within algal mucilage on pneumatophores and knee roots (Table 3).

Order Pleurocapsales

Family Hyellaceae

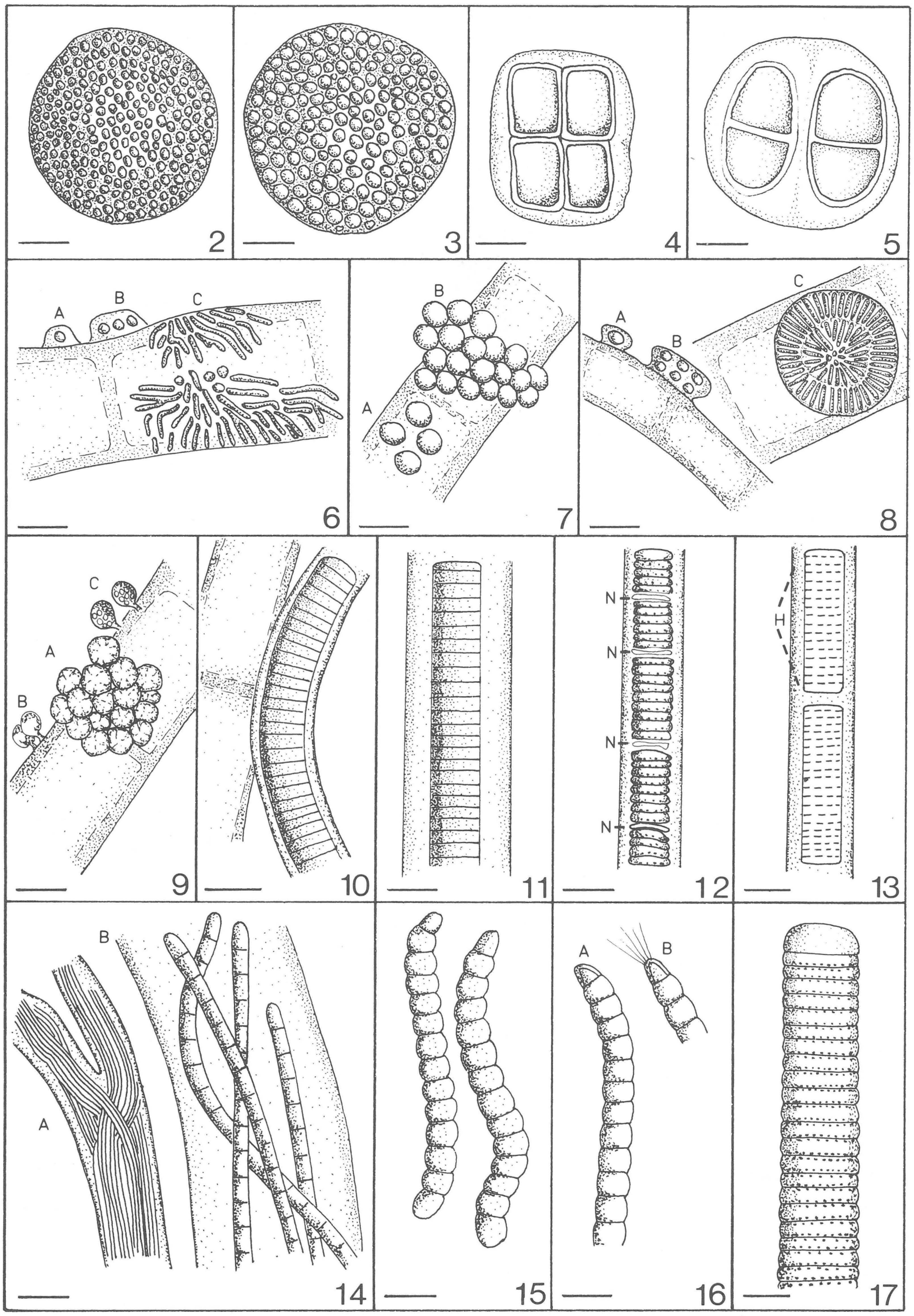
Genus *Hydrococcus* Kütz. 1833

Characteristics

Young thallus planar, of one to several cells. With maturity, cells lengthen and/or lobe and radiate within a discoidal, hemispheroidal or lobed thallus.

Distribution

Epiphytic (Desikachary 1959).



Figures 2–17 2. A colony of *Aphanocapsa elachista* var. *conferta*: scale line = 10 µm. **3.** A colony of *Aphanocapsa montana*: scale line = 10 µm. **4.** A 4-celled colony of *Chroococcus hansgirgii*: scale line = 10 µm. **5**. A 4-celled colony of *Chroococcus turgidus*: scale line = 10 µm. **6**. *Hydrococcus rivularis* showing developmental stages A–C: scale line = 10 µm. **7**. *Xenococcus acervatus* showing solitary (A) and clustered cells (B): scale line = 10 µm. **8**. *Xenococcus kerneri* showing developmental stages A–C: scale line = 10 µm. **9**. *Dermocarpa olivacea* showing clustered (A) and solitary cells (B) and endosporangia (C): scale line = 10 µm. **10**. *Lyngbya baculum* showing mid-length attachment to host: scale line = 10 µm. **11**. *Lyngbya cinerescens* with a very thick translucent sheath: scale line = 10 µm. **12**. *Lyngbya confervoides* showing a necridium (N) and a granular protoplasm: scale line = 10 µm. **13**. *Lynbya lutea* with a delicate sheath, hormogonium (H) and indistinct cells: scale line = 20 µm. **14**. *Microcoleus chthonoplastes* showing branching pattern of sheath (A) and trichome detail (B): scale line for B = 10 µm. A is not drawn to scale. **15**. *Oscillatoria chlorina* with oblique apical cell: scale line = 10 µm. **16**. *Oscillatoria corallinae* with thick-walled terminal cell (A) or terminal chaetae (B): scale line = 10 µm. **17**. *Oscillatoria limosa* with granules distinctly concentrated at the septa: scale line = 10 µm.

Table 3 Mangrove-associated substrata upon which algae were epiphytic or attached

Taxon	*A. marina*	*B. gymnorrhiza*	*R. mucronata*	*C. tagal*	Mud	Rock	*Bostrychia* spp.	*C. leprieurii*	*Enteromorpha* spp.	*Rhizoclonium* spp.
Aphanocapsa elachista var. *conferta*	x	x								
A. montana	x	x				x				
Chroococcus hansgirgii	x	x								
C. turgidus	x	x								
Hydrococcus rivularis							x	x	x	x
Xenococcus acervatus							x	x	x	x
X. kerneri							x	x	x	x
Dermocarpa olivacea	x	x					x	x	x	x
Lyngbya baculum	x						x			
L. cinerescens	x	x								
L. confervoides	x	x			x					
L. lutea	x	x								
Microcoleus chthonoplastes	x	x	x		x					
Oscillatoria chlorina	x									
O. corallinae	x									
O. limosa	x				x					
O. nigroviridus	x				x					
O. proboscidea	x									
O. schultzii	x				x					
O. subbrevis	x	x			x					
Phormidium ambiguum	x									
Schizothrix arenaria	x	x	x		x					
Spirulina subsalsa	x				x					
Calothrix contarenii	x	x			x	x				
C. scopulorum							x	x	x	x
Rivularia bullata	x		x	x						
Scytonema hofmannii	x	x	x	x	x					

1. Hydrococcus rivularis *Kütz*. 1833: 380; Geitler 1932: 362; Desikachary 1959: 180.

Develops from a single cell, 2.0 μm diameter, within sheath (Figure 6A), to a row of cells (Figure 6B), to a planar, discoid thallus of which marginal cells become elongate and spread over the substratum to form irregular shapes and lengths (Figure 6C).

Various growth stages were identified and unicellular colonies may be confused with young *Xenococcus kerneri* (Figures 6A & 8B). *Hydrococcus rivularis* was recorded in 14 of the 19 estuaries viz. Kosi, Richards Bay, Mlalazi, Beachwood, Mzamba, Mntafufu, Mngazana, Mtata, Xora, Mbashe, Nxaxo, Kobonqaba, Kwelera and Nahoon estuaries (Tables 1 & 2); always epiphytic on *Bostrychia* spp., *Caloglossa leprieurii, Enteromorpha* spp. and *Rhizoclonium* spp. (Table 3).

Genus *Xenococcus* Thuret 1875

Characteristics

Thallus develops from a single cell to a cluster of cells each enclosed by a thick sheath, adhering closely to a substratum.

Distribution

Cosmopolitan, epiphytic in brackish and marine tropical waters (Desikachary 1959).

1. Xenococcus acervatus *Setchell et Gardner* in Gardner 1918: 459; Geitler 1932: 333; Desikachary 1959: 182.

Each cell, 3.0 μm – 6.0 μm diameter, enclosed by thick sheath. Thallus of one cell (Figure 7A), or cells in clusters which retain spherical profile despite compactness (Figure 7B). Protoplasm clear, pale blue-green to purplish.

Xenococcus acervatus was recorded in all estuaries except Mgobezeleni, Sipingo Lagoon and Mkomazi estuaries (Tables 1 & 2); always epiphytic on *Bostrychia* spp., *Caloglossa leprieurii, Enteromorpha* spp. and *Rhizoclonium* spp. (Table 3).

2. Xenococcus kerneri *Hansg*. 1887: 111; Geitler 1932: 330; Desikachary 1959: 181.

Thallus develops from single ovate cell, 3.0 μm to 6.0 μm diameter, enclosed by sheath (Figure 8A). Growth by fission to one or two layers of a few cells (Figure 8B), then into a disc of adpressed cells more or less radiating from the centre; sheath always conspicuous (Figure 8C).

Xenococcus kerneri was recorded at Kosi, St Lucia, Richards Bay, Mlalazi, Beachwood, Durban Bayhead, Mkomazi, Mngazana, Mtata, Xora and Kobonqaba estuaries (Table 1 & 2); always epiphytic on *Bostrychia* spp., *Caloglossa leprieurii, Enteromorpha* spp. and *Rhizoclonium* spp. (Table 3).

Family Dermocarpaceae

Genus *Dermocarpa* Crouan 1858

Characteristics

Cells spherical, closely packed, each attached by mucilaginous stalk. Endospores produced.

Distribution

Epiphytic (Desikachary 1959)

1. Dermocarpa olivacea *(Reinsch) Tilden* 1910: 55; Geitler 1932: 401; Desikachary 1959: 174.

Cells oval to polygonal because of dense packing (Figure 9A) and each attached by short mucilaginous stalk (Figure 9B). Cells 3.0 μm to 6.0 μm diameter with yellow to blue-green protoplasm. Endospores observed in samples from Mngazana estuary (Figure 9C).

Dermocarpa olivacea was recorded in Kosi, Mngazana, Mtata, Xora, Nxaxo, Kobonqaba and Nahoon estuaries

(Tables 1 & 2); always epiphytic on *Bostrychia* spp., *Caloglossa leprieurii, Enteromorpha* spp. and *Rhizoclonium* spp. (Table 3).

Order Nostocales
Family Oscillatoriaceae
Genus *Lyngbya* C.Ag. 1824

Characteristics

Trichome within thick lamellated clear, yellow or brown sheath. Filaments free, wrapped about larger objects or adhering to a substratum.

Distribution

Cosmopolitan, free or epiphytic in brackish, marine and terrestrial habitats (Desikachary 1959; Humm & Wicks 1980). Desikachary (1959) recorded *Lyngbya cinerescens* as epiphytic in brackish and saline localities. Nurul Islam (1973) recorded *Lyngbya confervoides* as a mangrove associate in Bangladesh. This species was rated by Humm & Wicks (1980) as having the greatest biomass of all members of the family Oscillatoriaceae. *Lyngbya lutea* was recorded as an epipelic alga in the mangrove swamps of Queensland (Saenger *et al.* 1977).

1. Lyngbya baculum *Gomont* 1890: 354; Geitler 1932: 1039; Desikachary 1959: 285.

Filaments of 12.0 μm diameter, epiphytic attached at mid-length (Figure 10). Sheath conspicuous, translucent, firm; cells with blue-green protoplasm not conspicuously granulated, 9.0 μm diameter, 2.0 to 3.0 μm long. Terminal cell hemispherical, apex not attenuating.

Lyngbya baculum occurred in St Lucia and Mtata estuaries (Tables 1 & 2), epiphytic on *Bostrychia* spp. (Table 3).

2. Lyngbya cinerescens *Kütz.* 1849: 281; Desikachary 1959: 315.

Trichome of 20.0 μm to 30.0 μm diameter enclosed by very thick, non-lamellated sheath (Figure 11). Cells deep blue-green, not conspicuously granulated, 8.0 μm to 10.0 μm diameter, 1.0 μm to 2.0 μm long.

This species was recorded from Beachwood, Mngazana, Xora, Mbashe and Nxaxo estuaries (Tables 1 & 2); wrapped loosely about larger algae epiphytic on pneumatophores and knee roots (Table 3). The markedly thick sheath is very distinctive.

3. Lyngbya confervoides *C. Ag. ex Gomont* 1892b: 156; Geitler 1932: 1061; Desikachary 1959: 314; Humm & Wicks 1980: 133 [= *Microcoleus lynbyaceus* (Kütz.) Crouan].

Grey, pink or blue-green trichome of 12.0 μm to 18.0 μm diameter enclosed by clear, firm sheath (Figure 12). Cell diameter 6.0 μm to 8.0 μm, cell length 1.0 μm to 3.0 μm. Protoplasm with granules which may be concentrated at the constricted septa. Older cells loose and free, necridia single to numerous.

Though the trichomes of *Lyngbya cinerescens* and *Lyngbya confervoides* were similar, the much thicker sheath of the first species was distinctive. *Lyngbya confervoides* and *Lyngbya baculum* were morphologically similar but the latter species was never epiphytic.

Lyngbya confervoides was recorded at Mgobezeleni, St Lucia, Beachwood, Durban Bayhead, Mtata, Xora, Mbashe, Kobonqaba and Nahoon estuaries (Tables 1 & 2) and was epiphytic or wrapped about larger algae epiphytic on pneumatophores and knee roots (Table 3).

3. Lyngbya lutea *(C.Ag.) Gomont* 1890: 354; Geitler 1932: 1057; Desikachary 1959: 310.

Single delicate trichomes, 4.0 μm to 6.0 μm diameter, not embedded in algal mucilage (Figure 13). Sheath thin, firm and translucent. Cells indistinct, 3.0 μm to 5.0 μm diameter, 1.0 μm to 2.0 μm long. Hormogonia common.

Lyngbya lutea was narrower, more delicate with more indistinct cells than *Lyngbya confervoides. Lyngbya lutea* occurred at Beachwood, Mzamba, Mtata, Mbashe, Nxaxo and Kwelera estuaries (Tables 1 & 2); epiphytic on pneumatophores and knee roots (Table 3).

Genus *Microcoleus* Desmaziéres 1823

Characteristics

Many trichomes densely arranged within wide, occasionally branched sheath.

Distribution

Saenger *et al.* (1977) recorded *Microcoleus chthonoplastes* as an epipelic mangrove associate in Queensland. Humm & Wicks (1980) recorded *Schizothrix arenaria* as cosmopolitan and often mixed with *Microcoleus lyngbyaceus* in salt marshes and tidal flats.

1. Microcoleus chthonoplastes *Thuret ex Gomont* 1892a: 353; Geitler 1932: 1133; Desikachary 1959: 343; Humm & Wicks 1980: 73 [= *Schizothrix arenaria* (Berkeley) Gomont].

Numerous more or less parallel trichomes in dark blue-green twisted rope-like mass within thick, occasionally branched colourless sheath (Figure 14A). Cells longer than broad evenly arranged, hormogonia not apparent (Figure 14B). Protoplasm purple to blue-green with occasional black or white inclusions, cells 2.0 μm to 3.0 μm diameter, 4.0 μm to 5.0 μm long. Free sheathless trichomes occur in samples from very moist habitats and may develop in liquid laboratory cultures.

Microcoleus chthonoplastes was the most abundant Cyanophyceaen species of this study and occurred in all estuaries except Sipingo Lagoon and Mkomazi estuary (Tables 1 & 2). The large multiple trichomes were readily discernible on muddy substrata and epiphytic on pneumatophores, knee roots and prop roots (Table 3).

Genus *Oscillatoria* Vaucher 1803

Characteristics

Trichomes definitely lacking a sheath. Hormogonia common. Cells generally wider than long with protoplasmic granules often concentrated at the septa. Trichomes may have a bent or curved apex.

Distribution

Oscillatoria corallinae was an epipelic mangrove associate in Queensland (Saenger *et al*. 1977). Desikachary (1959) and Humm & Wicks (1980) recorded *Oscillatoria limosa* as cosmopolitan in marine habitats. *Oscillatoria schultzii* was an epipelic species in India (Desikachary 1959) and *Oscillatoria subbrevis* was an epipelic mangrove associate in Bangladesh (Nurul Islam 1973).

1. Oscillatoria chlorina *Kütz. ex Gomont* 1892b: 223; Geitler 1932: 951; Desikachary 1959: 215.

Trichome straight or coiled with apex hooked, or apical cell set oblique to axis (Figure 15). Cells 3.0 μm to 4.0 μm diameter, 3.0 μm to 5.0 μm long, protoplasm pale yellow to blue-green, lightly granular.

The oblique apical cell and quadrate intercalary cells were distinctive. This species was identified at Kosi and Nxaxo estuaries (Tables 1 & 2); on pneumatophores (Table 3).

2. Oscillatoria corallinae *(Kütz.) Gomont* 1892b: 218; Geitler 1932: 955; Desikachary 1959: 221.

Trichomes pale blue-green, weakly attenuated. Apical cell hemispherical with thickened terminal wall (Figure 16A). Cells distinctly constricted at septa, 5.0 μm diameter, 3.0 μm to 4.0 μm long. Some specimens have terminal chaetae (Figure 16B).

Compared to *Oscillatoria chlorina* this species was thicker, septal constrictions were more obvious, the trichomes were not as attenuated and the apex was not hooked. Compared to *Oscillatoria schultzii, Oscillatoria corallinae* was indistinctly attenuated apically and the optical aberrations were absent (Figure 19B). *Oscillatoria corallinae* was recorded in Mgobezeleni, St Lucia, Richards Bay and Mlalazi estuaries (Tables 1 & 2); on pneumatophores (Table 3).

3. Oscillatoria limosa *Ag. ex Gomont* 1892b: 210; Geitler 1932: 944; Desikachary 1959: 206; Humm & Wicks 1980: 81 [= *Microcoleus lyngbyaceus* (Kütz.) Crouan].

Protoplasm blue-green to purple and granules clearly concentrated at the septa which latter Humm & Wicks (1980) used to characterize *Microcoleus lyngbyaceus* (Figure 17). Trichomes of even diameter, cells 12.0 μm to 15.0 μm diameter, 3.0 μm long. Apical cell large, hemispherical with translucent, pale protoplasm bounded by thick cell wall.

Oscillatoria limosa differed from *Lyngbya confervoides* in lacking a sheath, having cells of almost twice the diameter and having protoplasmic granules densely concentrated at the septa. *Oscillatoria limosa* was recorded at Kosi, Mgobezeleni, Sipingo and Mbashe estuaries (Tables 1 & 2); in dense interwoven epipelic mats below mangrove trees and epiphytic on pneumatophores (Table 3).

4. Oscillatoria nigroviridus *Thwaites ex Gomont* 1892b: 217; Geitler 1932: 942; Desikachary 1959: 202.

Trichomes dark blue-green to olive-green slightly bent apically but more conspicuously attenuated by having a hemispherical apical cell of smaller diameter than the rest of the trichome with or without a thick cell wall (Figure 18). Intercalary cells 10.0 μm to 15.0 μm diameter, 2.0 μm to 3.0 μm long, slightly constricted at the septa. Necridia evident. Protoplasm granular, granules not concentrated at the septa.

Oscillatoria nigroviridus was recorded at St Lucia, Richards Bay, Beachwood, Durban Bayhead, Mntafufu, Mngazana, Mtata, Xora and Nxaxo estuaries (Tables 1 & 2) in epipelic mats below mangrove trees and about pneumatophores (Table 3).

5. Oscillatoria proboscidea *Gomont* 1892b: 209; Geitler 1932: 948; Desikachary 1959: 211.

Trichomes dull to dark blue-green, straight but clearly attenuated apically through numerous cells (Figure 19A). Apical cell very small and may be slightly capitate (Figure 19B). Intercalary cells 12.0 μm to 15.0 μm diameter and 3.0 μm long.

Oscillatoria proboscidea was recorded in Mzamba and Nahoon estuaries (Tables 1 & 2); intertwined with larger algae on pneumatophores (Table 3). The straight trichome attenuating through several cells to a very small apex was distinctive.

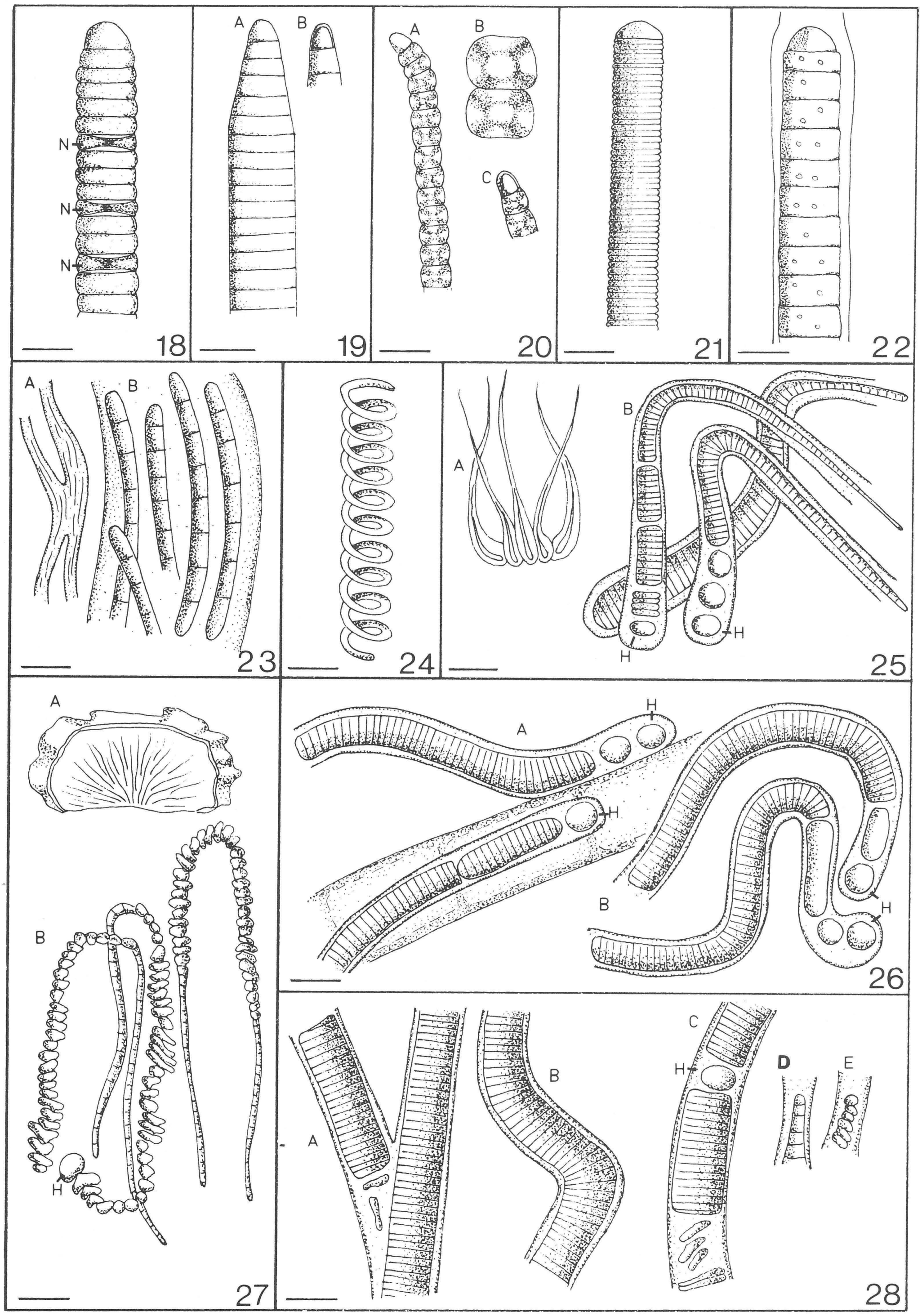
6. Oscillatoria schultzii *Lemmermann* 1905: 145; Geitler 1932: 970; Desikachary 1959: 232.

Pale blue-green trichomes conspicuously hooked and attenuating over several cells (Figure 20A). Conspicuous optical aberrations occur at the corners of each cell (Figure 20B), which were illustrated but not described by Desikachary (1959, pl.41, figure 11). Cells 3.0 μm to 5.0 μm diameter, 2.0 μm to 3.0 μm long. Terminal cell may be capitate (Figure 20C).

Oscillatoria schultzii was small and inconspicuous and this may account for its limited distribution at Durban Bayhead, Mtata and Nxaxo estuaries (Tables 1 & 2); mixed with epipelic algae and on pneumatophores (Table 3).

7. Oscillatoria subbrevis *Schmidle* 1901: 243; Geitler 1932: 949; Desikachary 1959: 207.

Trichomes straight, neither hooked, bent nor attenuating (Figure 21). Apical cell large, hemispherical with no



Figures 18–28 **18**. *Oscillatoria nigroviridus* with a granular protoplasm and a necridium (N): scale line = 10 μm. **19**. *Oscillatoria proboscidea* with attenuating trichome (A) and with terminal cell slightly capitate (B): scale line = 10 μm. **20**. *Oscillatoria schultzii* with attentuating apex (A), sometimes capitate terminal cell (B) and light aberrations at the cell corners (C): scale line for A & B = 10 μm. C is not drawn to scale. **21**. *Oscillatoria subbrevis* with a symmetrical trichome: scale line = 10 μm. **22**. *Phormidium ambiguum* with indistinct sheath and homogenous protoplasm with 1 to 2 large granules: scale line = 20 μm. **23**. *Schizothrix arenaria* showing branching pattern of sheath (A) and nature of trichomes (B): scale line for B = 10 μm. A is not drawn to scale. **24**. *Spirulina subsalsa* showing lack of septa and regular helix: scale line = 30 μm. **25**. *Calothrix contarenii* showing benthic habit with basal attachment (A), and nature of filaments (B). The heterocyst (H) is basal: scale line for B = 10 μm. A is not drawn to scale. **26**. *Calothrix scopulorum* showing epiphytic habit (A) and nature of long, clustered filaments (B): scale line = 10 μm. **27**. *Rivularia bullata* showing habit of globular thallus (A) in which the trichomes are embedded in a common mucilage (B). The heterocyst (H) is terminal: scale line for B = 10 μm. A is not drawn to scale. **28**. *Scytonema hofmannii* showing occasional false branching (A), nature of filament (B), intercalary heterocyst (H), attenuating apex (C) and capitate apex (D): scale line = 10 μm.

thickened cell wall. Cells not constricted at the septa, 6.0 μm to 10.0 μm diameter, 1.0 μm to 3.0 μm long. Occasional specimens larger, up to 15.0 μm diameter. Protoplasm dark blue-green with dispersed granules.

Oscillatoria subbrevis occurred in Mgobezeleni, St Lucia, Richards Bay, Mlalazi, Beachwood, Mzamba, Mntafufu, Mngazana and Nxaxo estuaries (Tables 1 & 2); as dark blue-green epipelic mats or epiphytic on pneumatophores and knee roots (Table 3).

Genus *Phormidium* Kütz. 1843

Characteristics

Filaments form gelatinous or leathery mat-like thallus, often attached to a solid substratum. Each trichome enclosed by a sheath of soft collapsible appearance, cells sometimes constricted at septa, apical cell often capitate.

Distribution

Planktonic or epiphytic in estuarine and marine habitats (Desikachary 1959).

1. Phormidium ambiguum *Gomont* 1892b: 178; Geitler 1932: 1015; Desikachary 1959: 266.

Trichomes straight or slightly curved with thin almost indiscernible hyaline sheath (Figure 22). Cells very regular, 6.0 μm diameter, 3.0 μm length, with no septal constrictions. Protoplasm uniformly blue-green or containing two or more hyaline bodies. Apical cell large, hemispherical, end cell wall appears thin.

Cellular disintegration within trichomes containing regular cells was not considered a preservation artefact. *Phormidium ambiguum* was the most conspicuous blue-green at Kosi and it also occurred at St Lucia estuary (Tables 1 & 2); in dense interwoven mats on pneumatophores (Table 3).

Genus *Schizothrix* Kütz. 1843

Characteristics

One to many trichomes within soft, pigmented sheath. Cells regular, neither heterocysts, spores nor hormogonia. Apical cells conical to hemispherical, end wall unthickened.

Distribution

Schizothrix arenaria has been recorded as cosmopolitan in saline habitats (Humm & Wicks 1980) and as an epipelic species in tidal pools and brackish water habitats in West Africa (Lawson & John 1982).

1. Schizothrix arenaria *(Berk.) Gomont* 1892a: 312; Desikachary 1959: 327; Humm & Wicks 1980: 73.

Few scattered trichomes within a common firm, translucent sheath (Figure 23A). Cells 2.0 μm to 3.0 μm diameter, 5.0 μm to 7.0 μm long, protoplasm purple to blue-green with occasional black or white inclusions (Figure 23B). Terminal cell generally conical.

Density of trichomes within the sheath was low compared to *Microcoleus chthonoplastes* (Figures 14 & 23). This species was recorded in Mtata and Nxaxo estuaries (Tables 1 & 2); intertwined with larger algae epiphytic on pneumatophores, knee roots and prop roots (Table 3).

Genus *Spirulina* Turpin em Gardner 1917

Characteristics

Trichomes helically coiled apparently without cross walls. Apices rounded. Cell walls and sheath inconspicuous.

Distribution

Cosmopolitan in brackish and marine waters (Geitler 1932; Desikachary 1959).

1. Spirulina subsalsa Oersted ex Gomont 1892a: 253; Geitler 1932: 927; Desikachary 1959: 193; Humm & Wicks 1980: 65.

Trichomes 1.0 μm to 3.0 μm diameter, pale blue-green, almost grey and regularly helically coiled (Figure 24). No cross walls evident. Apices rounded, sheath not evident.

Spirulina subsalsa occurred embedded in and was obscured by the mucilage of filamentous algae epiphytic on pneumatophores or in muddy substrata (Table 3). Its significance and smallness may account for the species being recorded in only three estuaries, Kosi, Mgobezeleni and Beachwood (Tables 1 & 2).

Family Rivulariaceae

Genus *Calothrix* C.Ag. 1824

Characteristics

Trichome polar with a basal heterocyst and proximal row of intercalary cells that may or may not taper, all enclosed by conspicuous sheath. If present, akinete is subterminal behind heterocyst. Filaments free or attached basally.

Distribution

Epipelic, epilithic or epiphytic (Desikachary 1959). Humm & Wicks (1980) recognized *Calothrix crustacea* as the only species with a basal heterocyst, and that it displayed much geographical variation. As Desikachary's classification scheme was followed, two species of *Calothrix* and one of *Rivularia* were identified. Humm & Wicks (1980) would have described all as *Calothrix crustacea*.

1. Calothrix contarenii *(Zanard.) Born. et Flah.* 1886: 355; Geitler 1932: 600; Desikachary 1959: 524; Humm & Wicks 1980: 84 (= *Calothrix crustacea* Schousboe & Thuret).

Filament single, flexuous, basally attached and proximally free (Figure 25A). Sheath colourless, brown or yellow; protoplasm dull grey to bright blue-green. Heterocyst may or may not be distinct and subterminal cells variable. Rest of trichome generally divided into hormogonia, and tapers to a very long hyaline point

(Figure 25B). Trichomes arise in clusters from a common substratum giving the appearance of a benthic thallus (Figure 25A).

Calothrix contarenii was recorded from Kosi, Mzamba, Mbashe, Nxaxo and Kwelera, and in the Mgobezeleni and Nahoon estuaries the filaments were very long and themselves formed the thalloid mats in which other algal species were embedded (Tables 1 & 2). This species occurred singly but more commonly as small, dense epiphytic clusters on pneumatophores, knee roots and in epipelic and epilithic algal mats (Table 3).

2. Calothrix scopulorum *(Weber et Mohr.) C. Ag. ex Born. et Flah.* 1886: 353; Geitler 1932: 600; Desikachary 1959: 524; Humm & Wicks 1980: 84 (= *Calothrix crustacea* Schousboe & Thuret).

Thallus single or loosely clustered, common as an epiphyte in algal mucilage and attached by a basal heterocyst (Figure 26A). Thallus enclosed by a conspicuous hyaline sheath. Loose trichomes may be irregularly associated, or many trichomes may arise from a common substratum (Figure 26B). Protoplasm bright to pale blue-green. Basal heterocyst conspicuous and oval, subterminal cell may be a large akinete or hormogonium. Remainder of the trichome free, short (Figure 26A) or very long (Figure 26B), might attenuate slightly, but never tapered to fine hair.

Calothrix contarenii differed from *Calothrix scopulorum* in never being an epiphyte and the long trichome tapered to a fine hair. Without locating the heterocyst, the very long filaments could be confused with *Lyngbya baculum* or *Lyngbya lutea*. Other than Kosi estuary, *Calothrix scopulorum* was recorded from the Mzamba, Mntafufu, Xora, Mbashe and Nxaxo estuaries in the Transkei (Tables 1 & 2). This species was an epiphyte which sheath adhered to thalli of *Bostrychia* spp., *Caloglossa leprieurii, Enteromorpha* spp. and *Rhizoclonium* spp. (Table 3).

Genus *Rivularia* (Roth) C. Ag. 1824

Characteristics

Trichomes, without branches, taper to a fine hair and are arranged more or less radially in a globular mucilaginous colony. Heterocysts basal or intercalary, no akinetes. Trichomes of *Rivularia* are colonial, those of *Calothrix* have individual sheaths.

Distribution

Rivularia occurred on soft and hard substrata in brackish and marine environments (Desikachary 1959; Humm & Wicks 1980). In India, Desikachary (1959) recorded *Rivularia bullata* in a variety of habitats including marine localities.

1. Rivularia bullata *(Poir) Berk. ex Born. et Flah.* 1886: 358; Geitler 1932: 648; Desikachary 1959: 549; Humm & Wicks 1980: 84 (= *Calothrix crustacea* Schoesboe & Thuret).

Blue-green to grey trichomes clustered densely in thick amorphous membranous sheath (Figure 27A). Cells proximal to heterocyst are distorted and quadrangular or discoid and loose (Figure 27B). Subterminal cell of equal or smaller diameter than heterocyst. Intercalary cells more regularly arranged, much longer than wide and trichome tapers to a fine hair-like point. Trichomes frequently folded upon themselves (Figure 27B).

Rivularia bullata was recorded only from Kosi (Tables 1 & 2) where it formed small mucilaginous mats on pneumatophores, prop roots and stem bases (Table 3). The distorted and folded nature of the trichomes embedded in common mucilage was distinctive.

Family Scytonemataceae

Genus *Scytonema* C. Ag. 1824

Characteristics

Trichome single within firm clear to pigmented sheath. False branches, hormogonia and heterocysts evident. Trichome diameter generally uniform but may be attenuated terminally.

Distribution

Cosmopolitan (Lawson & John 1982).

1. Scytonema hofmannii *C. Ag. ex Born. et Flah.* 1887: 97; Geitler 1932: 772; Desikachary 1959: 476; Humm & Wicks 1980: 86 (= *Scytonema hofmannii* C. Ag.)

Trichomes long, straight or slightly curved within a thick, firm sheath, translucent when young and yellow when mature. False branches uncommon, develop at a break in the trichome (Figure 28A). Cells 9.0 μm diameter, 6.0 μm length, uniform dark blue-green protoplasm not constricted at the septa (Figure 28B). Cells may become distorted and displaced (Figure 28B). Intercalary heterocysts common with conspicuous green to yellow translucent protoplasm. Apices not attenuating or sometimes attenuating through several cells, terminal cell hemispherical, ovoid and/or capitate (Figures 28C, D).

Scytonema hofmannii was distinctive with a thick yellow sheath, intercalary heterocysts and occasional false branching. Some samples from Beachwood and Nxaxo estuaries appeared to lack heterocysts. *Scytonema hofmannii* was also common in Kosi and Mzamba estuaries (Tables 1 & 2). The species formed dense epiphytic coverings on all mangrove substrata and within epipelic mats beneath the trees (Table 3).

Discussion

Pneumatophores were the most common substrata for 85%, knee roots 48%, epipelic habitats 37%, prop roots 15% and epilithic habitats and the bark of *Ceriops tagal* about 7% of the taxa (Table 3). The blue-greens *Calothrix scopulorum, Hydrococcus rivularis, Xenococcus acervatus* and *Xenococcus kerneri* occurred as epiphytes only on the larger and dominant species of the Bostrychieta (Table 3). *Dermocarpa olivacea* had the same habit and was also epiphytic on pneumatophores and knee roots. *Microcoleus chthonoplastes, Schizothrix arenaria* and *Scytonema hofmannii* occurred on most substrata (Table 3), and the first mentioned was the most common species (Table 2).

Epipelic mats were intricately interwoven with sediment and filamentous greens and blue-greens, particularly *Microcoleus chthonoplastes* and the green algae *Rhizoclonium* spp. As they occurred therefore in most estuaries, these taxa may play an important role in sediment stabilization. Dor (1984) noted also that *Microcoleus chthonoplastes*, with an abundance of colonial algae, such as *Aphanocapsa*, were epipelic dominants associated with mangroves in the Sinai Peninsula.

Abundance of blue-greens at Mgobezeleni, better known as Sodwana Bay, may be related to organic enrichment due to swamp detritus and human wastes in solution from the very popular camping resort. Nutrients in stormwater drainage and factory effluent most likely cause epipelic and epiphytic algal blooms at Beachwood, Durban Bayhead, Richards Bay Sanctuary and Nahoon estuary which are proximal to industrial areas and high density human settlements. Although there is little evidence to confirm these statements, it is known that most estuaries along the Natal and Transkei coastline are substantially polluted (Begg 1978, 1984a, b). Despite this, blue-greens contribute naturally to the recycling of nitrogen in the Philippines and Florida, USA (Potts 1984), Sinai Peninsula (Dor *et al.* 1977; Potts 1979, 1984) and at Beachwood, near Durban (Mann 1987).

Although heterocysts are the sites of nitrogen fixation (van Gorkom & Donze 1971), non-heterocystous trichomes also have this capability (Dugdale *et al.* 1964; Goering *et al.* 1966; Stewart & Lex 1970; Taylor *et al.* 1973; Carpenter & Price 1976; Pearson *et al.* 1979, 1981; Carpenter & Walsby 1979; Tozun & Gallon 1979; Stahl & Krumbein 1981; Mann 1987).

Acetylene reduction activity (ARA) in blue-green mats at Beachwood has been recorded in the non-heterocystous species *Lyngbya confervoides, Microcoleus chthonoplastes* and *Oscillatoria limosa* (Mann 1987). A rise in ARA can be correlated with population increase which is greatest during summer. *Lyngbya confervoides* is the main ARA component on pneumatophores, *Microcoleus chthonoplastes* and *Lyngbya confervoides* are active on dry and wet epipelic substrata, respectively. Tentative results suggest that natural populations of *Oscillatoria okeni, Oscillatoria proboscidea* and *Oscillatoria schultzii* might also fix nitrogen.

Nitrogenase activity was generally highest in non-heterocystous mangrove-associated communities in the Sinai Peninsula (Potts 1984). An isolate was found which, under aerobic conditions, reduced acetylene micro-aerophilically only as long as its thick mucilaginous sheath remained intact. Pearson *et al.* (1981) confirmed active nitrogenase activity in pure cultures of *Microcoleus chthonoplastes*, a dominant mangrove-associate with a thick sheath. Perhaps this species also fixes nitrogen aerophilically, then its prevalence suggests strongly that it might play a significant role as a source of nitrogen in southern African mangrove swamp ecosystems.

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