

## Benthic algae and seagrasses of the Walpole and Nornalup Inlets Marine Park, Western Australia

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### Abstract

A survey of the marine plants of the Walpole and Nornalup Inlets Marine Park has recorded 49 species of marine benthic algae and seagrasses, including 15 green algae, 11 brown algae, 18 red algae, 4 seagrasses, and one cyanobacterium, representing a substantial increase on the 14 previously recorded species. Most species are relatively common elements of the south-western Australian marine flora, but several are of taxonomic or biogeographic and ecological interest. Included in this group are: a new species of the green algal genus *Codium*, the first records of previously unknown reproductive phases in the red algae *Mazoyerella australis* and *Spermothamnion cymosum*, and a new distribution record for *Ossiella pacifica*, a species hitherto known only from warmer waters of the Pacific Ocean and not recorded for mainland Australia. The species diversity in the inlets decreases markedly with increasing distance from the ocean, reflecting a reducing marine and increasing estuarine influence.

**Keywords:** algae, benthic, *Codium*, *Mazoyerella*, Nornalup, *Ossiella*, range extensions, *Spermothamnion*, Walpole

### Introduction

The estuaries of Western Australia's (WA) south provide important highly productive and sheltered aquatic habitats on an otherwise typically high energy stretch of coast (Brearley 2005). While the physical conditions of estuaries vary widely due to the mixing of marine and fresh waters, the wave-dominated estuaries of southern WA vary also with regard to their underlying geomorphology, rainfall characteristics and frequency and duration of times at which they remain open to the ocean (Hodgkin & Hesp 1998; Chuwen *et al.* 2009). While systems in relatively high rainfall areas tend to be permanently or seasonally open to the ocean, those in the drier east of WA's south coast have longer periods of closure.

Estuaries typically accumulate terrestrially-derived sediments and nutrients in their lower basins, and for this reason they may support particularly high densities of some organisms such as invertebrates and fishes (Edgar 2001). However, as relatively few species can persistently tolerate the highly variable environmental conditions associated with, for example, seasonal freshwater flows and periods of bar closure, the number of true estuarine species is relatively low. It is more common for mobile organisms to opportunistically enter estuaries when conditions are suitable and/or exploit

their productivity and sheltered waters during particular stages of their life-cycle (Potter & Hyndes 1999). By accumulating sediments and nutrients from surrounding catchments, estuaries are also particularly susceptible to pollution and eutrophication, and many of WA's estuarine systems are significantly degraded from such impacts (Brearley 2005). In particular, massive growth of algae and seagrasses has occurred in some estuaries as a consequence of eutrophication.

The Walpole and Nornalup Inlets are among the few estuaries in the south west of WA that have not been significantly modified by development and/or catchment degradation. The inlets are a very popular recreation area for both locals and the broader WA community, and the high ecological and social conservation values of the inlet system led to it being gazetted as a marine park in 2009 (DEC 2009). The Walpole and Nornalup Inlets Marine Park comprises two discrete basin inlets and the tidal reaches of the Frankland, Deep and Walpole Rivers. The Nornalup Inlet is connected to the sea by a relatively narrow entrance channel that remains permanently open to the ocean due to the relatively high rainfall of this area, the highest in WA of *ca.* 1300 mm, and the protection of the channel entrance from wave action by a rocky headland (Hodgkin & Clark 1999). For this reason essentially marine conditions are maintained in most of the system throughout the drier months, and aspects of the biota are relatively diverse compared to most other estuaries in this region (Brearley 2005). In contrast to Nornalup Inlet, Walpole Inlet is much smaller and

shallower. Exchange between the two water bodies is via a narrow deep channel. During winter, the surface water of Nornalup Inlet can be quite fresh, although the bottom waters generally remain at about 30 ppt. Water in the Walpole Inlet, however, is generally of a lower salinity. The sediments of the inlets comprise fine mud in the deeper basins and clean, well-sorted sands in the entrance channel and shallows, which are particularly extensive around the Nornalup Inlet (Hodgkin & Clark 1999; DEC 2009). Notably, the inlets support little fringing marsh habitat and have relatively small areas of rocky shoreline or sub-tidal rocky substratum.

Creation of the marine park has provided impetus for updated and new scientific knowledge of the system to assist management and provide a basis for long-term monitoring of conservation values. The aim of this study was to conduct a methodical survey of marine plants in the entrance channel and Walpole and Nornalup inlet basins, with a particular emphasis on the relatively limited areas of hard substratum.

### Previous studies

Prior to the current study, records of marine plants from the Walpole and Nornalup Inlets were exceedingly scant, and Brearley (2005) suggested that there are "not many types of aquatic plants" growing in the system. The only specific accounts include a short summary provided by Hodgkin & Clark (1999), wherein they described surveys of the aquatic vegetation undertaken by Marion Cambridge (October, 1976) and Jane Chambers (January, 1987); on both occasions the vegetation was found to be "sparse". Ten species were recorded, including the seagrasses *Ruppia megacarpa* and *Heterozostera tasmanica* (probably *Zostera polychlamys*, see below), the brown alga *Cystoseira trinodis*, the red alga *Monosporus australis* (= *Mazoyerella australis*), and the green algae *Chaetomorpha billardierei*, *C. linum*, *C. aerea*, *Enteromorpha intestinalis* (= *Ulva intestinalis*) and *Acetabularia caliculis*. Later, Brearley (2005) also provided an account of the marine plants, this in part derived from unpublished notes by E. Hodgkin (Brearley, pers. comm., Nov. 2010), listing *Halophila ovalis*, *Halophila decipiens*, *Cladophora* sp. and *Polysiphonia* sp. in addition to the species recorded by Hodgkin & Clark (1999). For the most part these earlier records cannot be verified, as only a few specimens from the surveys are lodged in the Western Australian Herbarium, and only one of those named voucher (*Chaetomorpha linum*). These specimens include a plant of *Cystoseira trinodis* (with epiphytic *Polysiphonia infestans*, *Ulva paradoxa*, *Cladophora* sp. and the diatom *Melosira*), and the aforementioned *Chaetomorpha linum* voucher, which has been re-examined and found to be an admixture of *Chaetomorpha indica* and *C. billardierei*. Most species previously reported from the inlets, however, were recollected during the present survey.

Anecdotal evidence indicates that summer seagrass growth (probably *Ruppia megacarpa*) occurred to such an extent in the Walpole Inlet during the 1950s and 1960s that it clogged boat propellers (WAPC 2009). As this growth no longer occurs, it was most likely caused by nutrients entering the inlet from local agricultural sources that have since been controlled or removed (DEC 2009).

## Methods

### Sampling sites

Specimens were collected by JMH and MJR (assisted by Anna John and Darren Stevens) during April 2010; primarily from six shallow rocky substratum sites in the Walpole and Nornalup Inlets and by a single collection of *Halophila decipiens* (and associated epiphytes) made by benthic grab from a seventh site (Fig. 1).

- Site 1 (S35.03129, E116.73309) was at Skippy Rock, a granite formation on the western shore close to where the entrance channel meets the sea (Fig. 2A). This location was visited twice (20 and 21 April), the second occasion for an incidental collection at the adjacent jetty.
- Site 2 (S35.01460, E116.70937) was on rocky shoreline in Weedy Bay on the western shore of the Nornalup Inlet (Fig. 2B).
- Site 3 (S34.99208, E116.74197) was on the northern side of the Nornalup Inlet; on small sub-tidal reef structures not far east of the Coalmine Beach boat ramp.
- Site 4 (S34.98680, E116.72431) was in the Walpole Inlet on rocky shore on the southern side of this basin, one of the few areas of hard substratum.
- Site 5 (S35.00731, E116.71220) was on the rocky shoreline of Newdegate Island, a granitic outcrop on the west side of the Nornalup Inlet, adjacent to the Deep River delta.
- Site 6 (S34.99496, E116.73148) was close to Site 3, on the northern side of the Nornalup Inlet, on the rocky eastern shore of the Knoll.
- Site 7 (S34.99648, E116.73780) comprised sand and was located on the north-eastern side of the Nornalup Inlet basin.

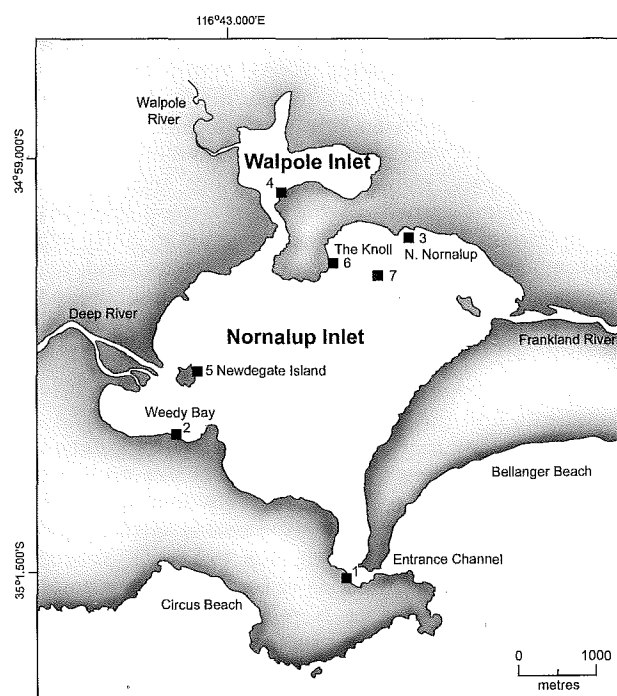


Figure 1. Map of the Walpole and Nornalup Inlets, showing the location of collection sites.

### Specimen collection/preservation

Specimens were collected by snorkeling and were photographed in-situ (see Figs 2A–H, 3A–H) by JMH using a Canon G9 camera in a housing. Voucher specimens were pressed onto herbarium sheets on the day of collection, with portions of larger plants and small filamentous species preserved in 5% formalin/seawater for later detailed examination. Additional portions were dried in silica-gel for DNA sequence analyses, although the results of these will not be reported here. In the laboratory, plant sections or whole-mounts were stained in a solution of aniline blue and mounted in 50% Karo/water. Microscope preparations were examined and photographed using either a Nikon SMZ800 stereo microscope or a Nikon Eclipse 80i compound microscope, in both cases with a Nikon DS Fi1 digital camera. All herbarium sheets and microscopic preparations have been lodged in the Western Australian Herbarium (PERTH). The distribution of species within the inlets (Table 1) is based on presence as observed during the survey, and on subsequent laboratory examination of smaller species and epiphytes.

### Environmental conditions

Environmental conditions across the Walpole and Nornalup inlets were measured at 19 sites (15 in the Nornalup and 4 in the Walpole) encompassing both the shallow peripheral sand flats and the deeper waters. At each site, a single measurement of temperature (°C), salinity (ppt), dissolved oxygen (mgL<sup>-1</sup>) and pH were taken using a calibrated Hydrolab DS5 Surveyor water probe. In addition, secci depth was measured at each site. For sites >1m deep, measurements were made both at the surface and approximately 30 cm above the bottom, and the readings averaged. All measurements were made between the hours of 8am–2pm on two consecutive days at the time of the algal collection.

### Arrangement of the taxonomic account

Taxonomic results are grouped into Phaeophyceae (= brown algae), Chlorophyta (= green algae), Rhodophyta (= red algae), Seagrasses, and Cyanobacteria (blue-green algae), with constituent species listed alphabetically. For each species, the name, authority, and date and page of publication are given (the place of publication listed in the references), with author names abbreviated according to Brummitt & Powell (1992). The PERTH voucher is cited, followed by a comments section.

## Results

### Environmental conditions

This study took place in autumn prior to the onset of significant river discharge and when environmental conditions in the inlet system were relatively stable and essentially marine. Only relatively small variations in physical parameters were apparent at the time of the survey. The mean water temperature was 20.6 °C, with the maximum (22.5 °C) and minimum (19.8 °C) occurring on the shallow peripheral sand flats and deeper waters of the Nornalup Inlet, respectively. Salinity was approximately 38 ppt throughout the inlet basins. The

mean dissolved oxygen was 7.3 mgL<sup>-1</sup>, and this ranged from 5.9 mgL<sup>-1</sup> in the Walpole Inlet to 8.4 mgL<sup>-1</sup> in the Nornalup Inlet. Although water clarity was notably high during the survey, underwater visibility in the Walpole Inlet was less than at other sites due to the widespread prevalence of fine muddy sediments in this basin.

### Taxonomic account

The following account details the species of seagrass, brown, green, and red macroalgae, and conspicuous cyanobacteria recorded from the Walpole and Nornalup Inlets. In addition to these taxa, numerous species of epiphytic diatoms and several microscopic cyanobacteria were present in the collections, but as these groups were not the primary focus of this study they will not be treated in detail. The former group included *Grammatophora oceanica* Ehrenb., *Striatella unipunctata* (Lyngb.) C.Agardh, *Biddulphia biddulphiana* (Sm.) Boyer, *Melosira moniliformis* (O.F.Müll.) C.Agardh, and species of *Licmophora*, the latter *Calothrix* sp. and *Lyngbya* sp.

## Phaeophyceae

*Colpomenia sinuosa* (Mert. ex Roth) Derbès & Solier 1851: 95.

Specimen: Entrance channel, Nornalup Inlet (Site 1), epilithic at 1.5 m depth, 20 Apr. 2010, J.M.Huisman (PERTH 08227624).

Only a single plant was collected and the species appears to be rare in the inlets. *Colpomenia sinuosa* is widely distributed and is found on all Australian coasts (Womersley 1987: 297).

*Cystoseira trinodis* (Forssk.) C.Agardh 1820: 67–68.

Specimen: East Coalmine, Nornalup Inlet (Site 3), 20 Apr. 2010, J.M.Huisman (PERTH 08243670).

This species formed dense beds near Newdegate Island (Fig. 2C) and was also common at Coalmine. *Cystoseira trinodis* is widespread in tropical and subtropical regions of the Indian Ocean and extends along southern Australia to Victor Harbour, S.A. (Womersley 1987: 358). It appears to be the only large brown alga capable of surviving in the upper reaches of south-western Australian estuaries (e.g., Waychinicup Estuary, see Phillips & Lavery 1997). *Cystoseira trinodis* was previously recorded for Nornalup/Walpole by Hodgkin & Clark (1999) and Brearley (2005: 366).

*Dictyota fastigiata* Sond. 1845: 50

Specimen: Entrance channel, Nornalup Inlet (Site 1), epilithic at 1.5 m depth, 20 Apr. 2010, J.M.Huisman (PERTH 08243468).

*Dictyota fastigiata* was formerly included in *Dilophus* (see Womersley 1987), but that genus was subsumed into *Dictyota* following DNA sequence studies (see De Clerck 2003). Plants have dark brown, dichotomously branched, flattened axes that structurally have a medulla several cells thick and a cortex of a single cell layer.

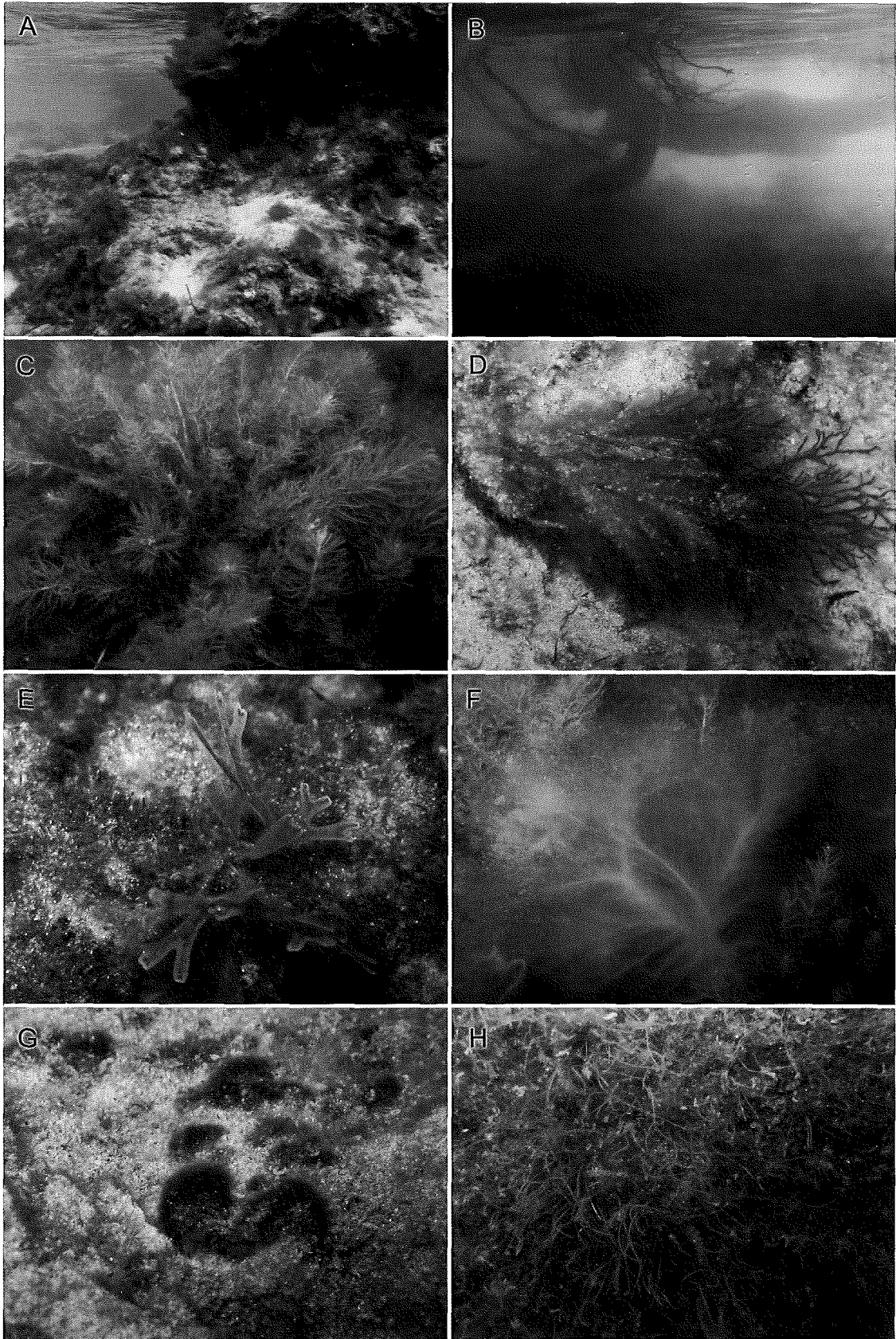
*Dictyota furcellata* (C.Agardh) Grev. 1830: xliii.

Specimen: Entrance channel, Nornalup Inlet (Site 1), epilithic at 1.5 m depth, 20 Apr. 2010, J.M.Huisman (PERTH 08227616).

Table 1

Algae species collected from six rocky sites in the Walpole and Nornalup Inlets Marine Park during April 2010. Sites are arranged from the most southern (Site 1) to northern (Site 4), reflecting increasing distance from the open coast.

Species	Site 1 Entrance Channel	Site 2 Weedy Bay	Site 5 Newdegate Island	Site 6 The Knoll	Site 3 N. Nornalup Inlet	Site 4 Walpole Inlet
<b>CHLOROPHYTA</b>						
<i>Acetabularia caliculus</i>					X	
<i>Chaetomorpha aerea</i>				X		
<i>Chaetomorpha billardierei</i>					X	
<i>Chaetomorpha ligustica</i>	X					
<i>Chaetomorpha indica</i>	X		X			
<i>Cladophora dalmatica</i>	X				X	
<i>Cladophora feredayi</i>			X			X
<i>Cladophora laetevoirens</i>	X					
<i>Cladophora lehmanniana</i>	X	X			X	
<i>Codium</i> sp.		X	X	X	X	X
<i>Rhizoclonium implexum</i>	X	X		X		
<i>Struvea plumosa</i>			X	X		
<i>Ulva paradoxa</i>	X	X			X	
<i>Uronema marina</i>	X	X	X	X	X	
<b>PHAEOPHYCEAE</b>						
<i>Colpomenia sinuosa</i>	X					
<i>Cystoseira trinodis</i>		X	X	X	X	X
<i>Dictyota fastigiata</i>	X					
<i>Dictyota furcellata</i>	X	X		X	X	
<i>Dictyota dichotoma</i>	X					
<i>Feldmannia irregularis</i>	X					
<i>Sphacelaria biradiata</i>	X					
<i>Sphacelaria fusca</i>		X	X			
<i>Sphacelaria rigidula</i>	X		X	X	X	X
<i>Sphacelaria tribuloides</i>	X					
<b>RHODOPHYTA</b>						
<i>Acrochaetium microscopicum</i>	X					
<i>Aglaothamnion tenuissimum</i>						X
<i>Centroceras clavulatum</i>	X	X		X		
<i>Ceramium cliftonianum</i>	X					
<i>Ceramium</i> sp.	X		X			
<i>Chondria angustissima</i>	X	X				
<i>Colaonema savianum</i>	X			X	X	X
<i>Erythrotrichia carnea</i>	X			X	X	X
<i>Gelidium crinale</i>	X	X	X			
<i>Gracilaria ramulosa</i>	X		X			
<i>Hincksia mitchelliae</i>	X	X	X	X	X	
<i>Mazoyerella australis</i>	X	X	X	X	X	X
<i>Ossiella pacifica</i>	X					
<i>Polysiphonia infestans</i>	X	X		X		
<i>Polysiphonia subtilissima</i>						X
<i>Polysiphonia teges</i>	X	X	X	X	X	X
<i>Spermothamnion cymosum</i>	X			X		
<i>Spyridia filamentosa</i>	X					
<i>Stylonema alsidii</i>	X	X		X		
<b>SEAGRASS</b>						
<i>Zostera polychlamys</i>	X	X				
<b>CYANOBACTERIUM</b>						
<i>Spirulina subsalsa</i>			X			
<b>Total # species</b>	<b>34</b>	<b>17</b>	<b>15</b>	<b>17</b>	<b>14</b>	<b>10</b>



**Figure 2.** A. Reef near channel entrance, Nornalup Inlet (Site 1). The filamentous brown alga is *Hincksia mitchelliae*. B. Weedy Bay (Site 2), with higher turbidity typical of most inlet sites. C. *Cystoseira trinodis*, a large brown alga common at several sites. D. *Dictyota furcellata*, another common brown alga. E. *Dictyota dichotoma* (Site 1). F. *Hincksia mitchelliae*, epiphytic on *Cystoseira trinodis* at Newdegate I. (Site 5). G. *Sphacelaria rigidula*, forming bristly tufts at the channel entrance (Site 1). H. *Chaetomorpha aerea*, a filamentous green alga attached to rock at the Knoll (Site 6).

*Dictyota furcellata* was moderately common near the Nornalup entrance and also near Coalmine and Newdegate Island (Fig. 2D).

*Dictyota dichotoma* (Hudson) J.V.Lamour. 1809: 42.

Specimen: Entrance channel, Nornalup Inlet (Site 1), epilithic at 1.5 m depth, 20 Apr. 2010, J.M.Huisman (PERTH 08214433).

The present specimen is not fertile but agrees with *Dictyota dichotoma* as described by Womersley (1987). De Clerck (2003: 166) suggests that many reports of this supposedly widespread species might be incorrect, and that *D. dichotoma* could be restricted to the north-east Atlantic and the Mediterranean. The identification of this and other southern Australian records of *D. dichotoma* are therefore tentative (Fig. 2E).

*Feldmannia irregularis* (Kütz.) Hamel 1939: XVII.

Specimen: Entrance channel, Nornalup Inlet (Site 1), 20 Apr. 2010, J.M.Huisman (PERTH 08243409).

This species forms light brown, filamentous tufts and is almost indistinguishable from *Hincksia mitchelliae* without microscopic examination. In *Feldmannia*, the meristematic zones (regions of active cell division, recognisable as series of shorter cells) tend to be proximal to long, unbranched, hair-like filaments. Fertile material is readily distinguished by the plurangia distinctly tapering to a point, whereas those of *Hincksia mitchelliae* are cylindrical with rounded apices (compare Figs 4A and 4B).

*Hincksia mitchelliae* (Harv.) P.C.Silva in Silva, Meñez & Moe 1987: 73, 130.

Specimen: Newdegate I., Nornalup Inlet (Site 5), epiphytic on *Cystoseira trinodis*, 21 Apr. 2010, J.M.Huisman (PERTH 08243727).

*Hincksia mitchelliae* is another filamentous brown alga (Figs 2A, 2F) and was very common at most sites in Nornalup, where it was both epilithic and epiphyte on a variety of larger algae and seagrasses. Several specimens in the collection were reproductive, with cylindrical plurangia characteristic of this species (Fig. 4B).

*Sphacelaria biradiata* Askenasy 1894: 15.

Specimen: Entrance channel, Nornalup Inlet (Site 1), mixed with *Sphacelaria rigidula*, 20 Apr. 2010, J.M.Huisman (PERTH 08243956).

Four species of *Sphacelaria* were collected during the survey. Each of these forms dark brown, bristly tufts and are similar in general appearance (see Fig. 2G of *S. rigidula*). They can be distinguished by their microscopic structure and the form of their propagules (vegetative reproductive structures); those of *S. biradiata* have two basally constricted, elongate arms, plus an apical elongate hair, those of *S. fusca* generally have three elongate arms, whereas propagules in *S. rigidula* have two arms and in *S. tribuloides* they are triangular without elongate arms (Womersley 1987: 168).

*Sphacelaria fusca* (Huds.) Gray 1821: 333.

Specimen: Newdegate I., Nornalup Inlet (Site 5), on old oyster shells, 21 Apr. 2010, J.M.Huisman (PERTH 08243611).

*Sphacelaria fusca* was found only on old oyster shells near Newdegate Island and was the least common of the four species of *Sphacelaria* recorded.

*Sphacelaria rigidula* Kütz. 1843: 292.

Specimen: Newdegate I., Nornalup Inlet (Site 5), on old oyster shells, 21 Apr. 2010, J.M.Huisman (PERTH 08214441).

This species (Fig. 2G) was more widespread but was also found on oyster shells near Newdegate Island, the same habitat as *S. fusca*. *Sphacelaria rigidula* has narrower branches and propagules typically with 2 arms (Fig. 4C).

*Sphacelaria tribuloides* Menegh. 1840: [2]

Specimen: Entrance channel, Nornalup Inlet (Site 1), on rock, 20 Apr. 2010, J.M.Huisman (PERTH 08227594).

*Sphacelaria tribuloides* was only found at the Entrance channel site (Site 1), where it formed epilithic tufts. The specimens bore the triangular propagules (Fig. 4D) characteristic of this species.

## Chlorophyta

*Acetabularia caliculus* J.V. Lamour. in Quoy & Gaimard 1824: 621.

Specimen: East Coalmine, Nornalup Inlet (Site 3), on old bivalve shells, 20 Apr. 2010, J.M.Huisman (PERTH 08243689).

*Acetabularia caliculus* is a common species that is often found growing in clusters on old bivalve shells on sandy substrata, which was also the habitat of the present specimens.

*Chaetomorpha aerea* (Dillwyn) Kütz. 1849: 379.

Specimens: The Knoll, Nornalup Inlet (Site 6), epilithic at 1 m depth, 21 Apr. 2010, J.M.Huisman (PERTH 08243379).

*Chaetomorpha* is a simply constructed genus that forms unbranched filaments composed of cylindrical cells. Species distinctions are based on habit (whether attached or free-floating) and differences in cells diameter and proportions (length/breadth ratio = L/B) (Womersley, 1984), although often published accounts vary in the size ranges included in single species. These morphological features, especially cell dimensions, are now regarded as poor indicators of phylogenetic relationships in the green algae (Leliaert *et al.* 2007) and it is clear that *Chaetomorpha* is in need of revision (Leliaert & Boedeker 2007). For the interim, however, it is prudent to at least recognise the different morphologies. *Chaetomorpha aerea* was one of four species of the genus recorded and was the only one found attached. Plants grew on rock in the shallow subtidal (Fig. 2H) and were mostly inundated with silt, such that they were only visible after cleaning. Cell diameters were 250–300 µm, with an L/B of 1–2 (–3). Their basal cells, at 600–1200 µm in length, can be slightly longer than those recorded by Womersley (1984: 172), but were comparable to dimensions recorded for this species from elsewhere (*e.g.*, Alves *et al.* 2009), and otherwise the specimens are comparable. The lowermost cells also had thicker walls than reported by Womersley (1984; to 30 µm as opposed to 2–4 µm), which relates these specimens to the unattached *C. valida*. *Chaetomorpha aerea* was also recorded by Brearley (2005: 366).

*Chaetomorpha billardierei* Kütz., 1847: 166.

Specimen: East Coalmine, Nornalup Inlet (Site 3), entangled on *Cystoseira trinodis*, 20 Apr. 2010, J.M.Huisman (PERTH 08243336).

Plants of this species were unattached, with cells 290–400



$\mu\text{m}$  in diameter and L/B 1–2, the largest of the four *Chaetomorpha* species recorded here. The cells are of a similar diameter to those reported for *C. linum* (Womersley 1984), but are generally longer than broad (L/B 1–2). *Chaetomorpha billardierei* was also recorded by Hodgkin & Clark (1999), epiphytic on *Ruppia* and *Zostera* (as *Heterozostera*), and Brearley (2005: 366). The spelling of the species epithet is variously given as “billardierii” (Womersley 1984: 176; Guiry & Guiry 2010) or “billardieri” (Index Nominum Algarum 2010) but as the name commemorates French botanist J.J. de Labillardière it should be corrected to “billardierei” (International Code of Botanical Nomenclature 2006: Art. 67, Ex. 15).

*Chaetomorpha indica* (Kütz.) Kütz. 1849: 376.

Specimen: Entrance channel, Nornalup Inlet (Site 1), unattached, 20 Apr. 2010, J.M.Huisman (PERTH 08243964).

This species formed entangled skeins and was common near the Nornalup entrance (Fig. 3A). The filaments were 70–100  $\mu\text{m}$  in diameter, which is at the lower end of the range reported by Womersley (1984), but the L/B ratios are comparable. Also recorded for Walpole Inlet by Womersley (1984: 180).

*Chaetomorpha ligustica* (Kütz.) Kütz., 1849: 376.

Specimen: Entrance channel, Nornalup Inlet (Site 1), unattached, 20 Apr. 2010, J.M.Huisman (PERTH 08243972).

Plants of *C. ligustica* were mixed with *C. indica* and have a similar appearance, but with slightly smaller filament diameters and cells that are proportionally shorter (L/B 1–2). Womersley’s (1984) treatment would place these specimens in *Chaetomorpha capillaris*, a species now regarded as a taxonomic synonym of *Chaetomorpha ligustica* (see Guiry & Guiry 2010).

*Cladophora dalmatica* Kütz., 1843: 268.

Specimen: East Coalmine, Nornalup Inlet (Site 3), growing on *Cystoseira trinodis* amongst *Polysiphonia*, 20 Apr. 2010, J.M.Huisman (PERTH 08243522).

This is one of four species of *Cladophora* collected. The specimens agree with the description provided by Hoek & Womersley (1984: 202). *Cladophora dalmatica* is sometimes treated as a taxonomic synonym of *C. vagabunda* (L.) C.Hoek, but is retained here due to its distinctly narrower apical cells (15–20  $\mu\text{m}$ , versus 25–70  $\mu\text{m}$  reported for *C. vagabunda* by Hoek & Womersley 1984: 203). *Cladophora dalmatica*, *C. laetevirens*, and *C. lehmanniana* are included in Section Glomeratae, differing primarily in their cell diameters.

*Cladophora feredayi* Harv. 1858: pl. 47.

Specimen: Newdegate I., Nornalup Inlet (Site 5), epilithic, 21 Apr. 2010, J.M.Huisman (PERTH 08243476).

*Cladophora laetevirens* (Dillwyn) Kütz. 1843: 267.

Specimen: Entrance channel, Nornalup Inlet (Site 1), 21 Apr. 2010, J.M.Huisman (PERTH 08243557).

*Cladophora lehmanniana* (Lindenb.) Kütz. 1843: 268.

Specimen: East Coalmine, Nornalup Inlet (Site 3), epilithic, 20 Apr. 2010, J.M.Huisman (PERTH 08243395). The branching pattern of *Cladophora lehmanniana* is similar to that of *C. dalmatica*, but plants are considerably larger, with apical cells ca 100  $\mu\text{m}$  in diameter.

*Codium* sp.

Specimens: Walpole Inlet (Site 4), 21 April 2010, J.M.Huisman (PERTH 08243492)

This species was common at Coalmine and Newdegate Island, and was the only large alga present in the Walpole Inlet (Fig. 3B), where it was attached to rock and typically covered in silt, such that it was visible only after cleaning. Plants are structurally similar to *Codium harveyi* P.C.Silva (see Womersley 1984: 236) but have flattened lower branches, some subtle differences in utricle morphology, and unique DNA sequences, suggesting they represent an undescribed species (Hart & Huisman 2010). A formal description will be published elsewhere.

*Struvea plumosa* Sond. 1845: 50.

Specimen: The Knoll, Nornalup Inlet (Site 6), epilithic, 21 Apr. 2010, J.M.Huisman (PERTH 08227640).

When fully developed, *Struvea plumosa* is one of the most distinctive and attractive of Western Australia’s marine algae, as it forms a paddle-shaped frond composed of anastomosing filaments forming a coarse net (see Huisman 2000). The present record, however, is based on less developed plants that are present as dense clusters of unbranched stipes (Fig. 3C). These are often indistinguishable from stipes of *Apjohnia laetevirens* Harv. (Womersley 1984: 182). Fortunately, one stipe in the collection showed some distal branching similar to that of fully developed *Struvea plumosa*, allowing a positive identification.

*Rhizoclonium implexum* (Dillwyn) Kütz. 1845: 206.

Specimen: Entrance channel, Nornalup Inlet (Site 1), unattached, 21 Apr. 2010, J.M.Huisman (PERTH 08243530).

This species occurs as unattached, unbranched filaments, similar in appearance to species of *Chaetomorpha* but with considerably narrower cells that are only 20–22  $\mu\text{m}$  in diameter.

*Ulva paradoxa* C.Agardh 1817: xxii.

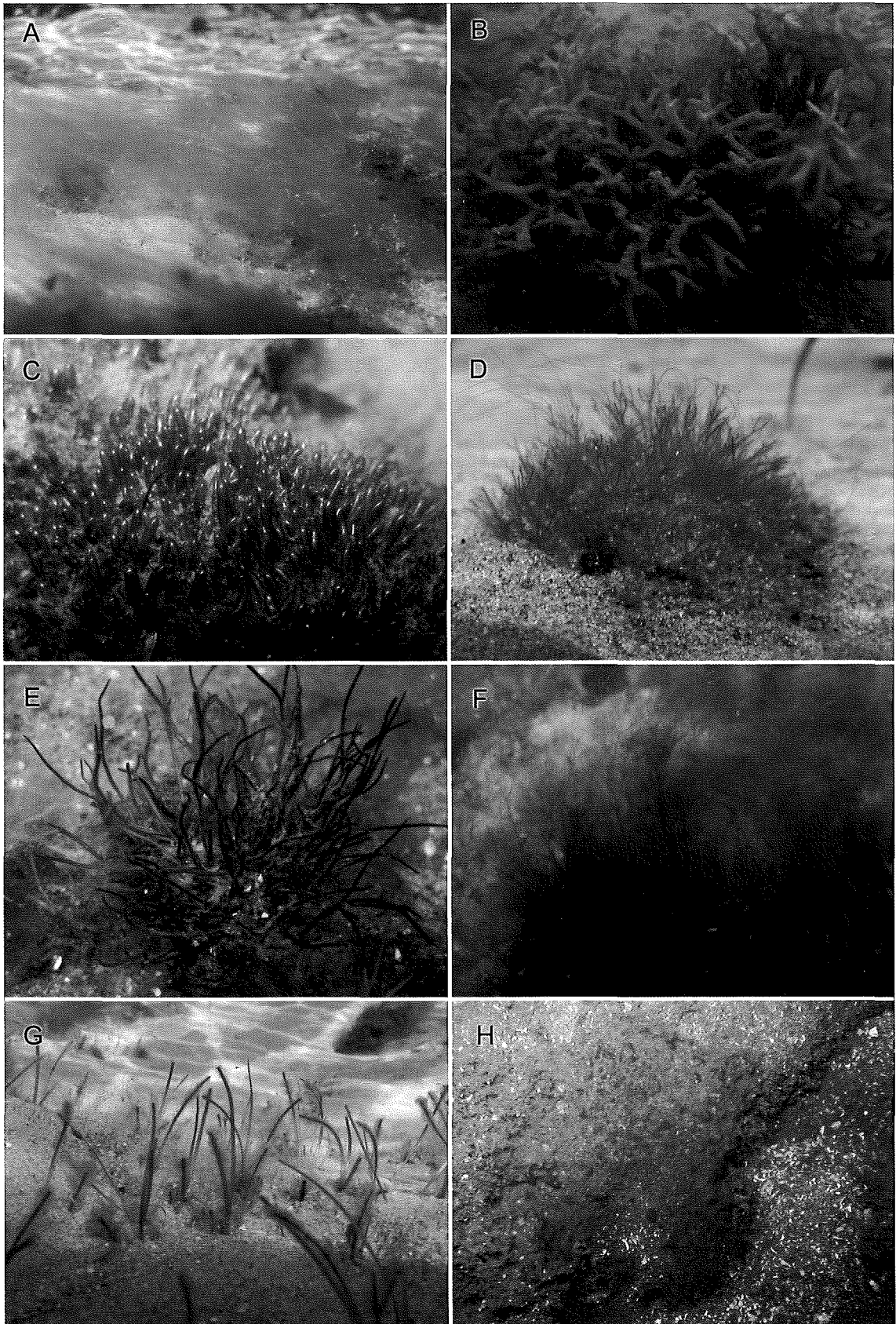
Specimen: Entrance channel, Nornalup Inlet (Site 1), 20 Apr. 2010, J.M.Huisman (PERTH 08243646) (Fig. 3A).

This species was common at most locations. *Ulva paradoxa* was previously included in the genus *Enteromorpha*, but that genus has been subsumed into *Ulva* (see Hayden *et al.* 2003). *Ulva paradoxa* is not typical of the ‘sea lettuce’ form of *Ulva*, with flat green sheets, or, superficially, the tubular form of the species previously included in *Enteromorpha*. Plants are very narrowly tubular, linear, with common uniseriate lateral branches (Fig. 4E). As is distinctive of this species, the cells are arranged in longitudinal and often transverse rows, with chloroplasts mostly with 3–4 pyrenoids.

*Uronema marinum* Womersley 1984: 131.

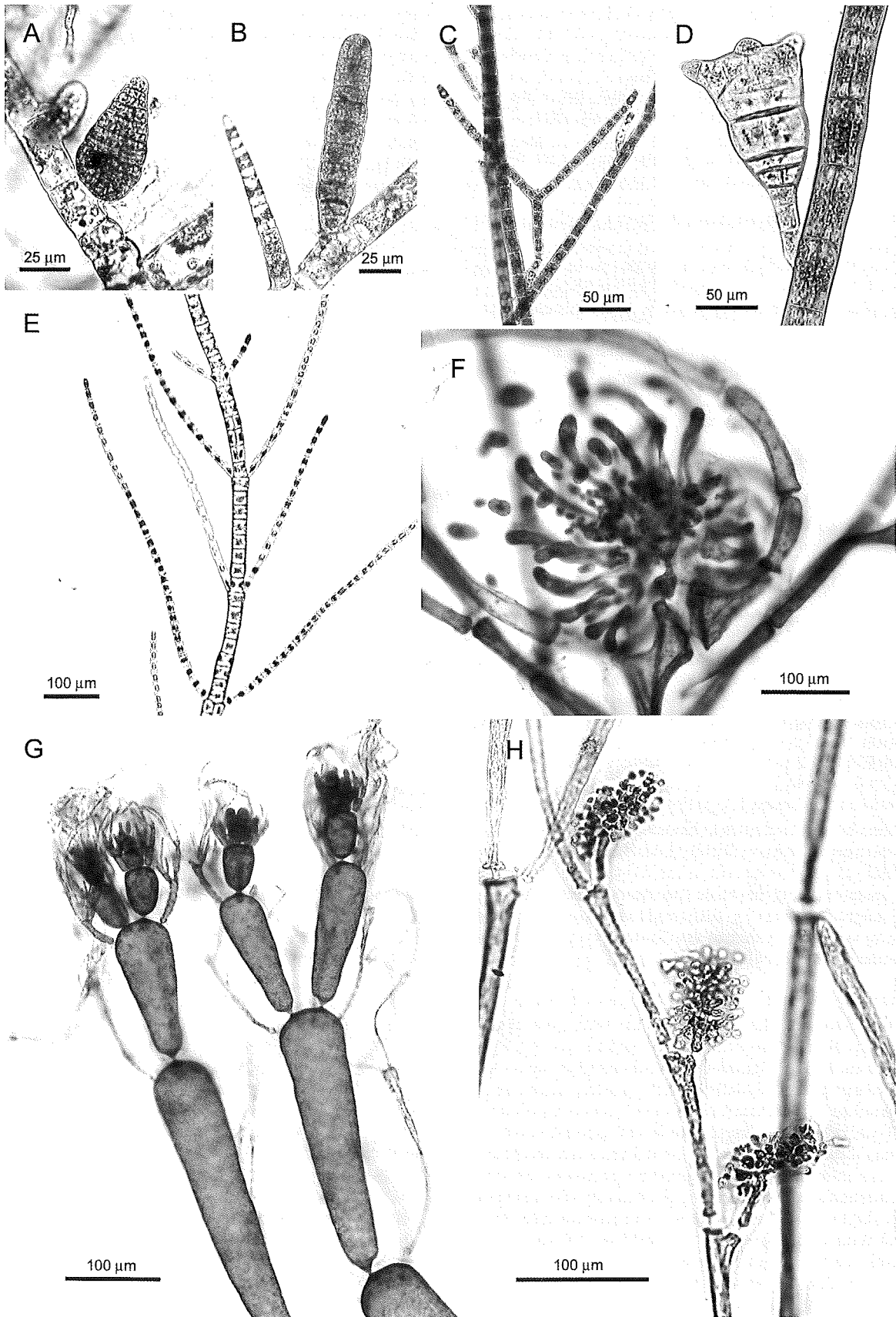
Specimen: East Coalmine, Nornalup Inlet (Site 3), epiphytic on *Cladophora*, 20 Apr. 2010, J.M.Huisman (PERTH 08243999).

This is a small, unbranched filamentous epiphyte, typically less than 250  $\mu\text{m}$  tall, which is generally only recorded during microscopic examination. It was very common in the inlets and was observed on larger algae collected from most sites. Leliaert *et al.* (2009: 493) queried the placement of this species in *Uronema*, but retained the name pending molecular investigation.



**Figure 3.** A. *Ulva paradoxa* and *Chaetomorpha* spp. at the channel entrance (Site 1). B. *Codium* sp., a likely new species and the only conspicuous alga in Walpole Inlet (Site 4). C. Massed stipes of *Struvea plumosa* at Newdegate I. (Site 5). D. *Centroceras clavulatum*, a filamentous red alga at the channel entrance (Site 1). E. *Gracilaria ramulosa* at Newdegate I. (Site 5). F. *Mazoyerella australis*, one of the most common red algae at inlet sites (Site 5). G. The seagrass *Zostera polychlamys* on sand at the channel entrance (Site 1). H. The cyanobacterium *Spirulina subsalsa* formed colonies on the sand surface at Newdegate I. (Site 5)





**Figure 4.** A. *Feldmannia irregularis*. Detail of conical plurangium. B. *Hincksia mitchelliae*. Detail of cylindrical plurangium. C. *Sphacelaria rigidula*. Slender propagule with 2 elongate arms. D. *Sphacelaria tribuloides*. Short, triangular propagule. E. *Ulva paradoxa*. Detail showing regular production of uniseriate lateral branches. F. *Mazoyerella australis*, the hitherto unknown carposporophyte stage. G. *Ossiella pacifica*, showing filamentous structure. H. *Spermothamnion cymosum*, the hitherto unknown spermatangial organs.

## Rhodophyta

*Acrochaetium microscopicum* (Nägeli ex Kütz.) Nägeli in Nägeli & Cramer 1858: 532, footnote.

Specimens: Entrance channel, Nornalup Inlet (Site 1), epiphytic on *Spermothamnion cymosum*, 20 Apr. 2010, J.M.Huisman (PERTH 08244014).

This species is a diminutive epiphyte on larger algae, only recorded during microscopical examination.

*Aglaothamnion tenuissimum* (Bonnem.) Feldm.-Maz. 1941: 3.

Specimen: Walpole Inlet (Site 4), epiphytic on *Cystoseira trinodis* 21 Apr. 2010, J.M.Huisman (PERTH 08243603).

Several plants were collected from the Walpole Inlet, representing all stages of the life history. This species was treated in Womersley & Wollaston (1998) as *Callithamnion byssoides* Harv. (1833: 342), but that species is regarded as a synonym of *A. tenuissimum* by Furnari *et al.* (1998). The specimens differ slightly from those described by Womersley & Wollaston (1998: 248) in having obovoid to ellipsoidal tetrasporangia, whereas those described in Womersley & Wollaston are subspherical. Maggs & Hommersand (1993), however, described ellipsoidal tetrasporangia similar to those of the Walpole specimens.

*Centroceras clavulatum* (C.Agardh) Mont. 1846: 140.

Specimen: Entrance channel, Nornalup Inlet (Site 1), on sand, 20 Apr. 2010, J.M.Huisman (PERTH 08244006) (Fig. 3D).

*Centroceras clavulatum* is a widespread species found on most Australian coasts. Plants are filamentous and dichotomously branched, somewhat similar to species of *Ceramium* but recognisable due to their complete cortication and the presence of whorls of spines at nodes.

*Ceramium cliftonianum* J.Agardh 1876: 93.

Specimen: Entrance channel, Nornalup Inlet (Site 1), on jetty pilings, 21 Apr. 2010, J.M.Huisman (PERTH 08243387).

Plants essentially agree with the description given by Womersley (1998: 415), although the frequency of branching is less than that of specimens depicted therein (Womersley 1998: figs 189H, I).

*Ceramium* sp.

Specimen: Entrance channel, Nornalup Inlet (Site 1), 21 Apr. 2010, J.M.Huisman (PERTH 08243417).

This species has prostrate axes and slender, sparsely branched upright axes with straight apices, 4 periaxial cells per node and only acropetal development of cortical cells. This morphology relates it to species such as *Ceramium affine* Setch. & N.L.Gardner, but accurate identification requires reproductive specimens, which were unfortunately not collected during the present survey. Whatever the eventual determination, this species will represent a new record for southern Australia, as the vegetative structure differs from all species recorded for the region by Womersley (1978; 1998).

*Chondria angustissima* Gordon-Mills & Womersley 1987: 531.

Specimen: Entrance channel, Nornalup Inlet (Site 1), on

jetty pilings mixed with *Ceramium cliftonianum*, 21 Apr. 2010, J.M.Huisman (PERTH 08243913).

Both cystocarpic and male specimens were present in the collection, both agreeing with descriptions of this species by Gordon-Mills & Womersley (1987: 531) and Womersley (2003: 426). This species is confined to sheltered estuarine conditions (Womersley 2003: 427) and was previously recorded from the Leschenault Inlet in south-west Western Australia (Womersley 2003: 427; AD A56818).

*Colaconema savianum* (Menegh.) R.Nielsen 1994: 715.

Specimen: Entrance channel, Nornalup Inlet (Site 1), epiphytic on leaves of *Zostera polychlamys*, 1 m depth, 20 Apr. 2010, J.M.Huisman (PERTH 08243506).

*Colaconema savianum* is a small (less than 2 mm tall), branched, filamentous epiphyte, distinguished by its straight filaments bearing monosporangia (single-celled vegetative reproductive structures).

*Erythrotrichia carnea* (Dillwyn) J.Agardh 1883: 15.

Specimen: Entrance channel, Nornalup Inlet (Site 1), epiphytic on *Chondria angustissima*, 21 Apr. 2010, J.M.Huisman (PERTH 08243921).

*Erythrotrichia carnea* is another small, filamentous epiphyte, distinguishable from other taxa sharing this habitat in being unbranched (*Acrochaetium*, *Colaconema* and *Stylonema* are branched)

*Gelidium crinale* (Turner) Gaillon 1828: 362.

Specimen: Weedy Bay, Nornalup Inlet (Site 2), epilithic, 20 Apr. 2010, J.M.Huisman (PERTH 08214468).

Plants of *G. crinale* are turf-like and wiry, with prostrate and sparsely branched erect axes that are terete or flattened. It is a common species in south-western Australia and elsewhere.

*Gracilaria ramulosa* J.Agardh 1876: 417.

Specimen: Entrance channel, Nornalup Inlet (Site 1), 20 Apr. 2010, J.M.Huisman (PERTH 08243360).

This species and *Gelidium crinale* were the only cartilaginous red algae encountered during the survey. Plants (Fig. 3E) grew to a height of approximately 12 cm and can be recognised by their terete branches and multiaxial construction (see Womersley 1996: 18). *Gelidium crinale* is a much smaller species and is structurally uniaxial.

*Mazoyerella australis* (Harv.) Huisman & Womersley 1998: 302.

Specimen: Weedy Bay, Nornalup Inlet, (Site 2), epiphytic on various larger algae, 20 Apr. 2010, J.M.Huisman (PERTH 08243719).

*Mazoyerella australis* is a filamentous red alga (Fig. 3F) that was one of the more common species in the inlets, being recorded at most sites (see Table 1). Collections from The Knoll also provided the first known record of field-collected reproductive specimens. Until recently, this species was included in *Monosporus*, a genus in which the only known reproductive structures are single-celled propagules (the genus name is based on the incorrect interpretation of these structures as monosporangia, see Huisman & Kraft 1982). Subsequently, Huisman & Gordon-Mills (1994) described the presence of sexual reproductive structures in material

grown in culture, demonstrating (at least) the potential for a sexual life history in addition to vegetative propagation by propagules. The structure of these reproductive organs then provided the basis for Huisman & Womersley's (1998: 302) transfer of the species to *Mazoyerella*, although this was somewhat tentative as fertilization, and subsequent post-fertilization events, were not observed in Huisman & Gordon-Mills' (1994) culture studies. As post-fertilization and the development of the carposporophyte generation are important in generic delineation, the discovery of these stages in the Nornalup collections (Fig. 4F) will allow confirmation (or not) of the taxonomic placement of *M. australis*. These results will be incorporated into a DNA sequence study and will be reported elsewhere.

*Ossiella pacifica* A.Millar & I.A.Abbott 1997: 89.

Specimen: Entrance channel, Nornalup Inlet (Site 1), mixed with *Polysiphonia infestans*, 20 Apr. 2010, J.M.Huisman (PERTH 08243514) (Fig. 4G).

This species was originally described in 1997 for specimens from Norfolk Island and the Hawaiian Islands (Millar & Abbott 1997), and was subsequently recorded from Micronesia (McDermid *et al.* 2002; Lobban & Tsuda 2003; Guiry & Guiry 2010). Given this known distribution in warmer waters of the Pacific Ocean, the occurrence of *O. pacifica* in Nornalup Inlet was certainly surprising. The specimen is not reproductive, but displays several distinctive vegetative features unique to this genus, including the simultaneous production of determinate whorl branches from the distal ends of axial cells (Millar & Abbott 1997: 94). Millar (pers. comm. July, 2010) examined images of this specimen and confirmed its identity. As this represents a new record for Western Australia (and mainland Australia), a full description of the specimen is given below.

Thallus filamentous, primarily upright, 8 mm tall, attached to the substratum by unicellular rhizoids arising from lower cells, uncorticated, dichotomously branched near apices, but unbranched for most of its length. Cells elongate, near base cylindrical, 120–145 µm diam., 680–1070 µm long, towards apices becoming shorter and clavate, 60–80 µm diam., 300–350 µm long, at apices obovoid to ellipsoid, 35–40 µm diam., only slightly longer than broad. Apical cells simultaneously cutting off distally a whorl of 4 villous pigmented caducous determinate whorl branches, these dichotomously branched, markedly thinner than the axial filament, basal cells 7–10 µm diam., 120–170 µm long, distal cells more slender and hair-like. Reproductive structures not observed.

*Polysiphonia infestans* Harv. 1855: 539.

Specimens: W of boat shed, Nornalup Inlet, epiphytic on *Cystoseira trinodis* on rocks on sand flat, 30–50 cm depth, 23 Oct. 1976, M.L.Cambridge (PERTH 07023146); Entrance channel, Nornalup Inlet (Site 1), epiphytic on *Dictyota furcellata*, 20 Apr. 2010, J.M.Huisman (PERTH 08227608). PERTH 07023146 is a dried specimen that did not rehydrate well, and the determination is therefore tentative. The specimen has 4 pericentral cells, tetrasporangia in gently spiral series, and the dimensions of *P. infestans*, but the origin of the lateral branches (important for species identification) could not be ascertained. Specimens from the present survey were

male and essentially agree with Womersley's description (2003: 188–189), including the lateral branches replacing trichoblasts. However, the segments were often proportionally longer and the spermatangial branches did not have a prominent sterile apical cell, which are usually present according to Womersley (2003: 189). *Polysiphonia infestans* is a common species in the region and was originally described from material from Princess Royal Harbour, Albany (Womersley 2003: 184).

*Polysiphonia subtilissima* Mont. 1840: 199.

Specimen: Walpole Inlet (Site 4), epiphytic on immersed branches of terrestrial vegetation, 21 Apr. 2010, J.M.Huisman (PERTH 08243549).

This species typically occurs in sheltered locations (Womersley 2003: 180). The specimens have a limited prostrate system attached by rhizoids in open connection to the bearing cell, upright axes with 4 pericentral cells, and no trichoblasts or scar cells. One specimen bore immature tetrasporangia in a straight series. All of these features agree with this species as described by Womersley (1979: 470–472; 2003: 178–180).

*Polysiphonia teges* Womersley 1979: 494

Specimen: Newdegate I., Nornalup Inlet (Site 5), epilithic on rubble, 21 Apr. 2010, J.M.Huisman (PERTH 08243565).

Prior to the present collection, this species was known only from the type locality at Frenchmans Bay, Albany, and Spencer Gulf in South Australia (Womersley 2003: 202). It is a distinctive species characterized by prostrate axes with rhizoids in open connection with the bearing pericentral cell, and axial cells each with 6 pericentral cells. Trichoblasts were absent or rudimentary in the present collection, but many apices were denuded.

*Spermothamnion cymosum* (Harv.) De Toni 1903: 1226.

Specimen: Entrance channel, Nornalup Inlet, epilithic, 20 Apr. 2010, J.M.Huisman (PERTH 08243980).

*Spermothamnion cymosum* is represented in the collections by several specimens comprising uncorticated prostrate filaments (cells 70–90 µm in diameter), bearing simple or sparsely dichotomously branched upright axes. Some plants bore tetrahedral tetrasporangia and polysporangia, these 55–80 µm in diameter and arising terminally on lateral branches. Both the habit and tetrasporangia agree with the description and figures given by Gordon (1972: 117–119, fig. 38E) and Womersley (1998: 225). The species is rarely collected and the only reproductive structures previously known are the aforementioned tetrasporangia. Consequently, its generic assignment has been regarded as tentative, as details of female reproductive structures and carposporophyte architecture are necessary for definite placement. The present collections include the first recorded male specimens. The arrangement of spermatangia (described in full below) in distinct heads (Fig. 4H) supports the inclusion of *S. cymosum* in *Spermothamnion*, but this placement must remain unconfirmed until female gametophytes and carposporophytes are collected.

Spermatangia in heads arising in unilateral series on upright axes, sessile or with single-celled stalks (Fig. 4F), if the latter then often in pairs. Spermatangial heads 75–120 µm long, 30–50 µm broad, with 4–6 axial cells bearing radial (often obliquely cut off) spermatangial

mother cells and spermatangia, the basal cell generally proximally naked.

*Spyridia filamentosa* (Wulfen) Harv. 1833: 337.

Specimen: Entrance channel, Nornalup Inlet (Site 1), 20 Apr. 2010, J.M.Huisman (PERTH 08243581).

*Spyridia filamentosa* is a widespread species found on most Australian coasts and temperate and tropical seas worldwide. The present specimens agree with the descriptions given by Womersley & Cartledge (1975: 222), Huisman (2000) and Womersley (1998: 372).

*Stylonema alsidii* (Zanardini) K.M.Drew 1956: 72.

Specimen: Entrance channel, Nornalup Inlet, epiphytic on *Chondria angustissima*, 21 Apr. 2010, J.M.Huisman (PERTH 08243948).

This species is a diminutive epiphyte that is common in most seas. Zuccarello *et al.* (2008) analyzed DNA sequences generated from geographically widespread specimens and concluded that this was a truly ubiquitous species.

### Seagrasses

*Halophila decipiens* Ostenf. 1902: 260.

Specimen: Nornalup Inlet (Site 7), 21 Apr. 2010, M.Rule & A.John (PERTH 08243654).

Fruiting plants of *H. decipiens* were collected by benthic grab from a relatively deeper site in the middle of Nornalup Inlet. Leaves of these plants displayed the spiny margins and surface typical of this species, features that distinguish it from the somewhat similar looking *Halophila ovalis*. Kuo & Kirkman (1995: 336) recorded this species from several inlets along the south coast of Western Australia, including Nornalup Inlet. Their record, however, was based on a 'drift leaf' and not an *in situ* collection. This species was also recorded by Brearley (2005: 366).

*Zostera polyclamys* (J.Kuo) S.W.L.Jacobs & Les 2009: 423.

Specimen: Entrance channel, Nornalup Inlet (Site 1), on sand at 1.5 m depth, 20 Apr. 2010, J.M.Huisman (PERTH 08227632) (Fig. 3G).

The present specimens matched the description of this species (as *Heterozostera*) by Kuo (2005: 124–126), including the smooth epidermis and lack of upright stems. The inclusion of *Heterozostera* species in *Zostera* is based on the phylogenetic scheme proposed by Les *et al.* (2002) and Jacobs & Les (2009), a scheme that has not been universally accepted (see Kuo 2005) but one that appears to be the most reasonable interpretation of the available data. This species was recorded by Hodgkin & Clark (1999) as *Heterozostera tasmanica*, which at that time was more broadly conceived. *Zostera* sp. (presumably this species) was also recorded by Brearley (2005: 366).

### Cyanobacteria

*Spirulina subsalsa* Oerst. ex Gomont 1892: 353.

Specimen: Newdegate I., Nornalup Inlet, forming mats on sand at 1.5 m depth, 21 Apr. 2010, J.M.Huisman (PERTH 08243638).

This species forms mats of fine green filaments on the

sandy bottom (Fig. 3H). The individual trichomes are very narrow (1–2 µm diam.) and are regularly and tightly spirally coiled. According to McGregor (2007: 43), this species is cosmopolitan and is considered to be euryhaline.

### Other Records

*Ruppia megacarpa* R.Mason 1967: 525, "swan grass"

This seagrass species was recorded by Hodgkin & Clark (1999) and Brearley (2005) as growing in shallow water on sand flats near the Deep River delta and stunted plants in south eastern shore, and was also recorded from Nornalup Inlet by Boyce *et al.* (2001) and Svensson *et al.* (2007). Brearley (2005: 366) suggested that it was not prolific and was often covered with epiphytes such as the red alga *Polysiphonia*. Although this species was not collected during the 2010 survey, it is well known and unlikely to be misidentified, and we therefore have no reason to question its occurrence in the Walpole and Nornalup Inlets.

*Halophila ovalis* (R.Br.) Hook.f. 1858: 45, "paddle weed"

This species was recorded by Brearley (2005: 366), along with the congeneric *H. decipiens*, but was not collected during the 2010 survey and no vouchers are present in PERTH. It is a distinctive species, however, and we therefore have no reason to doubt the record.

*Chaetomorpha linum* (O.F.Müll.) Kütz. 1845: 204.

This species is the only one of the older records represented in PERTH by a named voucher [Walpole Inlet, 9 July 1971, R.Lenanton (PERTH 07067011)]. As described by Womersley (1984: 176), *C. linum* has filaments 200–400 µm in diameter with a length/breadth ratio (L/B) of cells 0.5–1.5. PERTH 07067011 is a mixture of 2 species of *Chaetomorpha*, neither of which appears to be *C. linum*. One, with broad cells 190–260 µm diam, L/B 1–2, agrees with *C. billardierei* Kütz. The second, with cells 75–100 µm in diameter and L/B 2.5–5, has the size of *C. capillaris* but the cell proportions of *C. indica*. This latter specimen is identical to the recent collections referred to *C. indica* based on cell proportions. Both species on sheet 07067011 were therefore also collected in the 2010 survey, but not *Chaetomorpha linum*, the presence of which is regarded as uncertain. *Chaetomorpha linum* was also recorded by Brearley (2005: 366), along with *C. aerea* (Dillwyn) Kütz., as abundant in 1973–74.

*Ulva intestinalis* L. 1753: 1163.

This species was previously recorded as *Enteromorpha*, but all species of that genus are now included in a more broadly conceived *Ulva*, following the studies of Hayden *et al.* (2003). *Ulva intestinalis* was recorded for the inlets by Hodgkin & Clark (1999), and Brearley (2005: 367) noted that floating mats of *U. intestinalis* and *Chaetomorpha billardierei* were present in shallow water on the east side of the inlet in 1987. This species was not collected in the present survey and no vouchers are lodged in PERTH. Of congeneric species, only *Ulva paradoxa* was recorded in the 2010 survey. Recognition of species within *Ulva* can be difficult, but *U. intestinalis* and *U. paradoxa* are both distinctive and unlikely to be confused. Thus, while we are unable to confirm the record of *U. intestinalis*, we can equally not refute it.

## Discussion

### Taxonomy

Forty-nine species of marine algae and seagrasses are recorded for the Walpole and Nornalup Inlets, including 15 green algae, 11 brown algae, 18 red algae, 4 seagrasses, and one cyanobacterium. In addition, several epiphytic diatoms and inconspicuous cyanobacteria are noted. This represents a substantial increase on the 14 species previously known from the inlets and is a more realistic appraisal of the diversity. Unfortunately similar studies of south-western estuaries are mostly lacking, with only Waychinicup Estuary receiving comparable detailed attention (Phillips & Lavery 1997). That study recorded 40 species of macroalgae and 5 seagrasses, a diversity seemingly comparable to that recorded herein, but significantly only 5 species were common to the two estuaries (*Chaetomorpha aerea*, *Cystoseira trinodis*, *Colpomenia sinuosa*, *Dictyota dichotoma*, and *Heterozostera tasmanica*, the latter probably = *Zostera polychlamys*). Other studies have focussed primarily on macrophyte populations in respect to nutrient loading (*e.g.* Lukatelich *et al.* 1987), with floristic surveys of secondary importance. Hillman *et al.* (2000) recorded 4 seagrasses and 13 macroalgae for the Leschenault Inlet, but several of these were identified only to genus, making direct comparisons difficult. Nevertheless, they recorded the dominant species as the seagrass *Halophila ovalis*, the green alga *Chaetomorpha linum*, and the brown alga *Hormophysa cuneiformis* (as *H. triquetra*), of which only *H. ovalis* is reliably recorded for the Walpole and Nornalup Inlets. Lukatelich *et al.* (1987) reported that the seagrass *Ruppia megacarpa*, a species that is relatively rare in the Walpole and Nornalup Inlets, comprised over 90% of the marine plant biomass in the Wilson Inlet. These disparities suggest that the marine flora of each estuarine system is likely to be unique, and each will require dedicated floristic surveys.

Of the 49 species recorded for the Walpole and Nornalup Inlets, most are relatively common elements of the south-western Australian marine flora, but a few warrant particular mention. One of the more common species in the inlets proper is a species of *Codium*, a genus of green algae with an essentially worldwide distribution and represented on the southern Australian coast by 16 species (Womersley 1984). The present collection does not, however, agree with any previously described species and appears to be new to science. It will be described formally elsewhere, as part of a monograph of Western Australian *Codium* currently in preparation (see Hart & Huisman 2010). *Codium* includes the invasive pest *C. fragile* subsp. *fragile*, which has been introduced to eastern and southern Australia and was recently discovered in Albany harbour (Hart & Huisman 2010). The new species, however, is clearly distinct from *C. fragile*, both morphologically and molecularly, and does not appear to pose a threat to the Walpole and Nornalup Inlets Marine Park. Collections of two species, *Mazoyerella australis* and *Spermothamnion cymosum*, included specimens bearing reproductive structures that were hitherto unrecorded. In the case of *Mazoyerella australis*, these structures will be described in detail elsewhere, as part of a DNA sequence study assessing the generic affinities of this species. Preliminary results indicate that

it is incorrectly placed in *Mazoyerella*. The collection of *Spermothamnion cymosum* included male specimens and the structure of the spermatangial heads supports the inclusion of this species in *Spermothamnion*, although the still unknown female and carposporophytic specimens are required for confirmation. Lastly, *Ossiella pacifica*, a species hitherto known from warmer waters of the Pacific Ocean, is newly recorded for mainland Australia. The reasons for this unusually disjunct distribution are unclear and will require further study.

### Ecology

The marked disparity in the number of algae and seagrass species collected at sites in the entrance channel (34 taxa), Nornalup Inlet (14–17 taxa) and Walpole Inlet (10 taxa) indicates that the diversity of marine plants diminishes with increasing distance from the sea. Although it is beyond the scope of this study to clearly identify the cause of this distribution, some points relating to the hydrology of the inlet system are likely to be relevant. This survey was conducted in autumn (April) when water clarity is highest and environmental conditions were relatively stable throughout the system, but the inlet waters can change markedly with the onset of freshwater river flows during the winter (Hodgkin & Clark 1999). Winter water temperatures may drop from summer highs of >20 °C to ca. 12 °C and a pronounced halocline may form with water of <10 ppt salinity flowing above relatively saline deeper waters. Notably also, the typically tannin-stained river water can markedly lower water clarity in the inlets. Although the extent of these seasonal changes varies annually with the amount of rain received by the surrounding catchments, and the subsequent volume of riverine discharge, the change in water quality could reasonably be expected to be highest in the upper reaches, with the impact lessening further seaward where there is greater tidal exchange. These seasonally variable environmental conditions strongly influence the use of estuarine habitats by mobile organisms such as fish, which may leave the system for periods or move within it to avoid brackish water (Potter & Hyndes 1999). Such variable conditions are also most likely to limit the capacity of some marine algae and seagrasses to successfully establish within the Walpole and Nornalup inlets.

While twelve species that occurred at the entrance channel site were not recorded further inside the inlets, other species were present only within the inlet basins, including two algae species that occurred only in the Walpole Inlet (Table 1). Moreover, most of the species found in the inlet basins were reproductive, suggesting that these populations may be self-propagating and not dependent on oceanic recruitment. These findings suggest that the distributional patterns observed in this study are not simply a reflection of marine species entering the system and diminishing in diversity due to an increasing estuarine influence. It is likely that a number of the species collected during this survey are particularly tolerant of estuarine conditions, such as diminished temperature, salinity and water clarity. This may be especially so in the Walpole Inlet, which is relatively distant from the ocean and where fine silt is prevalent. In fact, some of the specimens recorded during this study were actually found to be covered by silt at the



time of collection. The particularly high tolerance to large ranges in water temperature and salinity of *Polysiphonia subtilissima*, which was found exclusively in the Walpole Inlet during this study, has been previously described in relation to its occurrence in the muddy upper reaches of a North American estuary (Fralick & Mathieson 1975).

#### Further study

While this survey significantly builds on the existing knowledge of marine plants in the Walpole and Nornalup Inlets, it does represent a single sampling event. More detailed taxonomic and ecological studies of these species in the inlet system are required, especially with regard to their response to environmental conditions associated with the hydrological cycle. Documentation of the marine flora (and fauna) provides a baseline for comparison with future surveys. The establishment of the Marine Park provides a degree of protection, but there will undoubtedly be increasing pressures with additional development and the potential for nutrient enrichment, plus the impact of global climatic change cannot be ignored. Studies such as this, with all records backed by voucher collections and therefore able to be re-examined, are vital if the values that led to the Park's declaration are to be monitored and maintained.

**Note added in proof:** Following the taxonomic revision of Draisma *et al.* (2010), *Cystoseira trinodis* (Forssk.) C. Agardh is now known as *Sirophysalis trinodis* (Forsskal) Kütz.

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