Rare Marine Macroalgae of Southern Australia

by

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Submitted in fulfilment of the requirements for the Doctor of Philosophy

University of Tasmania December 2012

Declaration of Originality

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Acknowledgements

I sincerely thank Graham Edgar, Jamie Kirkpatrick and Neville Barrett for guidance and support throughout my candidature.

Abbreviations and Sources of Data

AVH: Australia's Virtual Herbarium, Council of Heads of Australasian Herbaria, viewed March 2009, http://avh.ala.org.au/

AD: State Herbarium of South Australia, http://www.flora.sa.gov.au/index.html

PERTH: Western Australian Herbarium, http://www.dec.wa.gov.au/content/category/41/831/1821/

MEL: National Herbarium of Victoria,, Royal Botanic Gardens Board, Melbourne, MELISR database, dated 03/03/2009. http://www.rbg.vic.gov.au/science/information-and-resources/national-herbarium-of-victoria

HO: Tasmanian Herbarium, Hobart http://www.tmag.tas.gov.au/collections_and_research/tasmanian_herbarium2,

GA: Geosciences Australia, http://www.ga.gov.au/

CSIRO: Commonwealth Scientific Industry and Research Organisation, CSIRO Atlas of Regional Seas data. http://www.marine.csiro.au/~dunn/cars2009/

FS: Fiona Scott personal herbarium

Diving and logistic assistance

Neville Barrett, Matt Cameron, Toni Cooper, Marlene Davey, Graham Edgar, Amelia Fowles, Dane Jones, Gerald Kraft, Tania Mendo, Iona Mitchell, Elisabeth Oh , Prue Scott, Rick Stuart-Smith, Jemina Stuart-Smith , Robert Wills, Carolina Zagal.

Technical assistance

Justin Hulls and Mark Morphett (ArcGIS), Austin Pepper (database formatting), Russell Thomson (Random Forests), Brett Summerell (AVH data), Robert Baldock, Rex Hunt and Fred Gurgel (AD herbarium data), Timmothy Newlands and Lynnette Cave (HO herbarium data), Ann Preece (proof-reading), Parks Tasmania (collecting permits).

Financial assistance

National Environmental Research Program (NERP) / Commonwealth Environmental Research Facilities (CERF) Marine Biodiversity Hub, (PhD scholarship awarded to Fiona Scott).

The Winifred Violet Scott Charitable Trust (grant to Fiona Scott).

Australian Research Council (ARC) linkage project 'Incorporation of vulnerability and irreplaceability into marine protected area planning' (funding to Graham Edgar, the candidate's principal PhD supervisor).

Abstract

The aims of this thesis were to document the pattern of distribution of the apparently rare marine algal species endemic to southern Australia, test the validity of the apparent rarity and seek causes of the patterns. A review of the concepts and causes of rarity with special reference to the marine macroalgae of temperate Australia is preceded by a brief background to macroalgal taxonomy, growth patterns, reproduction and ecology.

One hundred and forty-two species met the selected rarity criterion of occurring at five or fewer localities, as data-based in the Australian Virtual Herbarium. Seventy-one rare species were of broad range (>500 km), forty-five of narrow range (50–500 km), and twenty-six of restricted range (<50 km). The characteristics common to > 60% of rare macroalgae were that of small size and of filamentous or coarsely-branched habit. Of the three major taxonomic groups (Divisions Chlorophyta, Heterokontophyta and Rhodophyta) rare species within the Heterokontophyta (brown algae) were proportionally under-represented. Recognised rare species are discussed in terms of taxonomic affiliation, range, form and function, and co-occurrence of species in localised areas.

Six ‘centers of rarity’, areas with high proportions of rare species, were identified. These were Rottnest I WA, King George Sound WA, Eucla WA, Fowlers Bay SA, Port Phillip Bay VIC and D’Entrecasteaux Channel TAS. Using the random forest procedure, analyses indicated that there are particular environments and distinct environmental extremes that favour high proportions of rare species. Associations were found between high proportions of rare species and extremes of sand substratum, nitrate, phosphate, and chlorophyll-*a*. Overall, the analyses suggested that rare species are predominantly associated with low-nutrient environments and sandy substrata, whereas highly productive waters appear to be bereft of rare species.

The potential association of rare species with rare environments was tested. Fifteen environmental domains were identified, and Port Phillip Bay VIC and south-east Tasmania emerged as areas particularly favourable for rare species. However, the

spatial extent of domains was not related to the mean proportion of threatened species within them. Other possible explanations for concentrations of rare species or high proportions of rare species, are associations with habitat complexity, or associations with escape routes along glacial drainage pathways during sea level change. Such conditions pertain to the areas with the highest concentrations of rare species.

A field program of target-searching for rare species was undertaken to elucidate rare species distributions. Results from underwater visual census surveys (UVC) supported the patterns of rare species found in historical herbarium records. A total of 489 macroalgal species were recorded collectively from 111 UVC surveys. Sixteen rare species were observed, representing ~11% of the 142 rare species. Notable range-extensions are reported for 7 rare species, and specific life history phases are newly recorded for 2 rare species.

A novel find that comprises a new family and probable new order, *Entwisleia bella* gen. et sp. nov. (F. Entwisleiaceae fam. nov.), was described upon a suite of morphological features that distinguish it from other known taxa. Planned genetic analyses will elucidate the ordinal classification of the new taxon and contribute to the formal proposal of the species.

Fifty rare marine macroalgae have been recorded from sites within sanctuary (no-take) zones of existing marine protected areas. A general paucity of adequate abundance and seasonality data thwarts confirmation of occurrence and/or persistence of these species within sanctuary zones, and therefore they cannot be firmly considered as adequately safeguarded.

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Note: Algae have been referred to as 'plants' in some passages of the text in order to retain consistency with historical literature.

Chapter 1: Rare marine macroalgae – Introduction

The maintenance of the biodiversity of the planet is an international and national goal. An essential precursor to maintaining biodiversity is to determine which species are rare or threatened, and to document their distributions. Marine algae are a biological group for which this task is just beginning, and the importance of the rare species in overall ecosystem functioning is poorly known.

In this introductory chapter I provide background material on rarity in the marine macroalgae of temperate Australian waters. The characteristics of macroalgae are introduced, followed by descriptions of geographic patterns of marine biota. The topics of rarity, the conservation of rare species, and the means of investigating these species are addressed. The rationale and layout of the thesis are given.

1.1 Marine macroalgae: an overview

High biomass, high primary productivity and various functional capabilities make marine algae critical components of photic ecosystems. The macroalgae provide food, shelter and oxygen to other components of the ecosystem. They are found in tropical, temperate and polar waters, across a variety of environments, including places where there can be extremes in temperature, salinity, water movement (wave energy) and immersion time. They have been used by humans, in fertilisers, in soil conditioners, as livestock feed, as 'biological scrubbers', in pharmacological and health products, and as food.

To highlight the diversity and ecological significance of macroalgae in the context of the current thesis on rare species of temperate Australian waters, essential characteristics of the algal groups are briefly described.

1.1.1 Algal taxonomy

Attempts to give names to living organisms enable us to communicate ideas about them. A natural by-product of our sorting them into related groups are classification schemes, usually based on either form or function. Although it is difficult for scientists to reach consensus as to which classification scheme is most appropriate for the algae, many accept their position within the Kingdom Eukaryota, a large and diverse group of organisms that includes many plant-like and animal-like forms (Huisman and Saunders 2007). At genus and species levels, the currently accepted binomials are collated within *AlgaeBase* (Guiry and Guiry 2010), an online database that reflects the principles of the International Code for the Nomenclature of Algae, Fungi and Plants (formerly the International Code for Botanical Nomenclature).

For the purpose of understanding the macroalgae in context of all the major algal groups, a list of algal divisions and classes is included here (Table 1.1). The macroalgae are found within two classes of Division Rhodophyta, a single class of Division Heterokontophyta, and five classes of Division Chlorophyta.

Table 1.1 (pro parte) Scheme of algal divisions and classes in general acceptance (from Huisman and Saunders 2007). Groups containing the marine macroalgae are highlighted in bold script.

PROKARYOTES		
	Division Cyanophyta	
		Class Cyanophyceae, including 'Prochlorophyceae'
EUKARYOTES		
	Division Glaucocystophyta	
		Class Glaucocystophyceae
	Division Cyanidiophyta	
		Class Cyanidiophyceae
	Division Rhodophyta	
		Class Rhodellophyceae
		Class Comsopgonophyceae
		Class Bangiophyceae
		Class Floridiophyceae
	Division Heterokontophyta	
		Class Bolidophycae
		Class Chrysophyceae
		Class Phaeothamniophyceae
		Class Pelagophyceae
		Class Synurophyceae
		Class Xanthophyceae
		Class Eustigmatophyceae
		Class Raphidophyceae
		Class Dictyophycophyceae
		Class Phaeophyceae
		Class Bacillariophyceae
	Division Haptophyta	
		Class Prymnesiophyceae
		Class Pavlovophyceae
	Division Cryptophyta	
		Class Cryptophyceae

Division Dinophyta
Class Dinophyceae
Division Euglenophyta
Class Euglenophyceae
Division Chlorarachniophyta
Class Chlorarachniophyceae
Division Chlorophyta
Class Prasinophyceae
Class Chlorophyceae
Class Ulvophyceae
Class Trentopohliophyceae
Class Cladophorophyceae
Class Bryopsidophyceae
Class Dasycladophyceae
Class Oedogoniophyceae
Class Trebouxiophyceae
Division Streptophyta (pro parte)
Class Zygnemophyceae
Class Chlorokybophyceae
Class Coleochaetophyceae
Class Klebsormidiophyceae
Class Charophyceae
Class Chaetosphaeridiophyceae

Table 1.1 (continued) Scheme of algal divisions and classes in general acceptance (from Huisman and Saunders 2007). Groups containing the marine macroalgae are highlighted in bold script.

Since the inception of the Linnaean binomial system in the late 1700s, major changes in taxonomy have been the result of advancement in methodologies such as light microscopy (structure), electron microscopy (ultrastructure), and nucleotide sequence studies (genetic makeup). Studies using gene phylogenies are now being used to infer taxonomic relationships and evolutionary processes, for example *rbc*L (RuBisCO large subunit, an enzyme that facilitates the primary CO_2 fixation step in photosynthesis, and is encoded in plastid genes) has proved successful in determining red algal phylogenies (Freshwater et al. 1994, Saunders 2005a, Withall and Saunders 2006). The gradual acceptance of molecular tools in taxonomy has highlighted the limitations of using only morphology-based taxonomic schemes, as well as the particular challenges that are faced by field biologists. The task of algal identification can be extremely difficult in the field or laboratory if species, or even genera are distinguishable from one another on molecular characteristics alone. Consequences of applying molecular criteria for taxonomy can include situations where algae formerly separated on the basis of distinct morphology are now taxonomically combined in concordance with molecular data, such as species of foliose *Ulva* and filamentous *Enteromorpha*, now combined under the one name, *Ulva* (Hayden et al. 2003, Zuccarello 2011). Equally, the establishment of new taxa based largely on molecular phylogenetic data (e.g. in the Bangiales (Sutherland et al. 2011)), whilst elucidating species and generic relationships may by their very nature result in schemes unusable in field situations.

The sheer volume of work generated by DNA bar-coding is daunting and very much an on-going concern (Dixon and Saunders 2011). For field biologists and ecologists, the classification of macroalgae into form and functional groups rather than taxonomic groups, may be a more realistic approach to investigating the algal components of marine ecosystems– using a variant of folksonomy rather than taxonomy. Even with its inherent limitations this approach addresses the problems of phenotypic plasticity and "intermediate" morphologies that may well represent hybrid forms. The classification scheme adopted for this current thesis is that of Huisman & Saunders (2007) which in itself is based on the work of van den Hoek *et al.* (1995).

1.1.2 Growth patterns and forms

As part of the Kingdom Eukaryota marine macroalgae comprise a large assemblage of diverse organisms, particularly with respect to their size and form and to some degree their phylogeny. Compared to seed plants there is little morphological differentiation in the macroalgae. The majority are multicellular, attached to substrata by means of a holdfast or filamentous rhizoids, and either have crustose or vertical growth of the photosynthetic parts of the thallus. Plant height can vary from a few millimeters as found in many turfing or crustose species to tens of metres, as evidenced in large canopy-forming species such the giant kelp (*Macrocystis pyrifera* (Linnaeus) C. Agardh). Exceptional circumstances, such as rapid tidal currents or waters of high nutrient load, may encourage seemingly excessive algal growth (*Ulva* plants > 2 m high have been observed by the author in waters adjacent to a sewage treatment plant), but it is not known whether or not species have intrinsic size limits.

Various categories of functional forms have been described for macroalgae. These are based on features of texture (for example fleshy, cartilaginous, mucoid, wiry, stony, leathery), thallus form (crustose, filamentous, membranous, coarsely-branched, jointed-calcareous, thick-leathery), height (canopy-forming, understory, turfing, encrusting), and habitat (e.g. intertidal, subtidal, or free-floating, estuarine or oceanic, substratum type) (Littler and Littler 1980, Nishihara and Terada 2010). Since there are no sharp boundaries between some of these functional groups, designating taxa to specific categories is not always simple and researchers need to exercise judgment and provide justifications when recording and interpreting algal functional-form observations.

Many macroalgae are annuals or even shorter-lived, such as species of the ubiquitous green algal genus *Ulva*. Others are perennial and may live for tens of years with growth varying according to the seasons and ambient conditions. A wide range of growth rates (the velocity of change in organic mass over time) have been reported for algae, the governing factors being temperature, day length, and seasonal and annual environmental cues (Thomas 2002). Linear growth rates in the realm of tens of centimeters per day are reported for giant kelp (*Macrocystis pyrifera* (Linnaeus) C. Agardh) fronds, although the vast majority of macroalgal species would not exhibit such phenomenal growth.

1.1.3 Reproduction and life histories

Life cycles of macroalgae may be complex and generally involve a basic pattern of a spore-producing asexual phase (the diploid sporophyte) alternating with a gamete-producing sexual phase (the haploid gametophyte). However the progression from one phase to another varies greatly between species and taxonomic groups, and even though there have been many detailed studies on structure and reproduction of the algae over the decades since the remarkable and comprehensive treatises on algae by Fritsch (Fritsch 1935, 1945), the life cycles for many species remain unknown.

Alternation of generations can occur in all three Divisions containing macroalgae and may be either isomorphic in which the different generations are of similar appearance, or heteromorphic in which the different generations are of different appearance. Species with extreme morphological variation between generations were sometimes placed within two different genera due to the lack of life history information known at the time (e.g. *Derbesia/Halicystis* (Chlorophyta), *Adenocystis/Dictyosiphon* (Heterokontophyta) and *Asparagopsis/Falkenbergia* (Rhodophyta)). Sexual reproduction allows variation within a species, but in some algae sexual reproduction does not occur either through its phylogenetic loss or because it has not developed; in such cases no opportunities for the exchange or recombination of genetic material exist, with the result of population increase, but no variation (Bold and Wynne 1982).

Within some species life cycles more complex than an alternation of two generations (sporophyte and gametophyte) can occur through additional phases such as parthenogenesis, apospory or apogamy, in which there are no changes of ploidy level (Lobban and Harrison 1994). The tremendous variation in morphologies, phases and ploidy levels of macroalgae are thought to reflect quite different strategies in species survival and dispersal of progeny (Thomas 2002). As the life cycles for many species are still unknown and are verifiable only through algal-culture studies or genetic research, the herculean task of determining the life cycles of any *rare* species can only be imagined.

1.1.4 Aspects of macroalgal ecology

Macroalgae function as providers of habitat, food, and oxygen, and as colonizers of marine substrata. They can create habitats by modifying the profile of substrata such as rock, sand and mud, thus earning the epithet of ecosystem engineers (Jones et al. 1994). The upward vertical growth of many macroalgae can result in the construction of 3-dimensional habitats that provide food and/or shelter for animals. A prominent example of this process is the giant kelp forests (*Macrocystis pyrifera* (Linnaeus) C. Agardh) of southern Tasmania and the understory plants and animals that are sheltered by them. Shoals of fish hide amongst the dense stands of kelp, emerging from cover to feed only at particular times of the day, and many sessile organisms live on the stipes and blades. The keen diver with time can find remarkable examples of animals finding safety from predators in algal habitats through the development of camouflage as displayed by the leafy seadragon *Phycodurus eques* Gűnther with its spectacular leaf-like appendages, or through biomimicry as seen in the *Caulerpa*-mimicking nudibranch *Stiliger smaragdinus* Baba. However habitats can also be provided by prostrate macroalgal species, with the outward horizontal growth of the algae such as *Peyssonnelia* species creating habitats for invertebrates and minute turf algae.

Whilst providing a habitat and food for animals, macroalgae are in effect occupying space (substratum or vertical space) that could otherwise be available to sessile animals such as bryozoans, ascidians, sponges or corals. Keen competition between many species of both plants and animals for substratum space exists in most benthic ecosystems, perhaps more so on rocky reefs than on (less stable) sand or mud. Algal recruitment is regarded as a major ecological process in determining the distribution and abundance of macroalgae (Goldberg and Kendrick 2007). Algae may be successful colonizers not only in natural habitats but also in disturbed habitats that can result from events such as dredging or displacement of substrata by storms, as well as on newly-created surfaces such as jetties.

Being photosynthetic, algae are keystone components of most marine ecosystems in their capacity as primary producers, using light, carbon dioxide and water to produce oxygen, sugars and amino acids. Oxygen released by macroalgae into the surrounding water becomes available for marine animals requiring it for their own continuing survival, albeit in arguably lower quantity and less widespread distribution than that produced by the microalgae of the oceans. What may be seen as an algal 'quest for the light' can affect their cellular and tissue makeup, and even in the thallus structure of the macroalgae; specialized features such as flotation vesicles, stipes, and arrangements of plastids have variously developed to optimise the plants' exposure to light.

The production of sugars and amino acids facilitate algal growth and these products can be used as a critical measurement of primary production. Measuring primary productivity by the ^{14}C method (Steemann-Neilsen 1952) or chlorophyll fluorescence using pulse amplitude technique (PAM) fluorometry (Hanelt 2012) are techniques often employed. Aguiler *et al.* (1999) reported primary productivity rates (PAM method, with results expressed as growth rates) in the realm of 2-4% plant height d^{-1} for kelp forest understory macroalgae. For similar algal kelp communities assessed using the ^{14}C method, Miller *et al.* (2011) found 1-2.5 g C $m^{-2}h^{-1}$ of net primary production.

Overall, the primary production of macroalgae can provide food for species occupying many trophic levels within marine food webs. As a source of food for grazers, macroalgae can be directly eaten by herbivores or consumed in the form of broken fragments or detritus. The decline of individual plants (either death or loss of biomass) is largely the result of consumption by grazers. It is not only the thin or fine-branched plants that are eaten. Thick or leathery plants can also be subject to grazing pressure, such as the robust red algae consumed by abalone (Shepherd and Steinberg 1992) and portions of giant kelp blades consumed by snails, sea slugs and crustaceans (Edgar 1987, Rothäusler et al. 2009).

1.2 Why southern Australia is so interesting

1.2.1 Biogeography of Australian taxa

Biogeography, the science that documents patterns of biodiversity at broad scales, can be best achieved by integrating evolutionary, systematic, geological and ecological research (Poore and O'Hara 2007). Australia is well known for possessing many areas of high algal richness (Norton et al. 1996) and has many marine endemic families, genera and species (Hommersand 2007). The continent separated from the Arctic edge of Laurasia during the Mezozoic and most of the Tertiary eras (200–34 million years ago), and from Antarctica 140–95 mya, slowly drifting northward and eventually colliding with South-East Asia about 20 mya. For a long period the continent was isolated from the influences of other land masses facilitating the development of distinctive marine and terrestrial biota. Ancient links between East Asia and (northern) Australasia, between Australia and New Zealand, and between Australia and Antarctica have been proposed, based on specific floristic connections at family and genus levels within the Rhodophyceae and Phaeophyceae (Hommersand 2007). Hommersand (2007) also proposed pathways of migration of Australasian marine algae (his Fig. 76) and concluded that Australia is “less significant as a recipient than as a donor area”.

The recent studies of Kerswell (2006) and Currie *et al.* (2004) provide summaries of the most popular theories for the origins of biodiversity patterns, latitudinal gradients and so-called hotspots. A number of major hypotheses —the *species–area hypothesis* (Rosenzweig 1995); the *species–energy hypothesis* (Kaspari et al. 2004); the *species–productivity hypothesis* (Rosenzweig 1995); the *climate–productivity hypothesis* (Rosenzweig 1995); the *climate–stability hypothesis* (Stevens 1989); the *species–competition hypothesis* (Underwood 2007); *speciation–productivity hypothesis* (Rosenzweig 1995); *speciation–rate* (Currie et al. 2004); and the *mid-domain effect models* (Colwell and Lees 2000, Gotelli and Colwell 2001) —provide a range of explanations for biogeographic patterns. It is also possible that both vicariance (in which populations are separated by a geographic barrier, for example through glacial advance and retreat) and jump-dispersal (Cowie and Holland 2006) (in which the barrier is temporarily removed or bypassed, for example by rafting) have influenced macroalgal distribution patterns world-wide. Regional biodiversity patterns are thought to be the product of historical (geological) events, ecological (competition, disturbance and habitat) processes, and phylogenetic (evolutionary) processes (Schulter and Ricklefs 1993, Phillips 2001).

Specific biogeographic elements or provinces have been identified for Australian coastal waters but precise geographical boundaries have proved difficult to define. Proposals for bioregions are usually descriptive, based on floristic and/or faunistic discontinuities, and often make assumptions about sparsely-surveyed areas (Bolton et al. 2004). Although attempts at regionalisation have met with varied levels of acceptance there has been general agreement as to the number (6-8) and general extent of provinces of the Australian continent in which relatively distinct and homogeneous assemblages of marine biota can be found. Bennett and Pope (Bennett and Pope 1953, 1960) succinctly illustrated a six-province scheme based on littoral biota (reproduced here in Fig. 1.1), and discussed in detail how it varied from other proposals. Provinces recognised were the Dampierian (NW), Solanderian (NE coastal), Great Barrier Reef (NE offshore), Peronian (E), Flindersian (S) and Maugean (SE) provinces, basically the same (with a few finer-scale modifications) as subsequently adopted for qualitative descriptions of macroalgal floras (Womersley 1981, 1984). Recent investigations of floristic composition suggest that the three northern provinces should be considered as a single (tropical) province having a flora that merges with that of South East Asia (Huisman 2007), whereas further division into sub-provinces may be more appropriate for the southern coast (Southern, Eastern, Western and Restricted ‘elements’) (Womersley 1981, 1990, Phillips 2001).

For marine *micro*algae, the majority of which are free-floating, six provinces are described by Hallegraeff (2010). There are notable location and boundary differences between the microalgal and macroalgal schemes but distinct western and eastern elements are evident in both. Hallegraeff’s figure 1.1 illustrates the following provinces– Tropical Neritic (NW shelf and Gulf of Carpentaria), Tropical Oceanic (NE plus warm eddies of the East Australian Current, and NW oceanic plus occasional extension southwards via the Leeuwin Current), Great Barrier Reef (NE inshore), Temperate Neritic (NSW–TAS–SA), Ocean Transition (S) and Subantarctic (S). For freshwater algae (micro- and macroalgae) the paucity of comprehensive data confounds attempts to define meaningful floristic regions (Entwisle 2007, Vyverman et al. 2007). However, a distinct north-south divide occurs in the flora and regional areas of endemism have been identified for both freshwater micro- and macroalgal functional groups.

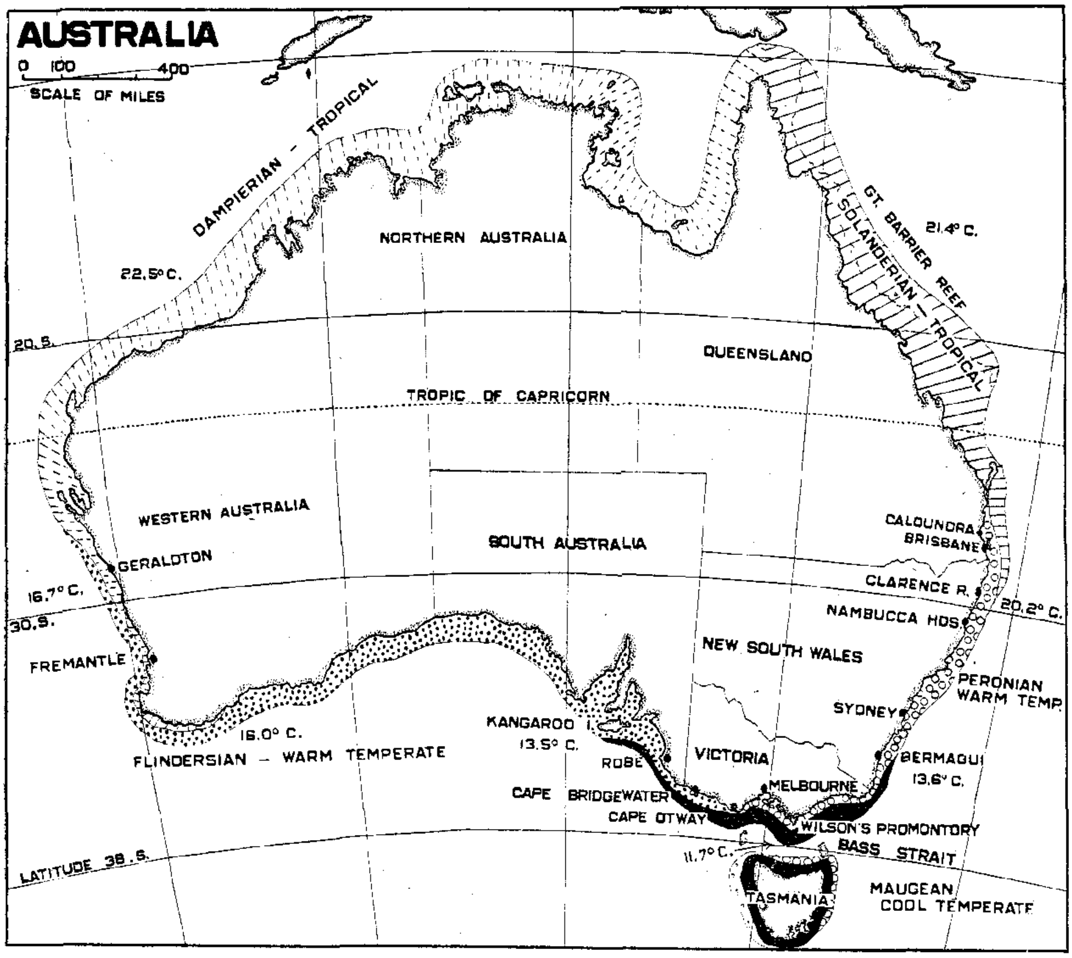

Fig. 1.1 Marine biogeographic provinces of the Australian littoral exposed coasts (reproduced from Bennett and Pope 1953: Fig. 5). Tropical biotas are hatched with approximately parallel lines, warm-temperate ones by circles and dots, and cool-temperate ones are solid black. Question marks on the west coast of Tasmania indicate lack of data on the fauna and flora. Minimum winter temperatures are included and appear opposite the part of the coast where they were recorded.)

1.2.2 Biogeography of southern Australian taxa

Australia has the longest east–west temperate coastline of the land masses in the southern hemisphere, spanning some 3000 km between longitudes 114°E and 148°E (roughly between Geraldton, WA and Cape Howe at the VIC/NSW border), and along which ~1500 species of macroalgae occur. Across southern Australia there are distinct ‘western’ and eastern’ species (Womersley 1990, Wernberg et al. 2009b, Waters et al. 2010) and it has been postulated that ‘western’ species could have evolved over a longer time period than those of the east, with both floras expanding along the southern coast where overlaps of marine flora components can be found (Hommersand 2007). Range-restricted species also exist and these isolated occurrences could reflect either relict populations or relatively recent evolutionary processes. The boundaries between the Flindersian and adjacent provinces remain concepts for ongoing discussion. In the west there are considerable overlaps of biota attributed to the Dampierian and Flindersian provinces, between Geraldton and Cape Leeuwin (Huisman 2007). In the east Millar (2007a) suggests a relatively sharp boundary between the Peronian and Flindersian provinces (in the vicinity of Green Cape), whereas others illustrate a Peronian province extending further westwards around the Victorian coast (Womersley 1981) and even to the NE of Tasmania (Bennett and Pope 1953).

The general patterns described by Bennett and Pope, Womersley, Phillips and others have been validated by the quantitative algal research of Waters *et al.* (2010) in which they described minor variations of the Flindersian, Maugean and Peronian provinces, and briefly discussed the applicability of the finer-scale bioregions proposed in the Integrated Marine and Coastal Regionalisation of Australia Version 4.0 (IMCRA 2006) to broad biological patterns. IMCRA evolved from the collations of data on distributions of biota and geomorphic features (IMCRA 1998, 2006). Patterns were illustrated through the generation of maps detailing Provincial Bioregions (based largely on demersal fish diversity data), Meso-scale Bioregions of inshore waters (defined using biological and physical information, including distributions of demersal fish, marine plants and invertebrates, seafloor geomorphology and sediments, and oceanographic data), and Geomorphic Units (14 classes of regions of similar geomorphology).

Studies of various taxa of southern Australian marine fauna have produced slight variations on the already familiar bioregionalisation patterns. Using cladistics for species occurrence data of echinoderms and decapods, O’Hara and Poore (2000) identified five primary subregions; three were identified on the basis of mitochondrial DNA phylogenetics of an asteroid sea-star Waters and Roy (2003); five were identified through studies of demersal fish distribution for continental slope and outer shelf depth (Last et al. 2005), and all show a general consistency with those described above for marine flora.

Both quantitative and qualitative approaches to regionalisation can be useful in the identification of local patterns nested within regional ones (Connell 2007, Bates et al. 2009). Along the southern Australian coast there are many estuarine, coastal and marine habitats for macroalgae. These are mangroves, sea grass beds, rocky reefs and unconsolidated sediments. Combinations of physical and environmental factors, such as temperature, light, salinity, exposure, nutrients and water movement, contribute to the establishment of macroalgae. Some communities are essentially driven by oceanographic processes that regulate the distribution, abundance and standing stock of ecosystem engineer species, such as the giant kelp (Graham et al. 2007).

Many species can tolerate variable habitat conditions and sometimes exhibit sufficient morphological plasticity to adapt (Lobban and Harrison 1994), even though the variation in morphology is neither consistent nor predictable. An example of such plasticity is found in *Macrocystis,* now recognised as a monospecific genus with *M. pyrifera* (Linnaeus) C. Agardh encompassing the four former species and numerous morphologies described from different environments (Demes et al. 2009, Macaya and Zuccarello 2010). Others species may require very specific conditions for survival, such as the typically tropical species *Acetabularia calyculus* Quoy and Gaimard and *Hormophysa triquetra* (J.Agardh) Kützing, both recorded for southern Australia but found only in the warm waters of the upper Spencer Gulf, surviving there possibly as relict populations from earlier periods of warmer conditions (Womersley 1984).

The temperate areas of southern Australia and Japan are the richest in macroalgae in the world, each containing some 350–450 genera (Kerswell 2006). At a species level these two areas plus the Mediterranean, the Philippines, the Atlantic European coast, Indonesia–Malaysia, New Zealand, Agulhas Province (RSA), California, the Caribbean and Korea are considered “species-rich” (>500 species) (Silva 1992, Bolton 1994, Phillips 2001). The polar regions are thought to be of the lowest diversity, and even if there are some distinguishable latitudinal or longitudinal richness gradients, globally the patterns are asymmetric (Bolton 1994, Norton et al. 1996, Phillips 2001). For southern Australia, the rich flora at family, genus and species levels is well recognised

(Kerswell 2006, Waters et al. 2010, Gurgel 2011, Smale et al. 2011a) and can be put into perspective when compared to estimated numbers of macroalgal species found worldwide, within Australia and its territories, in southern Australia, and at offshore Macquarie Island (subantarctic Tasmania) (Table 1.2).

	Chlorophyta (green algae)	Phaeophyceae (brown algae)	Rhodophyta (red algae)	TAXA COMBINED
WORLD (Thomas 2002)	1,000 -2,000	1,500 -2,000	5,000 -6,000	7,500-10,000
AUSTRALIA (incl. territories, excl. Antarctica) (Cowan 2006)	434	451	1541	2478
Southern AUSTRALIA (incl. TAS & territories, excl. Antarctica) (Waters et al. 2010)	n/a	n/a	n/a	~1500
Southern AUSTRALIA (Cape Naturaliste WA eastwards to Cape Howe VIC, incl. TAS) (Womersley 2003)	123	231	778	1137
Southern AUSTRALIA endemics (Geraldton WA eastwards to Cape Howe VIC, incl. TAS) (Phillips 2001)	50	130	435	615
TASMANIA (incl. offshore islands, but excl. Macquarie I.) (Sanderson and Balmer 2012)	69	145	421	635
MACQUARIE I. (Ricker 1987)	15	28	60	103

Table 1.2 Estimated numbers of marine macroalgae for the three major taxonomic groups, plus the combined taxa (n/a = not available).

The areas of highest macroalgal diversity within southern Australian coastal waters are south-west Western Australia, the Gulfs region of South Australia, Port Phillip Bay in Victoria and south-east Tasmania (this thesis, Chapters 3, 4), with distinct diversity ‘hotspots’ occurring in Western Australia in the general vicinity of Rottnest Island, Perth and Albany, in South Australia around Pearson Islands, Elliston, Kangaroo Island, Victor Harbour, Nora Creina and Port MacDonnell, in Victoria around Port Phillip Heads and Westernport Bay, and in Tasmania around the Tamar, Derwent and Huon Estuaries (Womersley 1990). Ricklefs (2004) surmises that regional species richness appears to be correlated with local species richness. A combination of physical and environmental factors may contribute to the existence of specific areas of algal richness. Nutrient-rich ocean currents and upwellings such as the Leeuwin Current off Western Australia, the Bonney Upwelling flowing past western Tasmania, western Victoria and south-eastern South Australia, and the Eastern Australian Current flowing southwards off the east Australian coast could conceivably contribute to seasonal productivity and diversity, although there appears to be little actual evidence that productivity-driven diversity of macroalgae exists, at least on a global scale (Kerswell 2006).

Opinions on global gradients of biological diversity vary. A latitudinal gradient of decreasing species richness from tropical to polar areas is recognised for many taxonomic groups (e.g. mammals, fish, insects, plants) (Roberts et al. 2002, Willig et al. 2003). For macroalgae, Bolton (1994) and Santelices and Meneses (2000) find no evidence of consistent latitudinal trends for seaweed floras (at species level), whereas Kerswell finds both distinct latitudinal (peaks in mid-latitudes) and longitudinal (Indo-Pacific and western Atlantic Oceans) gradients in algal richness (genus level). Analyses at the same taxonomic level would be required to investigate or reconcile the differences found by these authors.

Declines in habitat-forming species and changes in species diversity are documented for Australia's south-eastern coastal waters. Predictions have been made of further range-shifts of macroalgae and associated species with further increases in ocean temperature (Wernberg et al. 2011a, Wernberg et al. 2011b). Changes in climate and negative impacts resulting from human activity and demographic expansion are likely to directly or indirectly drive habitat-forming macroalgal population decline and changes in species distributions (Connell et al. 2008, Wernberg et al. 2009a).

1.2.3 Endemism of flora and fauna

The term endemism relates to species that occur only within a defined area (Anderson 1994). Because much of the management of coastal waters in Australia occurs at the

State level, biota are often described as endemic to a (political) state, but a more biologically meaningful approach would be to describe endemism in terms of natural ecological units. The oft-used term 'hotspot' either describes "those global areas where a high number of endemic species were found in a relatively small geographical area" (Myers 1989, Marcot and Flather 2007), or indicates areas of both high endemism and high levels of threat (Myers et al. 2000). Designating an area a 'hotspot' or 'coldspot' can be confusing if the area or the biotic characteristics are not clearly defined.

Quantitative or semi-quantitative methods for identifying areas of local endemism using cladistics or pattern analyses have been devised (Crisp et al. 2001, O'Hara 2002, Elith et al. 2006). For cases in which historical datasets are used it is important to interpret results bearing in mind collection biases. Various methods have been developed to interpolate information for such data-deficient areas to address the issue of lack of records from poorly-collected or un-surveyed areas (Williams et al. 2009).

Areas of high levels of species richness and endemism have been described for Australian marine fauna (Wilson and Allen 1987, Li et al. 1996, Last and Stevens 2009) and marine flora (Womersley 1990, Bolton 1994, Phillips 2001, Hommersand 2007, Waters et al. 2010). The southern Australian (Cape Naturaliste to Cape Howe) endemism at the species level in the marine flora has been estimated at 71% (Womersley 1981), 62% (Phillips 2001), 57% (Phaeophyceae only) (Norton et al. 1996), and 42% (Phaeophyceae only) (Bolton 1996). For this region Phillips (2001) finds that high levels of species endemism are associated with high levels of species richness. At the next highest taxonomic level (genus), endemism has been estimated at 26% (Womersley 1981) and ~12% (Kerswell 2006) including several monospecific genera. The highest proportions of both species and genus endemism are consistently found within the Rhodophyta (Table 1.3).

GENERA	Womersley 1981		Kerswell 1996 (data estimated from contour maps)		Phillips 2001 (*excluding Delesseriaceae & Rhodomelaceae)	
	no. endemic genera	% endemic genera	no. endemic genera	% endemic genera	no. endemic genera	% endemic genera
Chlorophyta	3	11%	-	-	2	5%
Phaeophyceae (Heterokontophyta)	12	19%	-	-	20	19%
Rhodophyta	72	30%	-		Gig 25 Cer 26	Gig 35% Cer 40%
Total Endemics & % endemic of all genera	87	26%	~53	~12%	-	-

SPECIES	Womersley 1981		Bolton 1996 (coastline section of Victoria)		Phillips 2001 (*excluding Delesseriaceae & Rhodomelaceae)		Norton *et al.* 1996 (Womersley 1987)	
	no. endemic species	% endemic species	no. endemic species	% endemic species	no. endemic species	% endemic species	no. endemic species	% endemic species
Chlorophyta	43	46%	-	-	50	40%	-	-
Phaeophyceae (Heterokontophyta)	134	70%	140	42%	130	59%	131	57%
Rhodophyta	538	75%	-	-	435	77%	-	-
Total Endemics & % endemic of all species	715	71%	-	-	615	62%	-	-

Table 1.3 Levels of macroalgal genus (upper table) and species (lower table) endemism in southern Australia (Cape Naturaliste to Cape Howe). Resolution of family groups, where available, have been maintained. [Gig = Gigartinales, Cer = Ceramiaceae]. * Phillips did not analyse the Delesseriaceae or Rhodomelaceae.

Several factors may have contributed the high levels of southern Australian endemism within the marine flora. One was the separation of Australia from Antarctica that was a gradual vicariance event that greatly influenced the evolution of Australian flora, and another was the formation of the Tasman Basin off the east coast (Hommersand 2007). Subsequent opening of the Drake Passage and the formation of the West Wind Drift, a current now circulating around the southern hemisphere, also influenced the flora in terms of facilitating species dispersal and greatly reducing water temperatures. Long range dispersal of macroalgal propagules (across oceans) was thought to be uncommon, with the genetic exchange between Australian coasts and those of other land masses essentially limited by particular characteristics of propagules, including their longevity and buoyancy (Hoek van den 1987, Santelices 2002). However, distinct patterns of directional long-range dispersal along the West Wind Drift has been described (Hommersand 1986, 2003). Through research based on DNA *rbc*L sequencing and inference of evolutionary history, and the subsequent identification of species affinities between southern hemisphere land masses and islands, Hommersand (2007) described the dispersal of species that originated along the eastern and southern coasts of Gondwana to the Antarctic Peninsula and South America, via the West Wind Drift to islands as distant as New Zealand. Evidence in support of long distance dispersal by means of rafting along the West Wind Drift was reviewed by Waters and Roy (2004) who undertook field and molecular research on the sea-star *Patiriella exigua* Lamarck and view such oceanic dispersal as an evolutionary force.

Southern Australia has closest macroalgal relationships with New Zealand, with some 139 species (94 Rhodophyceae, 26 Phaeophyceae, 19 Chlorophyta) presently recorded in common (see Hommersand Table 40) (2007). Less commonality of marine flora exists between Australia and the other southern hemisphere continents of Africa and South America. Ocean currents circulating in the Indian Ocean and flowing southwards past Mozambique together make an effective geographical barrier between Africa and Australia. Many distinctive families or genera (for example in the red algal families Solieriaceae, Dicranemataceae, Mychodeaceae and Mychodeophyllaceae) form basal groups in phylogenetic analyses, adding strength to the proposal that many assemblages evolved in isolation around the Australian continent with radiation occurring later (Hommersand 2007). Genetic divergence has also been described for some marine invertebrates; for example, allopatric divergence and speciation of the sea-star *Coscinasterias muricata* Verrill, endemic to southern Australian and New Zealand, suggest that glacial history, by means of creating or removing geographical barriers (such as the Bassian land bridge between Victoria and Tasmania) may be a factor contributing to the high levels of marine endemism of temperate Australia (Waters and Roy 2003).

Kerswell (2006) mapped global clusters of endemic algal genera (endemics were defined as taxa from only one location, or with a geographic range size of $< 10^6$ km^2); her Fig. 1b depicts an endemic genera cluster (with “13+” endemic genera) across a broad area roughly between the Recherche Archipelago (WA) and Discovery Bay (Vic). Specific labeling of centres of local endemism across southern Australia has received little attention, with the most comprehensive information being published within the works of Professor Bryan Womersley, his colleagues, and generations of students, from the mid-1940s through to the present time. Australian algal research progressed from the publications of species lists to general accounts of zonation and ecology, taxonomic monographs and more recently to molecular phylogenetics. Much of the scant information about algal endemism is based on subjective observation and collection, mostly contained within a number of regional or local floras, for example the floras of Pennington (Womersley 1948), American River (Womersley 1956), Vivonne Bay (Womersley 1950), Pearson Island (Womersley and Shepherd 1971), St Francis Isles (Shepley and Womersley 1976, Baker and Edyvane 2003), Victor Harbour (Shepherd and Womersley 1970), south-west Western Australia (Goldberg and Collings 2006), Rottnest Island (Huisman and Walker 1990), Port Phillip (Womersley 1966, Ducker 1993) and south-east Tasmania (Edyvane 2003). Information in these accounts must not be under-rated. Although they are rarely quantitative accounts, such decadal-old reports hold great value in being able to direct an observer to efficiently re-locate a species in the field (Kraft 2011).

The floristic elements of southern Australian endemic macroalgae at order, family, genus and species levels have been variously discussed in detail by Womersley (1984, 1990), Phillips (2001) and in the much broader context of global biogeography over geological time scales by Hommersand (2007). For southern Australia (Cape Naturaliste to Cape Howe), the following estimates of endemism have been made (Phillips 2001):

Within the Chlorophyta, nine of the twelve orders contain southern Australian endemics, the highest numbers within the orders Cladophorales and Caulerpales, and the coenocytic genera *Caulerpa*, *Udotea* and *Codium* being well-represented. Ten of the thirteen Phaeophycean orders contain endemics, the highest numbers within the Chordariales, Sphacelariales, Dictyotales and Fucales; as examples, there are endemic species of the genera *Padina*, *Dictyopteris*, *Hormosira*, *Phyllospora*, *Seirococcus*, *Cystophora* and *Sargassum*. Within the Rhodophyta, many of the endemic genera contain only one or two species; of the sixteen orders only two do not contain southern Australian endemics; the orders Gigartinales, Rhodymeniales, Corallinales and Ceramiales containing the highest numbers of endemic species. The red algal genera with notably high species endemism include *Mychodea*, *Plocamium*, *Gigartina*, *Antithamnion*, *Griffithsia*, *Callithamnion*, *Halopeltis* and *Dasya*.

Those southern Australian species based on specimens from a single locality (see chapter 2, this thesis) are considered to be range-restricted (short-range) endemics until further investigations convince scientists otherwise. It is possible that some range-restricted endemics represent relict populations of previously more widespread groups, for example *Predaea* (Hommersand 2007) and *Acetabularia calyculus* (Womersley 1984).

1.3 Rarity

1.3.1 Concepts of rarity

There are several definitions of rarity in common usage, definitions generally based on criteria of geographic range, habitat specificity and local abundance. Rare species are regarded as those of low abundance and/or of small range (Gaston 1994). Rarity is often used to imply some sort of vulnerability or supposed risk of extinction.
A species can only be rare relative to a threshold (Dobson et al. 1995, Flather and Sieg 2007). Gaston (1994) suggests the application of cut-off points to abundances and range sizes. Cut-off points that are absolute in value cannot take into account natural temporal changes in species abundance or distribution, and Gaston suggests that relative cut-offs, although not perfect, are more useful than absolute criteria for comparative studies. Gaston considers three approaches to the quantification of rarity along with their strengths and weaknesses; 1) Proportion of species: rare species are defined as the x%

with the lowest abundances or smallest range sizes in the assemblage, 2) Proportion of sum: rare species are defined as those with abundances less than x% of the summed abundances of all species in the assemblage, or as those with a range size less than x% of the largest range size possible in the study area, and 3) Proportion of maximum: rare species are defined as those with abundances or range size less than x% of those of the species that have the highest abundance and the largest range size in the assemblage. A disadvantage of adopting arbitrary cut-off points is that it considers a certain proportion of species being as predefined as rare for any given characteristic, and this may not accurately represent the true situation for an upper natural limit of a species.

In the early stages of development of the International Union for the Conservation of Nature (IUCN) Red Data Categories, rare was defined as 'taxa with small world populations that are not at present Endangered or Vulnerable, but are at risk. These taxa are usually localised within restricted geographical areas or habitats or are thinly scattered over a more extensive range' (IUCN 1994). In subsequent versions (IUCN Red List of Threatened Species 2001, 2006) this category was abandoned; instead, rigorously-defined conservation categories, including three categories for threatened species, are now in use (IUCN 2006).

McDonald (2004) initially defined a rare population as "one where it is difficult to find individuals because of small numbers, secretive and/or nocturnal behaviour, or clumped distribution over large ranges, that is, a lot of zeros in the data". In reviewing colleagues' definitions of a rare population and methods of sampling rare populations, McDonald concludes that from a statistician's viewpoint, rare biological populations are those with low probability of detection, and draws attention to the problems associated with surveying for detection.

The spatial scale at which rarity is applied, and the objective of the study has influenced some definitions of the term. I include a selective list as examples of definitions (Table 1.4). A species may be regarded as rare at a local scale (e.g. within a nature reserve), yet common at a regional or global scale. Unfortunately, the classification of species in terms of occurrence or 'rarity' is highly subjective and it is difficult to envisage a general threshold of rarity suitable across the many disparate taxa, life histories and habitats found in nature.

Reference	Taxa	Criteria for Rare	Criteria based on
Landolt (1991)	plants	Up to 200 individuals or very local (very rare, up to 20 individuals)	A/R
Dwzonko & Loster (1989)	plants	Occurred in <1/10 of localities	%S
Le Lay *et al*. (2010)	plants	1) be mentioned as threatened in the IUCN red lists of Switzerland, 2) have enough available occurrence data to allow model-fitting (>10 occurrences), and 3) be easily identified in the field, to minimize fallacious absence records	A/R
Morgan *et al.* (1991)	birds	Average relative abundance of 0.01–1.00	A/R
Hall & Moreau (1962)	birds	Range does not extend >250 miles in any direction	%S
Laurance (1991)	mammals	<1% of all capture	A/R
McGowan (1979)	copepods	<100 individuals in the 62 samples analysed (very rare, <10 individuals)	A/R
Faith & Norris (1989)	freshwater macroinvert-ebrates	Abundance comprising ≤0.5% of total abundance of all taxa	%S
Austin (2000)	marine inverteb-rates	Species recorded at 5 or fewer sites in British Columbia.	A/R
Maitland (1985)	freshwater fish	Native spp with only a few known populations in the British Isles, or native spp the populations of which are potentially unique individually and decreasing in number	%S
Buzas & Culver (1991)	forams	Recorded from 1 or 2 localities in a geographic area	A/R
Brodie *et al.*(2005)	marine algae	Occurs at ten sites or less in Great Britain and Ireland	A/R
Hardy & Guiry (2003)	marine algae	Dots (occurrences) on a map for only a few 10-km squares (across Britain & Ireland)	A/R
Edgar *et al.* (1999)	marine macrofauna	<10 individuals collected in the sampling program.	A/R

Table 1.4 Examples of definitions of rare species across a range of taxonomic groups. A/R=criteria based on abundance and/or range size. %S=criteria base on proportion of species in the assemblage.

1.3.2 Types of rarity

Rabinowitz (1981) proposes a classification scheme for seven different types of rarity based on the three ecological aspects– geographic range, habitat specificity and local abundance (Table 1.5). Her framework contains concepts fundamental to conservation management, particularly the issue of rarity being conditional on the geographic scale of interest. It is a useful guide when directing research towards rigorous population and ecosystem studies aimed at assigning criteria suitable for conservation purposes, even if it appears as a simplified view of very complex interactions that affect individual species.

GEOGRAPHIC RANGE →	**LARGE**		**SMALL**	
HABITAT SPECIFICITY →	**Wide**	**Narrow**	**Wide**	**Narrow**
LOCAL POPULATION SIZE **Large, dominant somewhere**	COMMON Locally abundant over a large range in several habitats	PREDICTABLE Locally abundant over a large range in a specific habitat	UNLIKELY Locally abundant in several habitats but restricted geographically	ENDEMICS Locally abundant in a specific habitat but restricted geographically
Small, non-dominant	SPARSE Constantly sparse over a large range in several habitats	Constantly sparse in a specific habitat but over a large range	Constantly sparse and geographically restricted in several habitats	Constantly sparse and geographically restricted in a specific habitat

Table 1.5 Classification of rarity types (after Rabinowitz 1981).

Other characteristics, complementary to those of abundance, range size, occurrence and ecological specialisation used by Rabinowitz, are used in a number of classification schemes devised to accommodate conservation priorities for rare species. Data on both distribution trend and abundance trend are included in Australia's Environment Protection Biodiversity and Conservation Act EPBC (1999) and in biodiversity conservation in U.S.A. (Master et al. 2000). Other ecological attributes used for species conservation efforts are species' reproductive potential (Cofré and Marquet 1999, Gallucci et al. 2006) and fragility (species' sensitivity to perturbations in its environment) (Master et al. 2000, Pandit and Laband 2007). In addition, data relating to extrinsic factors can be used in assigning species to rarity and conservation classes, such as attributes of habitat condition (Pärtel et al. 2005) and population viability (IUCN 2006). (The IUCN Red List of Threatened Species categories are covered in more detail in the ‘Assessment of Threat’ section of this chapter.) The strategies adopted for biodiversity conservation of rare species will in effect be driven by the conservation objectives in place, and the data available on species’ ecological attributes to be considered in the decision making process (Flather and Sieg 2007).

1.3.3 Causes of rarity

Two broad categories for the causes of rarity are described as: “(1) *natural* or *intrinsic* causes defined by a species’ inherent biological or ecological characteristics; and (2) *anthropogenic* or *extrinsic* causes defined by harmful human activities that have resulted in limited distribution and abundance, independent of their biology” (Pärtel et al. 2005, Flather and Sieg 2007). Factors within these categories may contribute to a state of rarity or to extremely narrow range-restriction either individually or in combination, and can apply to both flora and fauna in a range of environments such as terrestrial, freshwater or marine (e.g. (Kunin and Gaston 1993, Chapman 1999, Leeson and Kirkpatrick 2004)).

(1) The intrinsic causes for rarity may include a single natural factor or a combination of traits that affect the survival of a species at a given locale (Flather and Sieg 2007). Certain species traits are often associated with rarity such as low growth rates, long generation time or low vagility [the capacity or tendency of a species to disperse in a given environment]. In addition, an inherent specificity for companion biota as found in symbioses or facultative associations, is likely to contribute to rarity. The inherent feature of mutualism (symbiosis) is not common amongst marine macroalgae although several sponge-macroalga associations do exist (e.g. *Thamnoclonium*, *Ptilophora, Spongaplexus*). Requirements for a specific habitat (e.g. substratum, light regime, tidal movements), specific disturbance regimes, and both the dispersal capability (via water movement) and colonisation success of propagules, can also cause rarity.

For some biota there may be a distinct phylogenetic bias in plant rarity. Using herbarium data in analyses of rarity patterns in terrestrial plant groups across 33 floras from five global biomes, Domingo-Lozano and Schwartz (2005) found that both phylogeny and geographic region were drivers of rarity. Their study shows that “rarity in terrestrial plants is concentrated in species-rich taxonomic groups”, and that “floras with more species, independent of area, contain a higher fraction of rare species.” This type of global study would be an interesting exercise to perform for marine flora, in the light of the relatively high number of small plant families (< 10 taxa) in species-rich regions such as southern Australia.

(2) Extrinsic causes of rarity are essentially associated with some sort of threat to the species' or communities' health and longevity. Norse and Crowder (2005) identify five groups of threats, viz. overexploitation, physical alteration (of habitat), pollution, alien species and climate change. Many marine macroalgae may be susceptible to damage by single- or multiple threats, and specific preservation efforts may be warranted to ward off population decline, biodiversity loss or possible species extinction.

Overexploitation is not considered a common threat for macroalgae in Australia, but it is conceivable that overexploitation of other biota (e.g. fish, abalone, crayfish) could change the local community structure or ecosystem balance, by the removal of grazers of algae. Herbivory effects the species composition of algal communities in both tropical and temperate Australia, for example on coral reefs (Hatcher and Larkum 1983, Scott and Russ 1987) and temperate rocky reefs (Scheibling 1994, Valentine and Johnson 2005) (see Connell and Vanderklift (2007) for a comprehensive discussion on influence of predators and herbivores on prey and ecological systems). In addition, many studies conducted in marine protected areas provide evidence that continuous over-fishing alters community structure (Edgar et al. 2007).

The **physical alteration of habitat** can occur with developments related to increased population pressure in coastal areas in the form of construction of ports, marinas, groynes, land reclamation and foreshore development such as canal (housing) estates (Walker and Kendrick 1998). The newly available surfaces or habitats resulting from such constructions may not be suitable for the successful colonisation by local species, or for the recovery of former biotic communities (Carter et al. 1985) and interim sedimentation or scouring could obliterate some species or compromise recruitment success (Kendrick 1991). Suspected anthropogenic causes of macroalgal decline have been documented for both tropical and temperate waters. For example, on Australia's east coast a disappearance over decades of populations of rocky reef *Sargassum* species was largely caused by urbanization and eutrophication of local waters (Phillips and Blackshaw 2011). Further south, declines in the habitat-forming *Phyllospora comosa* (Labillardiére) C. Agardh occurred along urbanized shores around Sydney in the vicinity of sewage effluent, stormwater and other urban runoff (Coleman et al. 2008, DECCW 2010).

Pollution of coastal environments can result in changes in water quality that are detrimental to marine biota, for example, pollution by siltation causing reduced light penetration or runoff of nutrients, pesticides, or toxic chemicals unfavourable for algal growth. As an example, Crawfish Rock in Westernport Bay VIC was previously regarded as a site of high algal diversity, but increased sedimentation and turbidity since the 1970s has caused the disappearance of 66% of the algal flora (Shepherd et al. 2009). Intense (negative) impacts on the marine environment can be generated by oil spills, sewage effluent, heavy metal discharge, and chemical outfalls; although such impacts are generally highly localized, in extreme cases they can result in complete loss of flora and fauna (Crawford et al. 2000). The high nutrient loads and siltation often associated with fish-farms can be responsible for significant alterations to benthic communities (Brown et al. 1987, Mazzola et al. 2000, Oh 2009).

Alien (introduced) species can displace native flora in localised areas. There are many records of establishment of alien species in temperate Australian waters. As examples: *Undaria pinnatifida* (Harvey) Suringer is well established along the east coast of Tasmania (Sanderson and Barrett 1989); *Grateloupia turuturu* Yamada likewise is locally profuse at sites on Tasmania's east coast (Saunders and Withall 2006) (F. Scott and N. Barrett pers. obs.); *Caulerpa taxifolia* (Vahl) C. Agardh, the invasive "killer algae" of the Mediterranean (Meinesz and Hesse 1991, Meinesz 1999) is native to tropical Australia, but is now established in the cooler waters of Port River-Barker Inlet (Adelaide) waterway (Wiltshire 2010) and was reported in (but now eradicated from) estuarine waters of New South Wales (Creese et al. 2004, Glasby and Creese 2007). Increasing numbers of alien introductions have been recorded for many parts of the globe (Ribera and Boudouresque 1995, Maggs and Stegenga 1999, Johnson and Chapman 2007). By competing for settlement space, invading macroalgae could potentially impact on the successful recruitment of rare species, as well as non-rare ones.

Climate change: A number of reports have documented considerable changes in local populations of macroalgae in the world's oceans. Many biological changes in marine ecosystems appear to be responses to global climate change, including destruction of populations and habitat disturbance that results from extreme weather events (e.g. storms, prolonged flooding), as well as local alterations of ocean currents, temperature, salinity and acidity (Hoegh-Guldberg and Bruno 2010, Wernberg et al. 2011a), and species' range-shifts of grazing herbivores (Johnson et al. 2011). In the Galapagos

Archipelago a severe El Niño warming was associated with faunal and floral depletion and possible extinctions (Edgar et al. 2010).

The kelp species *Ecklonia radiata* (C. Agardh) J. Agardh is a key habitat-forming species of Australian temperate reefs. An erosion of its resilience, including a suppression of canopy recovery from external disturbances, is associated with rising ocean temperature (Wernberg et al. 2010). A dramatic decline in the populations of the canopy-forming giant kelp (*Macrocystis pyrifera* (Linnaeus) C. Agardh) is reported for Tasmania (Sanderson 1990, Johnson et al. 2011) and similar declines in *M. pyrifera* on Californian coasts have affected sub-canopy seaweed-based communities (Reed and Foster 1984).

Southward retreat of seaweed communities is described by Wernberg *et al*. (2011b), through studies based on interrogation of long-term herbarium records. For both Australia's west and east coasts, the authors found that over recent decades temperate macroalgal species have been driven southward by ocean warming, with many extant communities at sites now resembling past macroalgal communities farther north. Their data must be interpreted with care since herbarium records rarely represent systematic or comprehensive collecting efforts and early macroalgal collections may not have included specimens from their actual northern limits.

Notwithstanding this caveat, the trend of poleward seaweed retreat and rearrangement of ecologically important species appears real. Wernberg *et al.* (2011a) conclude that their data imply that there will be increases in macroagal community range-shifts and possible global extinctions of seaweed and seaweed-dependent marine organisms. Whether those rare macroalgae known from only the southernmost parts of the continent can resist demise or extinction under such circumstances has been little explored, but it would be interesting to assess their ability to survive either in small refugia, or their ability to be sufficiently generalist to survive in suboptimal habitats.

Both predictive modelling and monitoring programs can be useful in measuring the impacts of climate change on Australia's marine life. Increases in temperature that in turn are likely to affect trophodynamics, ocean acidification, changes in storm and rainfall patterns, and changes in species' resistance to disease are some of the likely impacts of climate change (Wernberg et al. 2011a). The rocky shore biota stands out as one of six good indicators of climate change and should be monitored (Hobday et al.

2006). Systematic broad-scale sampling and long-term monitoring would help assess biodiversity losses (Edgar et al. 2004).

1.3.4 Assessment of threat

Various systems of conservation categories have been devised to assess the levels of (extrinsic) threat that can cause rarity, population decline or extinction. At the international level, the IUCN (International Union for the Conservation of Nature) has developed a formal scheme of conservation categories based on specific definitions and extinction-risk criteria that infer conservation priorities. Many countries have developed their own schemes at national and subnational (state, province or territory) levels. Those relevant to southern Australian coastal waters are listed below, and include the act under which the categories are defined, the government department responsible for administering the act, the categories, and currently listed macroalgal species or ecological communities (see Appendix A1 for definitions and criteria relevant to each Australian scheme).

International scale– IUCN conservation categories

The IUCN 1994 Red List (2001) have eight conservation categories designated according to specific definitions and criteria. For the three ‘threatened’ categories (Critically Endangered, Endangered, and Vulnerable), the criteria are based on:

A. Reduction in population size (observed, estimated or inferred),

B. Geographic range (extent of occurrence or area of occupancy),

C. Population size estimated to be low and declining,

D. Population size estimated to extremely low, and

E. Probability of extinction in the wild.

Currently the IUCN lists seventy-eight marine macroalgae, all but one from the Galapagos Islands, Ecuador (Table 1.6). The overall IUCN project is on-going, and the Red List succinctly states that “our understanding of algae in terms of distributions is limited”, and that “these numbers were [are] expected to change”.

Category	Code	No. of marine macroalgae
Extinct	EX	1
Extinct In The Wild	EW	
Critically Endangered	CR	11
Endangered	EN	
Vulnerable	VU	4
Near Threatened	NT	
Least Concern	LC	4
Data Deficient	DD	57
Not Evaluated	NE	

Table 1.6 International Union for the Conservation of Nature (IUCN) conservation categories and number of macroalgal species.

A 2005 conservation assessment of algal species, both marine and freshwater, resulted from a workshop at the Eighth International Phycological Congress in 2005 (Brodie et al. 2009). The authors noted that lists of endangered algal species have been compiled for several countries including Germany, Japan, Australia and Britain, and that there were already a number of specific laws or legislation in place to afford protection for species threatened by habitat destruction and degradation. At least for marine macroalgae, they noted that data for endangered species were "scanty, often anecdotal or nonexistent", and pointed out the necessity of establishing whether a species is endangered globally or locally. De Grammont and Cuarón (2006) and Rodrigues *et al.* (2006) have found that the IUCN (2001) system had clearly defined criteria and assessment protocols, useful at national and regional scales.

National scale– Commonwealth of Australia conservation categories

Environment Protection and Biodiversity Conservation Act 1999 (EPBC Act 1999)
Australian Commonwealth Department of Sustainability, Environment, Water, Population and Communities
One marine macroalga is listed for the Commonwealth of Australia; *Vanvoorstia bennettiana* (Harvey) Papenfuss, (EX) (Table 1.7). http://www.environment.gov.au/cgi-bin/sprat/public/sprat.pl (searched 05 Feb 2012). The Australian Federal Government has recently (18 Aug 2012) listed the giant kelp forests (*Macrocystis pyrifera*) of south-east Australia as an endangered ecological community (http://www.environment.gov.au/biodiversity/threatened/index.html).

Category	Code	No. of marine macroalgae
Extinct	EX	1
Extinct In The Wild	EW	
Critically Endangered	CR	
Endangered	EN	1*
Vulnerable	VU	

Table 1.7 Commonwealth of Australia conservation categories and number of macroalgal species. **Macrocystis pyrifera* is the key species for the endangered giant kelp forest ecological community of south-east Australia.

National scale– COSEMA conservation categories

An *Overview of the Conservation Status of Australian Marine Macroalgae,* and associated website COSEMA (last updated 2002) was developed for Environment Australia during the 1990s by researchers at The University of Adelaide (Cheshire et al. 2000). The report encompassed both microalgae and macroalgae based on distribution data and species information available up to 2000, with the conservation categories based on a combination of number of known collecting localities and estimates of species' range. The COSEMA database lists 192 marine macroalgae from southern Australia (Table 1.8).

Category	Criteria	Code	No. of marine macroalgae
Vulnerable	recorded from 5 or fewer locations	VU	78
Vulnerable with Narrow Range	recorded from 5 or fewer locations not more than 500 km apart	VU-NR	56
Vulnerable, Potentially Endangered	recorded from 5 or fewer locations not more than 50 km apart	VU-PE	48

Table 1.8 Conservation Status of Australian Marine Macroalgae (COSEMA) conservation categories and number of macroalgal species.

State scale– Western Australian conservation categories

Wildlife Conservation Act 1950 (WCA 1950)

Department of Environment and Conservation, WA

Categories

Presumed Extinct	EX
Critically Endangered	CR
Endangered	EN
Vulnerable	VU

No marine macroalgae or algal ecological communities are listed for WA (Aug 2010).
http://www.dec.wa.gov.au/content/view/852/2010/ (Listing of species and ecological communities, searched 05 Feb 2012).

State scale– South Australian conservation categories

South Australia's National Parks and Wildlife Act 1972 (SANPWA 1972)

Department of Environment and Natural Resources, SA

In South Australia, a Regional Species Conservation Assessment Project adopts the IUCN Red List Categories and Criteria. At the state level threatened species are given formal legal recognition under the National Parks and Wildlife Act 1972 as follows:

Categories

Endangered	EN
Vulnerable	VU
Rare	R

No marine macroalgae or algal ecological communities are listed for SA.
http://www.environment.sa.gov.au/Plants_Animals/Threatened_species_ecological_communities/Threatened_species/Threatened_species_in_SA (List of Threatened species; accessed 05 Feb 2012).

State scale– Victorian conservation categories

Flora and Fauna Guarantee Act 1988 (FFG Act)

Department of Sustainability and environment Flora and Fauna, VIC

Ecological Vegetation Classes

Presumed Extinct	X
Endangered	EN
Vulnerable	VU
Depleted	D
Rare	R
Least Concern	LC

No marine macroalgae or algal ecological communities are listed for Victoria.
http://www.dse.vic.gov.au/plants-and-animals/native-plants-and-animals/threatened-species-and-communities/listed-items (List of Threatened species; accessed 05 Feb 2012).

State scale– Tasmanian conservation categories

Threatened Species Protection Act 1995 (TSPA 1995)

Department of Primary Industries, Parks, Water and Environment, TAS

Ecological Vegetation Classes

Extinct	X
Endangered	E
Vulnerable	VU
Rare and at risk	R

One marine macroalga is currently listed for Tasmania; *Cystoseira trinodis* (Rare), now recognised as a synonym of *Sirophysalis trinodis* (Forsskal) Kützing, is an example of a species considered rare on a local scale, yet common on a national and global scale, with populations occurring around Australia, Africa and Asia. http://www.dpiw.tas.gov.au/inter.nsf/WebPages/SJON-58E2VD?open (List of Threatened species; accessed 05 Feb 2012).

1.3.5 Macroalgal rarity

Marine macroalgae are one of many taxonomic groups for which gaps in taxonomic and distributional understanding make it difficult to assess the rarity of most species (Roberts and Hawkins 1999). The rare or little-known species span a wide range of taxonomic classes, life histories, habitat requirements, levels of abundance and distribution patterns, and the importance of individual species in their respective ecosystem is generally unknown. An almost inescapable issue is the possibility that rare taxa may simply have been overlooked due to relatively coarse (or misused) taxonomic systems. A combination of 'undercollecting' and a paucity of adequate taxonomic guides may easily have confounded early efforts to assess macroalgal rarity. For subtidal species in particular, the environment remains difficult to survey and the data needed to classify macroalgae into particular groups of rarity are not realistically attainable, regardless of whether the categories are of a conceptual type as described by Rabinowitz (1981) or of a measurable type as in the IUCN conservation categories (IUCN 2006).

1.4 Means of investigating distributions of rare species

Distributional data for rare species can be derived from field surveys or from historical data such as museum records or long-term data sets. These two methods were used in combination to support the nomination of the world's first recorded extinction of a seaweed *Vanvoorstia bennettiana* (Harvey) Papenfuss (Millar 2007b) as well as reports of macroalgal population declines (Phillips and Blackshaw 2011, Wernberg et al. 2011b). Both methods are also applied here.

1.4.1 Field surveys

It is important to consider the realities of logistics, economics and statistical adequacy in the design of field studies, given that in many ways rarity is simply a measure of local abundance or detectability. Random sampling for locating rare, or rarely-encountered species may be statistically more defensible than subjective sampling, but can actually be less efficient (Hedgren and Weslien 2008). Issues that can confound the detection of rare, elusive or clustered species include dealing with an area too large to completely survey, an inability to achieve complete counts, inefficient or inappropriate methodology, and attempting to detect biota that are sparse, clustered, mobile or extremely seasonal.

For marine macroalgae, surveying for rare species requires a specialised knowledge-base in which either human-based surveys or remote-sensing techniques can be used and best followed by verifying or 'ground-truthing' the data. Such an approach means spending a lot of time in the laboratory and the herbarium, to compare samples to descriptions and voucher-based specimens thus ensuring accurate identification. Arguably all valid botanical work is specimen-based, and time for specimen collection and processing must be built into any research project. Funding limitations will often dictate the extent of research efforts for rare and threatened species as well as the monitoring of their populations if they are found and (hopefully) reserved. Barrett and Buxton (2002) present discussions on underwater survey techniques including non-destructive human-based surveys by area-counts, nearest-neighbour distances of biota, belt-transects and timed-swims. These last two methods have been used for both accumulating base-line data of habitats and locating threatened marine species (Barrett et al. 2010).

Goldberg *et al*. (2007) applied targeted Adaptive Cluster Sampling (ACS) to diver-based sampling for rare marine macroalgae. They used this method to reveal relationships between three easily identifiable locally-rare species (*Codium mamillosum* Harvey, *C. pomoides* J. Agardh, and *Halimeda cuneata* Hering) and the physical parameter of wave exposure, and concluded the ACS method was less effective at sampling for low-abundance or non-spatially-clustered species than simple random sampling with comparable replication.

A comprehensive study comparing sampling methods for a threatened terrestrial (*Lesquerella filiformis* Rollins) plant in the U.S.A. was undertaken by Morrison *et al.* (2008). In comparing five sampling methods for rare populations, based on 4 years of field data [(1) simple random sampling, (2) adaptive simple random sampling, (3) grid-based systematic sampling, (4) adaptive grid-based systematic sampling, and (5) GIS-based adaptive sampling], they surmised that grid-based systematic designs were more efficient and practically implemented than the others, with respect to precision of density estimates for fixed sample size, cost, and distance travelled. It would be an exhausting but rewarding challenge to undertake a similar comparison for a rare or threatened marine species.

Diver-operated photo-quadrat and video-imagery techniques (Barrett and Edgar 2010), and combinations of remotely-operated-vehicle (ROV) imagery and acoustic techniques have also been used for studying marine biota. Whilst excellent for mapping and monitoring benthic habitat (Lucieer et al. 2009, Meyer et al. 2011) these methods appear to be inappropriate for locating rare macroalgae.

Remote-sensing techniques using historic digitized aerial images have been used to contribute to conservation plans for endangered species, by means of monitoring habitat dynamics of endangered fauna (e.g. butterflies) (Bartel and Sexton 2009). Satellite imagery has also been used to study rare broadleaf trees by identifying predictors for species distribution models (Zimmermann et al. 2007). For marine macroalgae, Edyvane (2003) incorporated data obtained from Landsat TM imagery and aerial photography (representing area of occupancy) in assessing giant kelp populations around Tasmania. The target taxon, *Macrocystis pyrifera*, is the the key species of the recently-listed threatened ecological community of southern giant kelp forests (2012) . Another method of remote-sensing has been used for investigating macroalgae, with algal fluorescence characteristics detected by instruments onboard an aircraft (Topinka et al. 1990). However the resolution of taxonomic information was relatively coarse (family level) and would not be practical in searching for rare species.

1.4.2 Historical records

Methods for analysing large datasets (from herbaria or museums) to assess species' distributions have greatly improved over the past 15 years and have recently been applied to research questions associated with the Australian macroalgal flora (Waters et al. 2010, Wernberg et al. 2011b). Both simple empirical models and complex mechanistic models can be used to predict species' distributions, including predicted biotic responses to global climate change (Thuiller et al. 2008, Franklin 2010). Occurrence-based datasets are becoming more frequently used when predicting rare species' occurrences (Witte and Torfs 2003, Guisan and Thuiller 2005, Elith et al. 2006, Williams et al. 2009) and with sufficient accuracy should be useful in conservation planning.

Species distribution models (SDMs) represent one analytical tool that can be usefully applied to marine landscapes. Correlative SDMs enable the modelling of spatial patterns of biota across an environment by spatially correlating species occurrence (presence-only, or presence-absence) records with environmental data to predict species' distributions in unsurveyed regions (Robinson et al. 2011). SDMs are most accurate when characteristics of marine biota such as dispersal, species interactions, and life history phases of organisms are incorporated. Nevertheless, whilst benthic marine macroalgae are relatively easily surveyed (compared to mobile species), accumulating sufficient data for any modelling of rare species distributions represents a major challenge.

SDMs typically rely on counts of individuals that are related to the actual population size at a sampling site by an unknown probability of detection. The probability of detection is estimated from the counts and supplemental information derived from features that may qualify as surrogate data such as characteristics of habitat, species interactions, or physical or environmental parameters.

SDMs have been used to assist fieldwork sampling for rare species. Le Lay *et al.* (2010) found such model-based sampling useful for sampling rare terrestrial plants that were easily identified in the field, but the usefulness of this process relied heavily on sufficient initial data on species distributions to produce the SDM. SDMs such as Random Forest (RF) and Maximum Entropy (ME) also appear to be useful in predicting rare species distributions, not forgetting that good models depend on adequate initial data (sufficient number of occurrence records) (Williams et al. 2009). Using the RF output to prioritise search efforts, they discovered sixteen new populations of (targeted) endangered montane plants.

Both temporal and geographical biases exist in herbarium data as a result of variable collection intensity. Perhaps the ideal situation for constructing SDMs is to only use well structured presence-absence datasets comprising adequate numbers of localities and samples. Promising results have emerged from using the technique of multivariate adaptive regression splines (MARS) to analyse herbarium datasets and associated environmental datasets for species' distribution patterns (Elith and Leathwick 2007). Methods are being developed to account for data-deficient areas (Engler et al. 2004, Elith and Leathwick 2007) but have not yet been applied to macroalgal datasets.

1.5 Structure of thesis

The present project evolved from a combination of thoughts about rarity in nature and my personal interest in the discipline of phycology gained through many years' work with marine plants, both microscopic and macroscopic. The aims of this thesis were to document the pattern of distribution of the apparently rare marine algal species endemic to southern Australia, test the validity of the apparent rarity and seek causes of the patterns emerging from the herbarium-based data. The thesis is structured as follows:

Chapter 1: A background to macroalgal taxonomy, growth patterns, reproduction and ecology; biogeography and endemism of southern Australian algae; a review of the concepts and causes of rarity with special reference to marine macroalgae; conservation categories; means of investigating rare species.

Chapter 2: Criteria and categories for rare macroalgae; features of taxonomy, morphology and geography pertaining to the apparently rare species; co-occurrence of rare species in localised areas or 'centres of rarity'.

Chapter 3: Identifying the 'centres of rarity' taking collecting bias into account; associations between high proportions of rare species and physical and environmental parameters of species' habitats.

Chapter 4: Identification of discrete environmental domains as a means of explaining concentrations of rare species; rare species and extreme and rare environments; investigating possible historic explanations for rare species' distributions.

Chapter 5: Field surveys for rare macroalgae support distribution patterns emergent from herbarium records; new occurrence records and range extensions.

Chapter 6: Description of a new red algal taxon (proposed new family, genus and species) as a novel find resulting from field surveys.

Chapter 7: Challenges in verifying whether rare species are adequately safeguarded within Australia's existing Marine Protected Areas; implications of findings; directions for future studies.

Appendices: Data in support of thesis chapters.

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Chapter 2: Rare marine macroalgae – Taxonomy and distribution

2.1 Introduction & background

Algal phylogeny and the estimation of algal species numbers are contentious issues. Both conceptual and methodological advances continue to impact on phylogeny and classification of algae, making a definitive classification scheme virtually impossible to achieve (Huisman and Saunders 2007). Molecular tools allow algal identification to be taken to a higher level of resolution than traditional alpha taxonomy. In particular, the DNA barcoding technique is proving a powerful tool for resolving problematic species-complex questions (Saunders 2005) and the refinement and application of these techniques will affect concepts and estimations of numbers of all macroalgae, worldwide.

The most comprehensive work on southern Australian benthic marine algae encompasses some 1200 species (Womersley 1984, 1987, 1994, 1996, 1998, 2003). Of these, 615 were regarded as endemic to temperate Australian waters (Phillips 2001). Subsequent studies have verified the prediction of Womersley (2003) that many more than 1200 species existed and Approximately1500 species have now been recorded across the biotic provinces of southern Australia (Waters et al. 2010). Over time new taxa are discovered and described and others are taxonomically reassigned, therefore the number of species (rare and non-rare) attributed to southern Australia should be considered as dynamic rather than absolute.

The aims of this chapter are to determine the potentially rare southern Australian macroalgae and to map geographic concentrations of these species.

2.2 Materials & Methods

2.2.1 Areas of interest

The geographical area of interest was the coastal waters lying between Geraldton, Western Australia, (28°46'S 114°34'E) eastward to Cape Howe, New South Wales (37°30'S 149°59'E), representing the longest east-west temperate rocky coastline in the world, and around Tasmania (Fig.2.1a-d). This includes eight of Australia's forty-one marine provincial bioregions as defined by the Integrated Marine and Coastal Regionalisation of Australia (IMCRA), and twenty meso-scale bioregions, nested within the provincial bioregions (IMCRA 2006). This area encompasses the majority of Australia's temperate reef systems.

The taxonomic area of interest comprised those marine macroalgae currently known only from temperate and rocky reefs of the Australian continental plate (that is, excluding offshore islands such as Norfolk I, Lord Howe I, Cocos-Keeling I, and subantarctic islands, such as Heard I, Macquarie I).

2.2.2 Sources of data

The main sources of data used in this study were published texts, scientific papers, databases of herbarium specimens (Australian Virtual Herbarium) and ArcGIS shapefiles (coastline maps). The 6-volume series *The Marine Benthic Flora of Southern Australia* (Womersley 1984, 1987, 1994, 1996, 1998, 2003) was consulted as major source of information on algal morphology and distribution. Many specialised research papers published subsequent to the above works were also consulted for distribution and additional information; these works typically concentrate on a specific family or genus, or a local census of the flora. The July 2000 report to Environment Australia *Overview of the Conservation Status of Australian Marine Macroalgae* (Cheshire et al. 2000) was a solid starting point for investigating rarely reported species. This report and its associated web-based tool COSEMA (last updated in 2003) were consulted closely during work on the present project. Known species distributions were checked and updated using information from the Australian Virtual Herbarium database (AVH), and great care was taken to update records according to currently accepted taxonomic names as listed on AlgaeBase (Guiry and Guiry 2010). A small number of modifications resulting from recent research efforts (species records) and philosophies (taxonomic assignation) have also been incorporated. The classification scheme adopted herein is that of the comprehensive (and ongoing) taxonomic series *Algae of Australia* (Huisman and Saunders 2007). The digital coastline map used was a 1:1000,000 scale coastline of Australia (GEODATA 2004).

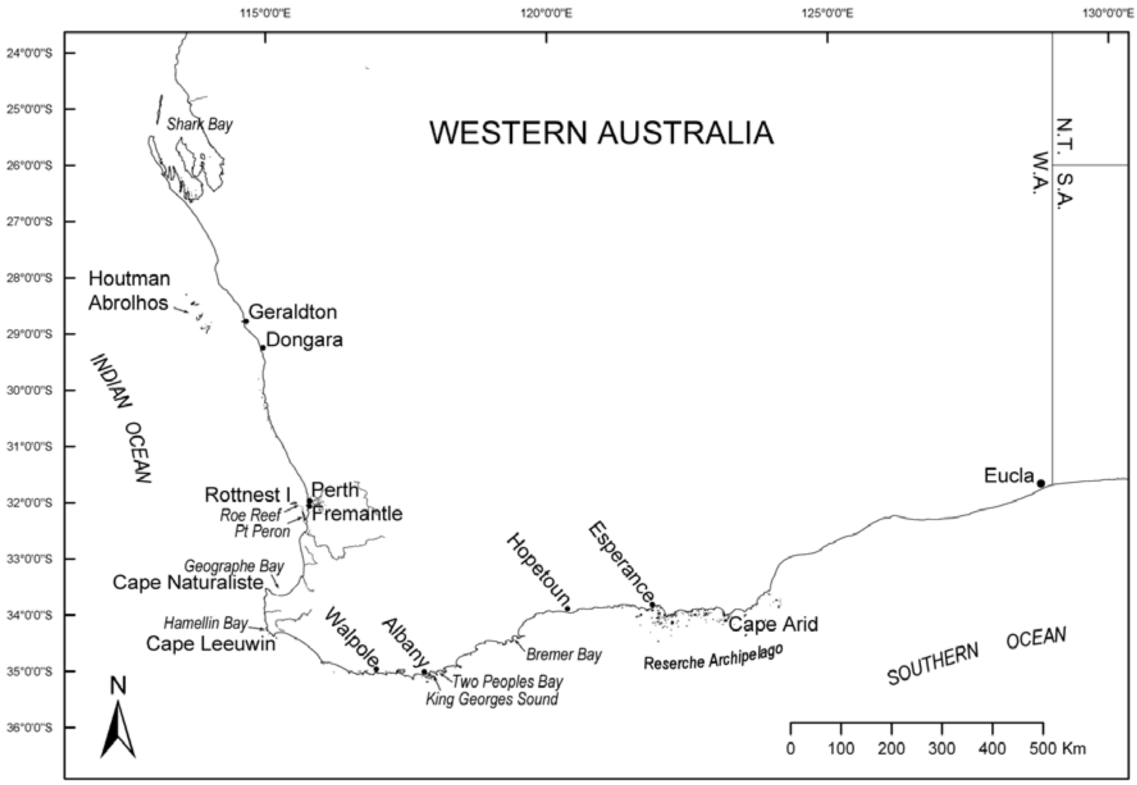
2.2.3 Definitions and criteria

Rarity was defined in the present study as a species' known occurrence at five or fewer localities. This definition has been used in other studies (Sanderson 1996, Austin 2000), and was adopted because it enabled direct comparison to records in the comprehensive COSEMA database (Cheshire et al. 2000).

Locality was regarded as distinct from another locality if the distance between separate populations was >10 km. This distance was used to represent the maximum distance travelled by algal spores or gametes before loss of viability, used here to accommodate the different modes of algal reproduction (brooders vs. broadcasters) (Santelices 2002). Given that average algal propagule dispersal has been estimated to be in the region of very much less than 1 km, and with a planktonic 'larval' period of very much less than 1 day (Kinlan et al. 2005), the 10 km distance used here was a conservative estimate, but one that provided a convenient scale for mapping purposes.

Range was defined as the straight-line distance between the furthest apart known localities of records. The areas referred to in Tables 2.1 and 2.2 were calculated as the product of the nominated range and a distance from shore of 1 km, even though the algae-bearing rocky reefs often extend seaward a much shorter distance than 1 km, and with depths of typically < 50 m. Three range categories were used; Broad range (> 500 km), Narrow range (> 10 km and < 500 km), and Restricted range (< 10 km).

a



b

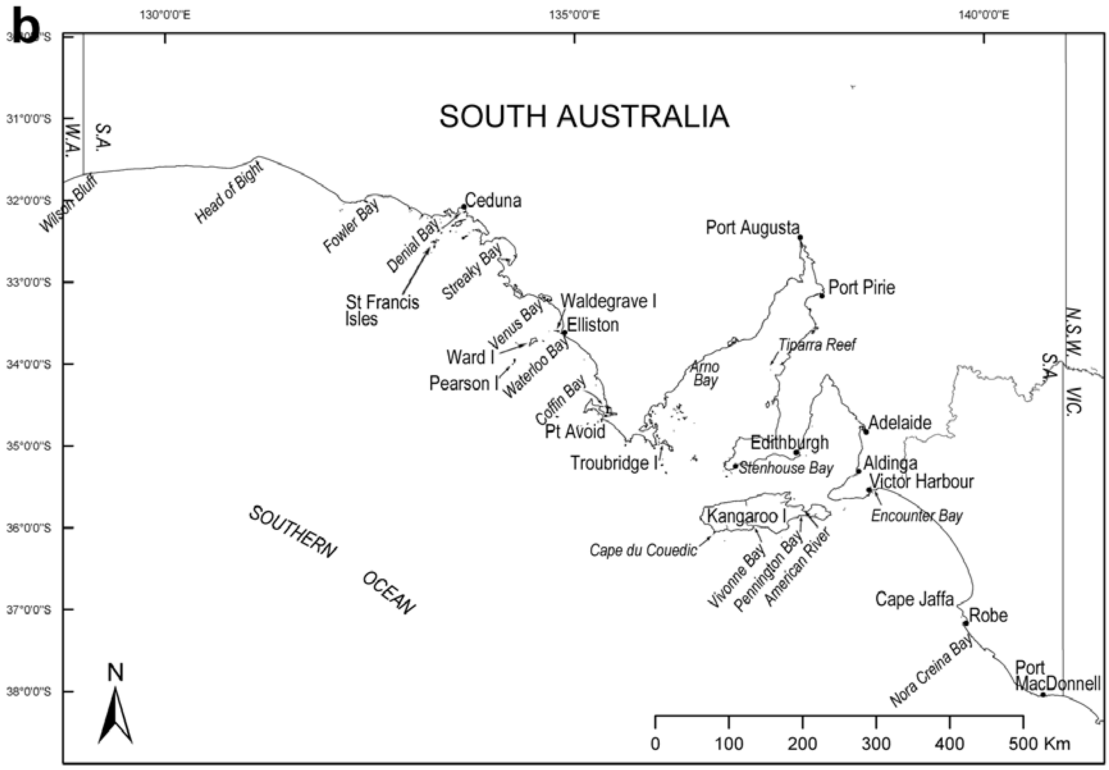


Fig. 2.1a-b Locality maps; a) Western Australia, b) South Australia.

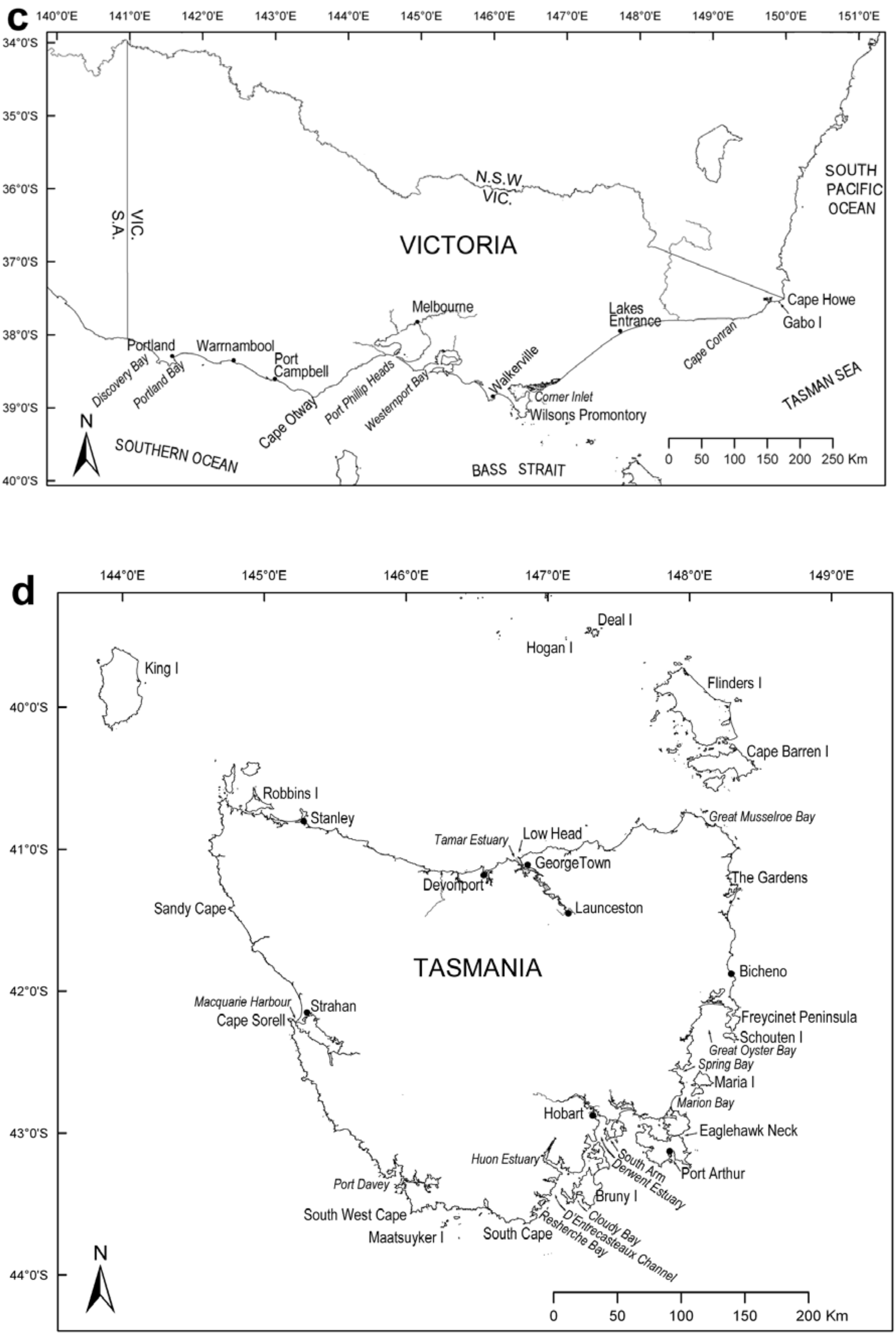


Fig. 2.1c-d Locality maps; c) Victoria, d) Tasmania.

2.2.4 Geographic rarity estimated from literature search

Three main sources of literature were searched for Australian endemic species recorded from five or fewer localities Cheshire *et al.* (2000), McCarthy and Orchard (2007) and Womersley (Womersley 1984, 1987, 1994, 1996, 1998, 2003). Species' names were checked via *AlgaeBase* (Guiry and Guiry 2010), a widely-used, web-based resource that lists the world's algae (searched on 12 October 2008), to ascertain the currently accepted taxonomic status of each species. In 2009 records were searched within the AVH database to gain the most recent species distribution data in preparation for mapping. The records of those species fulfilling the above definitions and criteria were collated in MS Excel workbook and imported into a Geographical Information System (ArcGIS 9, version 9.3). The geocode accuracy (confidence in the accuracy of the lat/long positions) for each record was recorded, but not displayed on the maps generated. Separate shape files (map layers) displaying Australian coastline and the 10^2 km grid cells were imported into the GIS, and all layers were transformed to the same geographic datum (GDA94).

2.2.5 Functional groups of rare species

Because the habit or form of a plant can have implications on perceptions of rarity (Littler and Littler 1980, Padilla and Allen 2000) the rare algae were ascribed to a number of functional forms based on morphological features and physical traits. A six-form scheme was adopted (Nishihara and Terada 2010), viz: (a) membranous, sheet-like forms (e.g. *Ulva*, *Schizoseris*,), (b) filamentous forms (e.g. *Cladophora*, *Callithamnion*), (c) coarsely-branched forms (e.g. *Caulerpa*, *Gelidiella*), (d) thick-leathery forms (e.g. *Cystophora*, *Sargassum*), (e) calcifying forms (e.g. *Lithophyllum*, *Spongites*), and (f) crustose forms (in which I include pulvinate forms) (e.g. *Elachista*, *Tylocolax*). Wherever any overlap of functional groups existed, the most salient features were used to assign species to just one functional group.

An arbitrary thallus height of 10 cm was chosen to further classify rare species. Even though any relationship between thallus height and rarity is difficult to test against the entire species dataset, the data are worthy of inclusion because plant height can be a factor that seriously affects the detectability of species *in situ*.

2.2.6 Statistical analyses

To determine whether the three taxonomic groups (Chlorophyta, Heterokontophyta, Rhodophyta), differed in their proportions of rare species, Pearson's chi-squared test for independence was used.

2.3 Results

2.3.1 Rare species

Of the southern Australian marine macroalgae, 142 species met the criterion of having been recorded from five or fewer localities (Table 2.1) (overleaf).

A number of arguably rare macroalgae known from only a single or very few records or from restricted habitats were excluded from the study because they did not meet the nominated criterion for rarity (Appendix 2).

Table 2.1 List of putative rare algae with indication of habit (form), number of known collection sites and range, listed in the categories of broad-, narrow- and restricted-range, and then alphabetically within these groups. Taxonomic Divisions: H = Heterokontophyta, R = Rhodophyta, C = Chlorophyta. Size: (-) indicates plants ≤10 cm high, (+) indicates plants ≥10 cm high). Functional groups: mem = membranous, sheet-like forms, fil = filamentous forms, cbr = coarsely-branched, leath = thick-leathery, cal = calcifying, cr = crustose/pulvinate. Collecting localities: per 10x10 km grid cell. * *Rhodymenia halymenioides* is now considered a synonym of *Halopeltis cuneata* (Harvey) Saunders. ‡ *Gelidiella ramellosa* was recently rediscovered from near the type locality (Huisman et al. 2009). † *Audouinella nakamurae* = *Colaconema nakamurae*

Taxon	Taxonomic Division	Height (+ = >10 cm) (- = <10 cm)	Functional group	No. of collecting localities	Range (km)
BROAD RANGE (>500 km^2)					
Acrothamniopsis eliseae Athanasiadis & Kraft	R	-	fil	2	606
Amansia mamillaris Lamouroux ex C.Agardh	R	+	cbr	4	1192
Amoenothamnion minimum Wollaston	R	-	fil	3	1153
Amphiplexia racemosa (J.Agardh) Kraft	R	+	cbr	5	1866
Antithamnion biarmatum Athanasiadis	R	-	fil	3	681
Antithamnion diminuatum Wollaston	R	-	fil	2	2524
Antithamnion pinnafolium Wollaston	R	-	fil	5	716
Antithamnionella glandifera Wollaston	R	-	fil	3	1031
Callithamnion circinnatum Womersley	R	-	fil	5	1343
Callithamnion confertum Womersley	R	-	fil	2	961
Callithamnion multifidum Harvey	R	-	fil	3	2733
Caulerpa ellistoniae Wollaston	C	+	cbr	5	2055
Ceramium cupulatum Womersley	R	-	fil	3	1276
Ceramium lenticulare Womersley	R	-	fil	5	1214
Champiocolax lobata Womersley	R	-	cr	4	604
Chondria foliifera (J.Agardh) Falkenberg	R	+	cbr	3	703
Cladophoropsis magna Womersley	C	+	+fil	3	550

Codium silvae Womersley	C	+	cbr	2	621
Coeloclonium debile (Harvey) Gordon-Mills & Womersley	R	-	cbr	3	1790
Crouania destriana Wollaston	R	-	fil	5	535
Cryptonemia digitata (J.Agardh) Womersley & J.A.Lewis	R	+	mem	3	611
Cryptonemia wilsonii J.Agardh	R	+	mem	3	602
Dasya crinita M.J.Parsons & Womersley	R	+	cbr	5	1454
Dasya hapalathrix Harvey	R	+	cbr	4	1156
Dasya wilsonis J.Agardh	R	+	cbr	3	712
Dasycladus densus Womersley	C	-	cbr	4	1279
Dasythamniella superbiens (Harvey) Womersley	R	+	fil	5	1521
Dipterosiphonia australica Womersley	R	-	fil	4	780
Doxodasya hirta (J.Agardh) Womersley & M.J.Parsons	R	+	cbr	3	2038
Erythronaema ceramioides J.Agardh	R	+	cbr	3	659
Ganonema codii Womersley) Huisman & Kraft	R	+	cbr	5	884
Gelidiella ramellosa (Kuetzing) Feldmann & Hamel [‡]	R	-	cbr	2	1915
Griffithsia balara Baldock	R	+	cbr	3	1332
Griffithsia pilalyea Baldock	R	-	cbr	4	1222
Halothrix ephemeralis S.G.Skinner	H	-	fil	5	1285
Herposiphonia monilifera (Hooker & Harvey) Falkenberg	R	-	fil	5	2409
Herposiphonia pectinella (Harvey) Falkenberg	R	-	fil	4	2467
Heterothamnion muelleri (Sonder) J.Agardh	R	-	fil	3	605
Hirsutithallia abaxialis E.M.Wollaston & Womersley	R	-	cbr	3	2758
Hymenocladia filiformis J.Agardh	R	+	cbr	5	1419
Interthamnion attenuatum E.M.Gordon	R	-	fil	3	1167
Kallymenia rubra Womersley & R.E.Norris	R	+	mem	4	1083
Kallymenia spinosa Womersley & R.E.Norris	R	-	mem	3	1763
Leptoklonion fastigiatum (Harvey) Womersley	R	-	fil	5	1020

Lithophyllum johansenii Woelkerling	R	-	cal	4	1124
Macrothamnion pectenellum Wollaston	R	-	fil	4	585
Melobesia rosanoffii Woelkerling	R	-	cal	4	913
Myriogramme cartilaginea (Harvey) Womersley	R	-	mem	3	1801
Myrionema ramulans S.G.Skinner & Womersley	H	-	cr	4	980
Nanopera merrifieldiae (J.Agardh) S.M.Wilson	R	+	cbr	5	770
Nereia lophocladia J.Agardh	H	+	cbr	5	1238
Nitophyllum fallax J.Agardh	R	+	mem	3	800
Palmoclathrus stipitatus Womersley	C	-	cbr	4	792
Phitymophora hypoglossum (J.Agardh) Womersley & L.E.Phillips	R	+	mem	4	3131
Platyclinia ramosa Womersley	R	-	mem	4	1856
Polysiphonia teges Womersley	R	-	fil	3	2881
Porphyrostromium ligulatm (Womersley) West & Zucarello	R	-	fil	3	1144
Predaea huismanii Kraft	R	-	cbr	2	1766
Pseudocodium australasicum Womersley	C	-	cbr	3	1220
Pseudolithoderma australis Woelkerling	H	-	cr	5	1667
Psilothallia siliculosa (Harvey) de Toni	R	-	cbr	4	1036
Pterocladiella minima (Guiry & Womersley) Santelices & Hommersand	R	-	cbr	4	1036
Ptilocladia gracilis (J.Agardh) Womersley	R	+	fil	4	1049
Rhipiliopsis robusta Womersley	C	-	cbr	3	1467
Rhodymenia halymenioides (J.Agardh) Womersley*	R	+	mem	3	601
Scageliopsis patens E.M.Wollaston	R	-	fil	5	1124
Schizoseris hymenena (Zanardini) Womersley	R	+	mem	5	617
Scinaia proliferata Huisman	R	-	cbr	2	651
Sphacelaria chorizocarpa Sauvageau	H	-	fil	3	2063
Spongites tunicata Penrose	R	-	cal	2	586
Vaucheria glomerata Blum & Womersley	H	+	fil	3	703

NARROW RANGE (10 – 500 km ^{2})					
Antithamnionella multiramosa Athanasiadis	R	-	fil	3	329
Bryopsis foliosa Sonder	C	+	cbr	5	450
Callithamnion crispulum Harvey	R	-	fil	2	13.4
Callithamnion shepherdii	R	-	fil	5	385
Chondria hieroglyphica Gordon-Mills & Womersley	R	+	cbr	3	136
Chondria subsecunda Gordon-Mills & Womersley	R	+	cbr	2	161
Cirrulicarpus polycoelioides (J.Agardh) Womersley	R	+	cbr	5	120
Cladophora aegagropiloidea van den Hoek & Womersley	C	-	fil	2	179
Corynophlaea cristata Womersley & S.G.Skinner	H	-	cr	3	484
Crouania brunyana E.M.Wollaston	R	-	fil	2	27
Cystophora cymodocea Womersley & Nizamamudin ex Womersley	H	+	leath	2	288
Cystophora tenuis Womersley	H	+	leath	3	335
Dasya atactica J.Agardh	R	+	cbr	2	51
Dotyophycus abbottiae Kraft	R	-	cbr	2	405
Elachista claytoniae S.G.Skinner	H	-	cr	3	75
Faucheopsis coronata (Harvey) Kylin	R	+	leath	2	353
Haraldia australica Womersley	R	+	mem	2	81
Helminthocladia beaugleholei Womersley	R	+	cbr	4	207
Heterothamnion sessile E.M.Wollaston	R	-	fil	2	130
Hormophora australasica J.Agardh	R	+	cbr	2	352
Hypoglossum harveyanum v. fimbriatum (J.Agardh) Womersley & Shepley	R	+	mem	2	100
Lithothamnion indicum Foslie	R	+	cal	3	154
Mesogloiopsis tasmanica Womersley & A.Bailey	H	+	cbr	2	316
Mychodea spinulifera J.Agardh	R	-	cbr	3	340
Myrionema myriodesmae S.G.Skinner & Womersley	H	-	cr	2	42
Nitophyllum pulchellum Harvey	R	-	mem	2	404

Nitospinosa littledipensis Womersley	R	-	mem	2	454
Papenfussiella extensa Womersley & A.Bailey	H	+	cbr	2	34
Pityophykos tasmanica (Sonder) Papenfuss	R	+	cbr	5	389
Platyclinia crenulata Womersley	R	+	mem	5	450
Polysiphonia haplodasyae Womersley	R	-	fil	2	39
Polysiphonia shepherdii Womersley	R	+	fil	3	333
Pseudochlorodesmis australis (Womersley) Womersley	C	-	fil	3	350
Pterothamnion flexile (E.M. Wollaston) Athanasiadis & Kraft	R	-	fil	2	208
Rhipilia pusilla (Womersley) Ducker	C	-	fil	2	54
Schizoseris perriniae (A.H.S.Lucas) Womersley	R	+	mem	5	258
Schizoseris tasmanica S.M.Lin & Kraft	R	+	mem	3	93
Spatoglossum australasicum Kuetzing	H	+	mem	5	219
Sphacelaria multiplex Womersley	H	-	fil	2	85
Sporochnema tomentosum Womersley	H	+	cbr	2	313
Strepsithalia leathesiae Womersley & S.G.Skinner	H	-	cr	2	40
Sympodophyllum reinboldii Shepley & Womersley	R	-	mem	2	18
Tylocolax microcarpus F.Schmitz	R	-	cr	5	322
Ulvaria shepherdii Womersley	C	-	mem	2	359
Vaucheria conifer Christensen	H	-	fil	3	207
RESTRICTED RANGE (<10 km^2)					
Acrotrichium amphibolis Womersley & S.G.Skinner	H	-	fil	1	<1
Antithamnion uniramosum Athanasiadis	R	-	fil	1	<1
Audouinella blumii Woelkerling	R	-	fil	1	9
Audouinella nakamurae (Woelkerling) Garbary †	R	-	fil	1	<1
Balliella hirsuta Huisman	R	-	fil	1	3
Bangia atropurpurea subsp. brevisegmenta Womersley	R	-	fil	1	<1
Callithamnion perpusillum P.C.Silva	R	-	fil	1	<1

Callithamnion propebyssoides Womersley	R	-	fil	1	<1
Champia parvula var. amphibolis Reedman & Womersley	R	+	cbr	1	<1
Dasya tenuis M.J.Parsons & Womersley	R	+	cbr	1	5
Dictyota crinita (Dilophus crinitus) J.Agardh	H	-	mem	1	<1
Ganonema helminthaxis Huisman & Kraft	R	+	cbr	1	<1
Gloiophloea rosea (J.Agardh) Huisman & Womersley	R	-	cbr	1	<1
Gymnothamnion nigrescens (J.Agardh) Athanasiadis	R	-	fil	1	<1
Hapalospongidion capitatum Womersley	H	-	cr	1	<1
Heterothamnion platythaliae Athanasiadis	R	-	fil	1	<1
Myriactula caespitosa Womersley & S.G.Skinner	H	-	cr	1	<1
Myriactula filiformis Womersley & S.G.Skinner	H	-	cr	1	<1
Myrionema latipilosum S.G.Skinner & Womersley	H	-	cr	1	<1
Pterothamnion aciculare (E.M.Wollaston) Athanasiadis & Kraft	R	-	fil	1	<1
Pterothamnion manifestum (E.M.Wollaston) Athanasiadis & Kraft	R	+	fil	1	4.7
Rhipiliopsis multiplex Kraft	C	+	fil	1	3
Strepsithalia aemula Womersley & S.G.Skinner	H	-	cr	1	<1
Tolypiocladia penningtonensis Womersley	R	-	cbr	1	5
Trithamnion tenellum (Harvey) Wollaston	R	-	fil	1	<1
Zosterocarpus australicus Womersley	H	-	fil	1	<1

In terms of the range categories the broad-range species (from all three algal divisions) accounted for half of the total number and for taxonomic groups the Rhodophyta accounted for about two thirds of the total (Table 2.2). There was no difference in the proportion of rare species between taxonomic groups (Table 2.3) ($Chi^2 = 0.94$, d.f. = 2, $P > 0.05$).

Range Category	**Chlorophyta**	**Heterokont -ophyta**	**Rhodophyta**	**TOTAL**
Broad (>500 km^2)	7	6	58	71
Narrow (>10 km^2 and <500 km^2)	5	12	28	45
Restricted (<10 km^2)	1	8	17	26
TOTAL rare species	13	26	103	142

Table 2.2 Range categories for rare macroalgae (number of species) within the 3 taxonomic divisions.

Observed/Expected	**Chlorophyta**	**Heterokont -ophyta**	**Rhodophyta**	**TOTAL**
Observed rare spp.	13	26	103	142
Expected rare spp.	15	29	97	
Observed non-rare spp.	110	205	675	990
Expected non-rare spp.	108	202	680	

Table 2.3 Observed and expected distribution of rare macroalgae (number of species) across the three taxonomic groups ($p > 0.05$).

2.3.2 Patterns of rare species distribution

One hundred and sixty-eight discrete areas contained rare species (Figs 2.2–3), spanning two hundred and fourteen 10 x10 km grid cells, each containing at least one rare species (Fig. 2.4). The continuous spread of rare species along the southern Australian coastline showed a degree of clustering into four regions (Fig. 2.3):

a) The Rottnest I – Swan River – Point Peron region in Western Australia (Fig. 2.3a) is an open-water region markedly rich in local endemics which may be attributed to an unusual combination of limestone reef habitats, open-water exposure and influx of seasonal warm ocean currents. This region is known for its overall species richness with a southern temperate flora plus some “tropical” species occurrences (Huisman and Walker 1990).

b) The Gulfs Region of South Australia (Fig. 2.3b) comprises a numbers of smaller open-water and sheltered-water centres of rarity. The open-water areas include the southern coasts of Kangaroo I (Vivonne Bay, Pennington Bay) and northern Encounter Bay (Victor Harbour, Granite I, West I). The somewhat discrete sheltered-water regions include the Investigator Strait area (Penneshaw, American River) and areas in Spencer Gulf (Edithburgh, Tiparra Reef) and St Vincent Gulf (Port Stanvac, Aldinga).

c) The Port Phillip Bay region of Victoria (Fig. 2.3c) (Pt Lonsdale, Queenscliff, Portsea, South Channel, Port Phillip Bay “central”, Port Melbourne, and Williamstown) and Westernport Bay (Crawfish Rock and San Remo) are deep embayments, effectively ancient estuaries that are typically subject to a constantly changing environment in terms of light availability, salinity and nutrient flow.

d) In south-eastern Tasmania (Fig. 2.3d) the confluence of the Huon and Derwent Estuaries (Ninepin Pt, Satellite I, Simpsons Bay, Tinderbox, Taroona, and South Arm) encompass sheltered-water centres of rarity.

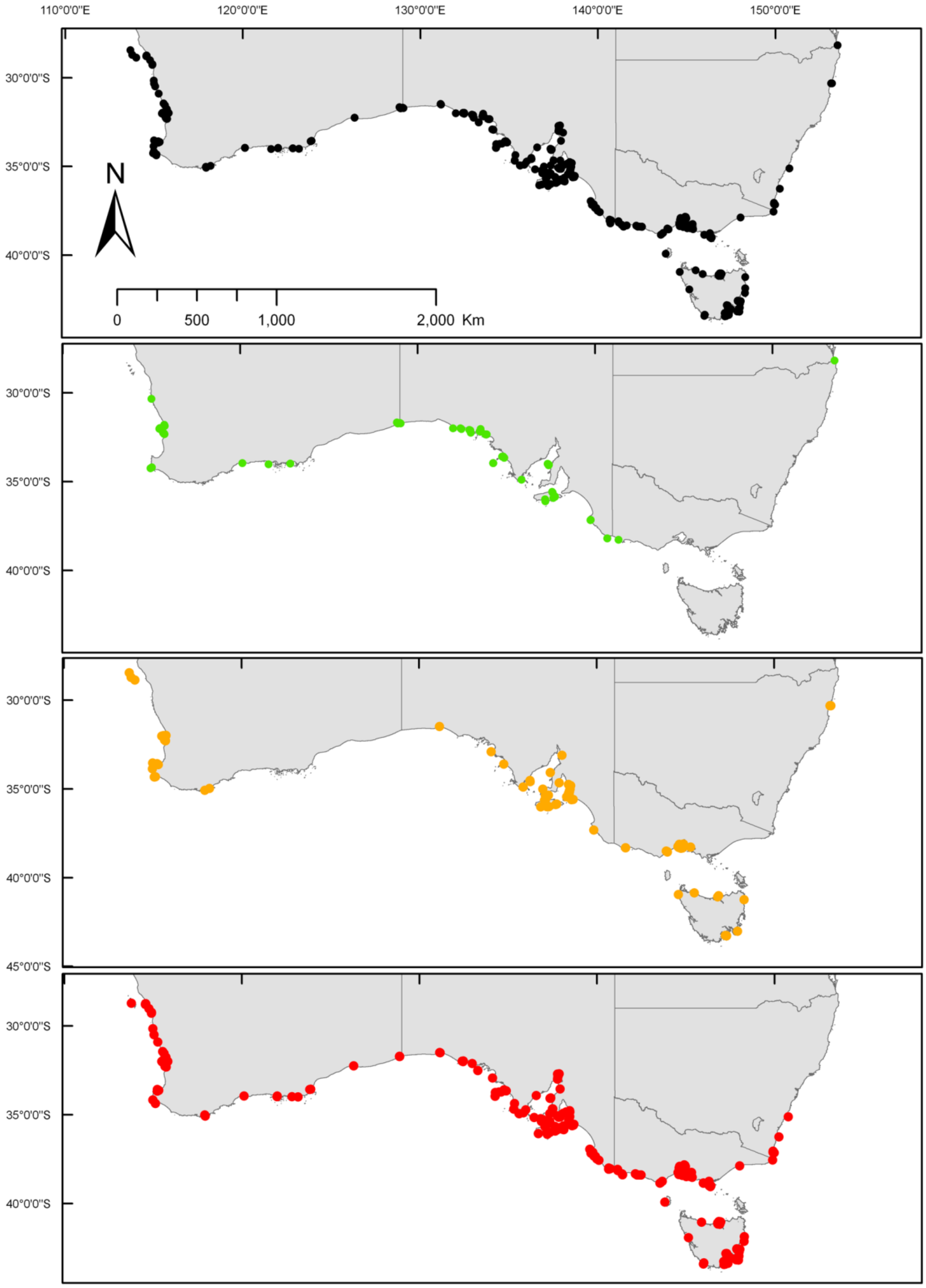


Fig. 2.2a-d Distribution of rare species, a) all taxa, b) Chlorophyta, c) Heterokontophyta and d) Rhodophyta. Each data point relates to a single herbarium specimen (either a pressed specimen or a microscope slide), but many data are occluded due to collection proximity.

10 km^2 gridcell Unique ID	Location (10 km^2 grid cell)	Total species number	Rare species number
88895	Pt Lonsdale VIC	485	23
89816	Port Phillip Bay (central)*VIC	269	17
102605	Pennington Bay SA	395	12
114055	Elliston (E) SA	387	10
102141	Vivonne Bay SA	387	10
88896	Portsea (N) VIC	225	9
63208	Ninepin Pt TAS	208	9
116628	Rottnest I (S) WA	311	8
106284	Port Stanvac SA	274	8
103990	Victor Harbour (W) SA	388	8
95738	Robe SA	438	8
105366	Aldinga SA	221	7
74223	Low Head TAS	300	7
112672	Pearson Isles SA	217	6
111783	Tiparra Reef (SE) SA	187	6
88901	Crawfish Rock VIC	226	6
115712	Pt Peron WA	316	5
116629	Roe Reef WA	137	5
114513	Waldegrave I SA	129	5
106737	Edithburgh SA	142	5
103525	Penneshaw SA	183	5
88876	Warnambool VIC	145	5
91193	Port Melbourne VIC	196	5

Table 2.4 Locations where ≥5 rare species co-occur. The unique grid cell ID numbers generated by ArcGIS software are included here for data provenance only. * The ‘central’ location nominated for some early Port Phillip Bay records.

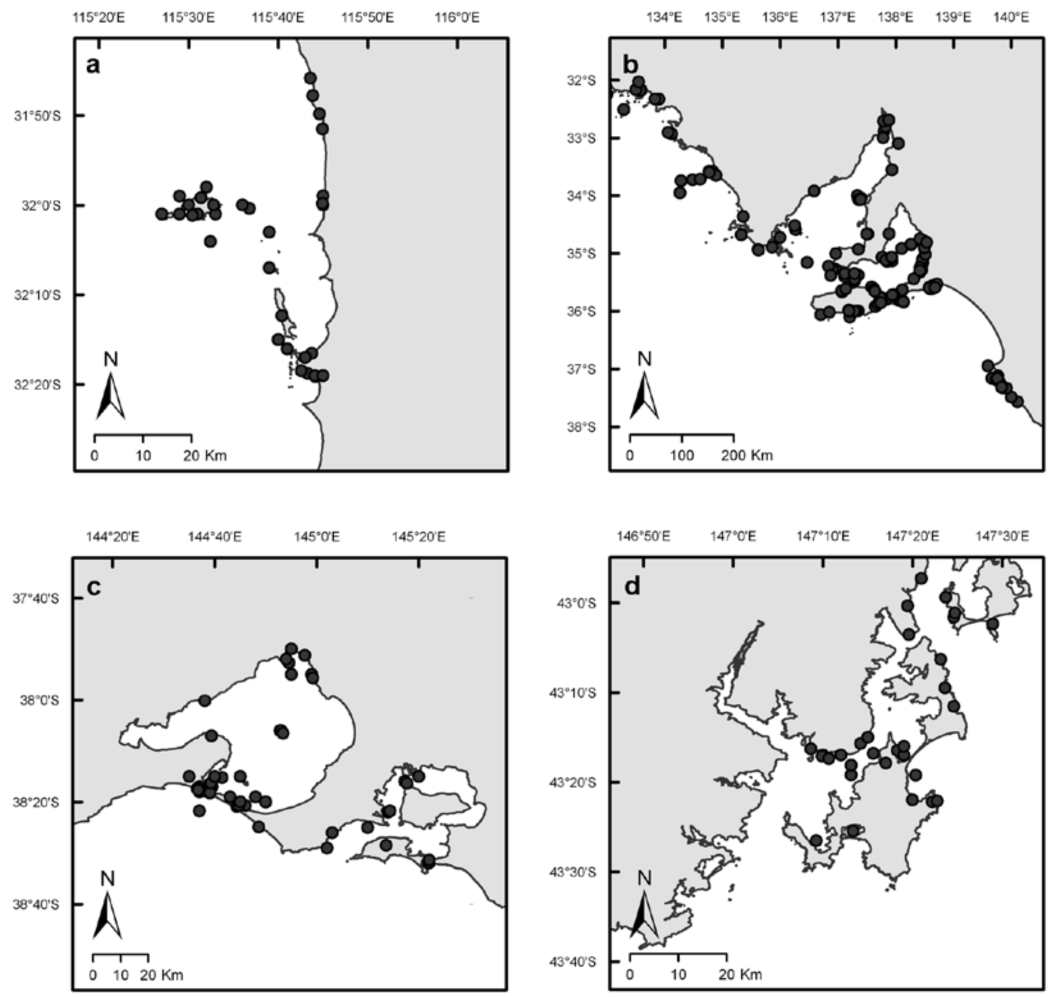


Fig. 2.3a-d Rare species records in the region of a) Rottnest I area (Rottnest I, Swan River, Fremantle, Roe Reef, Pt Peron), b) South Australian gulfs, c) Port Phillip Bay area (Pt Lonsdale, Portsea, Port Phillip "central", Williamstown, Port Melbourne), d) D'Entrecasteaux Channel area, Tasmania (Ninepin Pt, Satellite I, Simpson's Bay).

2.3.3 Co-occurrence of rare species

The 10 km grid cell overlay on the map allowed rare species co-occurrence data to be mapped and 'centres of rarity' to be visualised (Fig. 2.4). Rare species occurred in 214 of the 1311 10x10 km grid cells. A total of 96 localities were identified in which multiple numbers of rare species were recorded. Many were 'singletons' (only one rare species recorded for that grid cell), but 45% had multiple numbers of rare species (Table 2.5).

No. rare species per 10x10 km grid	1	2-5	6-10	>10
No. grid cells	118	80	13	3

Table 2.5 Overview of the co-occurrence of rare species recorded for the 10 km grid cells.

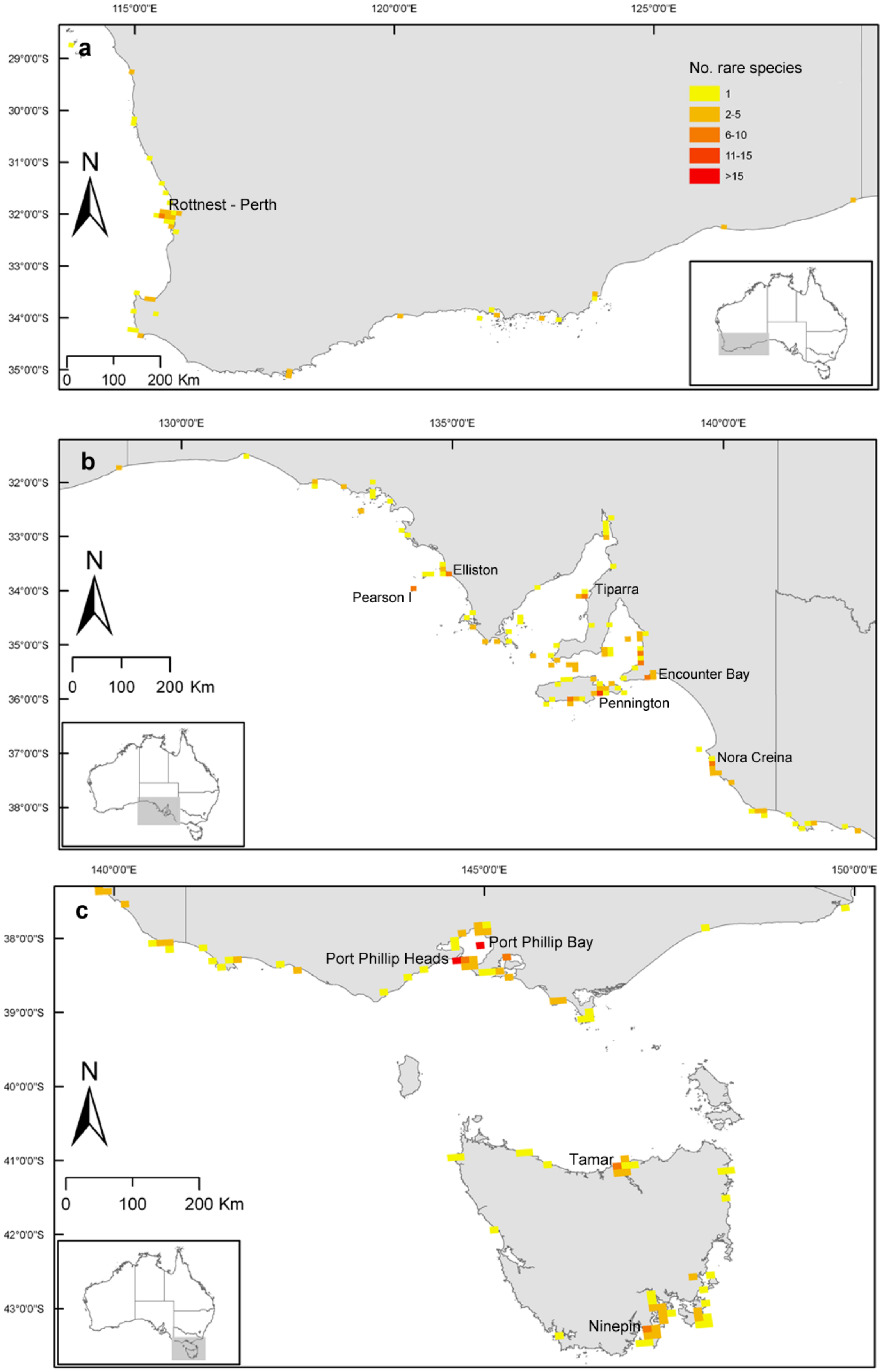


Fig. 2.4a-c Co-occurrence of rare species in 10x10 km grid cells across southern Australian coasts. a) Western Australia, b) South Australia, c) Victoria and Tasmania.

2.3.4 Functional groups of rare species

The suite of rare macroalgae in this study was dominated by species of small height, and of either filamentous or coarse-branched habit. The combined numbers of filamentous and coarsely-branched species constitute a substantial proportion (70.4%) of the functional forms of rare algae (Table 2.6). Fifty-six of the rare species (39.4%) are within the 'filamentous' group, that is having filaments or branches just one or only a few cells thick. Of the forty-five coarsely-branched species (31.6% of the total) half are also less than 10 cm high. In terms of plant height eighty-eight taxa (~62%) were ≤10 cm high (Table 2.1).

Functional group	No. Rare species	% of the 142 rare species
filamentous	56	39.4
membranous, sheet-like	21	14.7
coarse-branched	45	31.6
crustose	13	9.2
calcified	4	2.8
leathery, thick	3	2.1

Table 2.6 Functional groups of rare macroalgae from southern Australia.

2.3.5 Range-restricted rare species

Those rare species recorded from a single locality and those that were range-restricted (≤10 km^2) were of particular interest because they had a potential Red List conservation status of Vulnerable VU D2 (species with a very restricted range and high risk of extinction in the wild) (IUCN 2001). A subset of twenty-six species met these criteria distributed over 20 localities (Table 2.7).

Range restricted species were concentrated in the same areas as other rare species (Figs 2.5a–d). Specific strong regions of local endemism were Rottnest I, Kangaroo I, and the gulf areas of South Australia. Only one green alga (*Rhipiliopsis multiplex* Kraft) was of restricted range (Fig. 2.5b). Range-restricted brown macroalgae were only reported for mainland Australia (Fig. 2.5c) and range-restricted red macroalgae were reported for all four states (Fig 2.5d).

Location /Area (≤10 km^2)	Number of species	Taxon
WA		
Rottnest Is. – Swan River	6	*Rhipiliopsis multiplex*
		Dictyota crinita
		Balliella hirsuta
		Callithamnion perpusillum
		Ganonema helminthaxis
		Trithamnion tenellum
Cape Leeuwin	1	*Heterothamnion platythaliae*
King George Sound	1	*Hapalospongidion capitatum*
SA		
Wanna	1	*Myriactula caespitosa*
Arno Bay	1	*Antithamnion uniramosum*
Fisherman Bay (Port Broughton)	1	*Callithamnion propebyssoides*
Tiparra Reef	1	*Champia parvula* var. *amphibolis*
Investigator Strait	1	*Zosterocarpus australicus*
Onkaparinga Estuary	1	*Myrionema latipilosum*
Aldinga	1	*Myriactula filiformis*
Cape du Couedic	1	*Audouinella nakamurae*†
Sou'West River mouth	1	*Strepsithalia aemula*
Pennington Bay	1	*Tolypiocladia penningtonensis*
American River & Muston	1	*Dasya tenuis*
Antechamber Bay	1	*Audouinella blumii*
Victor Harbour	1	*Acrotrichium amphibolis*
VIC		
Warrnambool	1	*Bangia atropurpurea* subsp. *brevisegmenta*
Port Phillip Heads	2	*Gloiophloea rosea*
		Gymnothamnion nigrescens
TAS		
Ninepin Pt area	1	*Pterothamnion manifestum*
Taroona	1	*Pterothamnion aciculare*

Table 2.7. Localities where the 26 single-locality or range-restricted rare species occur. †*Audouinella nakamurae* = *Colaconema nakamurae*.

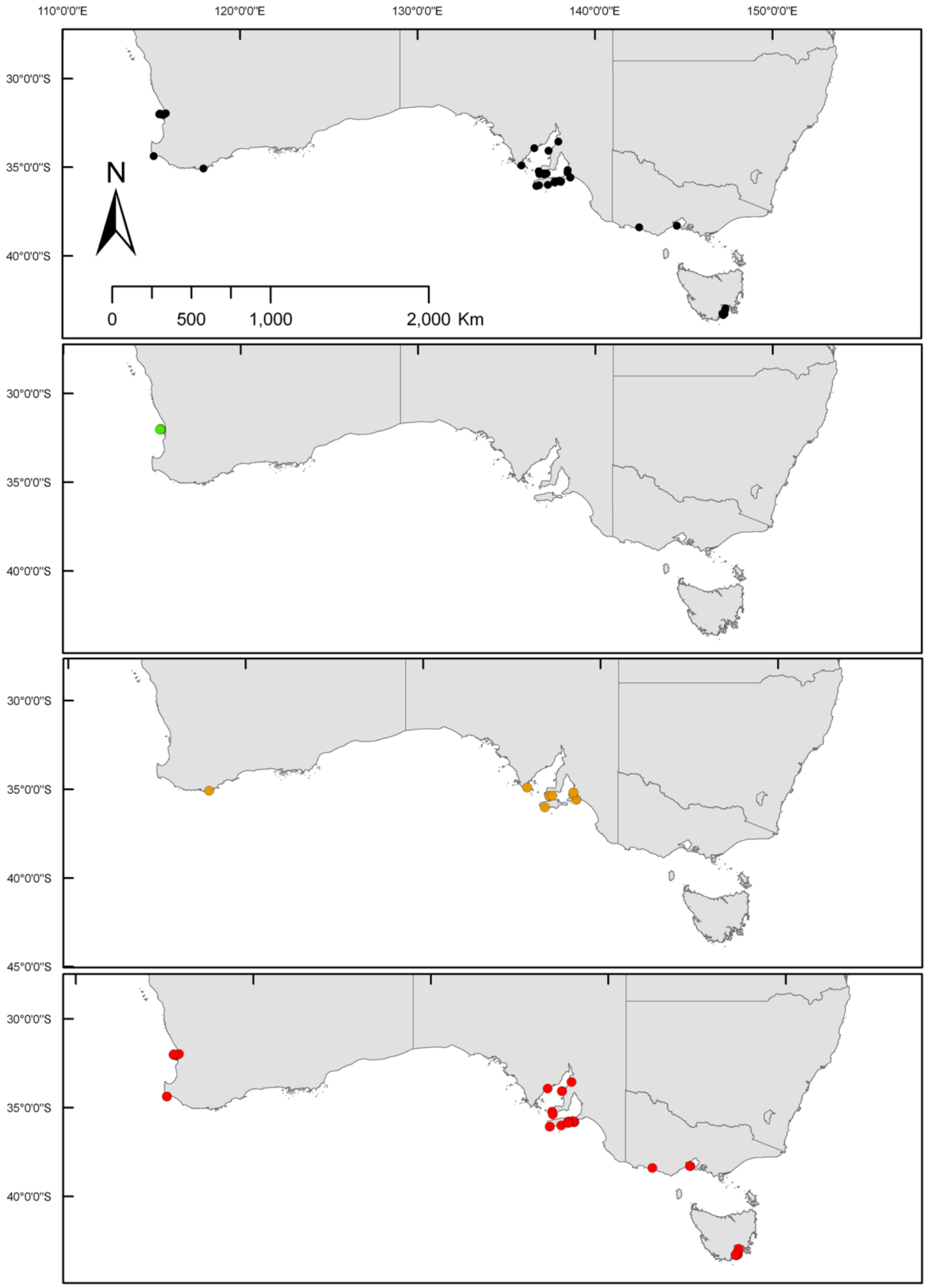


Fig. 2.5a-d Range-restricted, rare species; a) all taxa, b) Chlorophyta, c) Heterkontophyta, and d) Rhodophyta.

2.3.6 Species richness

The AVH data used included 1487 macroalgae; 134 rare species plus 1353 non-rare species. The majority of the 1311 sampled grid cells contained fewer than 100 species (Table 2.8). Five large (2-5 contiguous grid cells) and 19 small (1 grid cell) areas had ≥200 species per grid cell (Table 2.9). The five larger centres were (from west to east) Rottnest I–Perth (Fig. 2.6a), Encounter Bay, Nora Creina, Port MacDonnell (Fig. 2.6b), and Port Phillip Heads (Fig. 2.6c). The grid cell with the highest species richness was Pt Lonsdale (Port Phillip Heads, Victoria) with 485 species. Some of the 19 smaller centres of species richness were in the general vicinity of the larger centres, for example, St. Kilda and Port Phillip (central) were relatively close to Port Phillip Heads.

No. species per 10x 10 km grid	1-99	100-199	200-299	≥300
No. grid cells	1210	69	22	10

Table 2.8 Overview of species richness as known from AVH records, showing species numbers per 10 km grid cell.

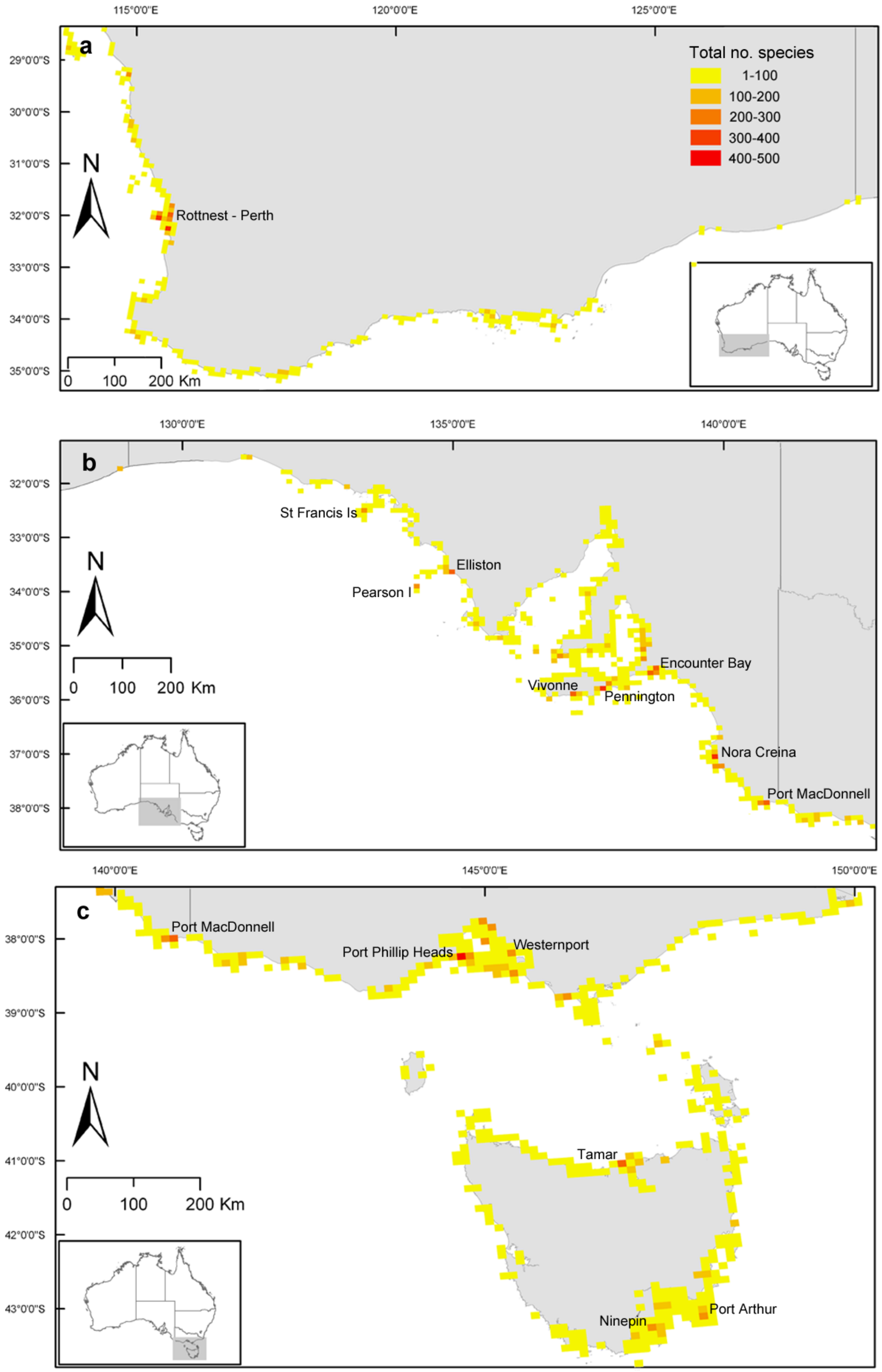


Fig. 2.6a-c Species richness in 10x10 km grid cells across southern Australian coasts (raw data, AVH records). a)Western Australia, b) South Australia, c) Victoria and Tasmania.

Centres of Species Richness	Unique ID (ArcGIS)	Locality (10x10 km grid cell)	Total species number	Rare species number
Rottnest I - Perth WA	115712	Pt Peron	316	5
	116628	Rottnest I (S)	311	8
	117089	Perth	249	2
	116630	Fremantle	231	3
Encounter Bay SA	103990	Victor Harbour (W)	388	8
	104450	Victor Harbour (N)	359	2
	103991	Encounter Bay	221	2
Nora Creina SA	94820	Nora Creina (W)	208	3
	94821	Nora Creina (E)	214	4
Port MacDonnell SA	91156	Port MacDonnell (E)	298	4
	91155	Port MacDonnell (W)	217	4
Port Phillip Heads VIC	88895	Pt Lonsdale	485	23
	88896	Portsea	225	9
Port Denison WA	130388	Port Denison	202	3
Great Australian Bight SA	120007	St Francis Isles	226	3
Eyre Peninsula (W) SA	112672	Pearson Isles	217	6
Eyre Peninsula (W) SA	114055	Elliston (E)	387	10
St Vincent Gulf SA	106284	Port Stanvac	274	8
St Vincent Gulf SA	105366	Aldinga	221	7
St Vincent Gulf SA	105811	Stenhouse Bay	270	3
Kangaroo I SA	102141	Vivonne Bay	387	10
Kangaroo I SA	102605	Pennington Bay (W)	395	12
Kangaroo I SA	103065	Pelican Lagoon	249	4
Robe SA	95738	Robe	438	8
Port Phillip Bay VIC	90735	St. Kilda	248	3
Port Phillip Bay VIC	89816	Port Phillip (central)	269	17
Westernport Bay VIC	88901	Crawfish Rock	226	6
Westernport Bay VIC	87524	San Remo	205	2
Waratah Bay VIC	85694	Walkerville	243	3
Tamar Estuary TAS	74223	Low Head	300	7
Derwent Estuary TAS	63673	Port Arthur	219	2
D'Entrecasteaux Channel TAS	63208	Ninepin Pt	208	9
Spencer Gulf SA	111783	Tiparra Reef (SE)	187	6
Rottnest I - Perth WA	116629	Roe Reef	137	5
Eyre Peninsula (W) SA	114513	Waldegrave I	129	5
St Vincent Gulf SA	106737	Edithburgh	142	5
Kangaroo I SA	103525	Penneshaw	183	5
SE VIC	88876	Warrnambool	145	5
Port Phillip Bay VIC	91193	Port Melbourne	196	5

Table 2.9 Centres of species richness; uppermost five large centres of species richness (≥200 species per grid cell) in which locality grid cells are contiguous; then smaller centres of species richness in non-contiguous grid cells; lowermost are grid cells of lower species richness and with ≥5 rare species, not contiguous with other grid cells.

2.4 Discussion

2.4.1 General observations

Visualising the distribution patterns of rare marine macroalgae is useful as a framework on which to build and test ideas. However, using only herbarium specimens inherently means that distribution patterns cannot account for any species occurrence in un-visited locations.

Several challenges await the researcher attempting to investigate, relocate or assess rare macroalgae. Many of the rare species are inadequately known in terms of habitat, life history, distribution and abundance. Plants of small size or cryptic habit are often difficult to identify under both field and laboratory circumstances. As examples, the small size and epiphytic nature of *Tylocolax microcarpus* F.Schmitz, *Strepsithalia* spp, *Acrotrichium amphibolis* Womersley & Skinner, *Myriactula* spp. and *Corynophlaea cristata* Womersley & Skinner make these species recognisable only at a microscopic level.

Phenotypic plasticity can also play a part in discerning rare species. Algae have a simple morphology compared to higher plants and animals, but they can show varying degrees of phenotypic plasticity in response to environmental factors (Fowler-Walker et al. 2005, Saunders and Lehmkuhl 2005b). Not only can this thwart identification of algae in the field but it can compromise efforts to classify algae in terms of form and function.

Different classifications for algal form and function have been devised over the years, according to the needs of the study and the outlook of the researchers. The resultant groups are usually logical but subjectively constructed rather than having strict definitions and species overlap between two functional groups is not uncommon (Littler and Littler 1980, Fowler-Walker et al. 2005, Nishihara and Terada 2010). For example, species of the epiphytic brown algae *Strepsithalia*, *Myriactula* and *Elachista* have endophytic and crustose basal parts plus minute distal filamentous tufts, thus falling into two of the above forms; *Dictyota* and *Spatoglossum* and *Phitymophora* are both membranous and coarsely branched; *Lithophyllum* and *Melobesia* are both crustose and calciferous; recently, some species of the calcareous genus *Bossiella* (Corallinoideae, Rhodophyta) were confirmed to have discrete erect fronds arising from an otherwise crustose thallus (Gabrielson 2011). In the present study, even though filamentous and coarsely-branched taxa accounted for substantial proportions of the total (Table 2.6), it is impossible to discern whether a particular group is over or under-represented amongst the rare species without knowing the proportions of functional groups for the entire data set.

A number of species have been described on the basis of either a single plant or a small number of plants from the one collection and have never been found since their original collection. The epiphytic *Acrotrichium amphibolis* Womersley & Skinner is only known from the type collection from Victor Harbour, *Strepsithalia aemula* Womersley & Skinner is only known from the type collection as an epiphyte on *Helminthocladia australis* Harvey. *Dictyota crinita* (*Dilophus crinitus*) J.Agardh is known only from the 1897 type collection from Rottnest Island. Such scanty records do not necessarily mean such species should be regarded as rare or threatened however– they may well be encountered during future target-searches.

A further problem exists with specimens previously collected only in the drift, in that information about their actual habitat can only be deduced. For instance the minute red alga *Heterothamnion platythaliae* Athanasiadis is known from a single collection of plants epiphytic on a drift *Platythalia angustifolia* Sonder specimen. Similarly *Myriactula filiformis* Womersely & Skinner is known only from the type collection of plants epiphytic on a drift *Cystophora monilifera* J. Agardh specimen. Other rare species require the application of specific taxonomic expertise or labour intensive histology for identification such as the crustose coralline species *Lithophyllum johansenii* Woelkerling, *Melobesia rosanofii* Woelkerling, *Pseudolithoderma australe* Woelkerling, and *Spongites tunicata* Penrose.

Several rare species are found within closely-related genera, although this may well be an idiosyncrasy of specific research focus. As examples, the epiphytic brown algae *Elachista*, *Myrionema*, *Myriactula* and *Strepsithalia* were studied for a specific project of Womersely and Skinner (Womersley 1987); several species of *Callithamnion* were described by Womersely in a single work (Womersley 1998); intensive work by Wollaston resulted in rare species descriptions of filamentous red algae in the genera *Antithamnionella, Antithamnion, Macrothamnion, Ptilocladia, Crouania*, and *Heterothamnion* (Wollaston 1967, Womersley 1998).

Included in the 142 rare species are a small number (8) that comprise monospecific genera; three broad-range species *Palmoclathrus stipitatus* Womersley (Palmellaceae), *Erythronaema ceramioides* J.Agardh (Cystocloniaceae) and *Nanopera merrifieldiae* (J. Agardh) Wilson (Rhodomelaceae); three narrow-range species *Hormophora australasica* J. Agardh (Kallymeniaceae), *Pityophykos tasmanica* (Sonder) Papenfuss (Rhodomelaceae) and *Tylocolax microcarpus* F. Schmitz (Rhodomelaceae); and two range-restricted species *Sympodophyllum reinboldii* Shepley & Womersley (Delesseriaceae) and epiphytic *Acrotrichium amphibolis* Womersley & Skinner (Chordariaceae). Since molecular studies have clarified the relationships of many algae at relatively high taxonomic levels (family, class, order) (Freshwater et al. 1994, Ragan et al. 1994, Huisman and Saunders 2007), application of such techniques may well shed light on any coincidence of rarity between closely-related taxa.

In the present study, the use of 10 km as a distance to designate separate populations was convenient, but perhaps overly conservative. The dispersal of algal propagules (spores, gametes or vegetative thallus fragments) is a complex process in nature and a critical factor contributing to species distribution. Propagule dispersal (and successful decolonization) can vary from species to species and may be subject to a combination of both biological processes (propagule viability, motility, longevity, buoyancy) and physical processes (water motion, currents, timing of release, distance from other gametes) (Bobadilla and Santelices 2005, Goldberg and Kendrick 2007).

Planktonic periods for marine propagules generally remain unknown. Seed dispersal for the common seagrass *Zostera marina* Linnaeus was demonstrated to be 3–4 m (Billingham et al. 2007) and for most algal propagules is thought to be in the realm of 10s of metres. However, average dispersal scales cannot be a true representation of extreme dispersal events and could not possibly account for colonisation of remote populations. Explanations of the processes involved in the connectivity of habitat patches will benefit from quantitative studies of species' growth and reproduction across the respective biogeographic ranges (Dethier et al. 2003, Kinlan et al. 2005). At least one recent study has indicated that kelp spores may be subject not only to passive horizontal dispersion but also to vertical transport into parts of the water column that could facilitate long-distance dispersal by means of wave and current flow (Cie and Edwards 2011). Due to the paucity of information about the biology and life histories of rare macroalgae it is unrealistic to speculate on the means or success of propagule dispersal.

2.4.2 Estimates of rare species numbers

The numbers of rare algae (defined as occurring at five or fewer localities) are lower than the earlier COSEMA 2000 estimates (Table 2.10). Most notable is the reduction in number of range-restricted species (48 to current estimate of 26). Intensive collections made during the last decade can explain this difference, with some of the recent records representing new localities or range extensions for species now ineligible for inclusion in the rare species list. However, additions can also be expected, such as species newly described (in contrast to species being merely phylogenetically reclassified). Additions may also result from a species' demise in population or range resulting in meeting criteria for a higher level of conservation status, as has been proposed for several species of *Sargassum* in subtropical Queensland waters (Phillips and Blackshaw 2011). To illustrate such changes, estimates of rare species number for both southern Australia and all of Australia can be compared to the IUCN estimates (IUCN 2012) (Table 2.10).

	Cheshire et al 2000 (southern AUS)	**Present study (southern AUS)**	**Cheshire et al 2000 (all AUS)**	**IUCN Red List 2000 (all AUS)**
Vulnerable, with broad range	78 (≤5 localities)	71 (≤5 localities)	**127** (≤5 localities)	129 (AOO 2000 km^2 EOO 20,000 km^2)
Vulnerable, with narrow range	56 (≤5 localities; < 500 km range)	45 (≤5 localities; < 500 km range)	**77** (≤5 localities; < 500 km range)	76 (AOO 500 km^2 EOO 5,000 km^2)
Vulnerable, potentially endangered	48 (≤5 localities; < 10 km range)	26 (≤5 localities; < 10 km range)	**143** (≤5 localities; < 10 km range)	0 * (AOO 10 km^2 EOO 100 km^2)

Table 2.10 Past and present estimates of rare macroalgal species numbers. Information in brackets relates to criteria used. IUCN (International Union for the Conservation of Nature) criteria: EOO = Extent of Occurrence; AOO = Area of Occupancy. IUCN website searched 6 Feb 2012. *The red alga *Vanvoorstia bennettiana* (Harvey)

Papenfuss (F. Delesseriaceae) from New South Wales was listed as Extinct by IUCN 2003.

It is worthwhile at this stage re-visiting the different concepts of geographic ranges. Two widely accepted concepts used by the IUCN are 1) the extent of occurrence (EOO) referring to the area bounded by the outermost geographic limits of the occurrence of a species, and 2) the area of occupancy (AOO), meaning the total area of gridded cells where the species actually occurs. These measures serve different purposes. The two areas *may* be equal, but the AOO is typically much smaller. Where there are small isolated populations of a species, the AOO may be only a minute fraction of the EOO (Hurlbert and Jetz 2007, Gaston and Fuller 2009). The tasks involved in estimating these values for marine organisms that are small or difficult to identify *in situ* are herculean, if not impossible using current technology.

Were more known about distribution and frequency of occurrence of rare species it is likely that several southern Australian macroalgae would meet IUCN criteria for one of the ‘vulnerable’ categories. In Australia, the few macroalgae with acknowledged threatened status include the brown alga *Cystoseira trinodis* (Forsskål) C. Agardh (Tasmanian conservation status: **Rare**) (DPIW 2011) and *Vanvoorstia bennettiana* (Harvey) Papenfuss (State Government of New South Wales, Fisheries Management Act: **Presumed Extinct)** (Chapman 1999). Under the federal Environment Protections & Biodiversity Conservation Act 1999, the giant kelp forests of south-east Australia based on the key species *Macrocystis pyrifera* (Linnaeus) C. Agardh have been recently (2012) listed as a “Threatened Ecological Community”.

2.4.3 Patterns of macroalgal rarity and richness

The strong distribution patterns that appear from these occurrence data, particularly of the range-restricted rare species, suggest specific areas of local endemism. Areas of concentrations of rare macroalgae may be found in a range of exposure habitats (with respect to exposure to wind-generated seas and long-distance ocean swell) from open to sheltered-waters. The four general regions (Rottnest–Perth WA, Gulfs SA, Port Phillip Heads VIC, and south-east TAS) are well-recognised as areas of high macroalgal biodiversity. There is little doubt that known distributions in part reflect the proximity of collecting sites to major population centres (capital cities) of southern Australia. This issue of collection bias is addressed in Chapter 3. The locations at which rare species have been recorded vary so greatly in terms of physical and biological environment, that suspected ‘centres of rarity’ would best be investigated at a finer scale, perhaps kilometres, or tens of kilometres. Possible associations with environmental variables are explored in Chapters 3 and 4.

Patterns for range-restricted rare species in general reflect those of broader-range rare species, but the data are too few in number to offer further insight. Identification of these regions are supported by the findings of Phillips (2001), in which four different distribution patterns were found for southern Australian endemics, viz, SW Australia, SE Australia, South Coast Australia and the combined W, S and E coasts Australia.

Both the gulf regions of South Australia and south-eastern Tasmania are known for their high levels of local endemism in marine fauna (crabs, shrimps, echinoids, holothurians, asteroids) (O'Hara and Poore 2000) and this is reflected in the concentrations of range-restricted rare macroalgae (Fig. 2.4). Current investigations suggest that the Huon Estuary is the site of at least one as yet undescribed range-restricted species (G. Saunders & G. Kraft, pers. comm.).

The coasts of Victoria have areas of high macroalgal species richness (e.g. Port Phillip Heads area with > 450 species) but the number of local rare endemics is relatively small; Pt Lonsdale has 23 rare species, yet very few (only 2) are range-restricted. A similar richness–rarity pattern (high richness, low rarity) was described for the marine decapod, echinoderm and molluscan fauna of the Victorian coast (O'Hara 2002).

The large number of records available for the study was sufficient to allow general distribution patterns to be visualised. An increase in the number of skilled phycologists willing to undertake field surveys would benefit our overall knowledge of rare species distributions and would provide information valuable to the safeguarding of genuinely rare macroalgae. The listing and mapping exercises are worthy of future repetition, at a similar interval (10 years) to that between the COSEMA study (Cheshire et al. 2000) and the present one.

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Chapter 3: Concentrations of rare macroalgae

3.1 Introduction

Species rarity maps generated directly from herbarium records do not account for spatial and temporal biases inherent in the collecting effort. Testing whether centres of rarity identified from herbarium specimens are a true reflection of nature is an important step in understanding rare species distributions, and in determining the locations of areas most important for species conservation.

Exploring associations between high proportions of rare species and physical and environmental features is one means of seeking explanations for distributions of rare species. Large datasets that encompass ocean chemistry, biology, and topography of coastal waters have become available in recent decades, enabling many correlates of species distributions to be investigated. For Australian temperate macroalgae, predictive models have been proposed for easily identifiable species (Hill et al. 2010, Wernberg et al. 2011b) and genera (Goldberg et al. 2006). But because rare macroalgae are difficult to locate in the field and there is such a paucity of distribution data, the task of predicting their occurrence is difficult.

Surrogate data, such as habitat environmental variables, have been used to model species occurrence and distribution for single or multiple species. Field studies have confirmed that models can provide significant improvement in discovery of new populations over simple random sampling (Goldberg et al. 2006, Guisan et al. 2006, Chatfield et al. 2010). Because of the varying niche requirements of individual species, exploring any combined influence of biotic and abiotic variables on their occurrence appears to be a logical approach to such modelling.

Species distribution models based on presence data, such as Random Forests (RF), have shown promise for rare plant species. Cutler *et al.* (2007) described high RF ecological classification accuracy as measured by cross-validation for rare lichen species and Williams *et al.* (2009) concluded that RF provided better predictions six rare plant species associated with ultramafic soils than three other frequently-used models (generalized linear model, artificial neural network, and maximum entropy). The RF statistical classifier has the ability to provide a measure of variable importance and to impute missing data, and is becoming more widely used for modelling components of marine ecosystems (Leaper et al. 2011, Pitcher et al. 2011). An important aspect of model application is that models only describe associations, rather than causal relationships between predictor- and response variables (Chatfield et al. 2010), which highlights the importance of undertaking fine-scale ecological niche studies as an adjunct to modeling.

The goal of the present chapter was to determine the environmental variables that best predicted rare species concentrations.

3.2 Materials & methods

3.2.1 Study area and species dataset

The study area was the southern Australian coast (including Tasmania) between Geraldton, Western Australia and Cape Howe on the Victoria–New South Wales border. Occurrence records up to October 2008 from four southern Australian herbaria—PERTH, AD, MEL and HO—were used for spatial analysis. These data are a a subset of those publicly availabe through the Australian Virtual Herbarium (AVH).

Approximately 1500 species of macroalgae have been reported for Australia's temperate coasts (Waters et al. 2010). One hundred and forty-two taxa were designated as *rare* (recorded from 5 or fewer localities, as defined in Chapter 2, Table 2.1), and the remainder as *non-rare*. Each record refers to a single geographically-referenced voucher specimen (~118,000 herbarium records), and was mapped using ArcGIS ver. 9.3. Records were in the form of presence-only data, therefore any absence of taxa from the dataset cannot be interpreted as an absolute absence of the taxon from any specific locale.

To analyse the region spatially, individual lat/long positions were integrated into 0.1 decimal degree (~10 km) grid cells, with each cell characterized by the macroalgal records. This effective integration of the AVH data was performed so that the scale matched that of the available physical and environmental data. The numbers of all specimens, all species, rare specimens and rare species were calculated for the resultant ~10,000 events (grid cells with records). To maximise robustness of analyses, only those events where the number of all specimens exceeded one hundred were included, thereby focusing the analyses on 188 sites.

3.2.2 Calculation of response variables

To create a measure of rare species occurrence that was independent of the collecting effort, the number of rare species recorded from a grid cell was expressed as a percentage of all other species recorded from that grid cell (%RareS). The validity of %RareS as an indicator of rare species concentration rests on the assumption that the proportionate identification of rare and common species at any particular site remains constant at different levels of collection effort. This may not be the case if regional rarity is associated with local rarity, as common species may be all identified while the rarest species are still being picked up.

CODE	VARIABLE	UNIT	SOURCE	RANGE (in this study)
SLO	Slope, mean	°(degrees)	GA	0.030–8.219
CRBNT	Carbonate	% (weight)	GA/MARS	2.929–96.570
SAN	**Sand sediments (63µm <Ø <2mm), mean**	**%**	**GA/MARS**	**34–99**
GRA	**Gravel sediments**	**%**	**GA/MARS**	**0–48**
MUD	Mud sediments (63µm < Ø <2mm), mean	%	GA/MARS	0–64
NO3-AV	**Nitrate, mean**	**µM**	**CARS**	**0.098–2.413**
NO3-SD	Nitrate, standard deviation	µM	CARS	0.162–1.829
PO4-AV	**Phosphate, mean**	**µM**	**CARS**	**0.122–0.396**
PO4-SD	Phosphate, standard deviation	µM	CARS	0.041–0.136
O2-AV	Oxygen, mean	mL/L	CARS	5.044–5.888
O2-SD	Oxygen, standard deviation	mL/L	CARS	0.106–0.410
S-AV	Salinity, mean	PSU	CARS	34.580–37.646
S-SD	**Salinity, standard deviation**	**PSU**	**CARS**	**0.095–0.853**
T-AV	Bottom water temperature, mean	°C	CARS	13.178–20.259
T-SD	Bottom water temperature, standard deviation	°C	CARS	0.966–2.627
SI-AV	**Silicate, mean**	**mL/L**	**CARS**	**0.461–2.287**
SI-SD	Silicate, standard deviation	mL/L	CARS	0.331–1.428
CHLA-AV	**Chlorophyll-a, mean**	**mg/m^3**	**CARS**	**0.311–7.601**
CHLA-SD	**Chlorophyll-a, standard deviation**	**mg/m^3**	**CARS**	**0.048–7.972**
K490-AV	Mean diffuse attenuation coeff. at λ490 mm, mean	m^{-1}	SeaWIFS	0.054–0.454
K490-SD	Mean diffuse attenuation coeff.at λ490 mm, SD	m^{-1}	SeaWIFS	0.005–0.317
SST-AV	**Sea surface temperature, mean**	**°C**	**SeaWIFS**	**13.132–20.847**
SST-SD	**Sea surface temperature, standard deviation**	**°C**	**SeaWIFS**	**0.842–3.809**
SST-MIN	Sea surface temperature, seasonal minimum	°C	SeaWIFS	8.867–18.417
SST-SR	Sea surface temperature, seasonal range	°C	SeaWIFS	2.636–11.200

Table 3.1 Environmental variables available at a 0.01° resolution and those used for RF analyses (bold). CARS = CSIRO (Australian Commonwealth Scientific and Industrial Organisation) Atlas of Regional Seas (Condie and Dunn 2006) , GA = Geoscience Australia (GA 2009), MARS = MARine Sediment database (MARS 2011) GEOMACS = Geological and Oceanographic Model of Australia's Continental Shelf (Hemer 2006), SeaWIFS – Sea-viewing Wide Field-of-view Sensor (NASA/Goddard Space Flight Center and Orbimage).

3.2.3 Physical and environmental predictor variables

Physical and environmental variables (n = 25) that were available at continental scales, including aspects of substrate sediment composition, water column macronutrient levels, primary production, and temperature were used in testing hypotheses for rare species distribution and generating maps (Table 3.1, Figs 3.4–5). Data were obtained from public sources—Geosciences Australia, (GA 2009, MARS 2011), GEOMACS (Hemer 2006), SeaWIFS (Condie and Dunn 2006) and CARS–CSIRO (Condie and Dunn 2006). For the most part these data represent values integrated over time (i.e. multiyear averages, ranges) and at a geographic resolution of 0.01°. This resolution results in grid cell size of approximately 1 km x 1 km (1.11 km x 0. 95 km at the northernmost site of Waldegrave Island, South Australia; 1.11 km x 0.82 km at the southernmost site of Muttonbird Island, Tasmania).

In order to compare models at different spatial scales, CARS data were integrated and analysed at resolutions of 100 x 100 km, 40 x 40 km, 20 x 20 km, and 10 x 10 km. Exploratory analyses revealed the most promising models for further investigation. Most models failed to give a good prediction for the response categories; those at the spatially simplified scales (20 x 20, 40 x 40, 100 x 100 km) in particular, did not appear to reflect natural systems. The 10 x 10 km area (grid cell size) was adopted for the present analysis.

A reduced set of variables (n = 9) was used for estimating the relative importance of variables (Fig. 3.1), and for fitted responses of these variables that best explain the differences in %RareS (Fig. 3.2). They were chosen on the basis that they were considered biologically meaningful in terms of marine macroalgal growth and reproduction, as well as to minimise problems that would arise from some variables in the CARS dataset not having the full set of data points for the continental inshore temperate domain.

3.2.4 Statistical methods

Random Forests (RF) (Breiman 2001)were used to model the relationships between the 9 predictor variables (physical and environmental parameters) and the response variables (%RareS) at 188 sites and to predict the values of the response variable at new sites across the continental domain of interest. As a classification/regression tree method, RF modeling allows for non-linearities and interactions amongst predictor variables by default. Each random forest was created by generating 1000 regression trees. Each tree is generated from a bootstrap sample of the data using a recursive partitioning procedure where the splits are selected from a random subset of the explanatory predictors.

The observations that were not selected in the bootstrap sample for a tree are called the out-of-bag sample. To estimate prediction error, these observations were compared to their predictions, in a similar way to cross-validation. To assess the importance of a predictor variable the accuracy importance (Figure 3.1), or mean decrease in accuracy when the predictor variable is randomly permuted, was measured. Accuracy was evaluated by comparing the predictions with the actual measures of the response variable, for those sites that were "out-of-bag" for a given tree. Accuracy importance was computed using the *importance* function in the R Library, *randomForest*.

From the generated RF, predictions were made at new sites by predicting the response variables using each tree individually and then taking the average. Predictions of the response variables were made at 2,395 sites around the coast. These predictions were plotted on a map, with different colours on the rainbow spectrum used to indicate different values of the predictions. For the span of the response variable, the ten highest and ten lowest predictions were each given the same colour.

In order to see the relationship between the predictions and the nine predictor variables, predictions were also made across the range of each of the predictor variables (Figure 3.2). As predictions are based on all nine predictor variables, to ascertain the relationship between the predictions and one predictor variable, the other eight variables were held at their mean values. These means were calculated using the 188 sites.

3.3 Results

3.3.1 Relative importance of variables

Two aspects of substratum sediment, gravel and sand, emerged as the most important predictors for %RareS (Fig. 3.1). Chlorophyll-*a*, nitrate and phosphate were the next most important predictors.

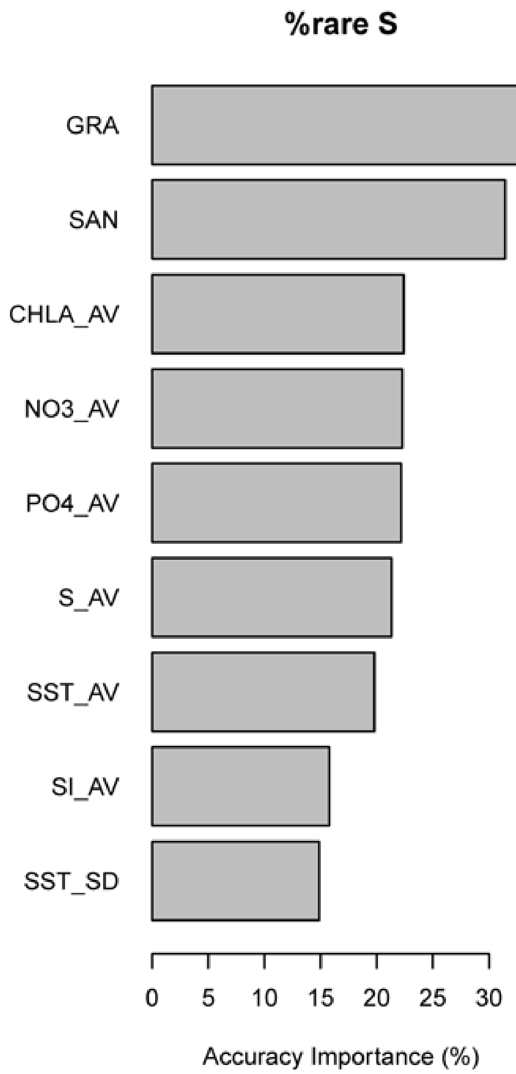

Fig. 3.1 Relative importance of physical and environmental predictors in terms of the importance of their contributions to models predicting %RareS. GRA (gravel), SAN (sand), CHLA_AV (chlorophyll-*a*, mean), NO3_AV (nitrate, mean), PO4_AV (phosphate, mean), S_AV (salinity, mean), SST_AV (sea surface temperature, mean), SST_SD (sea surface temperature, standard deviation), SI_AV (silicate, mean).

3.3.2 Fitted responses of variables

Non-linearities in the importance of the contributions of different levels of each environmental variable to Random Forest models were calculated as the relative number of classificatory breaks for each incremental change in level, such that high response values indicate numerous dichotomies in %RareS identified by modeling (i.e. a high frequency of change between high and low %RareS at that point). Four of the nine predictors showed major non-linearities with %RareS. High sand (>95%); low nitrate (<0.25µM); low phosphate (<0.15 µM); high chlorophyll-*a* (> 2 $mg.m^{-3}$) were associated with high values of %RareS (Fig. 3.2). Despite the importance of the physical predictor 'gravel' (Fig. 3.1), this variable exhibited no major non-linearities across the range of levels investigated (Fig. 3.2).

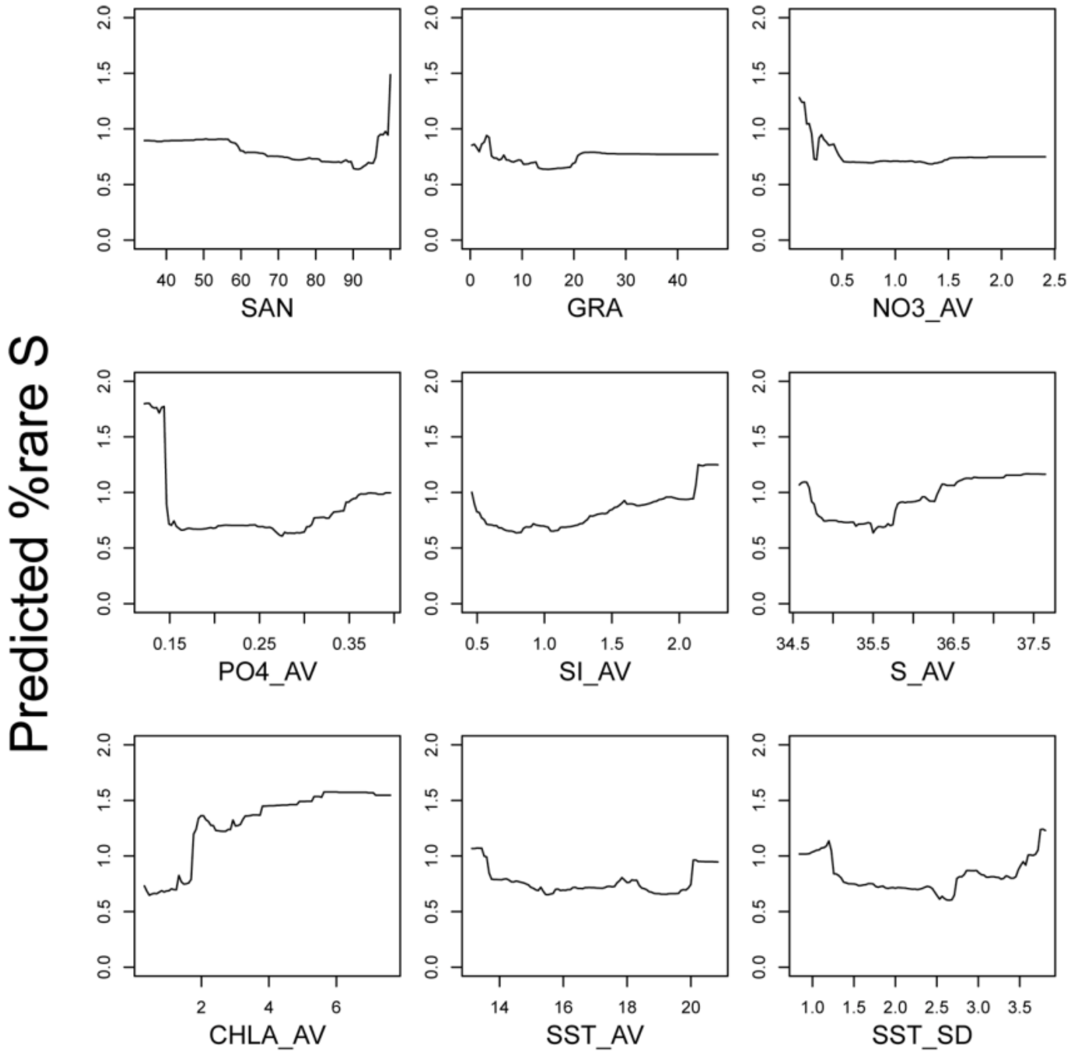

Fig. 3.2 Predicted responses of %RareS across the range of each of the nine environmental variables, given the eight variables were at a mean level (the means were calculated from the 188 sites). Response was calculated as total number of Random Forest tree breaks for each incremental change in environmental variables, relative to a mean of 1. GRA (gravel), SAN (sand), CHLA_AV (chlorophyll-*a*, mean), NO3_AV (nitrate, mean), PO4_AV (phosphate, mean), S_AV (salinity, mean), SST_AV (sea surface temperature, mean), SST_SD (sea surface temperature, standard deviation), SI_AV (silicate, mean).

3.3.3 Predictions of %RareS

Random Forest predictive models based on the nine environmental covariates examined indicated notable concentrations of high %RareS grid cells in the regions of Port Phillip Bay (VIC) and D'Entrecasteaux Channel (TAS) (Fig. 3.3). King George Sound (WA) had the maximum predicted %RareS value of the 2395 sites, as well as the highest actual (herbarium data) %RareS value (Table 3.2). Values for the twenty highest predictions are tabulated with their actual (herbarium data) %RareS values (Table 3.2).

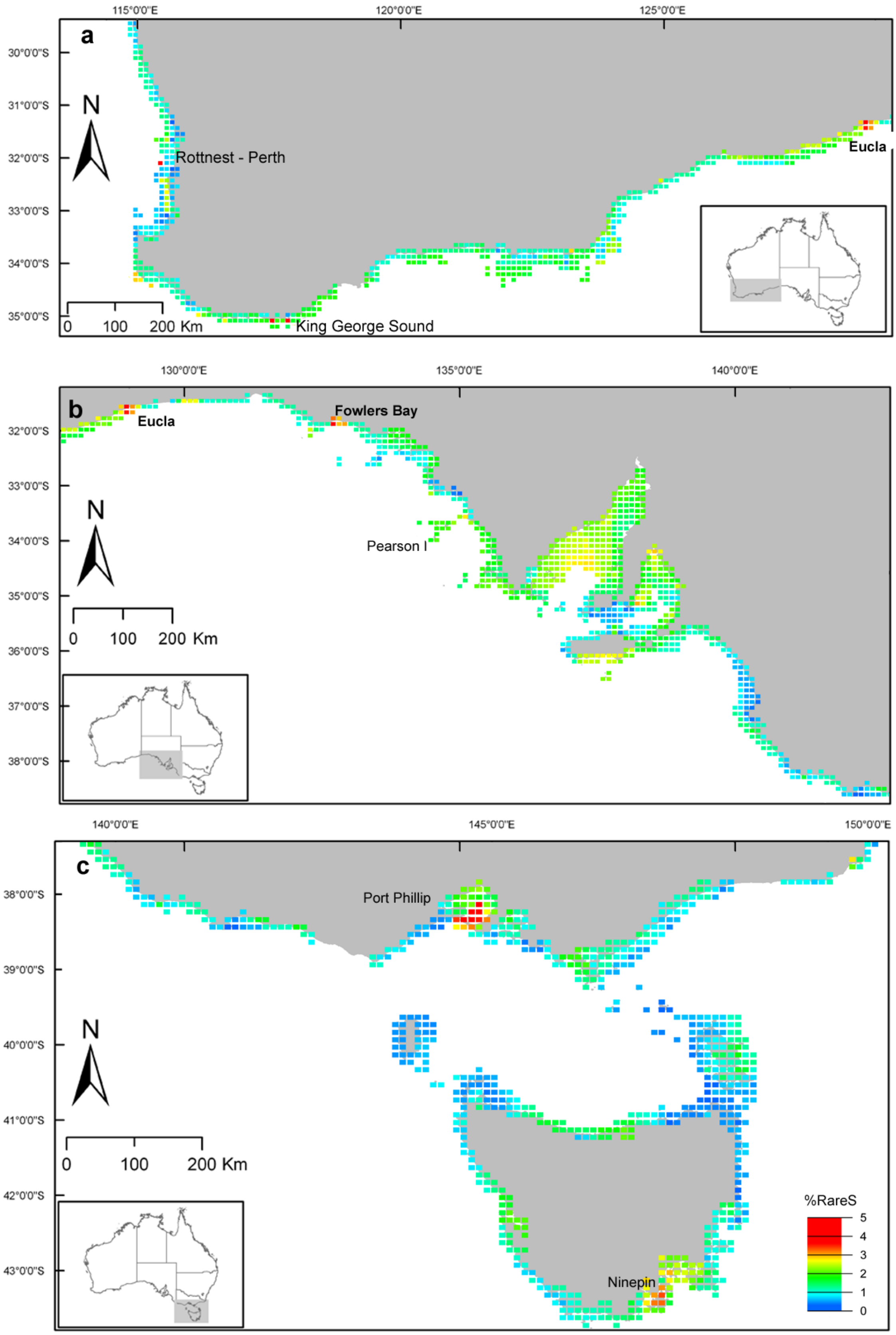

Fig. 3.3a–c Predicted %RareS values.

Grid cell (~10 x 10 km)	Lat	Long	Predicted %RareS	Observed %RareS
King George Sound, WA	-35.1	117.9	4.49	6.98
Port Phillip Bay (“central”), VIC	-38.1	144.9	4.35	6.23
Port sea Port Phillip Bay, VIC	-38.3	144.8	4.35	5.15
Rye Back Beach, VIC	-38.4	144.8	4.35	3.64
Port Phillip Bay (“central”), VIC	-38.1	144.9	4.13	6.23
Port Phillip Bay (“central”) vicinity, VIC	-38.2	144.9	3.89	6.23
South Channel, Port Phillip Heads, VIC	-38.3	144.7	3.89	4.65
West Cape Howe, WA	-35.1	117.6	3.78	0.00
Portsea Back Beach, VIC	-38.2	144.8	3.78	3.64
Eucla, WA	-31.7	128.9	3.77	5.26
Rottnest I, WA	-33.0	114.9	3.66	4.02
Fowlers Bay, SA	-32.0	132.5	3.64	5.00
Portsea, Port Phillip Heads, VIC	-38.3	144.8	3.53	5.16
Pt Lonsdale, Port Phillip Heads, VIC	-38.3	144.6	3.44	5.18
Simpsons Bay, se TAS	-43.3	147.3	3.37	4.00
Satellite I, se TAS	-43.4	147.3	3.28	3.52
Ninepin Pt, se TAS	-43.4	147.2	3.20	3.08
Sorrento Back Beach, VIC	-38.4	144.8	3.18	1.33
Gordon, se TAS	-43.2	147.3	3.10	0.00
Eucla vicinity, WA	-31.7	129.0	3.10	0.88

Table 3.2 Grid cells with the twenty highest predicted %RareS values plus the observed (herbarium data) %RareS values.

3.4 Discussion

3.4.1 Centres of rarity, accounting for collection bias

Through the development of predictive physical models based on algal distribution data and accounting for collecting bias, the true centres of algal rarity in southern Australia are identified as Rottnest I WA, King George Sound WA, Eucla WA, Fowlers Bay SA, Port Phillip Bay VIC and D’Entrecasteaux Channel TAS, a pattern differing somewhat from those predicted utilizing herbarium collection records alone. The areas formerly identified as centres of rarity of Pearson I, Pennington Bay, Tiparra Reef, Aldinga and Robe (all in SA), Westernport Bay VIC, and Tamar Estuary TAS (Chapter 2, Fig. 2.4) have neither high predicted nor observed %RareS, even though they are recognised as areas of high overall algal diversity and have high absolute numbers of rare species. The predictions appear largely accurate for the highest predicted %RareS sites, as evidenced by the high level of congruency between the predicted and observed (herbarium data) (Table 3.2) ($r = 0.646$, $P = 0.002$).

Some of the centres of rarity overlap with areas well recognised for high levels of local marine endemism, such as south-west WA (Huisman and Walker 1990, Kendrick et al. 2009), Kangaroo I SA (Womersley 1947, 1948, 1950, 1956), south-east Tasmania (O'Hara 2007). Community species-abundance profiles are often highly distorted or 'right-skewed', with most species being uncommon and only a few being very common (Gaston 1994, Flather and Sieg 2007). Whether some of the endemics in the areas mentioned above have been called 'rare', relies on the threshold of rarity used, and in some instances could simply be an artefact of sampling species-rich communities which results in the collection of more rare species.

In the present study, at the individual site level the environmental attributes with extremes associated with high proportions of rare species were sand, nitrate (mean), phosphate (mean), and chlorophyll-*a* (mean). Overall, the data suggest that rare species are associated with low nutrient environments and sandy substrata.

3.4.2 Importance of predictor variables

Substratum composition has been found to be among the most important predictors of the distributions of many marine species (Chatfield et al. 2010, Hill et al. 2010). Some marine flora have high substratum habitat specificity (e.g. the rhizophytic *Rhipiliopsis* sp. newly recorded from King George Sound vicinity, see Appendix 3). In their marine soft-sediment benthos study, Ellingsen *et al.* (2007) concluded that distribution of rare species (species of either restricted range or low abundance) was substratum habitat-related, and not random.

The predictor variables selected for analysis were chosen on the strength of their biologically meaningfulness, with respect to marine flora, but other biotic or abiotic variables will likely be required to provide a comprehensive understanding of rare species distributions. Physical data specific to coastal environments, such as exposure to wind, sea and swell, or ecological data specific to the biota such as population clustering, habitat continuity, competition and dispersal, may prove important. For benthic marine plants, the ecological factors of ontogenetic shifts and dispersal have been ranked as "important", and aggregation and competition as "critical", in evaluating species distribution models (Robinson et al. 2011). Other abiotic characteristics of the marine environment, such as sediment total organic carbon and habitat heterogeneity, have also proved useful for SDMs. For instance, Goldbold and Solan (2009) found that macroinvertebrate species richness and sediment total organic carbon together explained 65% of the variability in ecosystem processes. Localised reef habitat heterogeneity can influence species diversity (Balata et al. 2007, Smale et al. 2011a), and species diversity can also be related to wave-driven disturbance and exposure (Hill et al. 2010, Smale et al. 2011b).

The use of surrogate species, for example, using the presence/abundance of one species as a surrogate for the presence/abundance of another, or the use of species composition of one set of taxa to predict the occurrence of another set of taxa, has showed varying promise or reliability in terms of conservation planning (Goldberg et al. 2006, Rodrigues and Brooks 2007, Cushman et al. 2010, McMullan-Fisher et al. 2010, Mellin et al. 2011). This approach may be useful for host-specific epiphytes such as the rare broad-range *Heterothamnion muelleri* (Sonder) J. Agardh (epiphytic on *Cystophora platylobium* (Mertens) J. Agardh) or the narrow-range *Tylocolax microcarpus* F. Schmitz (occurring as epiphytic pustules on *Lenormandia spectabilis* Sonder). However, the overall paucity of such data for the vast majority of marine macroalgae confounds its use for the rare species at the present time.

3.4.3 Fitted responses of variables as explanations

For seabed substrata, a composition high in sand (>60%) can be regarded as a proxy for high wave energy environments (in which sand particles dominate the sediment). The data suggest that relatively exposed environments are favourable for rare species, rather than the presence of the sediment particles themselves being responsible for the predictions, but this fails to explain the high %RareS predictions for many relatively sheltered areas within south east Tasmania and Port Phillip Bay.

The possibility of competition for macronutrient resources needs to be considered in trying to understand the association between high %RareS and low nitrate (<0.25 µM) and low phosphate (<0.15 µM) levels (Fig. 3.2). Low macronutrient environments may exist due to natural conditions or because of nutrient consumption by biotic organisms, and the nature of the macronutrient resources may be fixed or moving (with tides and currents) (Dayton 1971, Underwood 2007). Rare macroalgae, as sedentary occupiers of habitats, might be subject to competition for space, which is likely to be less severe in oligotrophic environments than in eutrophic environments.

Conditions of high chlorophyll-*a* concentrations (>2 mg/m^3) are identified as favourable for high %RareS (Fig. 3.2), something of an anomaly given that low nutrient environments are also favoured by rare species. Chlorophyll-*a* density in the marine environment represents productivity (high chlorophyll-*a* = high productivity), and is most often manifested in the form of phytoplankton abundance. Chlorophyll-*a* has been described as a good predictor for presence of specific mobile marine biota such as fish (Friedland et al. 2012) and sea-turtles (Peavey 2010), ostensibly through food-web links via phytoplankton and zooplankton rather than through chlorophyll concentration alone. In the present study the high chlorophyll-*a* concentrations are most likely coupled with phytoplankton communities and the macronutrients already taken out of the water column by these organisms for growth and reproduction.

Silicates show no specific association with %RareS. Silicon, typically available in the form of silicate is a major requirement of the microalgal taxonomic groups such as the diatoms and silicoflagellates, and high concentrations in the water column indicate the presence of conditions inducive to diatom growth of overall high productivity.

As with other environmental variables, salinity (S-AV) can vary three-dimensionally in the water column. Low salinity typically indicates areas of considerable freshwater input, either continuously or episodically, and can be regarded as a proxy for proximity (closeness) to a rivermouth, from which plumes of freshwater discharge may extend to adjacent coasts. Salinity emerging as a relatively poor predictor for %RareS was expected, on the basis of the rare species' distribution maps generated from the observed algal records (chapter 2, Fig. 2.2). As a group, rare species are spread over vast areas of coastline bereft of any permanent rivers (for example, the Great Australian Bight), as well as over areas with considerable influx of fresh water. No significant associations of rare species with salinity were apparent, although it cannot be ruled out that such an environmental parameter could affect distributions of individual species, and that at the local scale few marine macroalgae are likely to tolerate the low salinity conditions associated with estuaries.

3.4.4 Implications

Two specific concerns exist with analyzing macroalgal species distributions with respect to physical or environmental parameters: 1) The set of 142 macroalgae designated rare species in this study (Chapter 2) belong to a number of different morphological, functional and taxonomic groups. They display a wide range of biological traits, and the ecological requirements for their survival and growth are likely to vary. Successful niche-based analyses or modeling may better be achieved for individual taxa rather than treating these autotrophs as a single unit, or, alternatively, by adopting a 'species assemblage and indicator species' approach to characterizing sites (Dufrêne and Legendre 1997); 2) Inadequacy of initial data exists for some species. Many of the 142 rare species are represented by very few individual records. Seventy-one species can be described as suffusively rare (Schoener 1987), in being found over a broad geographic range but consistently rare throughout their distribution (see Chapter 2, Table 2.1). Whether these taxa are more common than supposed and merely under-collected is unknown. Twenty species are known from just a single collection, and several were formally described on the basis of a single drift specimen.

The original AVH dataset, although strong in non-rare species records, is relatively poor in rare species records, and this represents a serious drawback for rare species predictive modelling work. Yet, low numbers of localities may still be sufficient to predict ecological requirements and geographic distributions of species, given a model robust enough to retain prediction accuracy upon the removal of variables, as demonstrated by Stockwell and Peterson (2002) for bird species of Mexico. They concluded that both the coarse surrogate method (CSM) and the Genetic Algorithm for Rule-set Prediction (GARP) predictive models showed near-maximal accuracy at 50 data points, and retained 90% accuracy with fewer than 10 data points.

The scope of the Australian Commonwealth Scientific and Industrial Research Organisation Atlas of Regional Seas (CARS) data imposes a limitation for coastal work. Most CARS data are measured at offshore sites, including sites adjacent to coasts, and represent much integrated (multi-season, multi-year) data, or averaging of data that can cause a 'smudging' of data and result in a loss of precision. The vast majority of Australian temperate marine macroalgae, including all the known rare species, occur near the shoreline, thus the environmental data used represent the best available, rather than data from exact species location occurrence.

Guisan and Thuiller (2005) discuss problems that may arise from possible mismatches of spatial scale when data sampling has been conducted at a different scale or resolution to that of the environmental parameters available . The grid lattice nature of the CARS dataset has a relatively coarse resolution of 0.01° with extrapolation of data from adjacent grid cells sometimes required. Under these circumstances, the data were applied as appropriately as possible, particularly when the biological data (AVH species and specimen records) occurred near grid intersections. In addition, the environmental data could not take into account micro-niches at the scale of hundreds of metres; micro-niches like those existing in estuaries in which salinity and tannin levels change with the ebb and flood tides and can locally affect algal distribution; or at acute headlands or reefs, where the topography can influence water current flow (and therefore possible nutrient availability and potential propagule settlement) and exposure.

The choice of spatial scale for modelling must be carefully considered. For conservation planning, general correlation-based models have been found useful for setting priorities for multiple species at large spatial scales (Cabeza et al. 2010). In marine trophic webs for shallow bay ecosystems, Fulton *et al.* (2004) found that a coarse spatial scale can result in loss of information about short-term variation, changes in predicted spatial patterns, and functional groups of contributing organisms. The appropriateness of the spatial scale used may well be dictated by the proposed application of predictive models, with detailed data and complex models likely to be required to address specific conservation questions at relatively fine spatial scales (Cabeza et al. 2010). Loiselle *et al.* (2003) recommend that predictive species-distribution models be applied both critically and cautiously.

The analyses presented here should be viewed as exploratory steps in our overall understanding of the requirements for rare macroalgal survival and distribution. Because individual species' tolerance of environmental variability probably differs according to taxonomic or functional grouping, it is doubtless essential to develop predictive models for single species, rather than multiple species. Nevertheless the analyses undertaken here indicate that concentrations of rare species are associated with particular environmental conditions, most notably areas where physical disturbance is frequent or macronutrients are in short supply.

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Chapter 4: Testing explanations for concentrations of rare marine macroalgae

4.1 Introduction

In the previous chapter I predicted the distribution of %RareS from nine environmental variables, and determined whether any extremes of these environmental variables were associated with a high %RareS, using the random forest procedure. Areas of low water-column macronutrients and sandy substratum were shown to have the highest proportions of rare species, and the random forest spatial predictions managed to replicate much of the reality of variation in %RareS.

These analyses indicate that there are distinct environments and distinct environmental extremes that favour high proportions of rare species. However, they did not directly address two of the major explanations for concentrations of rare species: their occurrence in rare environments; and their association with geographic contexts in which survival through glacial-interglacial cycles is possible. Consideration of extreme environments was also confined to nine variables out of the many that are available, and did not include any variables that may be surrogates for survival in response to environmental change.

As discussed in Chapter 1, rarity may be the result of intrinsic or extrinsic causes one of which is organisms being able to adapt to conditions in uncommon environmental situations. Rare environments have been demonstrated to support rare species not found in surrounding areas. A particularly well-known terrestrial example is that of the distinctive and often endemic flora associated with ultramafic soils (Reeves and Adigüzel 2004, Grace et al. 2007, Jules et al. 2011).

Historical explanations for algal rarity are worthy of investigation, particularly with respect to species' survivability through glacial cycles by means of range expansion from and contraction to habitat refugia. There are numerous terrestrial examples based on either fossil records or genetic variation of extant biota, suggesting that many species survived glacial maxima by retreating to lower altitude refugia (Hewitt 1996, Clark and Carbone 2008, Provan and Bennett 2008, Sommer and Zachos 2009, Stewart et al. 2010). Although there are fewer examples from the marine realm, the paradigm of glacial refugia has also been explored for marine fauna (Hewitt 1999, Faurby et al. 2011), and flora (Hu et al. 2010, Coyer et al. 2011, Fraser et al. 2012).

The aim of the present chapter is to determine to what extent rare environments and extreme environments are associated with high percentages of rare species, and to find out whether the availability of retreat routes over glacial-interglacial cycles is associated with rare species concentrations.

4.2 Materials and methods

4.2.1 Study area and species dataset

The study area and datasets are as described in Chapter 3.

4.2.2 Physical and environmental variables

The dataset of physical and environmental variables (n = 25) (Chapter 3, Table 3.1) was used in analyses. Additional geomorphic features (n=3) were also included (Table 4.1), using straight-line distances (km) calculated within ArcGIS from each of the 188 occurrence locations (i) to the nearest 100-m-isobath (representing an approximate shoreline during the last glacial maximum), (ii) to the nearest submarine canyon, trench or trough as defined by International Hydrographic Organisation (IHO 2001) and illustrated for continental Australia by Harris *et al.* (2005b) (representing a path of retreat during sea level fall during glacial periods), and (iii) to the mouth of the nearest permanent river as presented on Geosciences Australia waterways shapefile (GA 2012) (representing the possibility of an extant submarine river valley acting as an escape route).

CODE	VARIABLE	UNIT	RANGE (in this study)
100m_ISO	Distance to nearest 100–m-isobath (Geosciences Australia)	km	4–342
River-dist	Distance to nearest permanent river mouth (Geosciences Australia)	km	0–816
Canyon-dist	Distance to nearest submarine canyon (as defined by Harris *et al.* 2003)	km	11–290

Table 4.1 Additional environmental variables included in the PCA analysis. Range is the distance from centre of grid cell to geomorphic features, measured within ArcGIS software.

4.2.3 Statistical analyses

The primary inputs for the analyses were the response variable, %rareS, and the suite of twenty-eight physical and environmental predictor variables for the 188 10 x 10 km grid cells with more than 100 specimens. Data were analysed using Minitab 16® software.

A Principal Components Analysis (PCA) (Euclidean distance matrix) was performed on the predictor variables to produce a parsimonious set of compound variables. Most of the variation in the data (89.4%) was captured in nine components (Fig. 4.1). The scores for these nine components were used as the input to an agglomerative cluster analysis using Euclidian Distance and Ward's Linkage. On the basis of the change in similarities with successive fusions (Figure 4.3), fifteen environmental domains were selected. One-way ANOVA with Tukey's Post Hoc Test was used to determine the strength of differences between environmental domains on each of the environmental variables. ArcGIS was used to display the distribution of the fifteen environmental domains. Larger-scale maps were produced in the same environment to show the submarine topography in the regions in which there were high values of %RareS.

The areas of environmental domains were represented by the numbers of 10 x 10 km grid cells containing occurrence data, and the range of rare species occurrence (to a resolution of 5 km) was estimated through ArcGIS. Pearson's product moment correlation coefficient was used to test if there was a linear relationship between the mean %RareS and area and range of domains.

The environmental extremes were identified for each environmental domain. These were the equal highest and equal lowest values as indicated by the ANOVA analyses. The relationship between the number of environmental extremes per domain and mean %RareS was tested using Pearson's product moment correlation coefficient. Domains 1 and 15 were omitted from this analysis as they were extremes only because of the latitudinal cutoff in data collection.

4.3 Results

4.3.1 Classification of environmental domains

Large positive loadings on component 1 of the PCA were evident in chlorophyll-*a* (mean and standard deviation), oxygen (mean and standard deviation), mean diffuse light attenuation coefficient at λ490 (mean and standard deviation), bottom water temperature (standard deviation), sea surface temperature (seasonal range, standard deviation), the macronutrients nitrate (mean and standard deviation), phosphate (mean and standard deviation), silicates (mean and standard deviation), and canyon distance (Table 4.2, Fig. 4.2). Small positive loadings on component 1 of the PCA were evident in slope, gravel, mud and sand. Large negative loadings on component 2 of the PCA were evident in bottom water temperature (mean), sea surface temperature (mean and minimum), salinity (mean and standard deviation), substratum carbonate, 100-m-isobath distance, and river-distance.

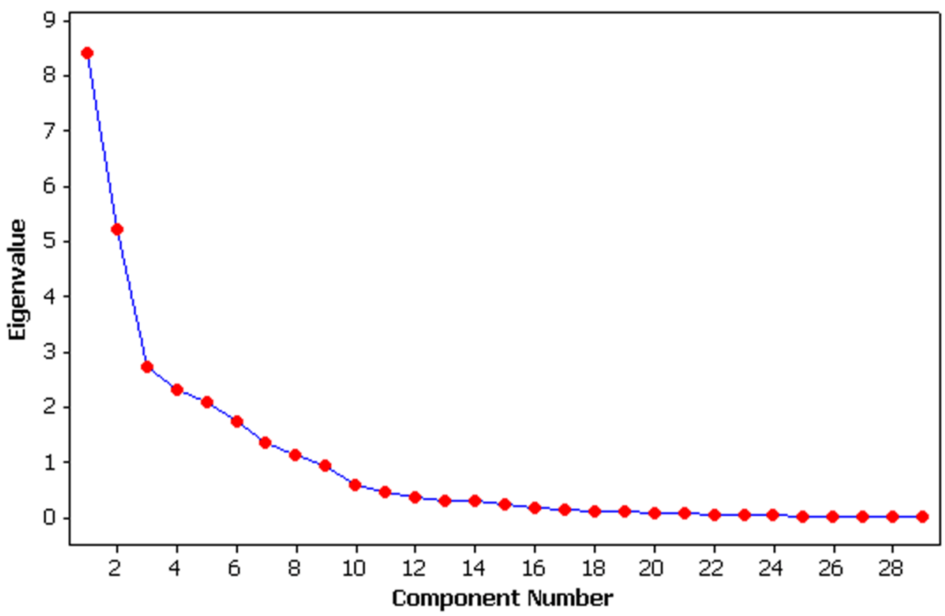

Fig. 4.1 The PCA scree plot shows that 89% of variability in rare species distributions can be explained by the first 9 principal components.

Variable	PCI	PC2	PC3	PC4	PC5	PC6	PC7	PC8	PC9
SLO	0.020	-0.106	-0.154	-0.125	-0.255	0.402	-0.411	-0.084	-0.035
CRBNT	-0.214	-0.021	0.075	0.364	0.047	0.018	-0.003	0.155	0.060
SAN	0.062	0.065	0.134	-0.232	0.477	0.032	0.278	-0.344	0.039
GRA	-0.101	0.013	0.014	0.106	-0.050	0.283	0.161	0.369	-0.719
MUD	0.025	-0.070	-0.219	0.163	-0.401	-0.236	-0.415	0.081	0.211
NOV3-AV	0.256	-0.169	-0.097	-0.106	-0.160	0.152	0.149	-0.175	0.080
NOV3-SD	0.287	-0.113	-0.080	-0.151	-0.137	0.173	0.101	-0.019	-0.029
PO4-AV	0.313	-0.048	-0.077	0.047	0.061	-0.037	0.058	0.033	0.105
PO4-SD	0.243	-0.079	0.191	0.096	-0.192	0.288	0.111	-0.164	0.016
O2-AV	0.278	-0.029	-0.109	0.233	0.201	-0.159	-0.011	0.129	0.023
O2-SD	0.248	-0.047	-0.105	-0.312	-0.148	-0.055	-0.022	0.146	-0.003
S-AV	-0.257	0.212	-0.040	0.036	-0.119	0.192	0.031	-0.194	0.085
S-SD	-0.109	0.225	0.018	0.169	-0.330	0.345	0.033	-0.113	0.067
T-AV	-0.283	-0.018	0.173	-0.259	-0.145	-0.039	-0.071	-0.067	-0.012
T-SD	0.086	0.229	-0.121	-0.377	-0.167	0.103	0.017	0.170	0.117
SI-AV	0.040	-0.202	0.275	-0.209	0.009	-0.080	-0.097	0.428	0.061
SI-SD	0.101	-0.202	0.280	-0.133	-0.059	0.308	0.086	0.327	0.150
CHLA-AV	0.193	0.163	0.373	0.072	-0.027	-0.053	-0.053	-0.096	-0.020
CHLA-SD	0.171	0.014	0.360	0.134	-0.070	0.046	-0.157	-0.173	-0.038
K490-AV	0.206	0.157	0.376	0.079	-0.049	-0.026	-0.123	-0.064	-0.010
K490-SD	0.200	0.007	0.386	0.115	-0.091	0.091	-0.140	-0.075	-0.055
SST-AV	-0.272	-0.050	0.162	-0.296	-0.114	-0.044	-0.043	-0.070	0.065
SST-SD	0.076	0.382	0.011	-0.164	-0.114	-0.005	0.035	0.026	-0.037
IRR	0.017	0.014	-0.112	-0.105	0.244	0.273	-0.604	-0.066	-0.130
SST-SR	0.082	0.382	0.027	-0.138	-0.114	-0.009	0.036	0.033	-0.040
SST-MIN	-0.255	-0.226	0.120	-0.189	-0.038	-0.025	-0.047	-0.083	0.072
river-dist	-0.110	-0.013	0.080	0.193	0.140	0.400	0.143	0.221	0.546
100-ISO	0.033	0.394	-0.039	-0.019	0.082	0.061	-0.105	0.231	0.114
canyon-dist	0.068	0.337	-0.044	-0.054	0.274	-0.106	-0.053	0.262	0.123

Table 4.2 Loadings of variables on the first nine components of the PCA analysis. SLO =Slope; CRBNT=carbonate; SAN=sand; GRA=gravel; NO3-AV= nitrate, mean; NO3-SD= nitrate, standard deviation; PO4-AV= phosphate, mean; PO4-SD= phosphate, standard deviation; O2-AV= oxygen, mean; O2-SD= oxygen, standard deviation; S-AV= salinity, mean; S-SD= salinity, standard deviation; T-AV= bottom water temperature, mean; T-SD= bottom water temperature, standard deviation; SI-AV= silicate, mean; SI-SD= silicate, standard deviation; CHLA-AV= chlorophyll-*a*, mean; CHLA -SD= chlorophyll-*a*. standard deviation; K490-AV= mean diffuse attenuation coefficient at λ490, mean; CHLA -SD= mean diffuse attenuation coefficient at λ490, standard deviation; SST-AV= sea surface temperature, mean; SST-SD= sea surface temperature, standard deviation; IRR= Irradiance; SST-SR= sea surface temperature seasonal range, mean; SST-SD= sea surface temperature seasonal range, standard deviation; SST-MIN= sea surface temperature minimum, mean; SST-MIN= sea surface temperature minimum, standard deviation; river-dist= distance to nearest permanent river mouth; 100-ISO= distance to nearest 100-m-isobath; canyon-dist=distance to nearest submarine canyon.

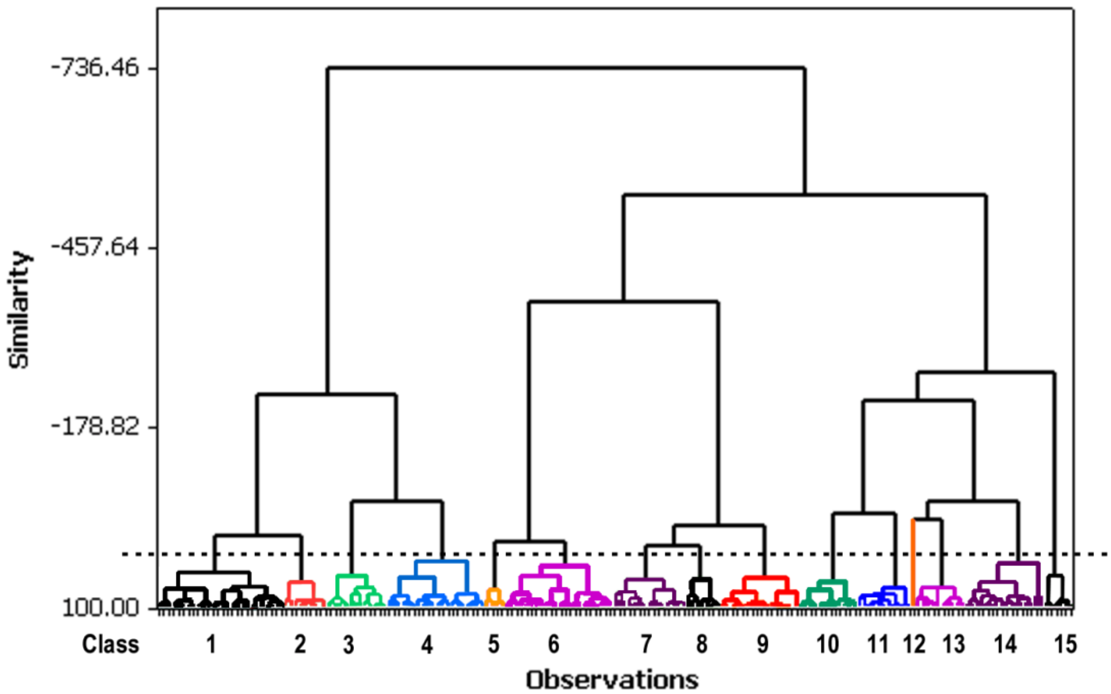

Fig.4.2 Dendrogram for environmental domains, showing split at the15- domain level.

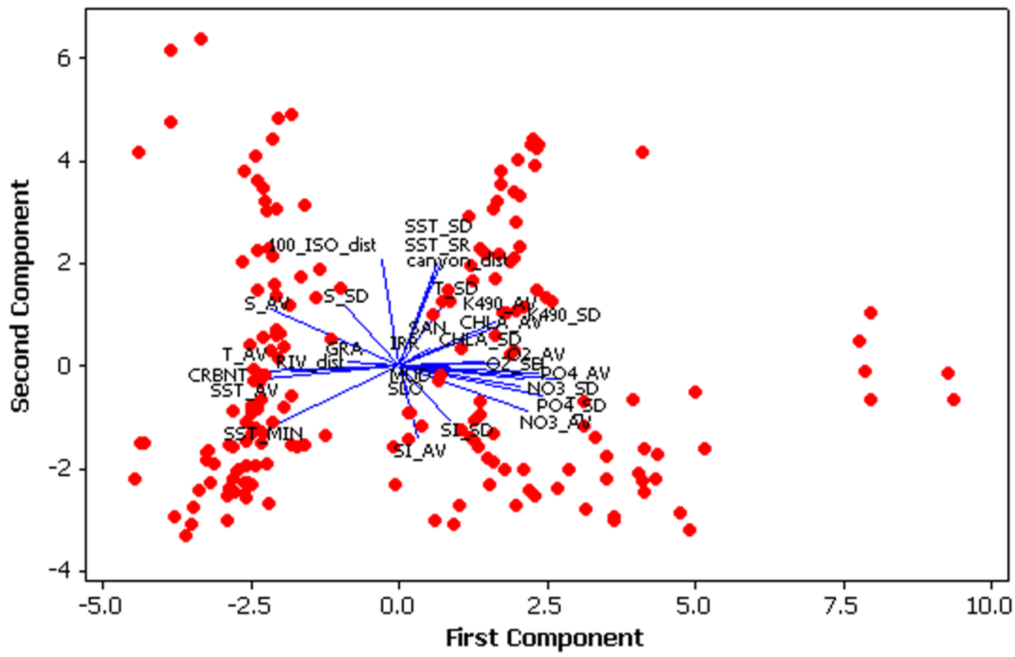

Fig. 4.3 The PCA biplot shows that macronutrients and productivity have large positive loadings on component 1, whereas salinity and river distance have large negative loadings. Codes for the variables are given in Table 4.2 caption.

Most environmental domains were strongly contiguous (Fig. 4.4). Most domains did not overlap in their distributions, the exceptions being 2, which was inset within 1, 8, which was scattered in the southeast, and 14, which was inset within 13 (Fig. 4.4).

The characteristics that best discriminated between environmental domains ($r^2 > 90\%$) were T-AV, S-AV, K490-SD, PO4-AV and NO3-SD, while those that contributed the least ($r^2 < 50\%$) were SLO and GRA (Table 4.2).

Distribution and environmental characteristics of domains:

Domain 1 included most of the samples in Western Australia. It had the highest mean values for SI-AV and SST-MIN, and the lowest mean values for PO4-AV, CHLA-AV, CHLA-SD, K490-AV and K490-SD (Table 4.3, Fig. 4.6).

Domain 2, nested within domain 1, included samples in the Rottnest I – Swan Estuary vicinity, Western Australia. It had the highest mean values for T-AV, SST-AV and SST-MIN, and the lowest mean values for NO3-AV, NO3-SD, river-distance and canyon-distance (Table 4.3, Fig. 4.6).

Domain 3 included samples from coasts between Eucla WA and Pearson I SA. It had the highest mean values for CRBNT, GRA, and river-dist, and the lowest mean values for MUD, NO3-AV, NO3-SD, T-SD, CHLA-SD, SST-SD, and SST-SR (Table 4.3, Fig. 4.7).

Domain 4 included samples in the South Australian regions of Investigator Straight and Kangaroo I. It had the highest mean values for CRBNT and GRA, and the lowest mean values for MUD, NO3-AV, NO3-SD, T-SD, CHLA-SD, SST-SD, and canyon-distance (Table 4.3, Fig. 4.8).

Domain 5 samples were all from sites in the mid-upper Spencer Gulf SA. This domain had the highest mean values for GRA, S-AV, S-SD, SST-SD, SST-SR, 100m-ISO, and the lowest mean values for NO3-AV, O2-AV, O2-SD, SI-AV, CHLA-SD, and canyon-distance (Table 4.3, Fig. 4.9).

Domain 6 samples were all from sites in the mid-upper Spencer Gulf SA. This domain had the highest mean value for GRA, and the lowest mean values for SLO, NO3-AV, NO3-SD, PO4-AV, SI-AV, SI-SD, CHLA-SD, and river-distance (Table 4.3, Fig. 4.9).

Domain 7 included samples from coasts between Cape Jaffa and Port MacDonnell SA. This domain had the highest mean values for MUD and PO4-SD, and the lowest mean values for SLO, SAN, T-SD, SI-SD, CHLA-SD, SST-SD, SST-SR, and canyon-distance (Table 4.3, Fig. 4.10).

Domain 8 included relatively widespread samples from Cape Jaffa, central Victorian coasts, and northern Tasmania. This domain had the lowest mean values for SLO, MUD, S-SD, SI-SD, CHLA-SD, and river-distance (Table 4.3, Fig. 4.11).

Domain 9 included samples from coasts between Discovery Bay and Cape Otway VIC. This domain had the highest mean value SAN, and the lowest mean values for GRA, S-SD, T-SD, SI-SD, CHLA-SD, SST-SD, SST-SR and canyon-distance (Table 4.3, Fig. 4.12).

Domain 10 samples were all from sites in the immediate vicinity of Port Phillip Bay and nearby Westernport Bay VIC. This domain had the highest mean value for canyon-distance, and the lowest mean values for SLO, MUD, NO3-AV, PO4-SD, S-SD, SI-SD, CHLA-SD, SST-MIN and river-distance (Table 4.3, Fig. 4.13).

Domain 11 included samples from northern Tasmanian coasts. This domain had the lowest mean values for CHLA-SD and river-distance (Table 4.3, Fig. 4.13).

Domain 12 samples were from sites in the immediate vicinity of Wilsons Promontory VIC. This domain had the highest mean value for SLO, and the lowest mean values for CHLA-SD (Table 4.3, Fig. 4.13).

Domain 13 included relatively widespread samples from the Kent Group (Bass Strait) to south-eastern Tasmania. This domain had the highest mean values for GRA and PO4-SD, and the lowest mean values for T-AV, T-SD, CHLA-SD, SST-AV, SST-MIN and canyon-distance (Table 4.3, Fig. 4.14).

Domain 14 nested within domain 13, included samples in south-east Tasmania. It had the highest mean values for PO4-AV, O2-AV, SI-AV, SI-SD, CHLA-AV, CHLA-SD, K490-AV, K490-SD, and the lowest mean values for MUD, S-AV, T-AV, T-SD, SST-AV, SST-MIN and river-distance (Table 4.3, Fig. 4.15).

Domain 15 included samples from eastern Victoria and southern New South Wales. This domain had the highest mean value NO3-AV, NO3-SD, O2-SD, T-SD, and the lowest mean values for CRBNT, S-SD, CHLA-SD, river-distance, 100m-ISO and canyon-distance (Table 4.3, Fig. 4.16).

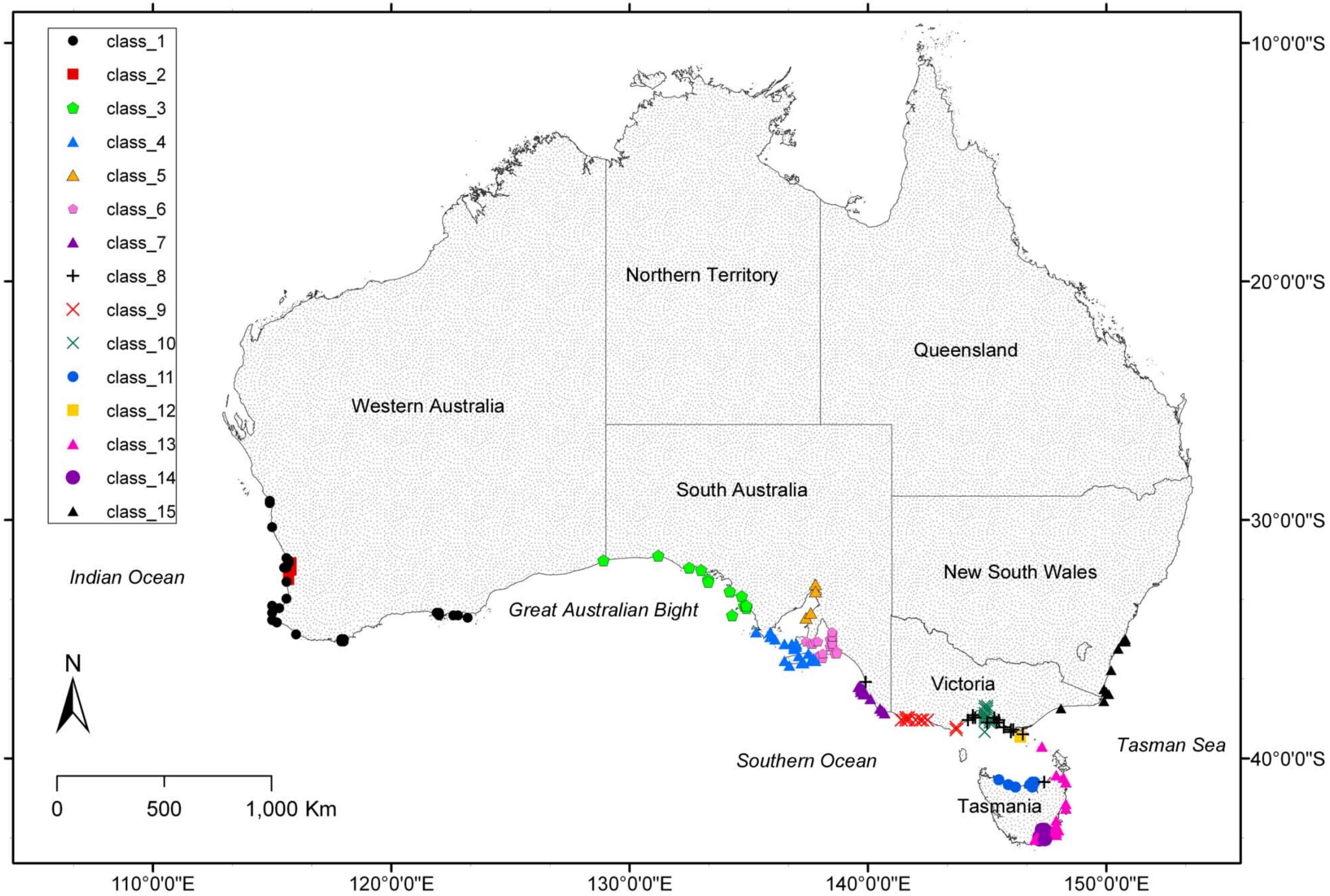

Fig. 4.4 Distribution of the environmental domains.

There was not a strong relationship between %RareS and either of the number of sites ($r = -0.305$, $P = 0.269$) or the extent (area) ($r = -0.360$, $P = 0.188$) of environmental domains (Fig. 4.5).

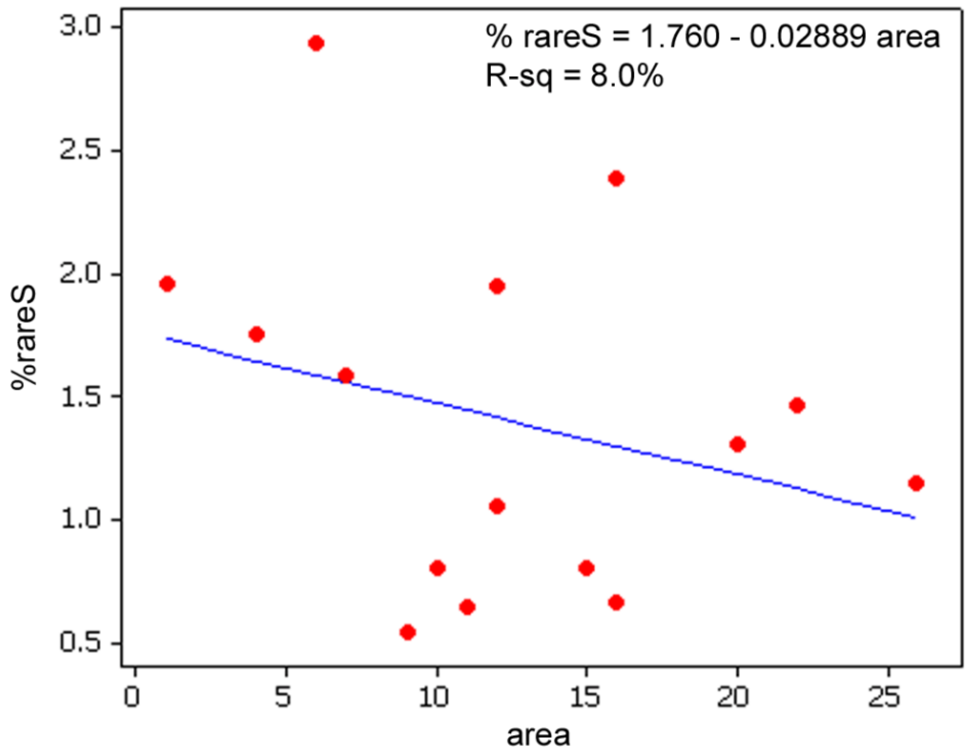

Fig. 4.5 Linear regression line fitted to scatterplot of %rareS plotted against area.

The highest mean %RareS values were found in domain 14 (south-east Tasmania) (2.93%) and Domain 10 (Port Phillip Bay) (2.39%) (Table 4.4, Fig. 4.14). While domain 14 was an extreme on most environmental variables of any domain (Table 4.2), domain 10 was in the lower middle of the field. Domains 1 and 15 were expected to have high numbers of extreme values and low concentrations of rare species because of their marginal locations in the study area. If they are taken out of the calculation there is still no significant linear relationship between number of extreme values (Table 4.2) and mean%RareS ($r = 0.136$, $P = 0.659$).

At the individual site level, the environmental attributes with extremes associated with high proportions of rare species were SAN, NO3-AV, PO4-AV and CHLA-AV (Fig. 3.2). The individual grid cells with ≥10 rare species and/or a %RareS ≥4% were Elliston, Pennington, Port Phillip Heads, Eucla, Pennington and Ninepin Point. They occurred in domains 3, 4, 10 and 14 (Table 4.4).

PCA domain	1	2	3	4	5	6	7	R^2 adj
No. grid cells **CODE ↓**	*26*	*9*	*12*	*20*	*4*	*22*	*12*	
SLO	BC	C	BC	BC	BC	C	C	43.26%
CRBNT	B	AB	A	A	ABCD	B	BC	67.34%
SAN	B	CDE	AB	B	BCD	BC	E	68.54%
GRA	A	AB	A	A	A	A	AB	24.99%
MUD	E	ABC	E	E	CDE	DE	A	69.91%
NO3-AV	F	F	F	F	F	F	CD	88.11%
NO3-SD	F	F	F	F	EF	F	D	93.99%
PO4-AV	H	GH	FG	GH	GH	H	BC	90.69%
PO4-SD	C	C	BC	BC	BC	BC	A	82.92%
O2-AV	E	DE	C	C	F	E	AB	82.29%
O2-SD	E	CDE	E	F	G	DE	BCD	80.47%
S-AV	D	DE	C	C	A	B	EF	91.96%
S-SD	F	EF	DE	C	A	B	DEF	89.08%
T-AV	B	A	DE	D	AB	C	GH	93.82%
T-SD	D	D	D	D	CD	BC	D	66.48%
SI-AV	A	AB	C	DE	E	E	D	87.40%
SI-SD	CD	DE	B	FG	EFG	G	G	80.01%
CHLA-AV	E	CD	DE	DE	C	CDE	CDE	80.80%
CHLA-SD	B	B	B	B	B	B	B	52.78%
K490-AV	F	CD	DEF	EF	C	DE	DEF	89.50%
K490-SD	E	CDE	CDE	CDE	BCDE	DE	CDE	95.51%
SST-AV	AB	A	CD	D	BC	CD	EFG	89.46%
SST-SD	E	CDE	E	E	A	AB	E	68.01%
SST-MIN	A	A	S	S	CD	C	CD	87.71%
SST-SR	G	DEFG	G	FG	A	ABC	G	66.11%
River-dist	DE	E	A	C	B	E	CD	83.46%
100m_iso	DE	DE	C	D	A	BC	DE	85.17%
Canyon-dist	D	D	BC	D	BC	C	D	82.62%

Table 4.3 (*pro parte*) Extreme values (highest and lowest) of variables, using Tukey method, resulting from one-way ANOVAs (28 individual physical and environmental variables versus environmental domains 1–7, p<0.001 for all ANOVAs. No. grid cells = number of grid cells with survey data per domain. Table cells that do not share a letter in rows are significantly different.

PCA domain	8	9	10	11	12	13	14	15	R^2 adj
No. grid cells **CODE ↓**	*15*	*11*	*16*	*7*	*1*	*16*	*6*	*10*	
SLO	C	BC	C	BC	A	BC	BC	B	43.26%
CRBNT	D	BCD	CD	ABC	CDE	CD	D	E	67.34%
SAN	AB	A	AB	DE	AB	B	AB	AB	68.54%
GRA	AB	B	AB	AB	AB	A	AB	AB	24.99%
MUD	E	CD	E	AB	BCDE	E	E	DE	69.91%
NO3-AV	EF	E	F	EF	DEF	B	BC	A	88.11%
NO3-SD	D	DE	D	C	CD	B	AB	A	93.99%
PO4-AV	DE	EF	D	DEF	BCDEF	AB	A	CD	90.69%
PO4-SD	BC	BC	C	B	ABC	A	A	A	82.92%
O2-AV	B	B	B	B	ABC	AB	A	CD	82.29%
O2-SD	BC	DE	B	B	BCDE	B	B	A	80.47%
S-AV	E	E	E	F	CDEF	F	G	EF	91.96%
S-SD	F	F	F	CD	DEF	DE	CDE	F	89.08%
T-AV	F	FG	F	GH	EFGH	H	H	CD	93.82%
T-SD	BC	D	BCD	AB	ABCD	D	D	A	66.48%
SI-AV	D	DE	DE	BC	CDE	C	A	C	87.40%
SI-SD	G	G	G	DEF	CDEFG	B	A	BC	80.01%
CHLA-AV	DE	CDE	B	CDE	CDE	CDE	A	CDE	80.80%
CHLA-SD	B	B	B	B	B	B	A	B	52.78%
K490-AV	DEF	DEF	B	DE	CDEF	D	A	DEF	89.50%
K490-SD	CDE	BC	BCDE	B	BCDE	BCDE	A	BCD	95.51%
SST-AV	EF	EF	E	FG	DEFG	G	G	C	89.46%
SST-SD	BC	E	AB	BCD	ABCDE	DE	BCD	CDE	68.01%
SST-MIN	DE	C	E	DE	BCDE	E	E	B	87.71%
SST-SR	ABCD	G	AB	CDEF	ABCDEFG	EFG	BCDE	DEFG	66.11%
River-dist	E	E	E	E	CDE	DE	E	E	83.46%
100m_iso	BC	DE	B	BC	B	DE	DE	E	85.17%
Canyon-dist	AB	D	A	B	AB	D	CD	D	82.62%

Table 4.3 (continued) Extreme values (highest and lowest) of variables, using Tukey method, resulting from one-way ANOVAs (28 individual physical and environmental variables versus environmental domains 8–15, p<0.001 for all ANOVAs. No. grid cells = number of grid cells with survey data per domain. Table cells that do not share a letter in rows are significantly different.

	Geographic area	Characterizing s.d. environmental variables	Max. #rareS	Max. %rareS	Mean %rareS	No. grid-cells	Range (km)
1	south-west Western Australia	warm water; low productivity; close to glacial retreats	8 *Cottesloe*	6.98% *King George Sound*	1.15%	26	1100
2	Rottnest I – Swan River	low nitrates; low macronutrients; high minimum water temp.; close to canyon & river	3 *Rottnest I*	1.26% *Rottnest I*	0.56%	9	120
3	Eucla – Pearson Is	high carbonate; mid-low macronutrients; far from river	10 *Elliston*	5.26% *Eucla*	1.95%	12	630
4	Investigator Strait – Kangaroo I	low nitrates; close to glacial retreats & river	12 *Penning-ton*	3.15% *Pennington*	1.31%	20	300
5	upper Spencer Gulf	high salinity; warm water; far from glacial retreats & river	6 *Tiparra Reef*	3.19% *Tiparra Reef*	1.75%	4	165
6	lower St Vincent Gulf – Encounter Bay	high carbonate; mid-low macronutrients	8 *Victor Harbour*	03.80% *Outer Harbour*	1.47%	2	170
7	Robe – Discovery Bay	mid-low macronutrients; close to glacial retreats	9 *Port MacDonn-ell*	2.33% *Port MacDonnell*	1.05%	12	155
8	Barwon Heads – Westernport Bay	high O2; mid-low macronutrients: close to river	6 *Crawfish Rock*	2.67% *Crawfish Rock*	0.80%	15	780
9	Discovery Bay – Cape Otway	high O2; mid-low macronutrients; close to glacial retreats & river	4 *Warrnam-bool*	2.48% *Warrnam-bool*	0.65%	11	230
10	Port Phillip Bay – Cape Liptrap	low nitrate, phosphate, silicate; far from canyon	22 *Port Phillip Heads*	6.23% *Port Phillip Heads*	2.39%	16	85
11	north coast Tasmania	high O2; mid-low macronutrients	9 *Low Head*	2.94% *GeorgeTown*	1.60%	7	130
12	Wilsons Promontory	high slope aspect	1 *Wilsons Prom.*	1.96% *Wilsons Prom.*	1.96%	1	10
13	east coast Tasmania	mid-high macronutrients; close to glacial retreats	3 *Spring Bay*	2.00% *Port Arthur*	0.67%	16	440
14	south-east Tasmania	clear, cold water; low nitrate	7 *Ninepin Pt*	4.00% *Ninepin Pt*	2.93%	6	50
15	south coast NSW	high macronutrients; close to glacial retreats & river	2 *Eden & Narooma*	2.38% *Narooma*	0.80%	10	430

Table 4.4 Characterizing combinations of significantly different (s.d.) environmental variables**;** #RareS = number of rare species in any single gridcell, within specified domain; %RareS = proportion of rare species in any single gridcell, within specified domain (grid cells with highest values in italics).

4.3.2 Migration pathways during environmental change

The three features explored in reference to this concept—proximity of %RareS areas to submarine canyons, the 100-m-isobath, and major rivers—emerged as extreme features for several environmental domains (Table 4.3). Data for environmental domains were mapped at smaller scales (Figs 4.6–16). The maps include bathymetry data and location of submarine canyons and trenches to facilitate discussions about potential migration pathways for marine algae via ancient river courses (see section 4.4.2).

Canyon-distance was significantly low for domains 1, 2, 4, 7, 9, 13 and 15 (Figs 4.6, 4.8, 4.10, 4.12, 4.14, 4.16), and significantly high for domain 10 (Fig. 4.13). 100m-ISO was significantly low for domain 15 (Fig. 4.16), and significantly high for domain 5 (Fig. 4.9). River-distance was significantly low for domains 2, 6, 8, 9, 10, 11, 14 and 15 (Figs 4.6, 4.9, 4.11–16), and significantly high for domain 3 (Fig. 4.7).

South-east Australia (highest %Rare S domains)

For domain 10 (Port Phillip Bay), the palaeodrainage route is via the Otway Depression extending roughly from the 200-m-isobath, northeastwards towards Port Phillip Bay.

Palaeodrainage for Derwent Estuary sites of domain 14 are south-eastward via Storm Bay, and southward for D'Entrecasteaux Channel sites (Fig. 4.15).

Other regions of southern Australia

For domains 1 & 2 (south-west Western Australia) most canyons lie relatively close to the coast; Albany Canyon Group (offshore from King George Sound), Knob–Gardner Canyons (Cape Leeuwin–Walpole), and Perth Canyon (Perth–Rottnest) (Fig. 4.6). However, the sites between Cape Naturalist and Cape Leeuwin, adjacent to the expansive offshore submarine feature of the Naturaliste Plateau, are far from submarine canyons. Along the Great Australia Bight, canyons lie far from sites of domain 3 (Fig. 4.7).

For domains 4, 5 and 6 paleodrainage routes exist through Backstairs Passage (eastern Kangaroo Island), ultimately to the Flinders canyons, and along submarine channels in Spencer Gulf and Investigator Strait and towards the dendritic canyon heads of the Lincoln and Couedic Canyons (Fig. 4.8, 4.9). The paleodrainage route for easternmost sites of domain 6 at the northern end of Encounter Bay (Victor Harbour area) is southward (eventually to the Murray Canyons).

For domain7, two likely drainage paths are evident (Fig. 4.10). Those sites near Cape Jaffa–Robe are nearest to the Blackford Drainage linking with the Flinders Depression and Murray Canyons. Those sites near the Robe–Cape Otway coast, plus those of domain 9 (Warnambool–Cape Otway) are nearest to numerous small canyons not too distant offshore. Sites of domain 8 (Barwon Heads–Westernport Bay) (Fig. 4.11) are closest to the drainage routes available for Port Phillip Bay.

For sites of domain 11 on the northern coast of Tasmania, the nearest canyons are evident to the west and east of the island, either side of the continental shelf (Fig. 4.13). For the single domain12 event palaeodrainage to the east-nor-east via the Bass Canyon is evident (Fig. 4.13). For domain 13 (east Tasmania) palaeodrainage occurs via the numerous small more canyons to the east of the coastline (Fig. 4.14).

For domain 15 (southern NSW) palaeodrainage is from the present continental shelf essentially eastwards towards the numerous submarine canyons lying within 60 km of the coast, and thence to the abyssal plain of the Tasman Sea (Fig. 4.16).

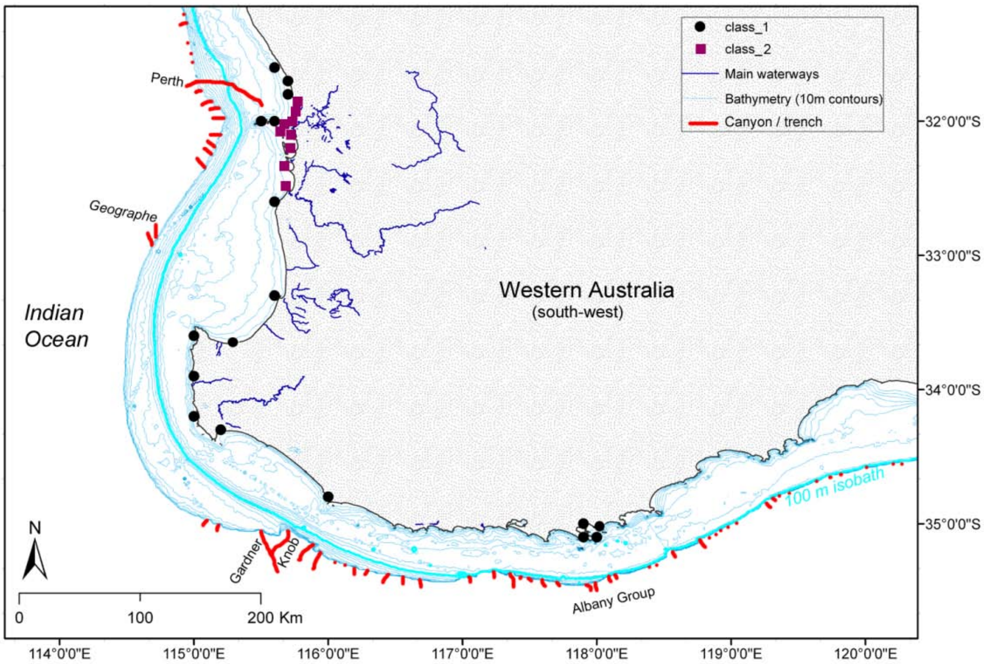

Fig. 4.6 Domain 1and 2 locations.

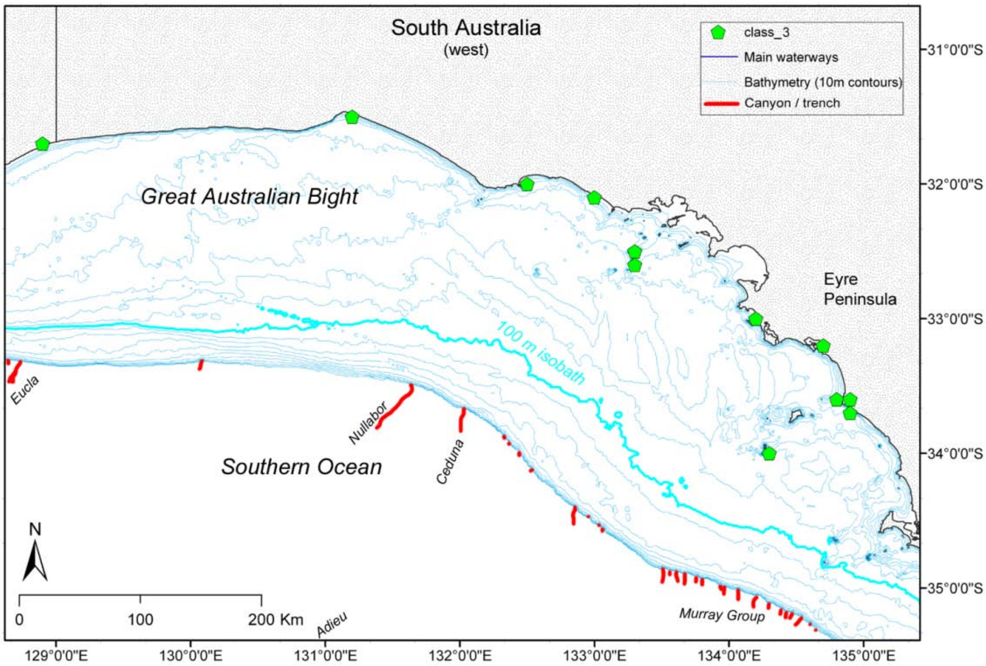

Fig. 4.7 Domain 3 locations.

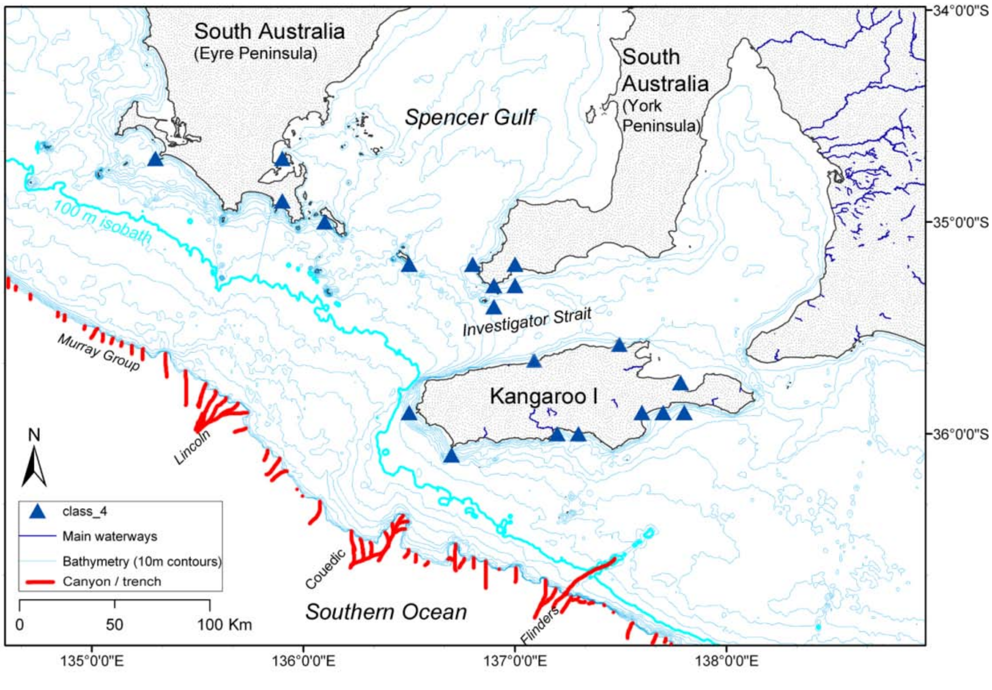

Fig. 4.8 Domain 4 locations.

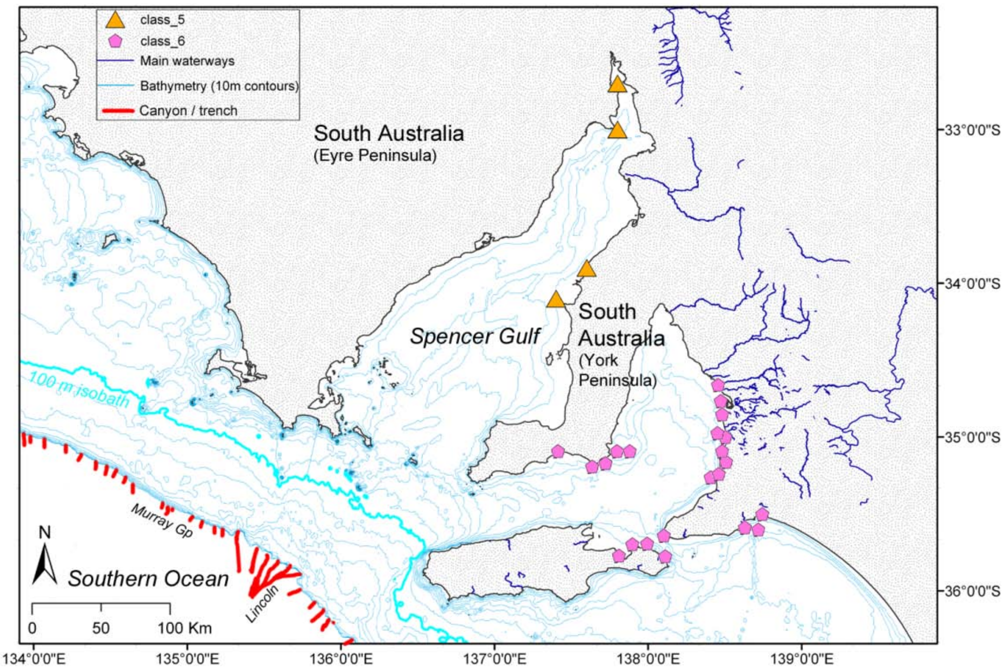

Fig. 4.9 Domain 5 and 6 locations.

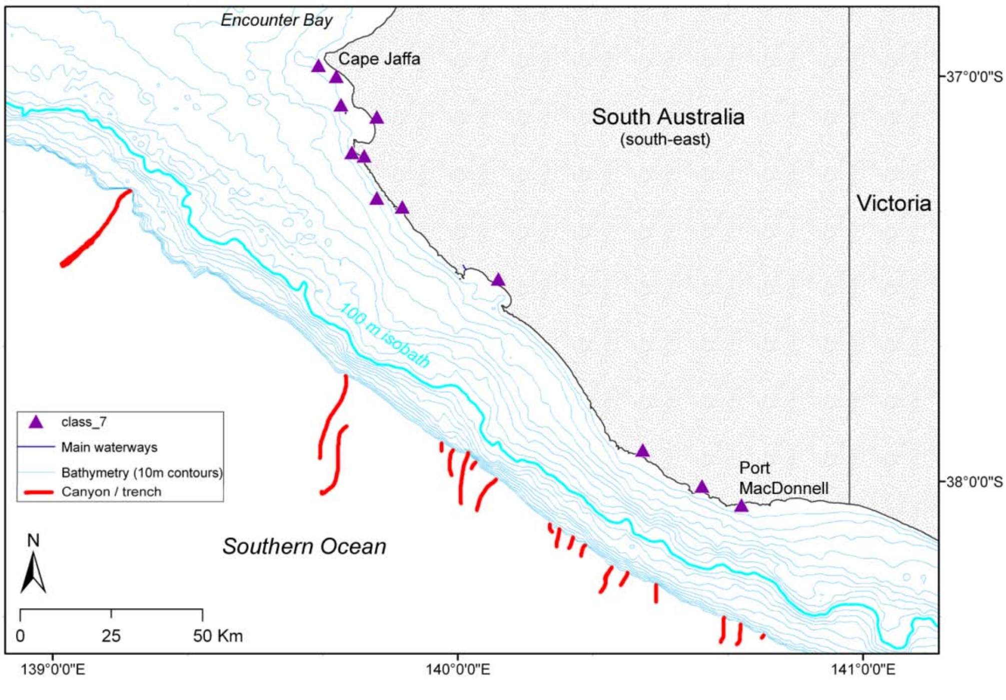

Fig. 4.10 Domain 7 locations.

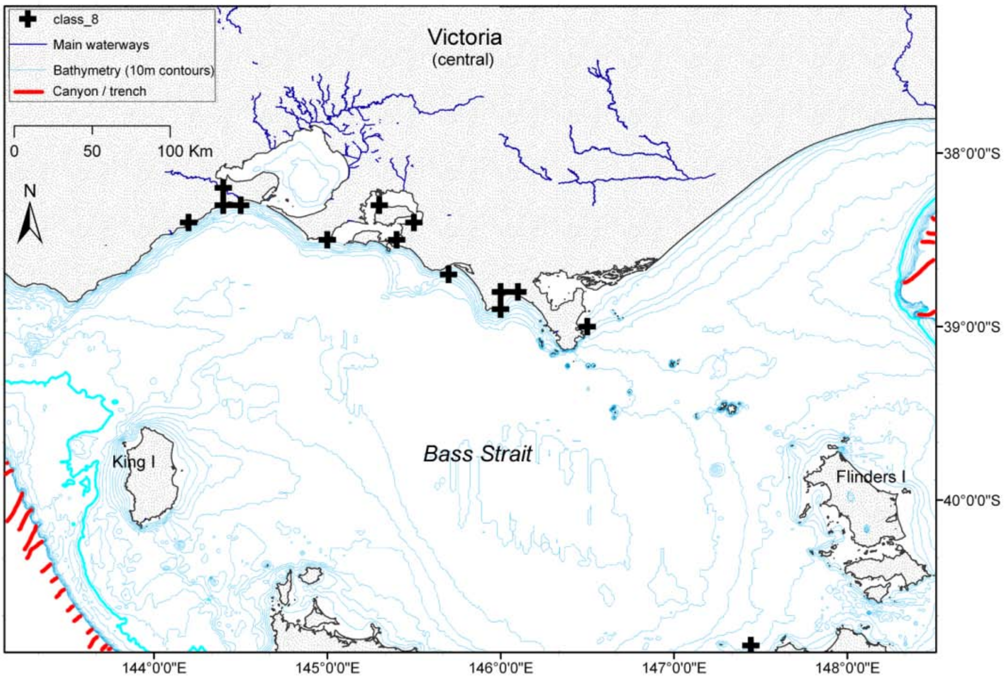

Fig. 4.11 Domain 8 locations.

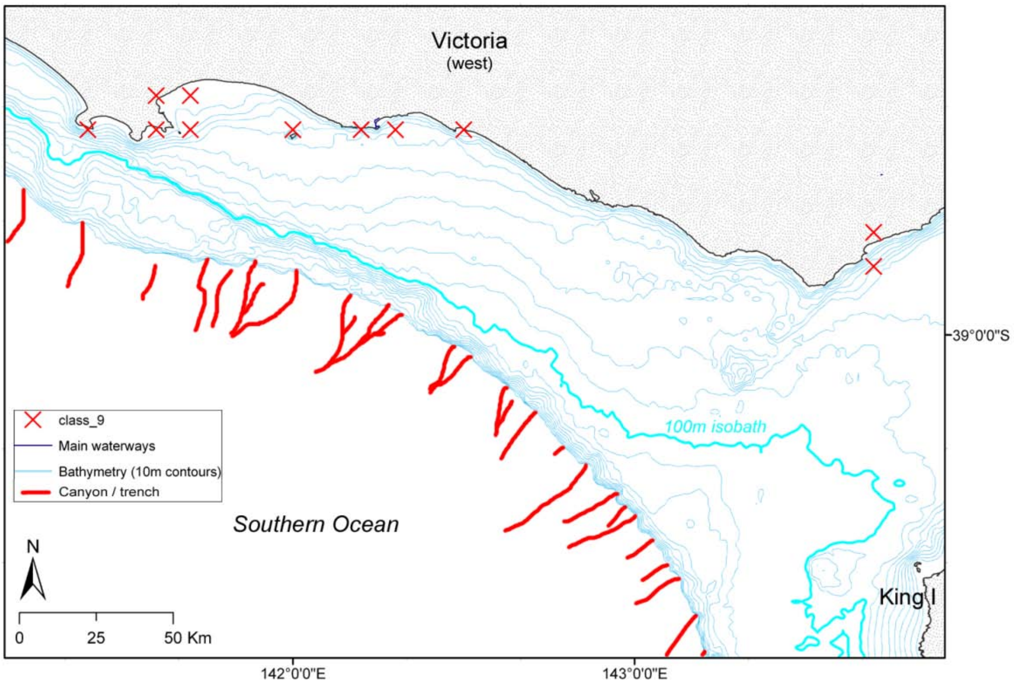

Fig. 4.12 Domain 9 locations.

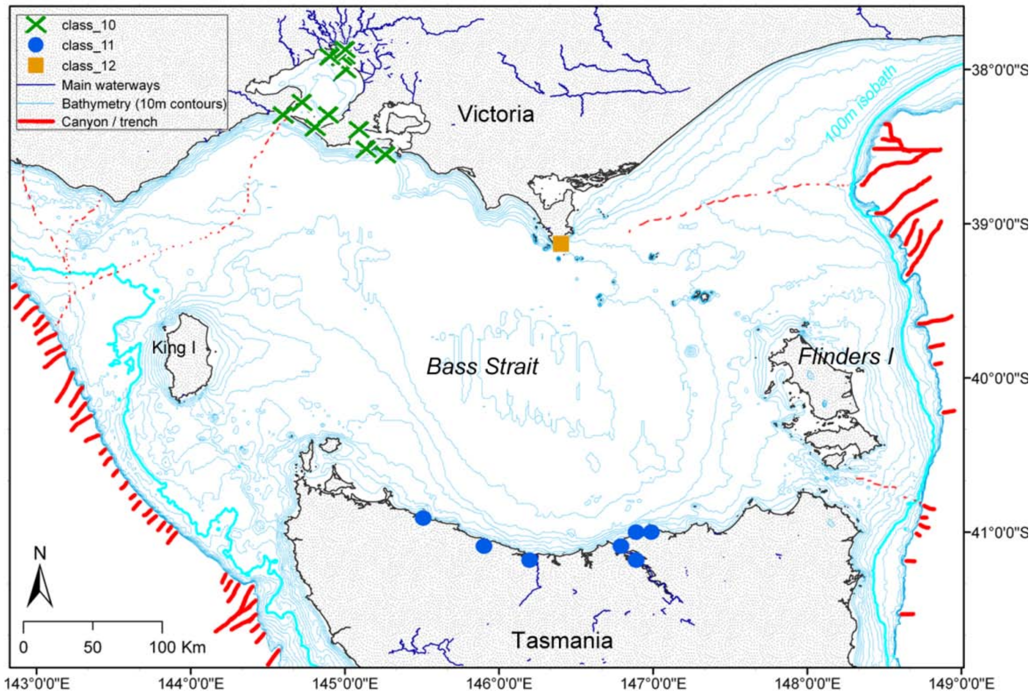

Fig. 4.13 Domains 10, 11 and 12 locations. Dashed red lines indicate ancient river courses.

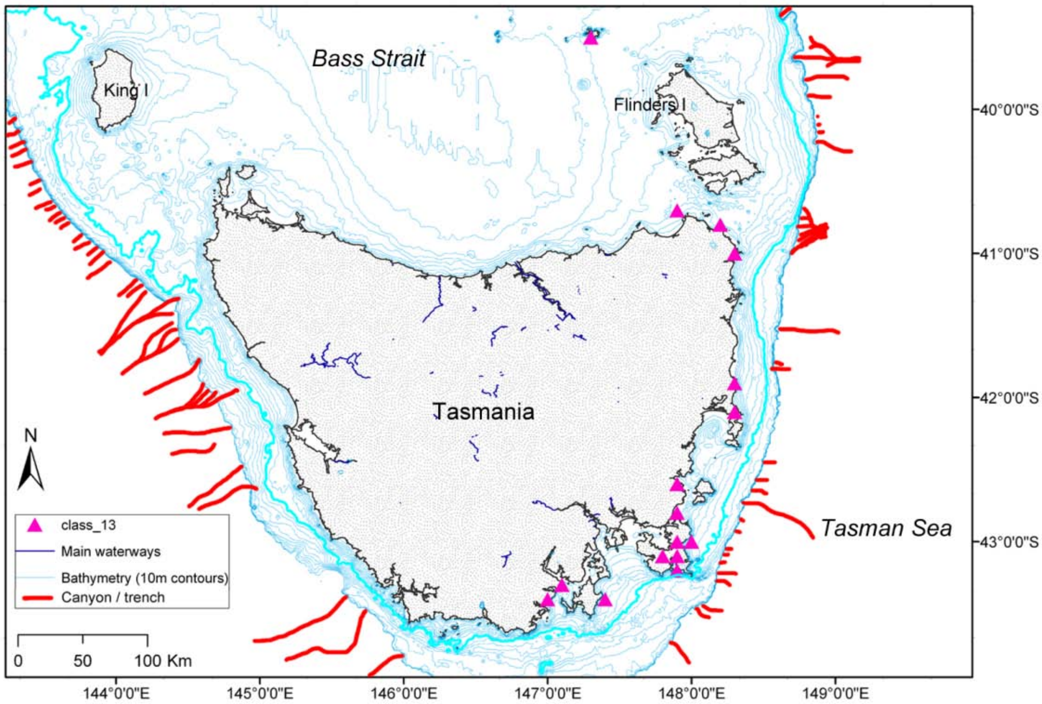

Fig. 4.14 Domains 13 locations.

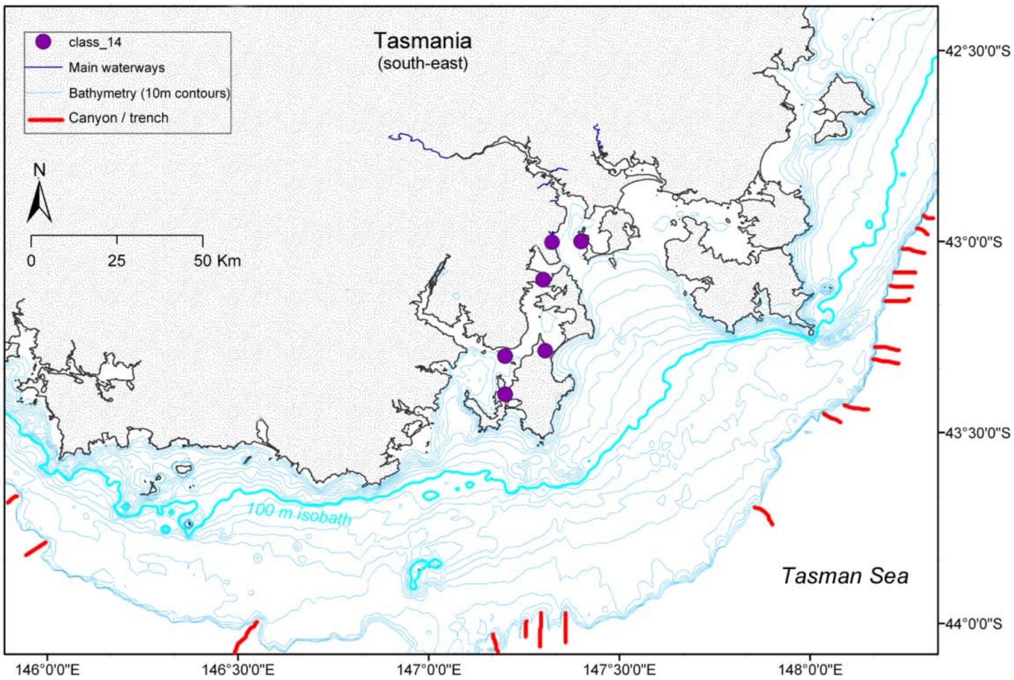

Fig. 4.15 Domain 14 locations.

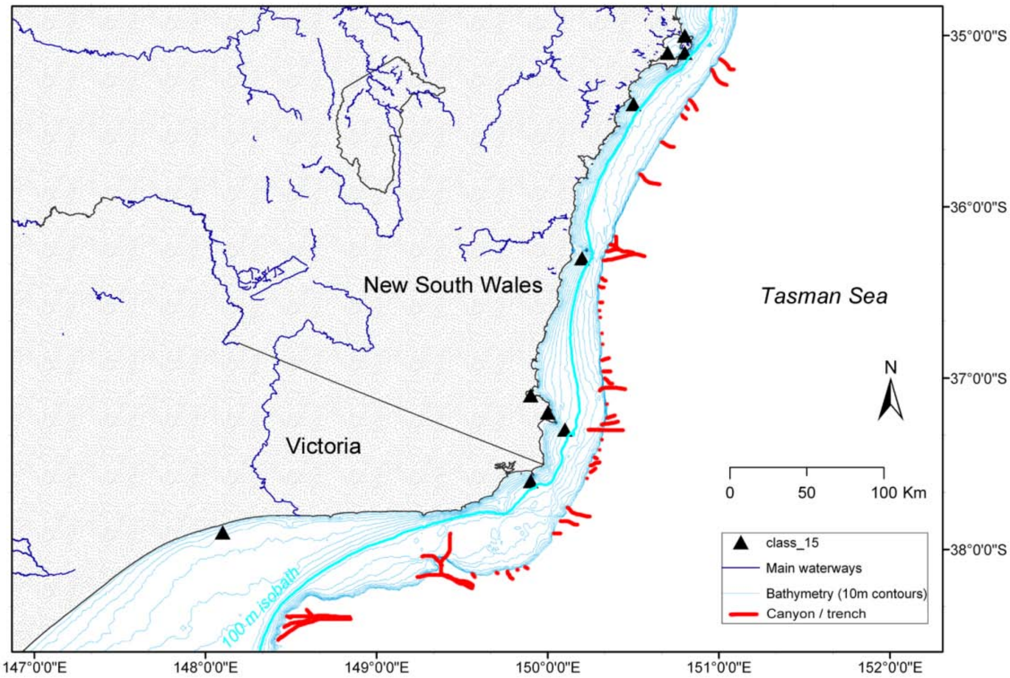

Fig. 4.16 Domain 15 locations.

4.4 Discussion

4.4.1 Rare species in rare and extreme environments

South-east Australia

The present analysis indicates that rare marine macroalgae occur in places where there are unusual conditions, with a preference for highly oligotrophic waters (low nitrate, phosphate, and chlorophyll-*a*). In contrast, highly productive waters are largely bereft of rare species. Interpretations made on the strength of the average proportions of rare species (mean %RareS) for each domain, identify south-east Tasmania and Port Phillip Bay as two centres of rarity with distinct environments. These are both areas of relatively complex geomorphology, encompassing a wide variety of micro-habitats in relatively small areas.

Port Phillip Bay (specifically Port Phillip Heads), with a high mean %RareS as well as high absolute number of rare species, is also a rare environment of small geographic range (85 km) and of macronutrient environment. The grid cell representing Port Phillip Heads has a high individual %RareS value (6.23%), and comprises the high diversity sites of the natural reefs of Point Lonsdale, Queenscliff, Portsea, Sorrento, as well as man-made substrata such as South Channel Light and Pope's Eye. There is no doubt that this is an extraordinary area, due to this grid cell also having the highest recorded rare species number (22) and a very high individual %Rare S value (6.23%) (Table 4.3). Port Phillip Heads is an area of high tidal current, up to 4.5 m s^{-1} (EPA 2011), with a dominant underwater feature of a steep-sided U-shaped valley approximately 300 wide and up to 90 m deep. The area is unique in its high profile reef topography of gullies, overhangs and pinnacles, with conditions of fast flowing water, and is known for high overall diversity of marine benthos (Wilson et al. 1998)

South-east Tasmania, the area of highest mean%RareS, is unique by a combination of small geographic range (50 km) and a suite of environmental features that produce essentially cold, oligotrophic waters. Individual grid cells (and sites) lie in the geographic areas of either the Derwent or Huon Estuaries, with many features of bathymetry and water movements in common. Within this domain, the highest number of rare species is found at Ninepin Pt (Huon Estuary). With variable water currents in the vicinity of 0.2 m s^{-1} and the seasonal input of tannin-stained freshwater, the Huon Estuary is a strongly-stratified waterway that experiences salinity layers, fast flushing times, and cold clear water with high light penetration (although episodically influenced by post-rainfall tannin-bearing freshwater) (CSIRO 2000). These quite specific conditions are associated with a high overall diversity of macroalgae, as well as the high proportion of rare species found at Ninepin Pt, Arch Rock, Charlotte Cove, Butts Reef, Huon Is, Huon Point, and Satellite Island, sites all subject to the influence of the Huon River where it flows into the D'Entrecasteaux Channel. They all lie within the Bruny Bioregion, the bioregion with the highest localised level of marine endemism in Tasmania (Edgar et al. 2000).

Environmental heterogeneity along the Victorian and Tasmanian coastlines at scales of 10–100 km is widely recognised (Crawford et al. 2000, O'Hara 2001). The best explanation for the centres of rarity may be that rare species occurrence is a function of the diversity of habitats.

Finding high proportions of rare species in rare environments is a phenomenon well demonstrated for terrestrial plants that are adapted to extreme conditions of ultramafic rocks– rocks (and soils) with high magnesium and iron content and elevated amounts of chromium and nickel. Distinctive low-stature vegetation develops in these rare environments, sometimes including endemic species and plants adapted to coping with otherwise toxic levels of specific elements (Amir et al. 2007, Grace et al. 2007).

The specialised conditions found along southern Tasmanian coasts (cold clear oceanic waters episodically inundated with dark tannin-laden freshwater) emerge as a rare environment associated with rare macroalgae. Because the tannin-bearing vegetation types south-eastern Tasmania (alpine vegetation, sedgeland and forest) were more extensive during times of a vastly lowered sea level than occurs in the current glacial-minimum times (MacPhail 1979), this marine environment would have persisted through glacial cycles, promoting the persistence of macroalgae now recognised as rare.

Other regions of southern Australia

Other domains of high mean %RareS are identified, but they are based on fewer significant features than south-east Tasmania and Port Phillip Bay. Domain 12 is represented by a single grid cell and therefore of very restricted range. It comprises few individual records, making it difficult to make any meaningful interpretation of its relatively high %RareS value (1.96%).

Sites of domain 3 span the Great Australian Bight from Eucla eastwards to Elliston on the west coast of the Eyre Peninsula, and include sites of known high macroalgal diversity, including Fowlers Bay, St Francis Isles, Pearson I, Venus Bay and Waldegrave I (Shepherd and Womersley 1971, Shepley and Womersley 1976, Womersley and Baldock 2003). The two grid cells at the extremes of the range are notable: Eucla has a high individual %RareS value (5.23%) of a local macroalgal diversity of 76, and Elliston has a very high #RareS (10). Occurring in the region are representatives of genera generally considered as warm-water taxa; *Dasycladus densus* Womersely, *Predaea huismanii* Kraft, and *Rhipiliopsis robusta* Womersely. *D. densus* has previously been described as "possibly dependent on slightly warmer temperatures of the Great Australian Bight region" (Womersley 1984). The scalloped coastline that characterises much of open coast South Australia may well have been formed over millennia due to along-shore sediment transported driven by wind and waves shaping today's coastal features of capes and cuspate forelands. The rare environments based on substrata features of high carbonates, low gravel and low mud composition, mid-low macronutrients in the water column, plus the remoteness from major rivers and submarine canyons that together typify the sites, alone do not appear sufficient to explain the relatively high mean %RareS value of 1.95% for this domain.

For the upper Spencer Gulf (domain 5), the sites lie in waters of the highest measurements for salinity and seasonal range of sea-surface temperature. The relatively high mean %RareS value (1.75%) is attributed to the combination of an environment reminiscent of tropical conditions with warm-water conditions similar to those of the Great Australian Bight, and a small number of rare species in common with that flora (domain 3), *Rhipiliopsis robusta* Womersely and *Coeloclonium debile* (Harvey) Gordon-Mills & Womersley.

South-west WA (domain 1) and southern NSW (domain 15) were extreme in variables of water temperature, essentially due to their locations on the northern margins of the study area. Both regions are well known as regions of high levels of macroalgal diversity and local endemism in the areas such as Rottnest I and Cape Peron (WA) (Huisman and Walker 1990, Kendrick et al. 2009), and southern NSW (Millar 2007a).

4.4.2 Escape routes during environmental change

The concept of high proportions of rare species occurring in rare or extreme environments has some credence, but it does not fully explain the mechanisms underlying concentrations of rarity, so other possible explanations for concentrations of rare species or high proportions of rare species must be considered. Whereas extirpation and extinction of marine algae are difficult to substantiate without long-term quantitative data on abundance, distribution and persistence (Edgar et al. 2004, Millar 2007b, Phillips and Blackshaw 2011), geographical range-shifts may help explain survival of niche-specific algae during glacial/interglacial cycles. Different types of refugia are possible, varying in size and length of time during which organisms are isolated. Temperate-adapted algae may be confined to refugia during glaciation, while cold-adapted algae may retreat to refugia during interglacial periods. Rare marine macroalgae have had to cope with changing sea levels during the glacial/interglacial cycles by migration, as suitable habitats shift location. Such migration is easiest where there is habitat continuity or the locations of environments shift the least. For rare macroalgae, the transition between sandy and rocky habitats is important to reconstructing range-shifts, because sand and rock (and gravel and mud) substrata support very different floristic communities.

Over prehistoric times there have been many glacial periods and associated fluctuations in sea level. From the last glacial maximum (LGM) some 18–20,000 years ago to the current era, is considered a short period of time for algal speciation, so movement of populations is considered. Focussing on changes since the LGM, globally the melting snow and ice must have caused a slow, imperceptible rise of the sea level. This overall ~100 m rise to our current day sea level resulted in the inundation of coastlines, embayments and land around Australia. During this sea level rise, succeeding generations of algal spores and plant-fragment drift material probably would have migrated according to the habitat suitability as the coastlines were changing. Whereas motile marine organisms may have had the means to choose a migration path, migration of marine benthic plants occurs either through thallus fragmentation and drift, or during the motile-propagule, planktonic stage of their life history—generally annual reproductive events subject to the movements of tides and ocean currents. Establishment of a species in a new area is subject to dispersal of viable propagules as well as success in settlement, growth and reproduction of the species (Goldberg and

Kendrick 2007), and such range extensions/shifts can occur over long distances (Lindstrom 2001, Waters and Roy 2004, Waters 2008).

Ancient river-course paleodrainage lines along Australia's temperate margins can be readily identified (Harris et al. 2005a). Such drainage pathways may offer a continuum of the environment(s) needed for macroalgal survival during large changes in sea level, by means of *de novo* recolonisation by species preferring specific environmental conditions, not available through relatively simple range-shifts. This idea is supported by the study of Schultz *et al.* (2008), who found that present-day distributions of freshwater crayfish on the Victorian coastline were partly explained by connectivity through river-to-sea paleodrainage lines.

Most macroalgal examples of migration during glacial cycles are from the northern hemisphere. For robust and widespread macroalgae, such as the fucoid *Ascophyllum nodosum* (Linnaeus) Le Jolis that is long-lived and considered resistant to extinction but vulnerable to catastrophic events, there is some evidence that glacial events little affect latitudinal distributions (Olsen et al. 2010). By contrast, extant population distributions of the widespread, intertidal ecosystem engineers *Fucus serratus* Linnaeus and *Ishige okamurae* Yendo are thought to be mainly shaped by the LGM by means of glacial refugia and recolonisation determined by ocean currents (Hoarau et al. 2007, Lee et al. 2012). For algae less robust or more habitat-restricted than these fucoids, the evidence for survival of species in subtidal marine refugia is more scant. Findings of Provan *et al.* (2005) suggest that the now widespread European red alga *Palmaria palmata* has persisted throughout the LGM in a deep trench in the English Channel, one of a series of marine refugia off the coast of Europe.

In the southern hemisphere, many references to temperate relict algal populations are anecdotal, or are based solely upon local occurrence of species. For example, *Acetabularia calyculus* Quoy & Gainard, a widely distributed tropical Australian green alga, has isolated populations in the warm Gulfs regions of temperate South Australia (Womersley 1984). Molecular techniques are becoming more frequently used in range-shift studies and used to infer postglacial species' recolonisation routes. From recent DNA sequence analyses of an Australian endemic brown alga Fraser *et al.* (Fraser et al. 2009, Fraser et al. 2012) describe a glacial refugium in south-east Australia. They postulate that the Australian bull kelp, *Durvillaea potatorum* (Labillardière) Areschoug has recolonised west-coast Tasmania from a mainland refugium by means of postglacial dispersion via the southward flowing Zeehan Current.

In the present study, the three distance variables (distance to canyon, 100-m-isobath, and extant rivermouth) were used in the analysis to partly test this historical explanation for rare species distributions. Distance data for all *non-sample* sites need to be generated to fully interpret the results. The 100-m-isobath and river-distance features emerged as extreme for only a small number of domains, but are not considered useful covariates in this analysis. However, relationships between the canyon-distance variable and rare species are worthy of comment. Of the two domains with the highest %RareS values (14 and 10) only domain 10 was associated with a significant canyon-distance, with sites occurring far from submarine canyons (Fig. 4.14). The "escape route" idea does however have some credence, in that some domains of high mean %RareS, although not considered to be in close proximity to a defined submarine canyon or ancient coastline, are near to, or have distinct pathways to obvious paleodrainage routes.

During the LGM, the Bass Basin existed as a brackish lake, isolated from the sea by the sills on its western and eastern sides, and the rising sea levels after glacial maxima. The marine-inundated paleodrainage of the Otway Depression (Harris et al. 2005b, Schultz et al. 2008) is the obvious migration route for marine benthic macroalgae of domains 10 (Port Phillip Bay) and 8 (Barwon Heads–Westernport Bay), as the shallow seabed/land-bridge between Tasmania and mainland Australia emerged and receded during glacial cycles. The vast area of the Bassian Plain, now Bass Strait, has sites on both its northern boundary (Phillips Heads, Crawfish Rock) and southern boundary (Tamar Estuary) known for high macroalgal diversity (Ducker 1993, Shepherd et al. 2009) as well as for high numbers of rare species (Chapter 2, Fig. 2.4).

The present coastline of Tasmania could be characterised by rocky shores and deep-cutting estuaries plus some beaches, whereas during the LGM extensive plains grading to beaches would have comprised the majority of coastline features. Gulfs and embayments, for example St Vincent Gulf and Port Phillip and Westernport Bays, and estuaries, such as Derwent, Tamar and Swan could offer refuges for species not suited to more exposed coasts. The high incidence of restricted-range rare species in these regions fits well with the idea of residual or remnant population of endemic species, considering that 18,000 years is a relatively short time to expect evolution alone to have resulted in such numbers and distributions.

Submarine canyons, while providing potential escape routes for macroalgae can also be the path of oceanic upwellings that can influence coastal environments, typically through a decrease in temperature, salinity, and dissolved oxygen, and an increase in nutrients, especially N, P and Si. These conditions are a seasonal source of high nutrient concentrations, and can stimulate chlorophyll (microalgal) blooms. The eastern section of the Great Australian, the South Australian gulfs regions, and the Cape Jaffa–Port MacDonnell region, are all seasonally affected by ocean upwellings from submarine canyons. One example is the Bonney Upwelling, a summer upwelling event—sometimes weak, sometimes strong—feeding cool nutrient-rich water into the Flinders Current that flows along the coast, roughly from northwestern TAS, along western VIC, southern SA and offshore to Cape Leeuwin WA. In contrast surface currents can affect species distributions, such as the seasonal warm-water East Australian Current that strongly influences dispersal of plankton and nekton (Suthers and Waite 2007) and macroalgae (Wernberg et al. 2011b), and possibly the coastal flora of domain 15. It is possible that the high nutrient levels associate with upwellings or ocean currents may contribute to conditions that are unfavourable for rare algae and the low %RareS values predicted along the respective coasts (Chapter 3, Fig. 3.2).

In Chapters 3 and 4, I conclude that the distribution of rare marine macroalgae can be only partly explained by associations with physical and environmental parameters, and that habitat diversity and species’ range-shift during glacial cycles may also contribute to distribution patterns. Irrespective of the type of analysis attempted, some measure of cross-validation for either a proposed explanation for concentrations of rarity is desirable. Field surveys for rare species were embarked upon to elucidate rare species distributions (Chapter 5). It is possible that new taxa, range extensions and abundance data may be observed, as well as opportunity to collect more comprehensive information on endemicity and/or true rarity of organisms.

4.4 Bibliography

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Chapter 5: Field surveys for rare macroalgae

5.1 Introduction

For many decades floristic surveys have added to our overall knowledge of Australian algal flora, and in part have supported the identification of biogeographic regions. For freshwater *micro*algae, specific regional areas of endemism have been identified but the most recent considered opinion is that there are insufficient data Australia-wide to define meaningful floristic regions (Entwisle 2007). In the marine realm, clearly recognisable biogeographic provinces have been variously described in terms of macroalgae (Womersley 1981, Huisman et al. 1998, Waters et al. 2010) and a finer scale regionalisation of the Australian coast based on both fauna and flora— the Integrated Marine and Coastal Regionalisation of Australia (IMCRA) (2006)—has been generated and is widely used by Commonwealth and State management agencies for spatial priority setting. Along the temperate coasts of Australia three provinces have been recognised; the Flindersian, Peronian and Maugean, each with evident regions of overlap near the respective boundaries and yet often marked by a marked a major change in the suite of key species (Phillips 2001, Huisman 2007, Millar 2007a). The boundaries of eighteen meso-scale bioregions are nested within the provincial bioregions (IMCRA 2006). These geographic provinces and finer-scale bioregions have been determined as a result of combined fieldwork and observations by researchers over many decades.

Inherent value exists in the collection of primary data for which provenance and accuracy are known. Many macroalgal studies over the decades of the 1900s have necessarily been qualitative, essentially based on occurrence data and voucher specimen collection. Not least for subtidal habitats the advent of SCUBA (self contained underwater breathing apparatus) has enabled more comprehensive studies to be conducted, encompassing aspects of species populations and abundance. Simple repeatable methods allow comparison of data across both spatial and temporal scales (Oxley 1997). These are easily implemented given a reasonable level of expertise of the observer. Visual surveys (photographic, or by human observer) have been successfully used to assess and monitor the flora of subtidal habitats but, other than easily recognisable canopy-forming species, the taxonomic resolution has often been only achievable to genus level. For rare macroalgae many species are of small size and unidentifiable *in situ* and destructive sampling is often the only means by which a positive identification can be made. The approach of target-searching for rare macroalgae calls for a concentrated underwater technique in a difficult environment, exploring sub-canopy, cryptic and epiphytic habitats often overlooked in rocky reef studies.

The aims of the field program were to investigate the incidence of macroalgal rarity, where possible from rare or extreme environments identified previously (see Chapters 3 and 4) by means of a time-controlled data-set and subsequent post-processing and to establish whether the patterns found in the historical AVH datasets are truly representative of the proportions and distributions of rare algae in nature.

5.2 Materials and methods

5.2.1 Study regions and site selection

Potential study regions and underwater visual census (UVC) sites were selected on the basis of the maps generated using existing herbarium records (as identified in Chapter 2, Fig. 2.1) and identification of areas of known high numbers or proportions of rare species (Chapters 3 and 4). From within the four general regions of interest (south-west Western Australia, the gulfs region of South Australia, Port Phillip Bay region in Victoria, and Tasmania) seven areas were selected for specific investigation (Table 5.1, Fig. 5.1).

Surveys were conducted within a range of management zones associated with Marine Protected Areas and Fisheries Research Areas and thus encompassed a variety of protection levels for marine biota and habitats. Macroalgae are unlikely to be directly targeted for collection in fishing-permitted areas, but detrimental impacts on individual plants or their habitat may result from fishing for predators of sea urchins and other grazing invertebrates, with consequent increase in grazing pressure on algae (Tegner and Dayton 1999, Babcock 2010).

Region	Relevant reference for maps and general area description
S-W Australia (Rottnest I – Albany)	(Richardson et al. 2005)
Victoria (Port Phillip & Westernport Bays)	(Blake and Ball 2001, Ball and Blake 2007)
N-E Tasmania (Kent Group & Hogan Group)	(Jordan et al. 2005)
N Tasmania (Tamar Estuary)	(Lucieer et al. 2009)
E Tasmania (Maria I & vicinity)	(Barrett et al. 2009)
S-E Tasmania (Derwent-D'Entrecasteaux)	(Barrett et al. 2009, Wild-Allen et al. 2009, Herzfeld et al. 2010)
S-W Tasmania (Port Davey & vicinity)	(Barrett and Edgar 2010)

Table 5.1 Study areas and numbers of Underwater Visual Census (UVC) sites.

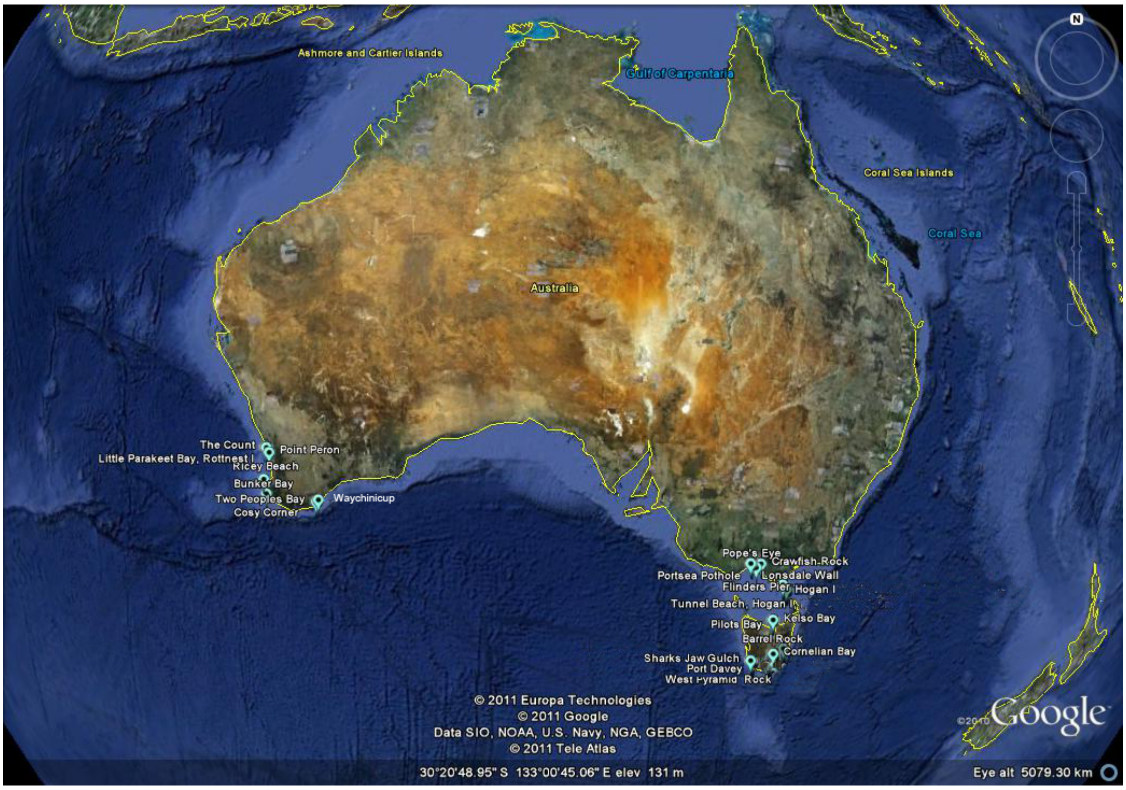

Fig. 5.1 Overview of UVC field survey sites (Google Earth 2011 image).

Individual underwater visual census (UVC) sites were generally located in rocky reef habitats, but included a few sites within sand-to-reef transition zones. Sites were largely chosen to minimize logistic constraints, including the viability of access (by shore or boat) and available logistic support for dive operations (timeframe, weather, coordination of dive team, costs of field expeditions). A total of 111 sites was selected for UVC dives and surveyed between November 2008 and February 2011 (Table 5.2, Appendix). Detailed descriptions and mapping of inshore habitats for the seven study areas are covered in various research reports (referred to in Table 5.1) but a brief description of each region is also given below.

South-west Australia: A distinct array of geomorphology, oceanography, habitats, flora and fauna can be found along the coastal areas of south-west Australia. The offshore areas are generally subject to the warm low-salinity nutrient-poor Leeuwin Current that flows southward along the coast from the North West Shelf to the Great Australian Bight in winter (DEC 2006). However, in times of high rainfall, localised plumes of nutrient-laden freshwater may flow and be transported away from the mouth of permanent estuaries (e.g. Swan-Canning, Peel-Harvey) or seasonally open systems (e.g. Leschenault, Nornalup) (Brearley 2005). The Capes Current, in contrast to the Leeuwin, is closer inshore and north-flowing, and may influence seagrass and macroalgal dispersal (Walker 1991).

Rottnest Island, an isolated island of roughly 10 x 5 km area, located ~18 km westward of Perth. With an absence of rivers and shallow water muddy environments from the island, local habitats for marine plants are largely structured by the influence of winds, currents, and ocean swells upon the fringing limestone reefs (Wells and Walker 1993). Extensive platform reefs emergent during low tides and high-relief submarine reefs offer complex habitats. A total of 371 macroalgae have been recorded from the island ~20% of which are endemic to Western Australia (Huisman and Walker 1990, Huisman 1993). During the LGM (last glacial maximum) some 20,000 years ago when the sea level was ~130 m lower than at present, the island was well inland of the continent coastline (Brearley 2005). As part of the marine reserve, a number of “no-take” zones exist around the island.

Pt Peron, ~20 km SSW of Perth has a surface geology of white sand dunes composed largely of shell material built up since the end of the last ice age (Brearley 2005). The near-shore limestone reefs are oriented more or less parallel to the coast eastward (inshore) of the ancient shoreline that now forms Five Fathom Bank, and are included in the Shoalwater Island Marine Park. Shallow reefs offer biotic habitats similar to those of nearby Rottnest and Garden Islands. Many noteworthy historical collections were made in this high diversity area of the state (Cowan and Ducker 2007).

Bunker Bay is a north-facing shallow bay at the western end of Geographe Bay, sub-tidally with low relief limestone reef communities, sand and shoreline reef (DEC 2006). The Leeuwin Current effectively bypasses Geographe Bay and the inshore area is subject to a local easterly current (Hill and Ryan 2002). Seasonally, large amounts of algal wrack accumulate on some parts of the rocky shore.

Canal Rocks faces west and is part of a narrow continental shelf with nearshore granite and gneiss drop-offs that are eroded on the seaward side. Nearby Cape Naturaliste is a "high energy exposure site dominated by low frequency (storm/seasonal) events" (Hemer 2006). The UVC site investigated was located on the lee side of the north-south oriented line of rocks in an area of low relief reef scattered with boulders. Isolated limestone reefs also occur close by where benthic communities comprise a mixture of tropical and temperate species (DEC 2006).

Cosy Corner Sanctuary Zone, some 15 km north of Cape Leeuwin at the southwest corner of the Australian continent, faces west and is therefore subject to the typically high-energy predominantly southwesterly ocean swell. The mixed limestone and granite reefs support rich macroalgal and seagrass communities, particularly in vicinity of the sheltered cave formations and limestone platforms (DEC 2006).

Waychinicup Inlet, with no sand or rock bar at its entrance to the sea, is a granite-sided gulch even though physical factors of the water column indicate it has the character of a seasonally stratified estuary (Brearley 2005). The algal and seagrass flora that reflects open coastal marine areas, with 40 species of macroalgae recorded and with clear spatial patterns of biota throughout the estuary (Phillips and Avery 1997). From their detailed study these authors concluded that freshwater inflow from the only riverine source, the Waychinicup River, is a key determinant of the composition and distribution of biota despite the oceanic water exchange. This is one of the few sites in southern Australia at which *Cystoseira trinodis* (Forsskål) C. Agardh occurs.

Two Peoples Bay is a moderately exposed bay nestled between granite headlands, with Gardener Lake Creek intermittently draining into the southern end. It is adjacent to the Two Peoples Bay Nature Reserve and open to recreational and commercial fishing boats. The sea floor is essentially of patchy rocky reef and sand with extensive seagrass beds (*Amphibolis antarctica* (Labillardiere) Sonder and Ascherson, *Heterozostera* *tasmanica* (Martens *ex* Ascherson) den Hartog, and *Halophila ovalis* (R. Brown) J.D. Hooker).

Victoria: Two regions in Victoria were selected for survey, in deference to numerous historical records of high macroalgal diversity and high numbers of rare species records.

Port Phillip Heads is located between two roughly parallel geological fault-lines and is essentially an ancient river mouth of the combined rivers that now flow into Port Phillip Bay. Between the two headlands of Pt Lonsdale and Pt Nepean, a strong tidal flow (The Rip) provides a relatively high-energy environment (Plummer et al. 2003). Currents have contributed to the diverse seabed communities found on both soft sediments, and low- and high-relief rocky reefs. The geology is of Pleistocene calcareous dune sequences resulting in pitted rock platforms and caverns. Seagrass beds, kelp forests and diverse algal communities are located within various sections of the Port Phillip Heads Marine National Park. Algal UVC sites included Lonsdale Wall, Queenscliff, Pope's Eye and Portsea Hole.

Westernport Bay, to the east of Port Phillip Bay, is a coastal embayment fringed in many places with mangrove and saltmarsh communities. The UVC survey site was at Crawfish Rock, an outcrop of ferruginous sandstone, effectively a pinnacle reef lying in the main tidal channel of the North Arm. Subtidally it is an environment of strong tidal currents, high salinity, and mud/sandstone substratum, extending down to 20 m deep. The algal flora was widely considered as "rich" (138 species recorded in 1971) but by 2006, 66% of algal species had disappeared due to increased turbidity and sedimentation and algal growth observed down to only ~4 m deep (Shepherd et al. 2009). Crawfish Rock is zoned as an ECC (Environment Conservation Council) Special Management Area for the preservation of benthic fauna communities.

North-eastern Tasmania: The *Kent Group* and the *Hogan Group* of islands, both lie in Bass Strait between Wilsons Promontory (VIC) and Flinders Island (TAS) under the seasonal influence of the warm, south-flowing East Australian Current. The islands are devoid of rivers or estuaries although there are some seasonal creeks, and the underwater terrain is generally of high-relief with scattered boulders offering complex habitats for flora and fauna, even though barren areas formed through overgrazing by sea urchins have become more apparent in recent years (Barrett et al. 2007). Sites on subtidal reefs of Deal I, Erith I, Dover I, Hogan I, and NorthEast I were surveyed and included sites both inside and outside existing Marine Protected Areas.

Northern Tasmania: The Tamar Estuary is formed by the confluence of the South Esk and North Esk Rivers, flowing into a combined drowned river valley of some 70 km length. The main channel is up to 45 m deep and flanked for great distances by tidal mud flats (Pirzl and Coughanowr 1997). Dredging and shipping activities have undoubtedly modified marine habitats and several invasive species are now well established. Areas of the lower estuary are subject to a 3 m tidal range and are known for high biodiversity and productivity. Three sites in the lower Tamar Estuary were surveyed. A fourth survey at Bombay Rock, a pinnacle reef well known for being the collecting site of many interesting historical algal collections, was aborted due to excessive current flow.

Barrel Rock (Fish Rock) is a rocky pinnacle exposed at low tide and extending down to ~40 m deep on the eastern side of the main channel, near Low Head. An abundance of *Ecklonia*, *Phyllospora* and *Sargassum* plants among the boulders shelter a highly diverse algal flora.

Pilots Bay near Low Head and *Kelso Bay*, some 6 km further south, form discrete shallow embayments, of mixed sand and rocky reef substrata where seagrass beds occur.

Eastern Tasmania: Sites were surveyed along the moderately-exposed inshore coastline of Maria Island both inside and outside the Maria Island Marine Reserve. Sites were generally of low to medium-relief rocky reef with high percentage algal cover, at Ile du Nord, Darlington Jetty, Painted Cliffs, Return Pt, Pt Lesseur, and Green Bluff.

Also surveyed were nearby low-exposure coastal sites at Spring Bay, Point Holme and Okehampton, where reefs were generally of high relief.

South-eastern Tasmania: This is a region well known for its high marine biodiversity (Barrett et al. 2009). A number of sites in two waterways were surveyed.

Derwent Estuary: The morphology of the Derwent Estuary is that of a drowned river valley formed between 6,500 and 13,000 years ago, after which sea level rose ~60 metres to near its current level (Green and Coughanowr 2003). The estuary is of a salt wedge type, with freshwater surface flow heading downstream and marine flow in the bottom waters heading upstream (Herzfeld et al. 2005). The tidal behaviour is predominantly of diurnal mixed character with a tidal range of 0.5 m to 1 m. Macroalgal diversity is low in upper reaches and increases towards areas of higher ocean-water exchange (Barrett et al. 2010). UVC surveys were conducted at a range of sites, listed here in order of increasing in salinity and exposure towards the lower estuary where it adjoins Storm Bay; Montague Bay, Cornelian Bay, Geilston Bay, Rosny, Tranmere, Battery Point, Maning Reef, The Grange, Crayfish Point, Trywork Reef, Gellibrand Grave, White Rock, Gypsy Shoal, Alum Cliffs, Blackmans Bay, Hales Farm, and Pierson's Point.

D'Entrecasteaux Channel: This extensive waterway between Bruny Island and coastal (mainland) Tasmania and is essentially an ancient river bed (Meyer et al. 2011). Many areas of the channel are under estuarine influence from either the Derwent or Huon Estuary and undergo seasonal or rainfall-event driven conditions of varying salinity and light regime. Deeper parts of the channel reach at least 55 m, with shallower marginal reefs grading up to the shorelines. Rocky reefs generally occur as narrow zones along the shoreline with strong depth zonation evident in the reef biota and quickly merge into a soft seabed of sand and/or silt (Nichol et al. 2009). Sites surveyed for macroalgae (from north to south) included Dennes Pt, Tinderbox, NorthWest Bay, The Shepherds, Blight Pt, Simpson's Pt, Satellite I, Ninepin Pt, Huon I, Huon Pt, Butts Reef, Charlotte Cove, Garden I, Partridge I, Southport, and George III Reef.

South-west Tasmania: Port Davey, in Tasmania's south-west, lies at the confluence of Payne Bay and Bathurst Channel. Fed by a large annual rainfall, these estuaries provide high freshwater inputs of dark (tannin-stained), low nutrient water to surrounding embayments of Port Davey (Barrett et al. 2006). Sub-tidal reef structure is essentially rocky, of high relief and of varying exposure to ocean seas and swell. A high degree of marine biotic endemism has been documented for this area (Edgar et al. 2006b). Eleven sites of varying exposure and biotic protection/preservation category were surveyed, including Milner Head, Norman Cove, Inner Saddle Bight, Outer Saddle Bight, Turnbull I, Spain Bay, South Channel Head, and South Whalers Point. A number of sites beyond Port Davey were also surveyed; Muttonbird Island, Shark Jaw Gulch, and West Pyramid Rock. In the vicinity the Australian bull kelp *Durvillaea potatorum* (Labillardiére) Areschoug dominates exposed sites from the intertidal and down to depths of ~5 m.

5.2.2 Underwater Visual Census (UVC) method

Two methods resulted in positive findings of rare macroalgae.

Method 1: The diver-based UVC survey design employed here was based on the UVC method used to monitor densities of fishes, invertebrates and plants for a number of ecosystem monitoring programs (Edgar and Barrett 1999, Edgar et al. 2006a, Barrett et al. 2009), with the modification of using a time-based rather than an area-based recording technique. To record presence and (presumed) absence of macroalgae, using SCUBA equipment and a writing slate, a standard search time of 30 minutes was undertaken, during which every species observed was recorded on an underwater writing slate. The search area was approximately 100 m^2; the search area was smaller at sites of high biodiversity (where populating the time-controlled species list occurred without having to move very far from the starting point), but was larger at sites of low diversity. This procedure ensured surveys were easily achievable on a single tank of air, and with a relatively small support team. GPS locations were recorded as close to directly above the settled anchor as possible. To take into account the swing of the boat at anchor, the geocode accuracy was estimated at 50 m for each site. The coordinate system used was WGS 84.

This method enabled largely non-destructive sampling and data collection and had the advantage of allowing searches to include cryptic or sub-canopy habitats that could be otherwise easily overlooked. Identifications were made *in situ*. When this was not possible, plants (or plant fragments) were collected and photographed for subsequent examination. These post-dive processing steps facilitated positive identification of many small, filamentous or cryptic species that were unidentifiable *in situ*. Each survey was conducted by the author thus eliminating any “between-diver” effects necessarily factored into other studies (Edgar et al. 2006a). In the study time available and in keeping with feasible logistics, the focus was on acquiring a broadscale overview of distributions therefore a large number of sites were surveyed once at the expense of gathering information from replicate surveys. Three test runs of the method were performed before the extended survey program began to ensure that data could be collected consistently.

The time-based survey method was favoured over a fixed-transect type of survey, the latter being more appropriate for long-term monitoring programs where inter-annual replicability of surveys is paramount. Alternative methods that rely solely on image-based underwater surveys were rejected on the grounds that they have serious limitations with respect to taxonomic resolution of such a heterogeneous group as the macroalgae. Such image-based methods are suitable for investigating benthic habitats and populations of large or unmistakable species (Lucieer 2007, Williams et al. 2009) and typically produce data of biota recorded to the taxonomic level of genus or into functional groups (Oh 2009, Meyer et al. 2011). The adaptive cluster sampling for rare species method described by Goldberg and co-workers (Goldberg et al. 2007) used for selected sizeable rare macroalgae could not be applied in the present study because many rare species were unidentifiable *in situ*.

Method 2: Either immediately following the 30 min UVC dive time or on separate species-specific target-search dives altogether, algae of particular interest were photographed when possible (using a Canon G10 camera in an underwater housing), and subsequently collected. This opportunistic method allowed further investigation of plants that were unidentifiable *in situ* and proved valuable in the collection of three rare species not encountered during Method 1 UVC surveys.

5.2.3 Species identification

Species were identified using information and keys available for southern Australian benthic marine algae (Womersley 1984, 1987, 1994, 1996, 1998, 2003, Herzfeld et al. 2005, Butler 2006, Baldock 2010). Current taxonomic status of species was confirmed through AlgaeBase (Guiry and Guiry 2010). For selected specimens, permanent slide mounts were made of aniline-blue stained fragments according to techniques described in the Womersley text (Womersley 1984). Identifications for some problematic specimens were verified by Assoc. Prof. G.T. Kraft (The University of Melbourne). Any specimens remaining unidentifiable were subsequently referred to by their voucher number. Photomicrography was accomplished with a Leica MZ 7.5 stereomicroscope and a Leica DM LB2 compound microscope, equipped with digital camera.

Voucher specimens have being lodged into the Tasmanian State Herbarium (HO), as a requirement of the collecting permit issued by Tasmanian Parks & Wildlife.

5.3 Results

5.3.1 Species diversity

From field surveys and post-processing work, 489 macroalgae were recorded collectively from 111 UVC (method 1) surveys (see Appendix for full list and data set). The number of total species found on UVC surveys varied between 4 and 52, and of rare species between 0 and 2 (Table 5.2). Seven of the 18 sites of highest biodiversity (≥40 species) were in the lower Huon Estuary (TAS) where it joins the D'Entrecasteaux Channel; Huon I (UVC nos. 18, 80), Huon Pt (102), Ninepin Pt (5, 79), Butts Reef (81), and Charlotte Cove Light (6). Six other sites were also in SE Tasmania; Southport (UVC no. 9), Blackmans Bay (66, 72), Alum Cliffs (71), Lucas Pt (13), and Bligh Pt (3). The Tasmanian sites of Erith I north in NE TAS (UVC no. 46) and Inner Saddle Bight SW in Port Davey SW TAS (21) were also amongst the most diverse sites. Three sites in WA were amongst those of highest diversity; Cosy Corner (survey no. 110) and 2 sites at Rottnest I, Little Parakeet Bay (UVC no. 53) and Ricey Beach (106).

The sites of lowest algal diversity (<10 species) were in the middle reaches of the Derwent Estuary in the immediate vicinity of the city of Hobart (UVC nos. 73, 75, 76, 77).

The UVC surveys enabled the collection of a time-controlled data-set. In terms of search effort, observations of both rare species and all species followed a similar pattern, with the rate of rare species observations decreasing over time (Fig. 5.2).

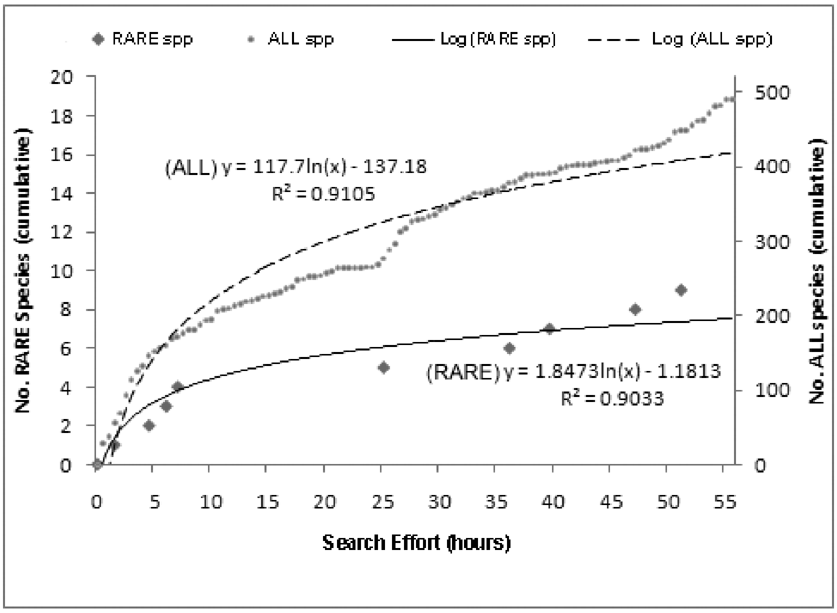

Fig. 5.2 Species numbers observed according to search effort, with MS log trendline.

Table 5.2 (pro parte) Details of study sites, plus numbers of species recorded on UVC surveys, arranged in order of descending species richness.

UVC no.	SITES	Depth (m)	Latitude	Longitude	Region	Date	No. ALL spp found	No. RARE spp. found
18	Huon I (18)	6.3	-43.29370	147.14115	SE TAS	1/04/2009	52	1
53	Little Parakeet Bay (53)	7.7	-31.98888	115.51793	WA	25/07/2009	52	0
110	Cosy Corner (110)	6	-34.25767	115.02658	WA	24/11/2010	49	1
9	Southport (9)	9.5	-43.46099	146.99550	SE TAS	9/12/2008	48	1
66	Blackmans Bay (66)	7.2	-43.01720	147.33247	SE TAS	25/11/2009	48	2
80	Huon I (80)	7.1	-43.29404	147.14168	SE TAS	12/03/2010	47	0
5	Nine Pin (5)	9.2	-43.27912	147.18317	SE TAS	26/11/2008	46	0
81	Butts Reef (81)	7.5	-43.27588	147.12712	SE TAS	15/03/2010	46	0
72	Blackmans Bay (72)	7.1	-42.99837	147.32967	SE TAS	11/02/2010	45	2
79	Ninepin Pt (79)	5.6	-43.28409	147.16743	SE TAS	11/03/2010	45	1
71	Alum Cliffs (71)	7.6	-42.96660	147.34175	SE TAS	11/02/2010	43	1
21	Inner Saddle SW (21)	10	-43.31224	145.98644	SW TAS	22/04/2009	43	0
13	Lucas Pt (13)	7.4	-43.03831	147.33904	SE TAS	19/03/2009	42	0
106	Ricey Beach (106)	2	-32.00032	115.4888	WA	17/11/2010	42	0
46	Erith I north (46)	10.4	-39.44375	147.28526	Bass Str.	28/06/2009	40	0
3	Bligh Pt (3)	11	-43.08396	147.32294	SE TAS	19/11/2008	40	1
6	Charlotte Cove Light (6)	7.5	-43.27311	147.14354	SE TAS	26/11/2008	40	0
102	Huon Pt (102)	7.7	-43.2836	147.1012	SE TAS	14/07/2010	40	1
82	Butts Reef (82)	10.5	-43.27466	147.12695	SE TAS	16/03/2010	39	0
95	Arch Rock (95)	8.8	-43.28744	147.17945	SE TAS	17/05/2010	39	0
55	Pocillopora Reef (55)	12.3	-32.02446	115.52979	WA	26/07/2009	39	0
37	Dover I (37)	10.6	-39.46529	147.28712	Bass Str.	24/06/2009	38	0
14	Tinderbox "central" (14)	6.3	-43.05895	147.33257	SE TAS	20/03/2009	38	1
17	Nine Pin Pt (17)	4.7	-43.28417	147.16668	SE TAS	1/04/2009	38	0
74	White Rock (74)	5.2	-42.97745	147.39230	SE TAS	12/02/2010	38	0
83	Garden I (83)	7.5	-43.26229	147.13287	SE TAS	16/03/2010	38	0

23	Mutton Bird I (23)	10.2	-43.42191	145.96959	SW TAS	23/04/2009	38	0
57	Fish Hook Bay (57)	12.3	-32.02468	115.45157	WA	27/07/2009	38	0
49	North East I (49)	10	-39.44680	147.37689	Bass Str.	29/06/2009	37	0
24	Mutton Bird I (24)	6.1	-43.41674	145.97122	SW TAS	23/04/2009	37	0
42	Hogan I (42)	8.3	-39.21913	146.99231	Bass Str.	26/06/2009	36	0
33	Painted Cliffs (33)	5.5	-42.59235	148.05067	E TAS	13/05/2009	36	0
16	Charlotte Cove (16)	6.4	-43.27219	147.14244	SE TAS	1/04/2009	36	0
61	Alum Cliffs central (61)	5.8	-42.96453	147.34142	SE TAS	14/11/2009	36	0
97	Pope's Eye (97)	10.9	-38.27667	144.69944	VIC	26/06/2010	36	1
35	Karitane Bay east (35)	12.7	-39.49284	147.34212	Bass Str.	23/06/2009	35	0
69	Crayfish Point (69)	4.6	-42.95207	147.35603	SE TAS	10/02/2010	35	0
111	Tinderbox (111)	8.2	-43.02661	147.33545	SE TAS	18/01/2011	35	0
19	Outer Saddle Bight (19)	10.5	-43.31817	145.87360	SW TAS	21/04/2009	35	0
100	Flinders (100)	4.7	-38.47578	145.02500	VIC	29/06/2010	35	0
84	Spring Bay (84)	7	-42.58376	147.91600	E TAS	27/04/2010	34	0
92	Barrel Rock (92)	5.6	-41.06596	146.79179	N TAS	12/05/2010	34	0
10	Partridge I (10)	6.4	-43.40293	147.10431	SE TAS	11/12/2008	34	0
12	Piersons Pt (12)	6.4	-43.05204	147.34385	SE TAS	19/03/2009	34	1
63	Hales Farm (63)	9.1	-43.04371	147.34192	SE TAS	15/11/2009	34	1
22	South Whalers Pt (22)	11.1	-43.30344	145.91704	SW TAS	22/04/2009	34	0
51	The Count (51)	7.2	-32.01458	115.55802	WA	24/07/2009	34	0
54	Crystal Palace (54)	17.1	-32.02539	115.54514	WA	26/07/2009	34	0
107	Point Peron (107)	3	-32.27142	115.68721	WA	20/10/2010	34	0
40	Dover I isthmus (40)	9.2	-39.46482	147.29480	Bass Str.	25/06/2009	33	0
4	Tinderbox (4)	13.1	-43.05688	147.33748	SE TAS	19/11/2008	33	0
7	Satellite I (7)	6.1	-43.32163	147.22935	SE TAS	8/12/2008	33	0
68	The Grange (68)	3.9	-42.93326	147.36162	SE TAS	10/02/2010	33	0
15	Dennes Pt (15)	5.7	-43.06289	147.35082	SE TAS	20/03/2009	32	1
103	Ninepin Pt (103)	7.9	-43.28422	147.16733	SE TAS	14/10/2010	32	0

34	Okehampton (34)	8	-42.52454	147.96992	E TAS	13/05/2009	31	0
88	Darlington Jetty (88)	5.5	-42.57632	148.06232	E TAS	3/05/2010	31	0
2	NW Bay(2)	7.8	-43.05753	147.31147	SE TAS	18/11/2008	31	0
25	West Pyramid Rock (25)	11.4	-43.29735	145.81958	SW TAS	25/04/2009	31	0
27	Norman Cove (27)	13.3	-43.36957	145.93304	SW TAS	26/04/2009	31	1
109	Canal Rocks (109)	3	-33.66951	114.99550	WA	22/11/2010	31	0
39	Erith I (39)	9.7	-39.44466	147.30128	Bass Str.	25/06/2009	30	0
32	Green Bluff (32)	6.6	-42.72018	148.01164	E TAS	11/05/2009	30	0
91	Return Point (91)	6.2	-42.62899	148.02459	E TAS	5/05/2010	30	0
65	Soldiers Rocks Sth (65)	4.5	-43.01334	147.33089	SE TAS	25/11/2009	30	0
1	Shepherds (1)	11.2	-43.08944	147.30101	SE TAS	18/11/2008	29	0
60	Gellibrand's Grave (60)	7.3	-42.96646	147.40373	SE TAS	13/11/2009	29	0
101	Crawfish Rock (101)	7	-38.26995	145.29695	VIC	3/07/2010	29	0
105	Thompson Bay (105)	2	-32.00013	115.54622	WA	15/11/2010	29	0
41	Hogan I (41)	11.7	-39.21919	146.99583	Bass Str.	26/06/2009	28	0
86	Okehampton (86)	6.1	-42.52401	147.96925	E TAS	30/04/2010	28	0
20	Inner Saddle SW (20)	9.4	-43.31234	145.89600	SW TAS	21/04/2009	28	0
29	Milner Head (29)	6.8	-43.32276	145.98651	SW TAS	26/04/2009	28	0
30	South Channel Head (30)	6.2	-43.32943	145.98819	SW TAS	27/04/2009	28	0
31	Turnbull I (31)	8.3	-43.33143	145.99562	SW TAS	27/04/2009	28	0
26	Sharks Jaw Gulch (26)	11.4	-43.30943	145.84282	SW TAS	25/04/2009	27	0
48	Jetty Bay (48)	7.2	-39.46922	147.31026	Bass Str.	30/06/2009	26	0
94	Kelso Bay (94)	2.9	-41.10954	146.80394	N TAS	13/05/2010	26	2
8	Simpsons Pt (8)	9.9	-43.24900	147.28825	SE TAS	8/12/2008	25	0
38	Dover I (38)	7.7	-39.46529	147.28712	Bass Str.	24/06/2009	24	0
45	East I (45)	5.5	-39.21384	147.02145	Bass Str.	27/06/2009	24	0
50	Green I (50)	13.3	-32.01774	115.49950	WA	24/07/2009	24	1
52	Eagle Bay (52)	5.1	-32.01805	115.45234	WA	25/07/2009	24	0
104	Waychinicup Inlet (104)	2	-34.89278	118.33352	WA	28/10/2010	24	0

11	Huon Pt (11)	6.6	-43.28310	147.10087	SE TAS	11/12/2008	23	0
98	Portsea Hole (98)	16.4	-38.31140	144.71085	VIC	27/06/2010	23	1
43	Tunnel Beach (43)	10.9	-39.22600	146.97958	Bass Str.	27/06/2009	22	0
85	Point Holme (85)	6	-42.5532	147.94638	E TAS	27/04/2010	22	0
67	George III Reef (67)	11.6	-43.50742	146.98469	SE TAS	21/01/2010	22	0
28	Spain Bay (28)	6.8	-43.36115	145.95784	SW TAS	26/04/2009	22	0
56	Green Island Wall (56)	10.5	-32.02472	115.50535	WA	27/07/2009	22	0
108	Two Peoples Bay (108)	2	-34.97174	118.18186	WA	30/10/2010	22	0
87	Ile du Nord (87)	6.5	-42.56167	148.06781	E TAS	30/04/2010	21	0
89	Magistrates Pt (89)	6.2	-42.58691	148.05179	E TAS	3/05/2010	20	0
58	Bunker Bay (58)	2	-33.53709	115.03221	WA	29/07/2009	20	0
59	Trywork Reef (59)	5.1	-42.94022	147.40892	SE TAS	13/11/2009	19	1
36	Karitane Bay east (36)	6.2	-39.49501	147.33067	Bass Str.	23/06/2009	18	0
47	Erith I north-west (47)	6.4	-39.44364	147.27716	Bass Str.	28/06/2009	18	0
96	Queenscliff (96)	2.5	38.26778	144.66778	VIC	25/06/2010	18	0
93	Pilots Bay (93)	2.7	-41.06654	146.79665	N TAS	12/05/2010	17	0
99	Lonsdale Wall (99)	25	-38.29125	144.63042	VIC	27/06/2010	17	0
90	Point Leseuer (90)	5.8	-42.66105	148.00744	E TAS	5/05/2010	15	0
70	Tranmere Pt (70)	4.4	-42.93042	147.40926	SE TAS	10/02/2010	13	0
44	Tunnel Beach (44)	6.8	-39.22600	146.97958	Bass Str.	27/06/2009	11	0
62	Maning Reef (62)	2.5	-42.90611	147.34470	SE TAS	14/11/2009	10	0
78	Rosny Point Nth (78)	3.1	-42.87378	147.35132	SE TAS	16/02/2010	10	0
64	Gypsy Shoal (64)	12.1	-42.94961	147.41687	SE TAS	15/11/2009	9	0
73	Battery Point (73)	2.9	-42.88971	147.33942	SE TAS	11/02/2010	9	0
75	Cornelian Bay (75)	2.2	-42.85181	147.32785	SE TAS	16/02/2010	8	0
77	Montague Bay (77)	4.6	-42.86165	147.35025	SE TAS	16/02/2010	7	0
76	Geilston Bay (76)	2.9	-42.84532	147.33737	SE TAS	16/02/2010	4	0

Table 5.2 Details of study sites, plus numbers of species recorded on UVC surveys, arranged in order of descending species richness.

5.3.2 Targeted searches for rare species

Sixteen rare species were observed, representing ~11% of the 142 nominated rare species. Twelve were found during UVC survey dives (method 1) and four during non-UVC survey dives (method 2) (Table 5.3).

Taxon	**Survey number (method 1)**
Amansia mamillaris	110
Antithamnion biarmatum	12,15,27
Ceramium lenticulare	14,18,59,63,71,72
Cirrulicarpus polycoelioides	63
Crouania brunyana	method 2
Cryptonemia wilsonii	94
Dasya hapalathrix	method 2
Herposiphonia pectinella	94
Macrothamnion pectenellum	79,99,100
Pterothamnion aciculare	9,66
Ptilocladia gracilis	method 2
Rhipiliopsis multiplex	50
*Rhodymenia halymenioides**	3,7,64
Schizoseris hymenena	102
Schizoseris perriniae	3, 66
Entwisleia bella	72, method 2

Table 5.3 Rare species found during UVC surveys. (* *R. halymenioides* is now considered a synonym of *Halopeltis cuneata* (Harvey) G.W. Saunders)

Rare species encountered

Because they are little known, it is appropriate to include brief notes about the rare species found during the study. The following data include new records, herbarium collection (FS) numbers, information about species range, a record of a new life history phase *(Pterothamnion aciculare*), and the discovery of a previously unknown species (*Entwisleia bella* proposed sp. nov.).

Amansia mamillaris J.V. Lamouroux (Rhodomelaceae, Ceramiales) is an erect red alga (to 30 cm high) with alternately pinnate, complanately branched, basally constricted laterals arising from terete axes (Fig. 5.3). Already known from isolated, usually deep-water sites in Western Australia from Geraldton to Eyre, this recent collection (FS 6045) of vegetative material from a shallow limestone reef habitat at Cosy Corner WA represents a new site but no extension of the 1192 km species range (Fig. 5.4).

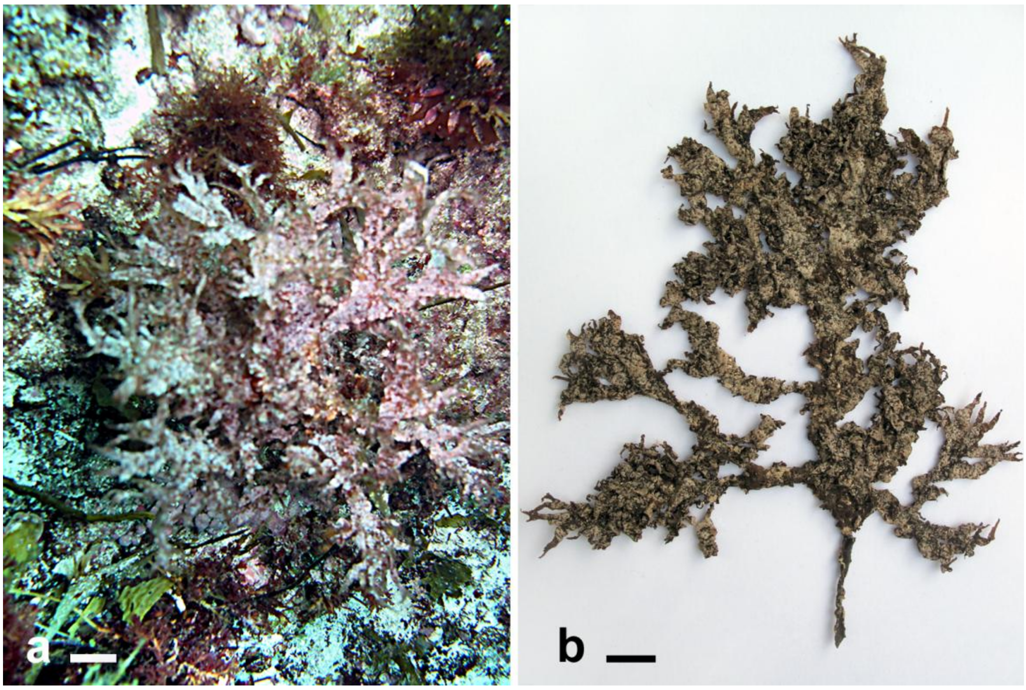

Fig. 5.3a-b *Amansia mamillaris*. a) Habit *in situ*, b) Habit, dried herbarium specimen. Scale bars: a, b =1 cm.

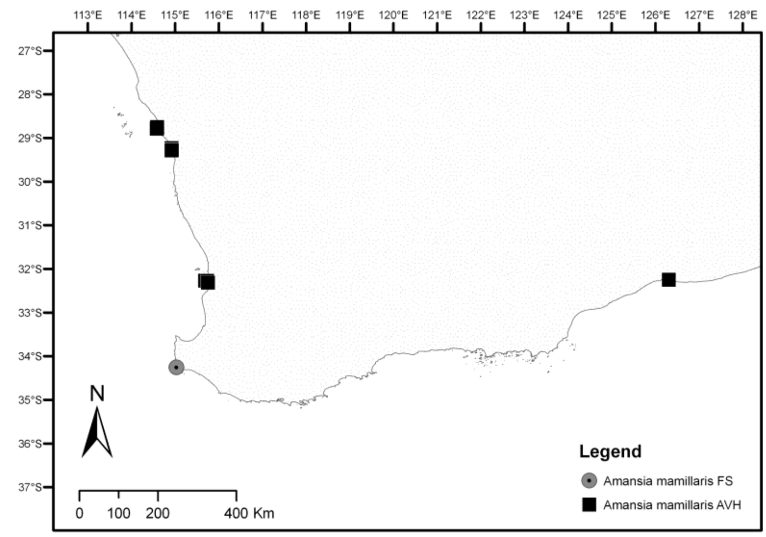

Fig. 5.4 *Amansia mamillaris*. Known range, including previous (AVH) and recent (FS) collections.

Antithamnion biarmatum Athanasiadis (Ceramiaceae, Ceramiales) is a small (to 15 mm high) epiphytic filamentous red alga with whorl branchlets (pinnae) distichously arranged along the axes and the smaller branches (pinnules) arising from both adaxial and abaxial faces of pinnae (Fig. 5.5). Already known from isolated sites in Victoria and Tasmania, the recent collections of vegetative material from rocky reef habitats at Blackmans Bay (FS 5356), Dennes Point (FS 5177) and Piersons Point (FS 5275) (all south-east TAS) and Norman Cove (Port Davey, south-west TAS) (FS 6286) collectively represent a range extension from 685 to 730 km (Fig. 5.6). This species has now also been reported for Althorpe Island SA (Janine Baker, pers. comm.).

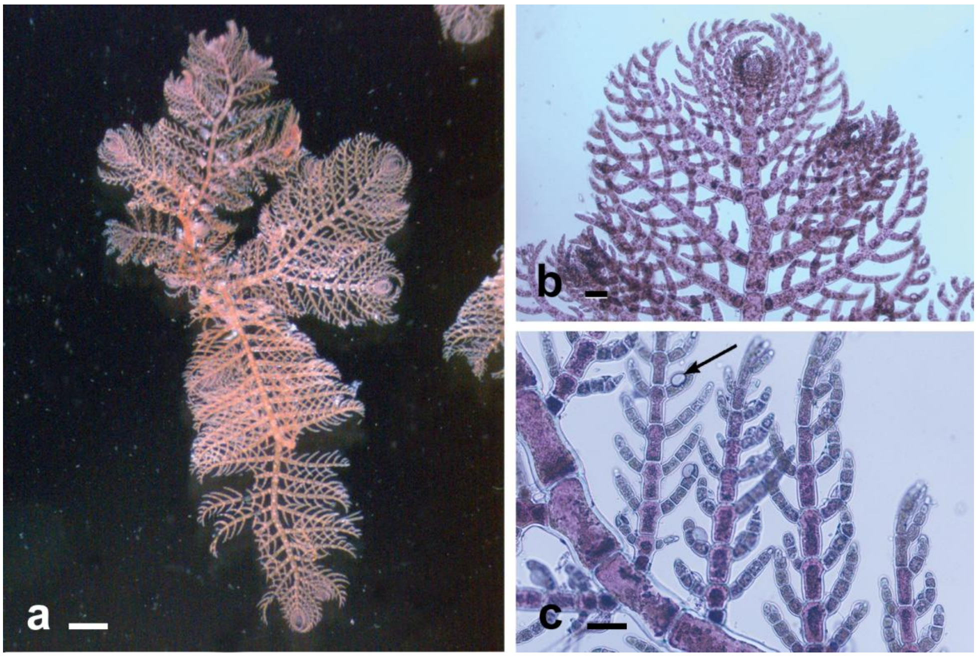

Fig. 5.5a-c *Antithamnion biarmatum*. a) Habit of plant, b) Upper branch with opposite pinnae, c) Gland cell (arrow) in contact with two bearing cells of the pinnules. Scale bars: a =500 µm, b, c =100 µm.

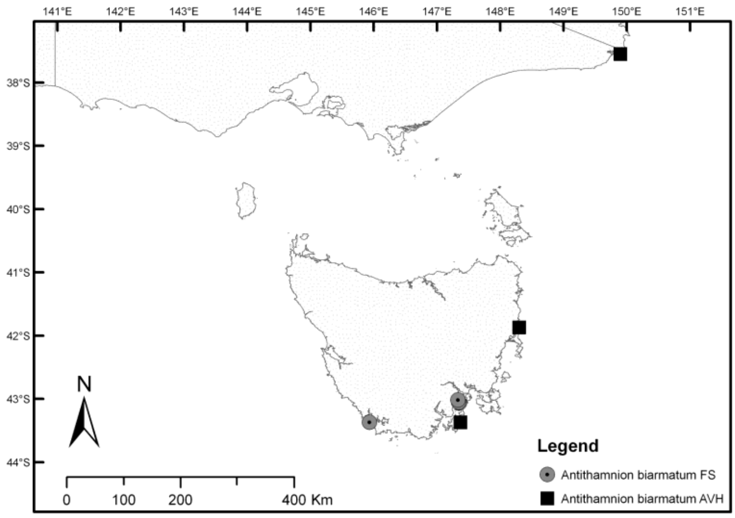

Fig. 5.6 *Antithamnion biarmatum*. Known range, including previous (AVH) and recent (FS) collections.

Ceramium lenticulare (Ceramiaceae, Ceramiales) Womersley is a relatively small (to 7 cm high) filamentous red alga, with complanate branching and characteristic lens-shaped internodal spaces in the outer cortex (Fig. 5.7). It is of broad range (1218 km) and the recent collections of vegetative and tetrasporangial material from rocky reef habitats at Tinderbox (FS 5118), Blackmans Bay (FS 5414), Trypot Reef (FS 6166), Huon Island (FS 5304) and Alum Cliffs (FS 5441) (south-east TAS) represent new sites but no extension of the 1218 km species range (Fig. 5.8).

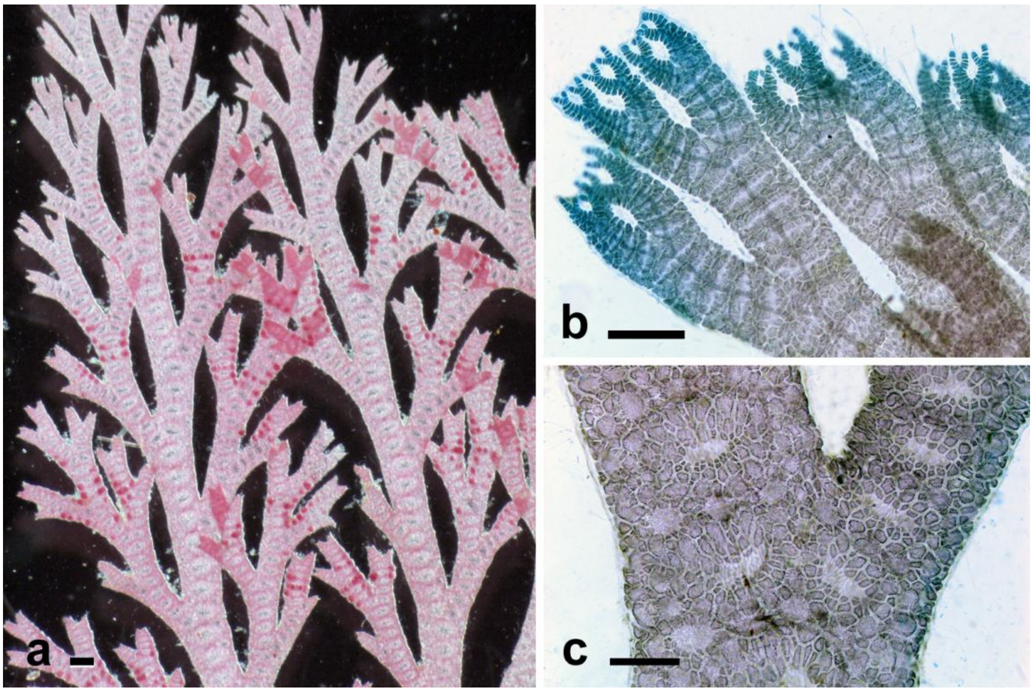

Fig. 5.7a-c *Ceramium lenticulare*. a) Upper axes with tetrasporangia, b) Apices, aniline-blue stained, c) Conspicuous, lens-shaped gaps in cortication, aniline-blue stained. Scale bars: a-c = 100µm.

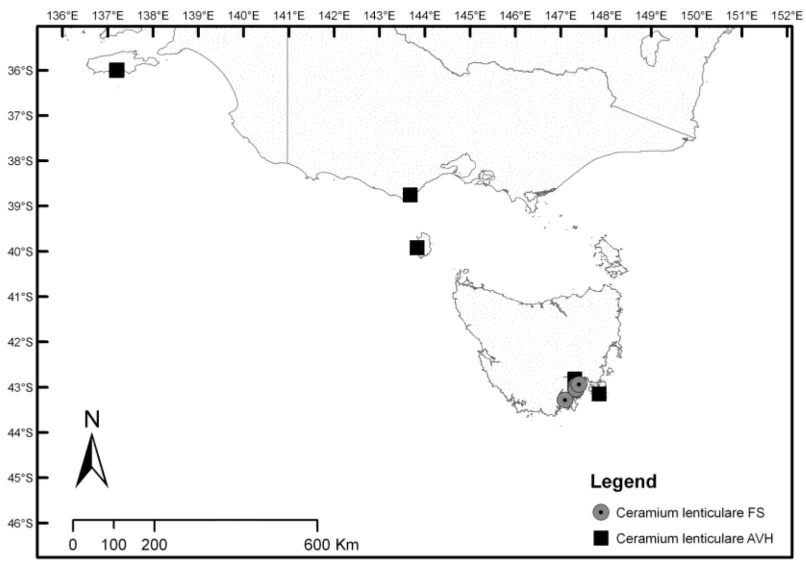

Fig. 5.8 *Ceramium lenticulare*. Known range, including previous (AVH) and recent (FS) collections.

Cirrulicarpus polycoelioides (J. Agardh) Womersely (Kallymeniaceae, Gigartinales) is a membranous soft-textured red alga (to 12 cm high) with a short stipe and much-divided thallus and final branches of 1–1.5 cm wide (Fig. 5.9). The recent collection of vegetative material from a rocky reef habitat near Tinderbox (south-east TAS) (FS 6136) represents a new site but no extension of the species range of 120 km (Fig. 5.10).

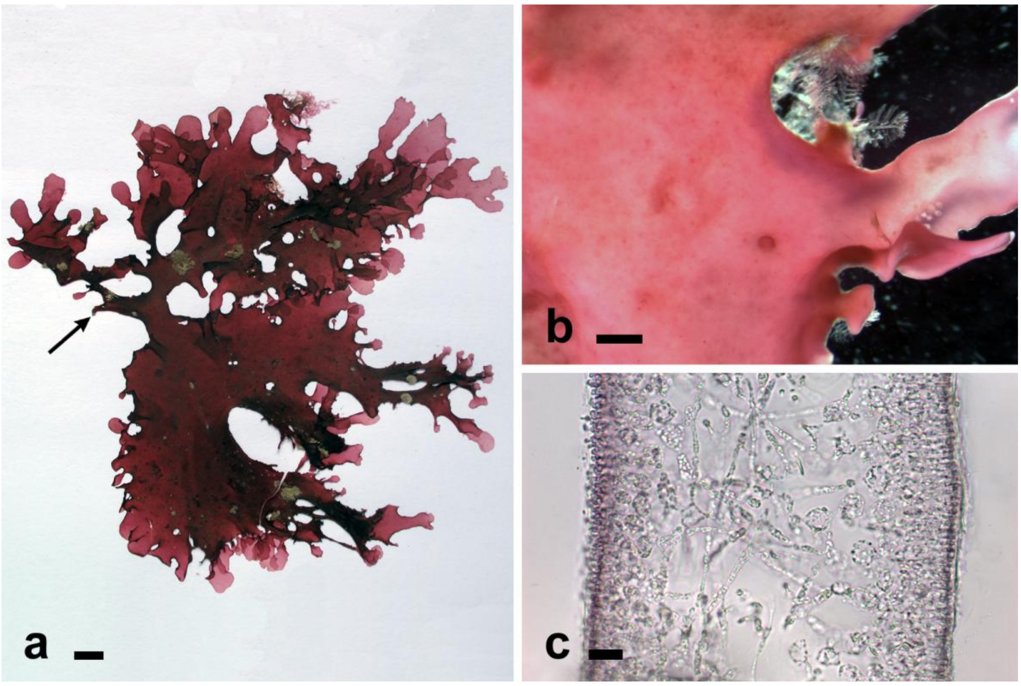

Fig. 5.9a-c *Cirrulicarpus polycoelioides*. a) Habit of plant with small holdfast (arrow), b) Blade margin (with epiphytes), c) Transverse section of a blade. Scale bars: a = 1 cm, b = 1 mm, c = 50 µm.

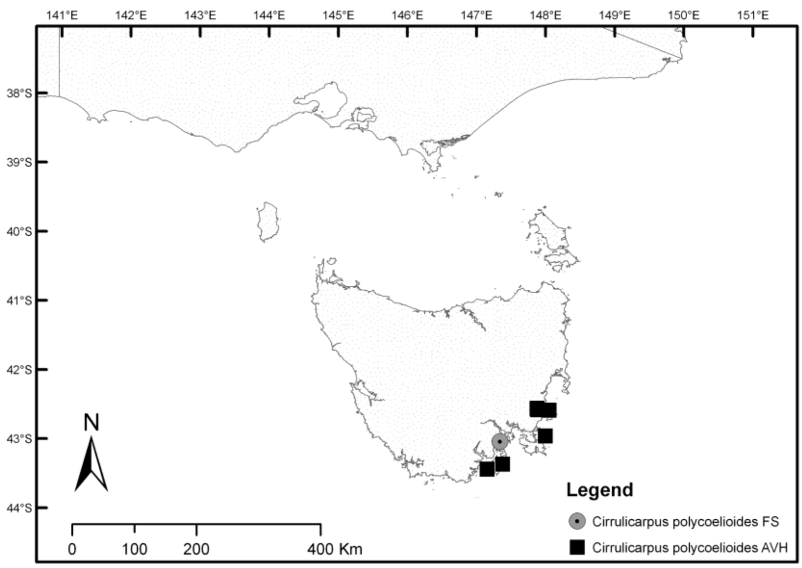

Fig. 5.10 *Cirrulicarpus polycoelioides*. Known range, including previous (AVH) and recent (FS) collections.

Crouania brunyana (Callithamniaceae, Ceramiales) Wollaston is a small (to 4 cm high) ecorticate filamentous red alga. The main branches bear distinct whorl-branchlets (in whorls of 3) that are well-separated and arranged such that the axial cells of the main branches remain exposed (Fig. 5.11). Previously only known from Tinderbox and Bruny Island (south-east TAS), the recent collection of vegetative and tetrasporangial plants from a rocky reef habitat (–7 m) at nearby Blackmans Bay (FS 6086) extends the known range marginally to 31 km (Fig.5.12).

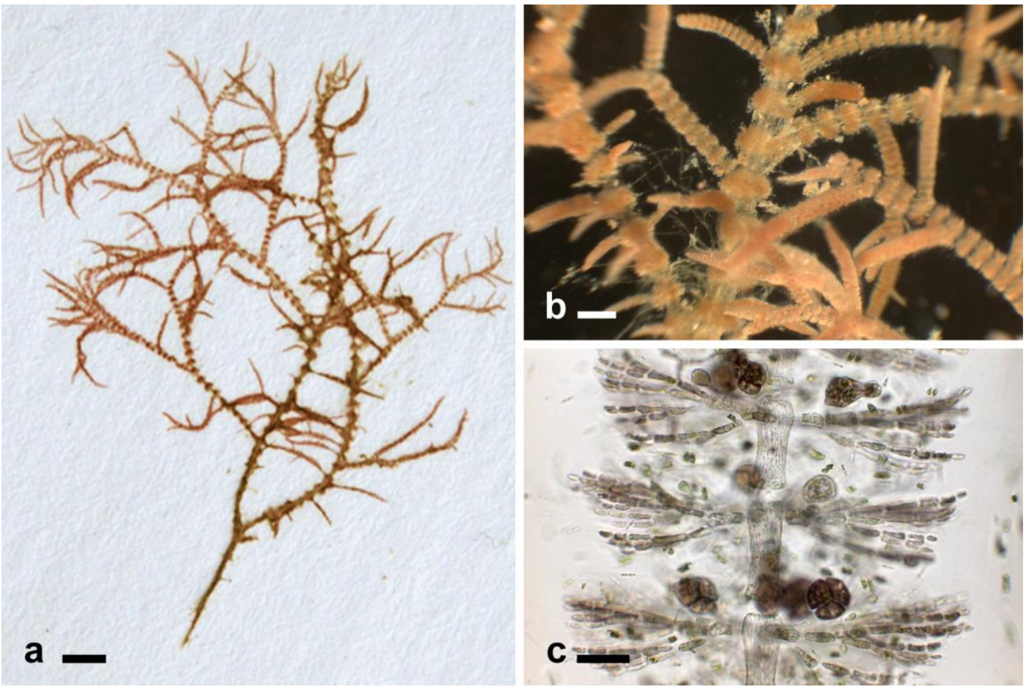

Fig. 5.11a-c *Crouania brunyana*. a) Habit of plant, b) Upper branches with clearly separated whorls, c) Branch with tetrasporangia. Scale bars: a = 200 µm, b = 100 µm, c = 50 µm.

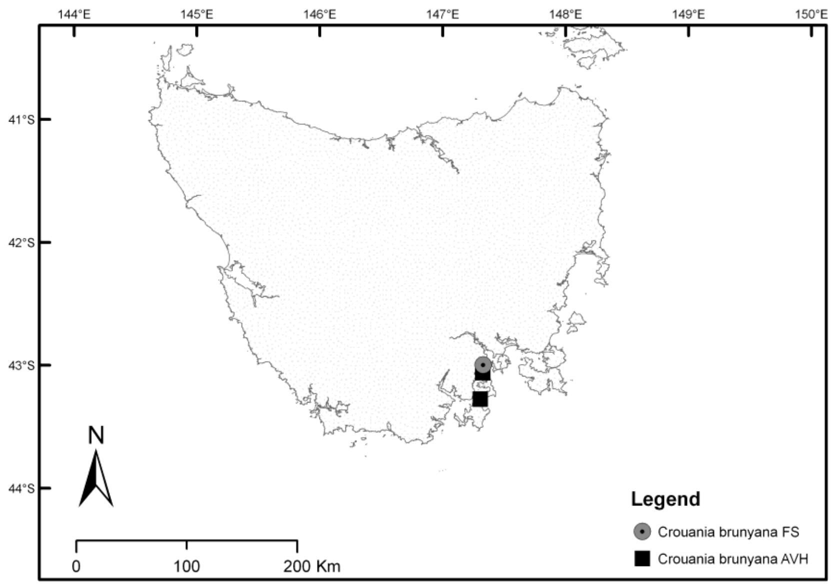

Fig. 5.12 *Crouania brunyana*. Known range, including previous (AVH) and recent (FS) collections.

Cryptonemia wilsonii J. Agardh (Halymeniaceae, Halymeniales) is a membranous red alga (to 17 cm high). The single recent collection from a transition reef/sand habitat (–2.9 m) at Kelso Bay (northern TAS) (FS 5669) comprised a small vegetative plant with a short stipe (Fig. 5.13). This represents an increase in distribution records but not of overall species range (600 km) (Fig. 5.14).

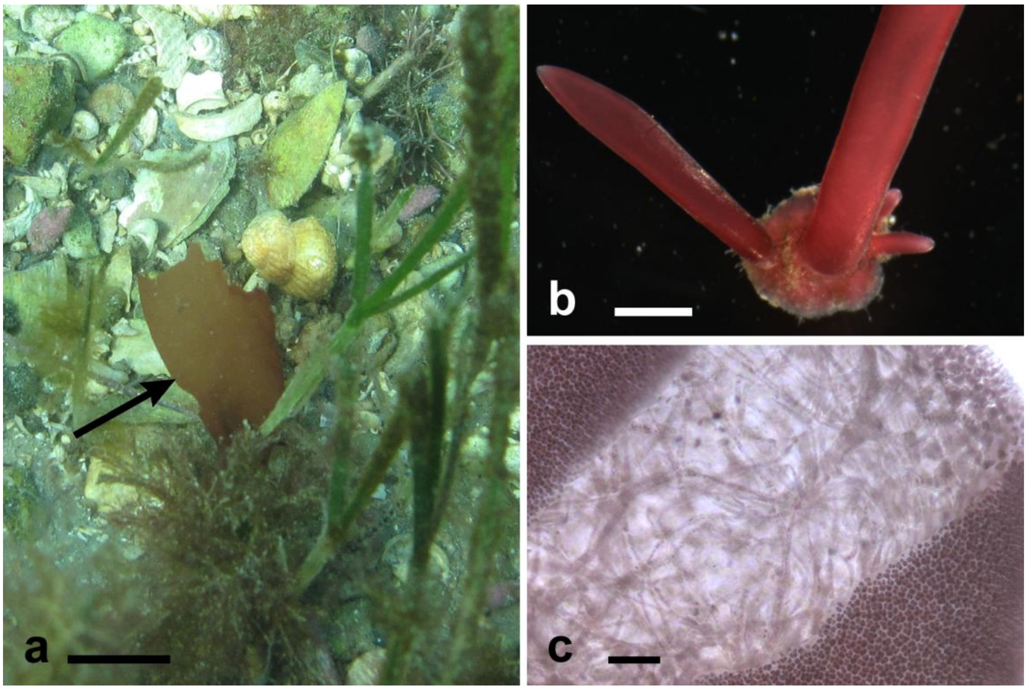

Fig. 5.13a-c *Cryptonemia wilsonii*. a) Habit of plant *in situ* with basal part obscured, b) Holdfast of plant in previous figure, c) Fractured blade with filamentous medulla (centre) and cortex (edges). Scale bars: a = 1 cm, b = 1 mm, c = 20 µm.

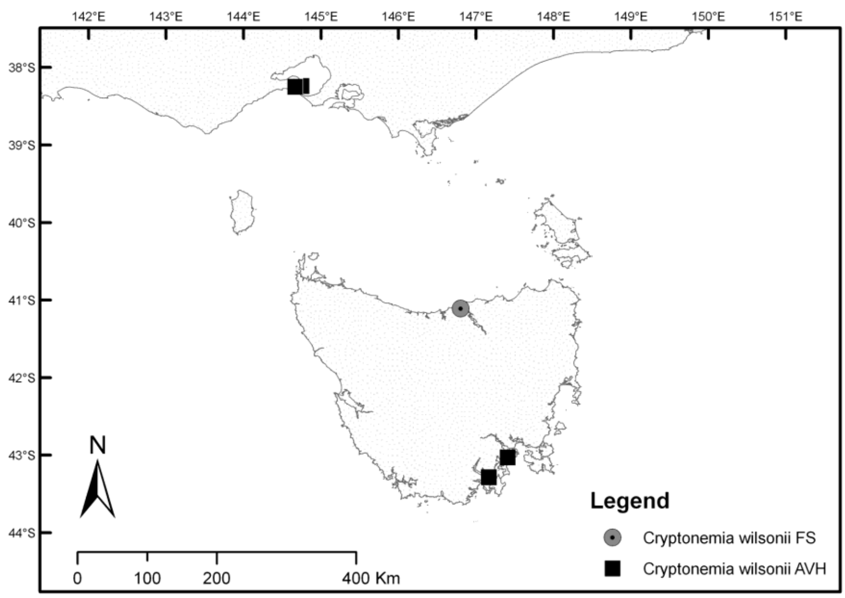

Fig. 5.14 *Cryptonemia wilsonii*. Known range, including previous (AVH) and recent (FS) collections.

Dasya hapalathrix Harvey (Dasyaceae, Ceramiales) is a filamentous, yet fairly robust red alga (20 cm to 2 m high). Main axes are typically heavily corticated from close to the apices (Fig. 5.15). The recent collection of a single small vegetative plant from a transition reef/sand habitat (–2 m) in Kelly Basin (south-west TAS) (FS 5101) expands the species range from 1156 to 1262 km (Fig. 5.16).

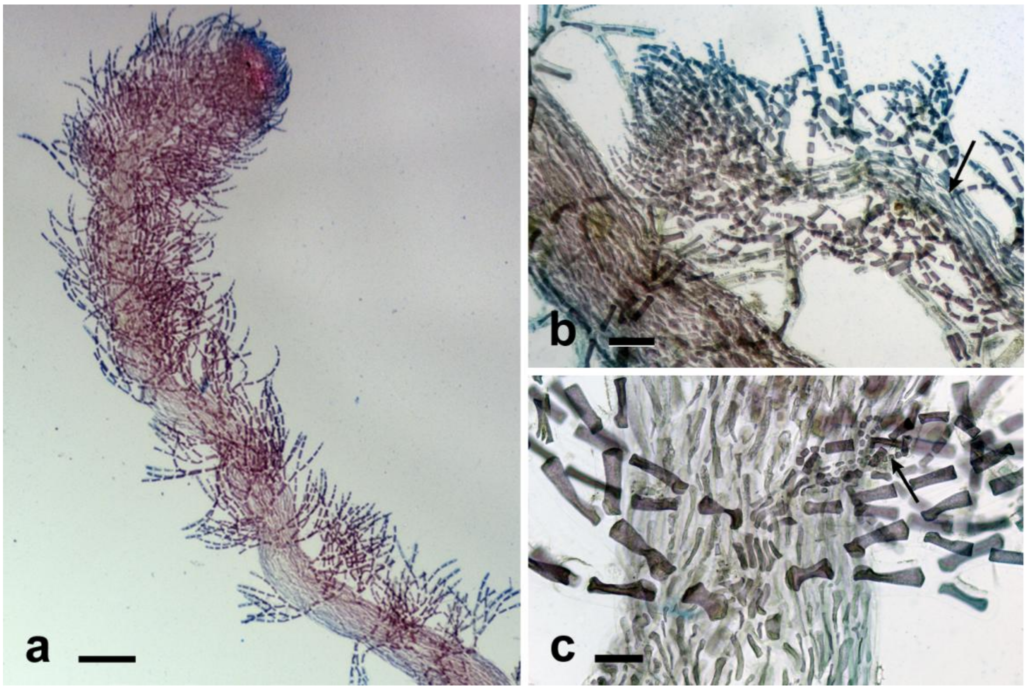

Fig. 5.15a-c *Dasya hapalathrix*. a) Main axis, b) Young branch with cortication (arrow) occurring shortly below apex, aniline-blue stained, c) Monosiphonous pseudolaterals and indeterminate lateral (arrow) arising from main axis, aniline-blue stained. Scale bars: a = 500 µm, b = 100µm, c = 50µm.

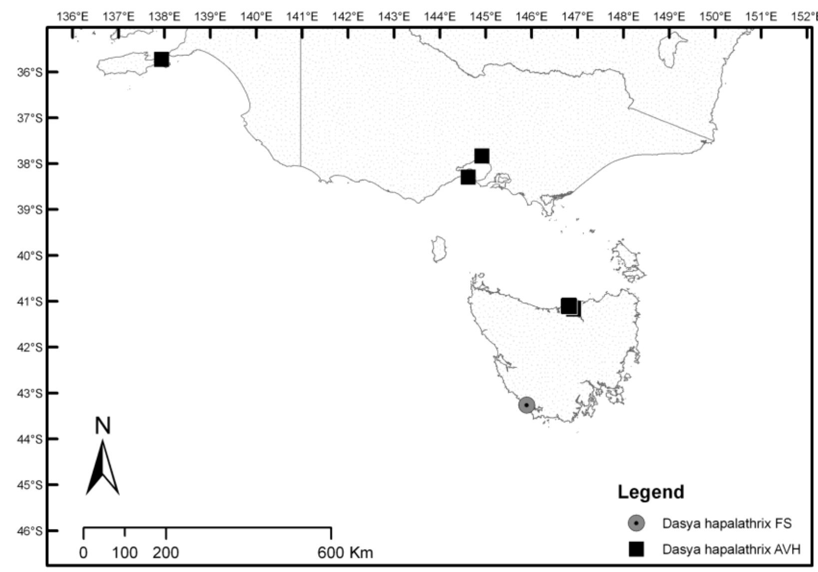

Fig. 5.16 *Dasya hapalathrix*. Known range, including previous (AVH) and recent (FS) collections.

Herposiphonia pectinella (Harvey) Falkenberg (Rhodomelaceae, Ceramiales) is a filamentous red alga (to 6 cm high) with slender axes bearing extensive indeterminate laterals (Fig. 5.17). Previously collected from King George Sound WA, Pearson I. SA, Port Phillip Heads VIC, and Westernport VIC, the recent collection of vegetative material from Kelso Bay (northern TAS) (FS 5667) increases the species range southward from 2467 to 2628 km (Fig. 5.18). Womersley (2003) noted that the record from Rottnest I WA of Harvey (1855) is doubtful.

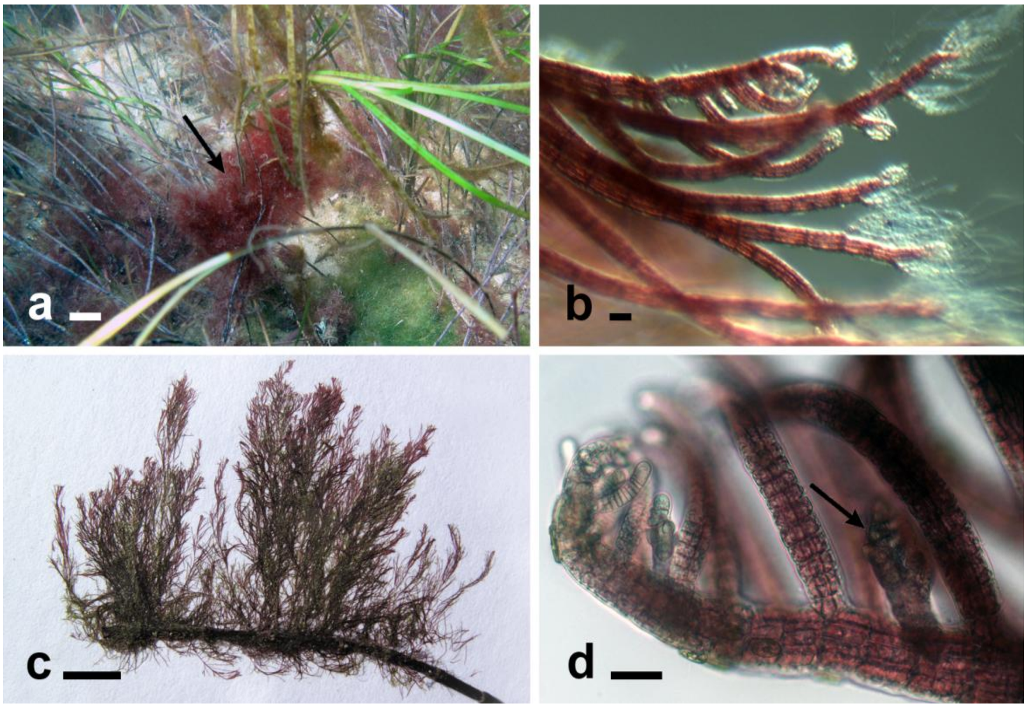

Fig. 5.17a-d *Herposiphonia pectinella*. a) Habit (arrow) *in situ*, b) Axis with lateral branches and terminal trichoblasts, c) Habit, dried specimen, epiphytic on *Heterozostera*, d) Apex of branch with indeterminate and determinate (arrow) laterals. Scale bars: a, c =1 cm, b, d = 50 µm.

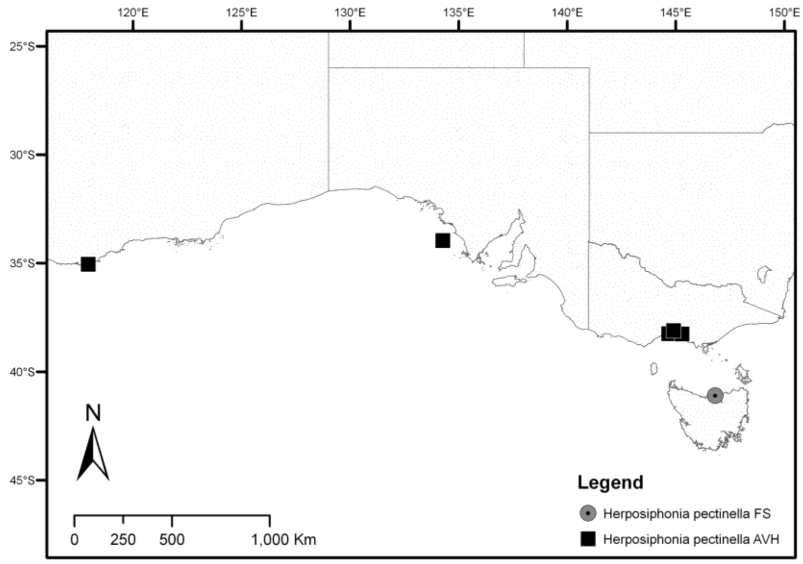

Fig. 5.18 *Herposiphonia pectinella*. Known range, including previous (AVH) and recent (FS) collections.

Macrothamnion pectenellum Wollaston (Ceramiaceae, Ceramiales) is a filamentous red alga (to 8 cm high). Axes are mostly ecorticate and bear whorl branchlets (in whorls of 3) with both mucronate terminal cells and gland cells borne singly on short 2-celled branches (Fig. 5.19). Recent collections of vegetative or tetrasporangial material from rocky reef habitats at Portsea Hole (FS 5854) and Pope's Eye (FS 5860) VIC and Ninepin Point (south-east TAS) (FS 6205) were all in the geographic vicinity of previous records and the species range now increases marginally to 597 km (Fig. 5.20).

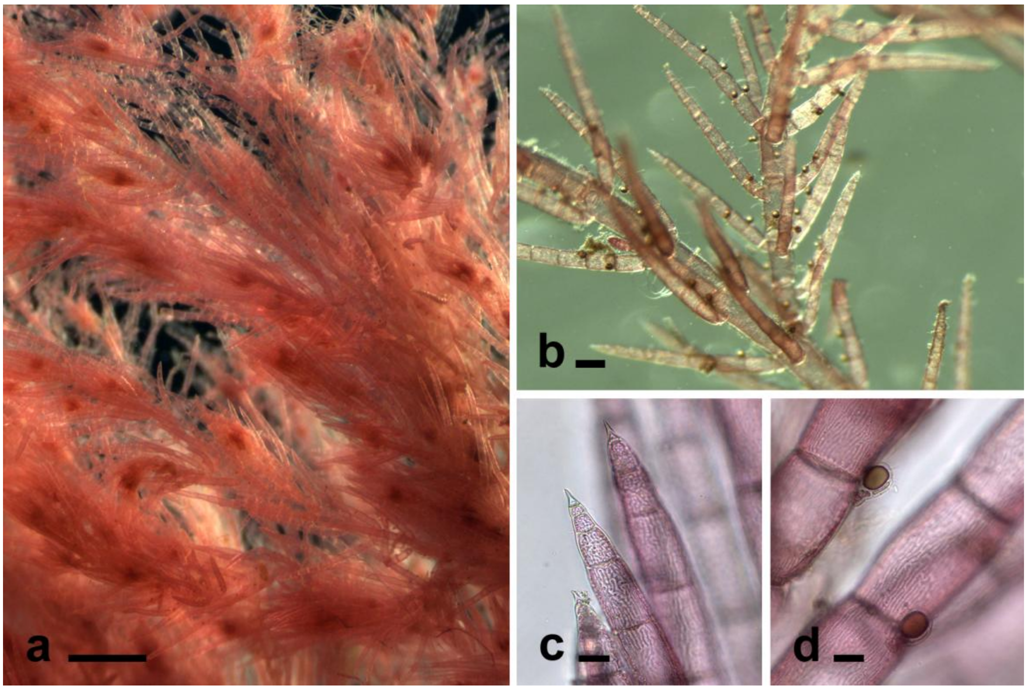

Fig. 5.19a-d *Macrothamnion pectenellum*. a) Upper thallus, b) Branch with whorl-branchlets in whorls of 3, c) Mucronate apices, d) Gland cells on minute, 2-celled branchlets. Scale bars: a = 500 µm, b = 50 µm, c-d = 25 µm.

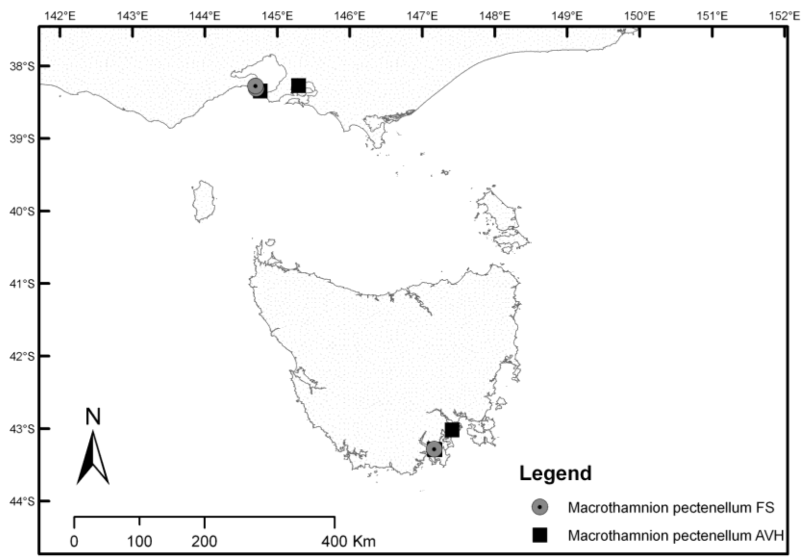

Fig. 5.20 *Macrothamnion pectenellum*. Known range, including previous (AVH) and recent (FS) collections.

Pterothamnion aciculare (Wollaston) Athanasiadis & Kraft (Ceramiaceae, Ceramiales) is a small (to 2 cm high) filamentous plant with whorl branchlets borne on axial cells of the ecorticate branches. The occasional formation of 2–4 armed slender spines is characteristic for the species (Fig. 5.21). Recent collections comprised tetrasporangial material, as well as the first records of female gametophytes from rocky reef habitats at Blackmans Bay (FS 5718) and Southport (FS 6260) (south-east TAS). The range is now expanded beyond the type locality of Taroona TAS to 64 km. (Fig. 5.22).

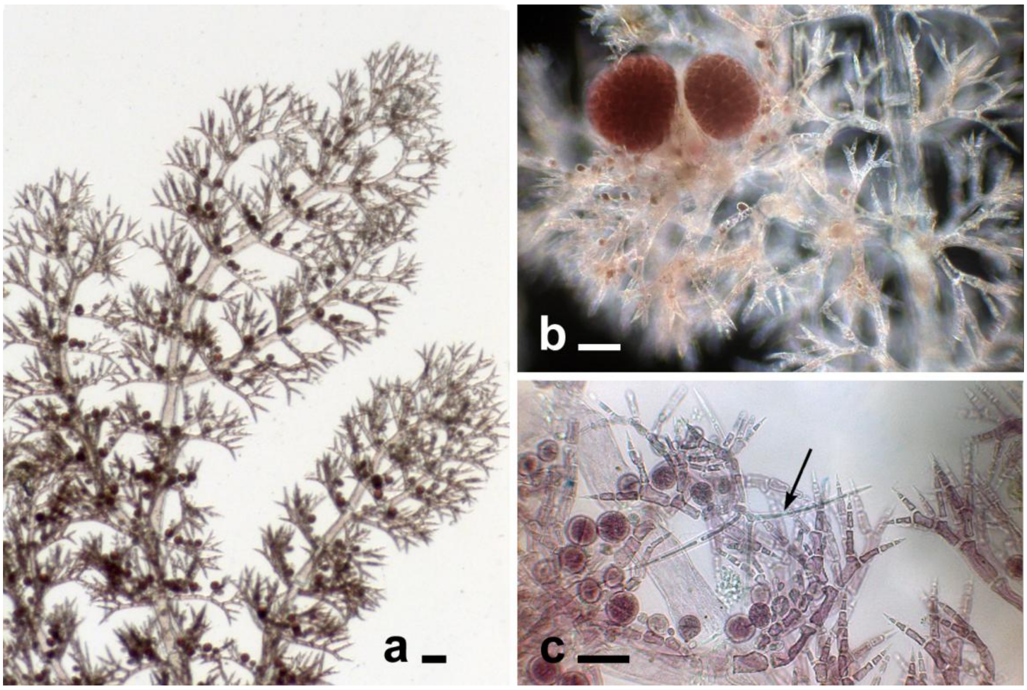

Fig. 5.21a-c *Pterothamnion aciculare*. a) Upper branches of tetrasporangial plant, b) Mature cystocarps and smaller gland cells borne on pinnules, c) Characteristic 2-5 armed spine (arrow) on pinnule of tetrasporangial plant. Scale bars: a-b = 100 µm, c = 50 µm.

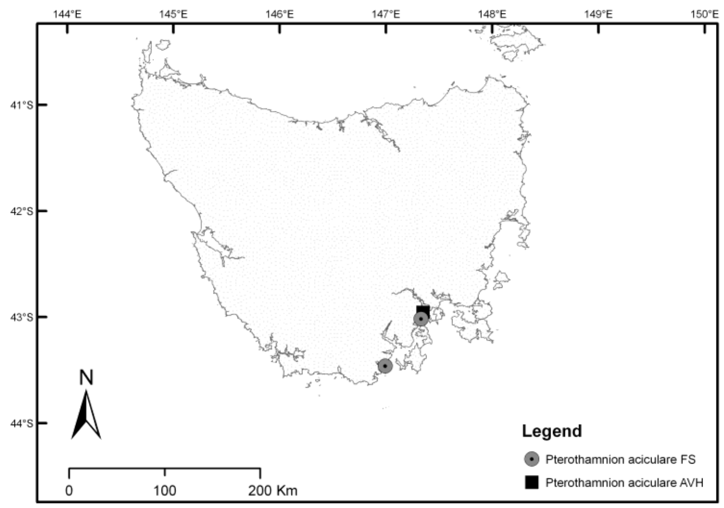

Fig. 5.22 *Pterothamnion aciculare*. Known range, including previous (AVH) and recent (FS) collections.

Ptilocladia gracilis (J. Agardh) Womersley (Callithamniaceae, Ceramiales) is a filamentous red alga (to 18 cm high) loosely corticated towards the base. Branches bear whorl branchlets (in whorls of 4) that are clearly separated along the branches (Fig. 5.23). Recent collections of both female and tetrasporangial material from a rocky reef habitat (–5 m) at Blackmans Bay (south-east TAS) (FS 6803) extend the species range from 1239 to 1408 km (Fig. 5.24). The 50–60 µm diameter tetraspores were slightly smaller than previous records and were born on basal and distal cells of the whorl branchlets. However, all other anatomical features align the specimens with *P. gracilis*.

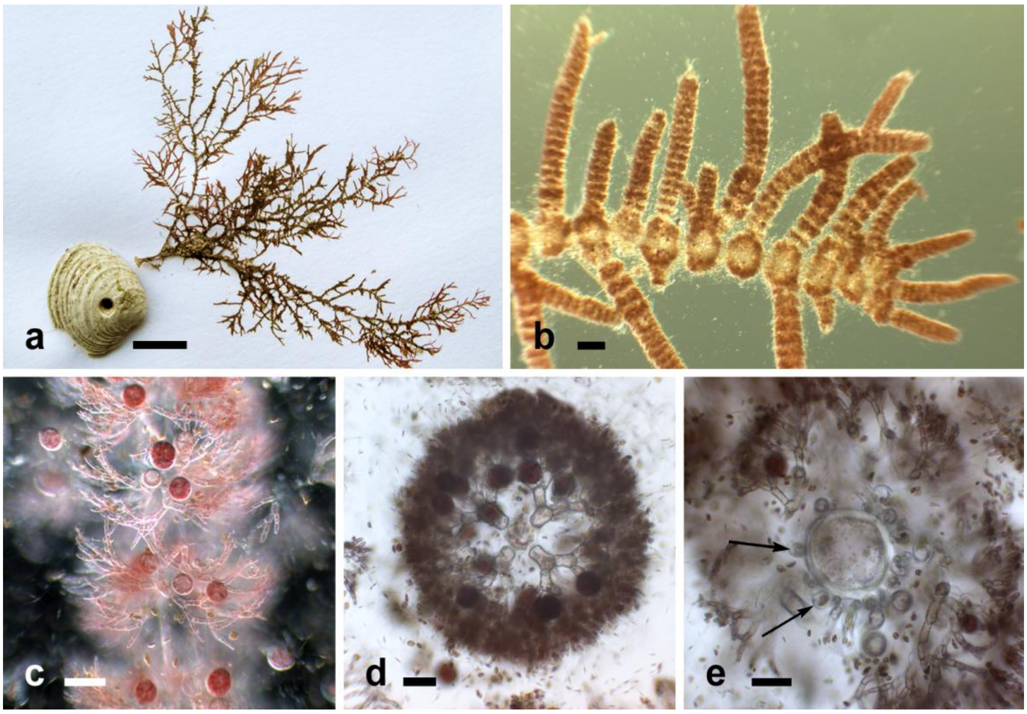

Fig. 5.23a-e *Ptilocladia gracilis.* a) Habit of plant, b) Upper branches with clearly separated whorl branchlets, c) Branch with tetraspores, d) Four whorl branchlets viewed in transverse section of branch, e) Rhizoids (arrows) located outside of axial cell sheath. Scale bars: a = 1 cm, b-e = 100 µm.

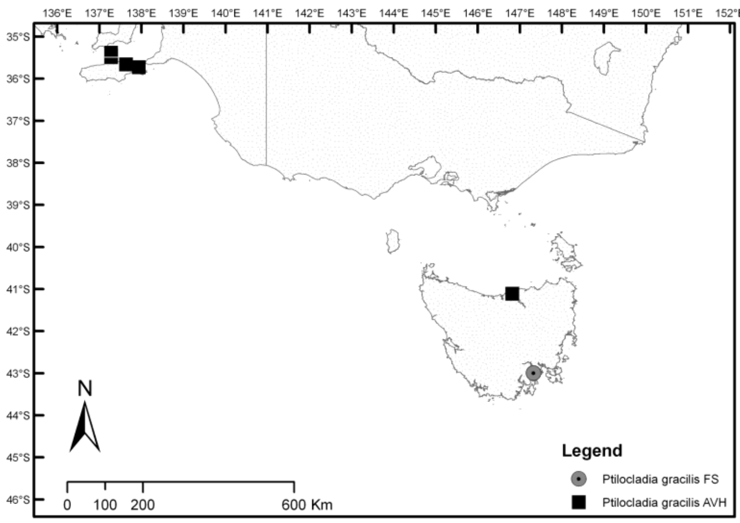

Fig.5.24 *Ptilocladia gracilis*. Known range, including previous (AVH) and recent (FS) collections.

Rhipiliopsis multiplex Kraft (Rhipiliaceae, Bryopsidales) is a distinctive felt-like green alga with an extensive prostrate system and with upright stipes that give rise to a single or multiple fan-shaped blades up to 3 cm across (Fig. 5.25). *R. multiplex* may be locally quite common on shaded, limestone reefs and is reported for a very small number of localities (only known from Rottnest Island WA). The recent collection represents a new locality (on limestone reef (–9–13 m) at Green Island (Rottnest I, WA) (FS 5200) but the species range remains at 5 km (Fig. 5.26).

Fig. 5.25 *Rhipiliopsis multiplex*. Habit of plant *in situ*. Scale bar = 2 cm.

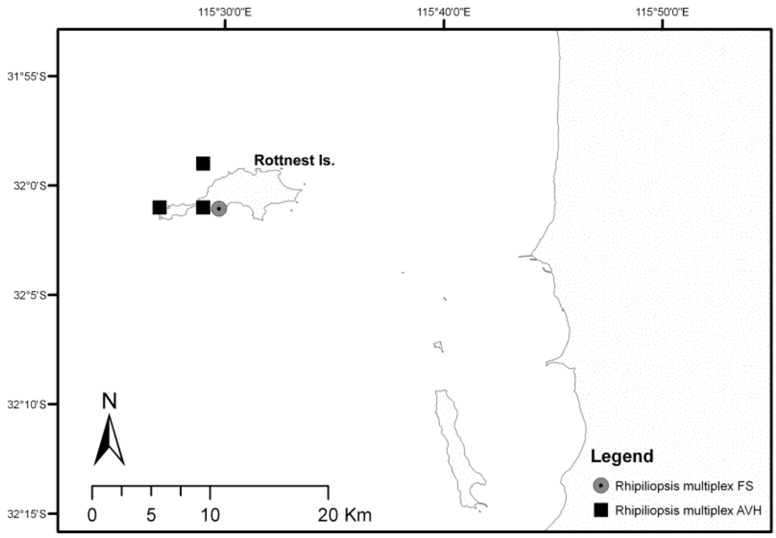

Fig. 5.26 *Rhipiliopsis multiplex*. Known range, including previous (AVH) and recent (FS) collections.

Rhodymenia halymenioides (J. Agardh) Womerseley (Rhodymeniaceae, Rhodymeniales) is a foliose smooth-surfaced red alga (to 20 cm high) comprising a single or several lobes. Recent collections from rocky reef habitats at Gypsy Reef (FS 5331), Bligh Point (FS 6263) and Satellite Island (FS 6243) (south-east TAS) included both tetrasporangial and female material (Fig. 5.27). *R. halymenioides* is reported here with a species range of 604 km (Fig. 5.28). *R. halymenioides* originally met the nominated geographical criterion for rarity, but now considered a synonym of *Halopeltis cuneata* (Harvey) G.W. Saunders (Saunders and McDonald 2010) the entity reverts to having a 'non-rare' status and the species range above is not applicable.

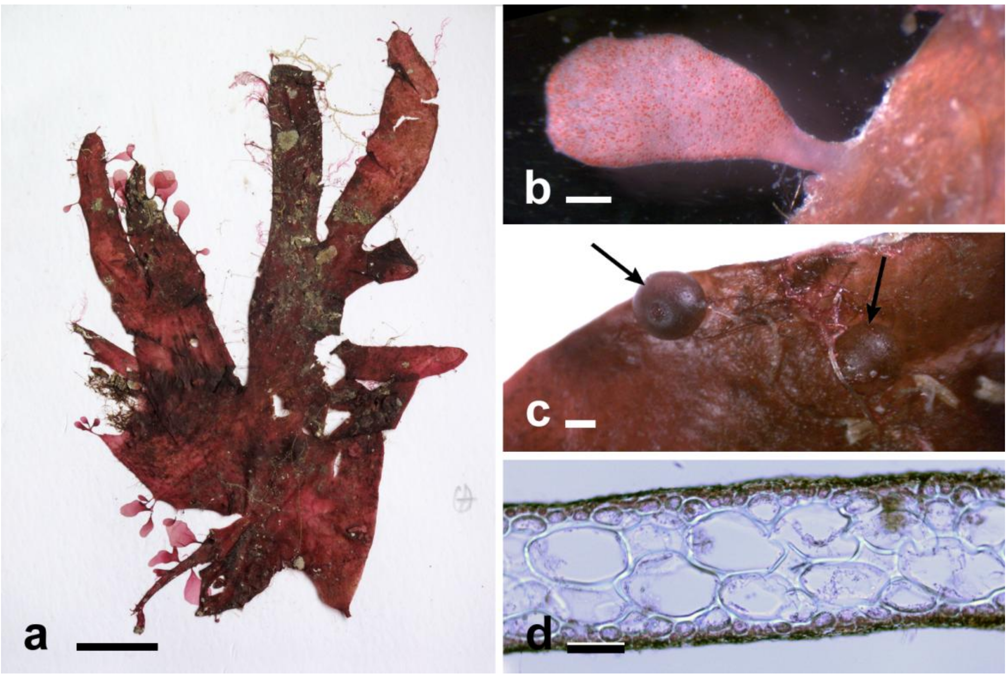

Fig. 5.27a-d *Rhodymenia halymenioides*. a) Habit of plant, b) Tetrasporangial proliferation on blade margin, c) Cystocarps (arrows), d) Cross section of vegetative blade. Scale bars: a = 2 cm, b-c = 500 µm, d = 100 µm.

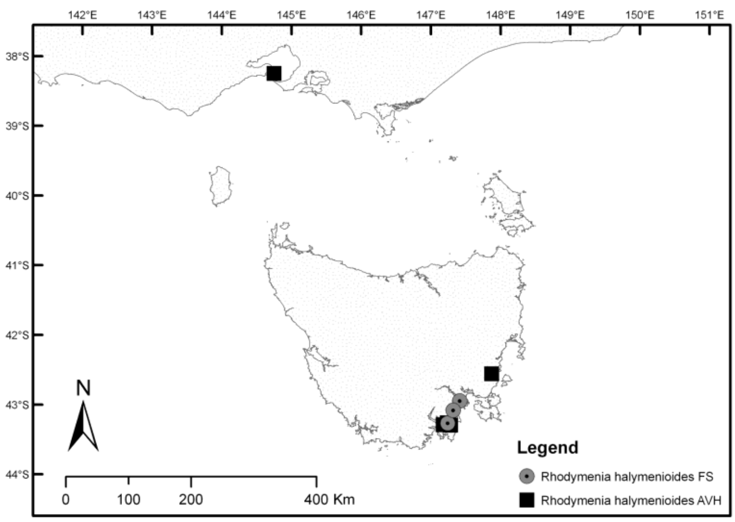

Fig. 5.28 *Rhodymenia halymenioides*. Known range, including previous (AVH) and recent (FS) collections

Schizoseris hymenena (Zanardini) Womersely (Delesseriaceae, Ceramiales) is a delicate membranous red alga (to 20 cm high) with a short stipe, convolute margins and with fine, yet prominent forked veins (Fig. 5.29). Recent collections from rocky reef habitats at Huon Point (FS 5818), Butts Reef (FS 5365) and Flathead Bay (FS 5878) (south-east TAS) included vegetative, tetrasporangial and female material. The collections represent new sites within the existing species range of 617 km (Fig. 5.30).

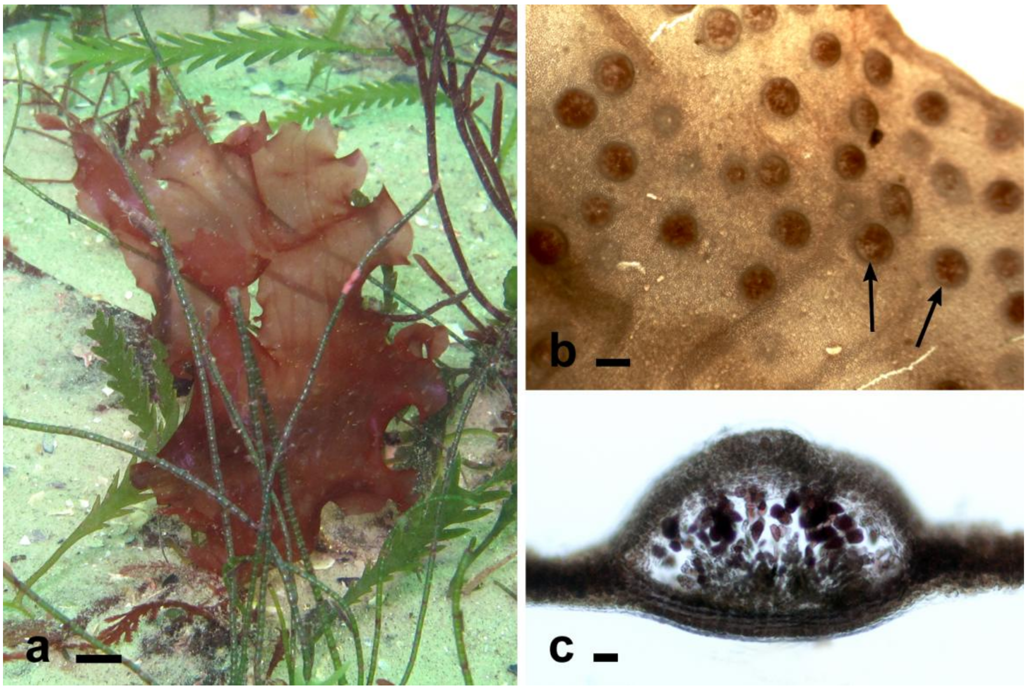

Fig. 5.29a-c *Schizoseris hymenena.* a) Habit of plant *in situ*, behind green *Chaetomorpha coliformis* strands, b) Cystocarps (arrows) near blade margin, c) Cross section of mature cystocarp. Scale bars: a = 1 cm, b = 1 mm, c = 100 µm.

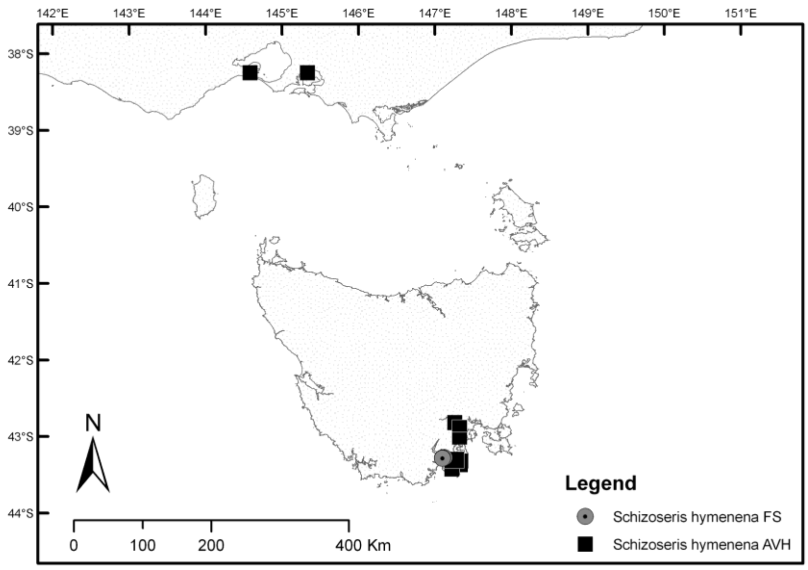

Fig. 5.30 *Schizoseris hymenena*. Known range, including previous (AVH) and recent (FS) collections.

Schizoseris perriniae (Lucas) Womersley (Delesseriaceae, Ceramiales) is a delicate membranous red alga (to 20 cm high) with convolute margins and with thick branched stipes each merging into a prominent central vein (Fig. 5.31). Finer veins arise from the central veins and are usually visible until close to the blade margins. Recent collections from rocky reef habitats at Bligh Point (FS 6265) and Blackmans Bay (FS 5905) were of vegetative material only. They represent new distribution records but are within the known species range of 260 km (Fig. 5.32). With reproduction unknown in *S. perriniae*, Baldock (2010) proposed that "this species may turn out to be merely be old plants of *S. hymenena* where the stalk grows new blades perennially".

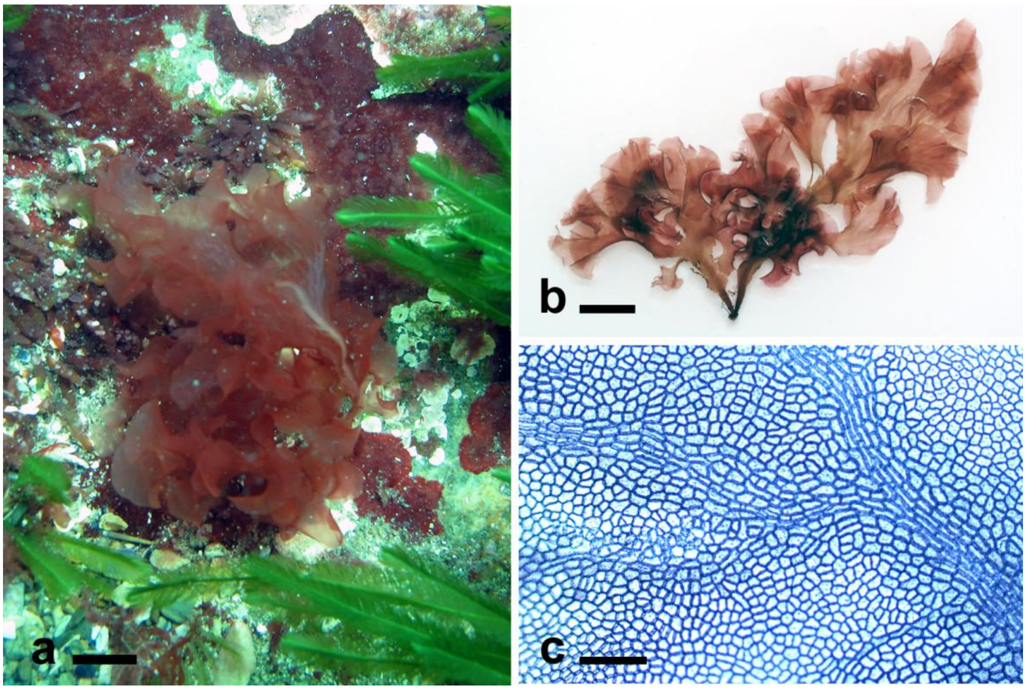

Fig. 5.31a-c *Schizoseris perriniae.* a) Habit of plant *in situ*, b) Habit of plant with conspicuous stipe, c) Surface view of microscopic veins (aniline-blue stained). Scale bars: a-b = 2 cm, c = 200 µm.

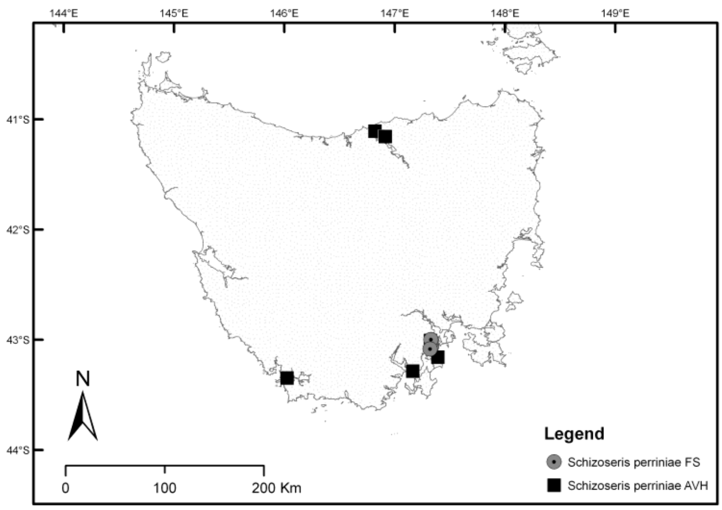

Fig. 5.32 *Schizoseris perriniae*. Known range, including previous (AVH) and recent (FS) collections.

Entwisleia bella (proposed gen. nov., sp. nov.) is a small (to 8 cm high) filamentous red alga (Fig. 5.33). The main branches bear regular whorls of determinate laterals that are well-separated towards the apices but compact in lower branches forming continuous branch outlines. This new species unambiguously qualifies as rare and was discovered, and is still only known from the type location and unique environment at Blackmans Bay, south-east TAS (FS 5425) (Fig. 5.34). This alga differs from all other known red algae to the extent that it provides the basis for a new monotypic family (Chapter 6).

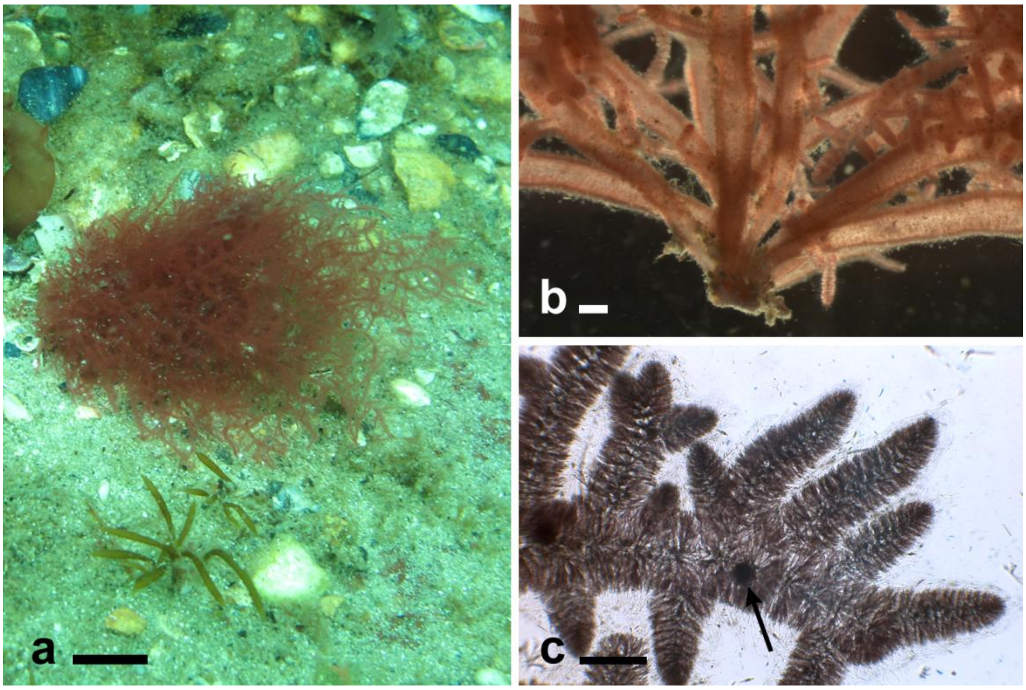

Fig. 5.33a-c *Entwisleia bella* (proposed nov. sp.) a) Habit of plant *in situ*, b) Holdfast and lower axes of plant, c) Upper axes with cystocarps (arrow). Scale bars: a = 1 cm, b = 1 mm, c = 200 µm.

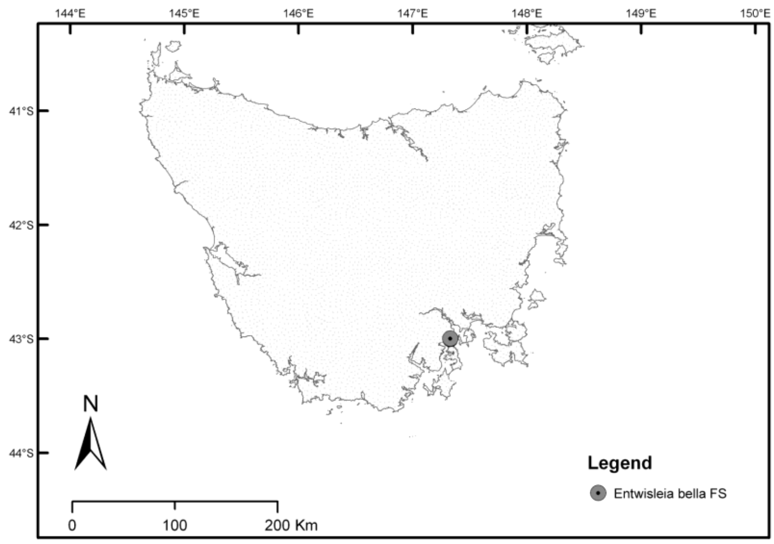

Fig. 5.34 *Entwisleia bella* (proposed nov. sp.) Known range is the type locality only (FS collections).

5.3.3 Noteworthy records or range extensions

A number of observations or 'non-rare' algal collections deserve particular mention, in that they represent either a notable range extension, are a previously unreported life history phase of the species, or have other noteworthy feature(s) of form or habit:

Melanema dumosum (Harvey) Min-Thein & Womersely (Fig. 5.35a): The known distribution is from West Island (SA) to Queenscliff (VIC) and Bicheno TAS (Womersley 1994). The recent collection from Hogan Island (FS 6416) is the first distribution record from eastern Bass Strait.

Porphyropsis minuta Womersley & Conway (Fig. 5.35b): The known distribution is from Garden Island (WA) around the south coast of mainland Australia to Collaroy (NSW) (Womersley 1994). The recent record from Blackmans Bay (south-east TAS) (FS 5956) represents a notable range extension and first record for Tasmania.

Zonaria spiralis (J. Agardh) Papenfuss (Fig. 5.35c): The known distribution of this distinctive macroalga is from Rottnest Island (WA) to Flinders (VIC). Recent records from Tasmania, as far south as Lady Bay (south-east TAS) (FS 5408) represents a notable range extension.

Cladurus elatus (Sonder) Falkenberg (Fig. 5.35d): This is a common species known from Cliff Head (WA) around the south coast of mainland Australia to Currie River (near Low Head, northern TAS). The recent record from Huon Point (south-east TAS) (FS 5867) represents a notable range extension into cooler waters.

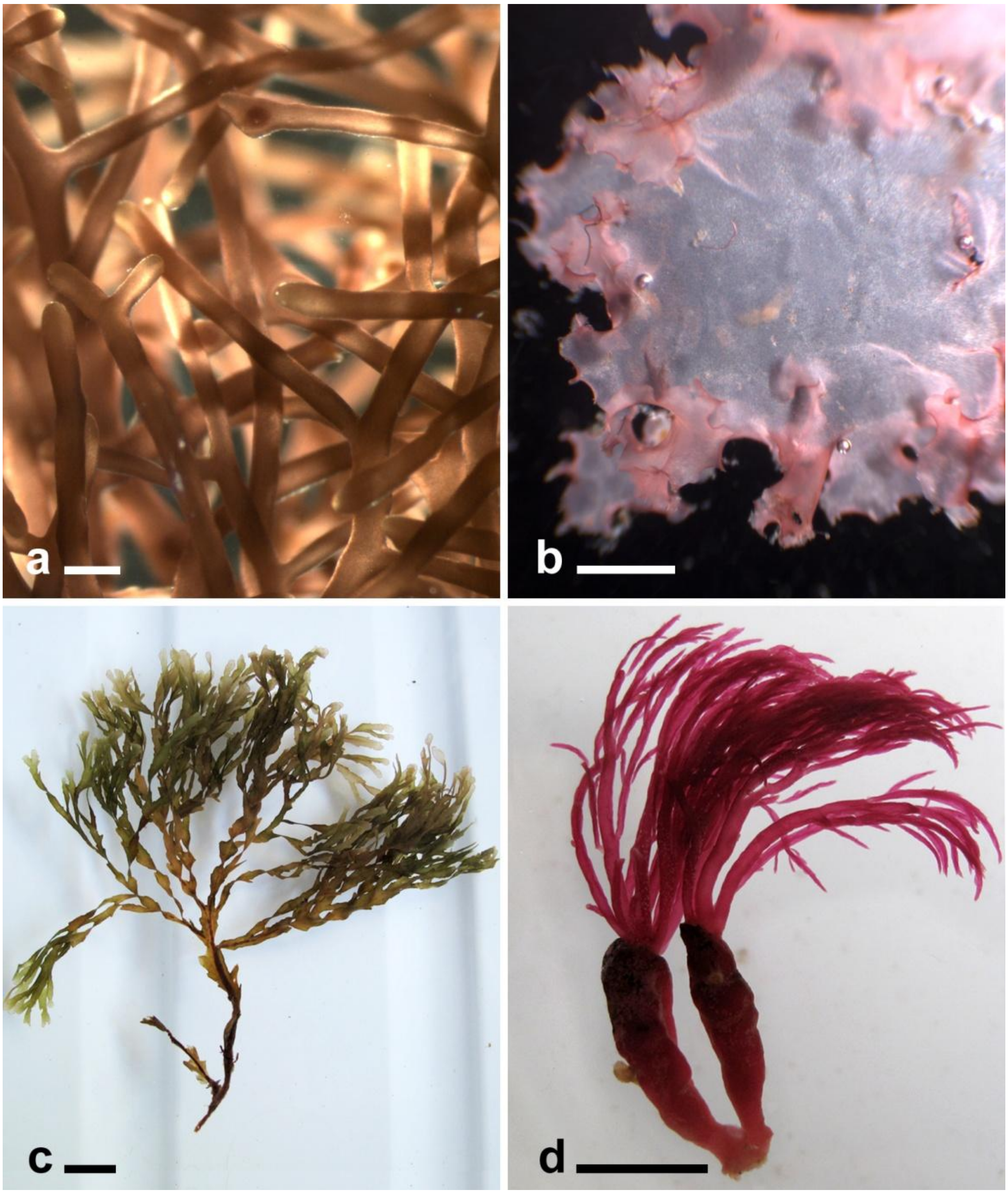

Fig. 5.35a-d. Noteworthy records; a) *Melanema dumosum*, upper branches. b) *Porphyropsis minuta*, thallus margin. c) *Zonaria spiralis*, upper axis. d) *Cladurus elatus*, branches arising from short stipes. Scale bars: a = 2 mm, b = 5 mm, c-d = 10 mm.

Heterosiphonia muelleri (Sonder) De Toni (Fig. 5.36a): This species is known to be common on southern mainland Australian coasts (Womersley 1998). The recent records and observations from southern Tasmania (e.g. Huon Point, south-east TAS, FS 5835) confirm a more widespread distribution.

Aeodes nitidissima J. Agardh (Fig. 5.36b): This species is known only from New Zealand and south-east Tasmania. The few early records (1949-1991) from Tasmania were all from the Derwent Estuary (Womersley 1994). In the current study, plants occurred as a common component of the flora at the mid-upper Derwent Estuary sites of Montague Bay (FS 5370), Battery Pt (FS 5397), Rosny Pt (FS 5383) and Maning Reef (FS 5346) and a single specimen was collected from the more seaward Derwent Estuary site of The Grange (FS 5705).

Halopteris novae-zelandiae Sauvageau (Fig. 5.36c-d): The known distribution is New Zealand (Three Kings I, North I, South I, Stewart I, Chatham I, Snares I) and Tasmania (Waterfall Bay). The recent collection of material was from a depth of –25 m at Lonsdale Wall, Port Phillip Heads, VIC (FS 5759), the first record for coastal waters of mainland Australia.

Deucalion levringii (Lindauer) Huisman & Kraft (Fig. 5.36e): *Deucalion* is a monospecific genus and was (as *Callithamnion levringii*) considered adventive from New Zealand having only recently been found in Australia (Huisman and Kraft 1982). Its known Australian distribution includes localities in SA, VIC, TAS and NSW (Womersley 1998) and recent records from the riverine end of the Derwent Estuary (FS 6071, 6161) add to those from already known from other parts of eastern Tasmania.

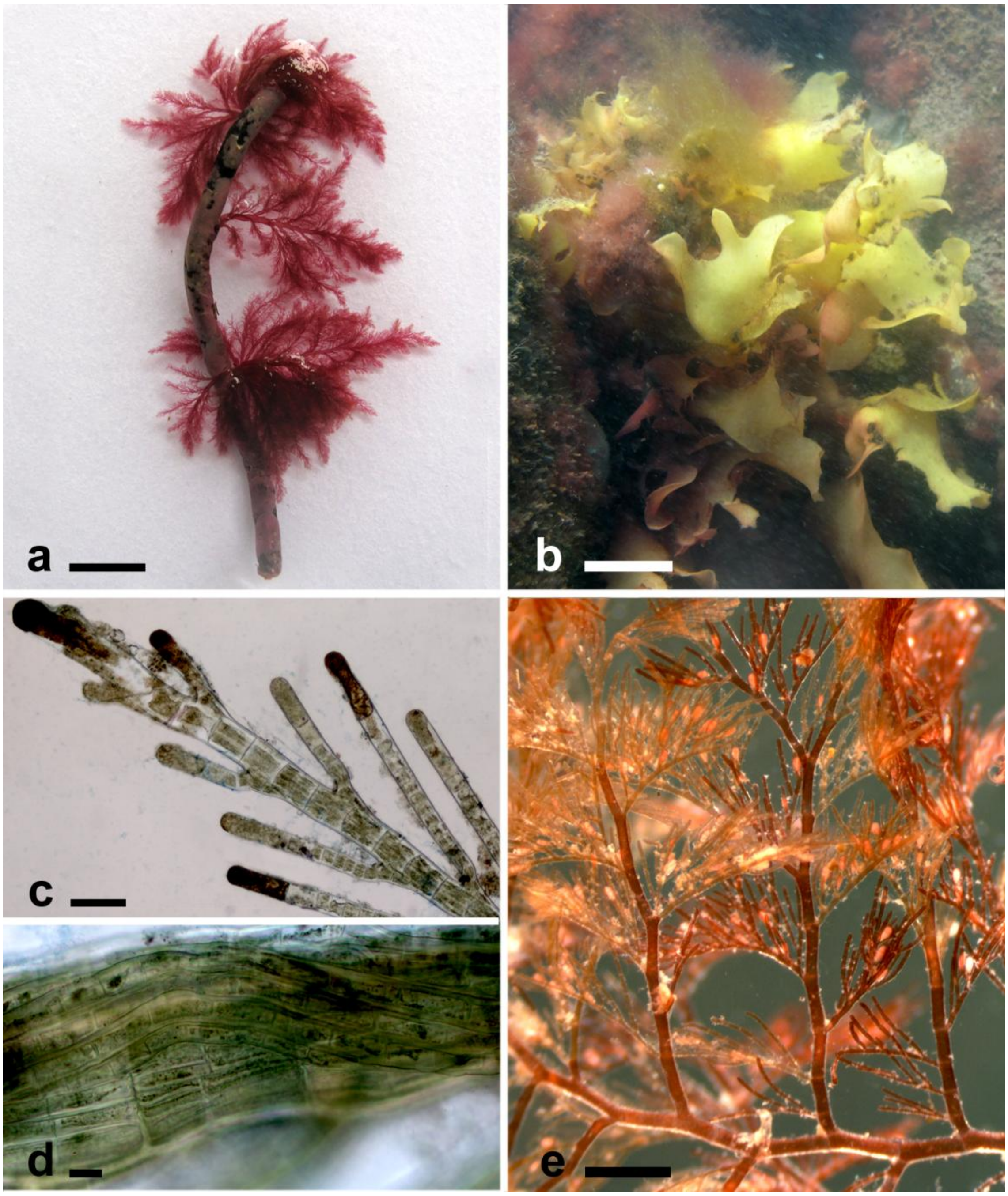

Fig. 5.36a-e. Noteworthy records; a) *Heterosiphonia muelleri*, epiphytic. b) *Aeodes nitidissima*, *in situ*, c-d) *Halopteris novaezelandiae*, upper (c)and lower (d) regions of axis, e) *Deucalion levringii*, upper branches. Scale bars: a = 5 mm, b = 1 cm, c-d = 300 μm, e = 1 mm.

5.4 Discussion

5.4.1 Targeted searches for rare algae

Positive observations of rare species using the methods for target searches described here requires a combination of two critical factors; actual occurrence of the plant at the site and observer recognition of the plant according to the season (e.g. when plants are in a sizeable macroscopic phase of its life history, compared to a microscopic phase). Any field project of this type requires observers with relevant expertise in the native flora, to be able to distinguish rare species from non-rare and introduced species. Taxa that are small, epiphytic, or occupy cryptic microhabitats present challenges for field observers, in that they can be difficult to detect or identify.

Of the rare species recorded *Antithamnion biarmatum*, *Ceramium lenticulare, Crouania brunyana*, *Dasya hapalathrix*, *Herposiphonia pectinella*, *Macrothamnion pectenellum* were positively identified only upon microscopic examination. The extremely small size of these taxa meant that species identification *in situ* was rarely possible, and meticulous post-processing work was often required for the small rare species, such as members of the genera *Dipterosiphonia*, *Elachista*, *Gymnothamnion*, *Amoenothamnion*, *Callithamnion*, and *Polysiphonia.*

By its nature the UVC survey method produces presence-only data, and only by replication of surveys within seasons and between seasons would sufficient data be generated to infer or test species absence from a site, irrespective of any specific rarity status. The extent of the current field program was subject to a combination factors dictating the selection of UVC sites, viz. suitable weather conditions, logistics, and time available to access remote areas. More comprehensive data could be attained by an expanded field program, particularly from the identified centres of rarity in the gulfs regions of South Australia and the estuarine environments of south-west Western Australia.

Unless there are only extremely specific geographical pockets for rare species' populations as described for some terrestrial plants, for example *Ozothamnus reflexifolius* Leeson & Rozefelds (Leeson and Kirkpatrick 2004) and *Prasophyllum stellatum* Jones (DSEWPC 2011) and some marine plants, for example *Feldmannia lewisii* Kraft (Kraft 2009), *Halimeda cereidesmis* Kraft (Kraft 2007) and G*anonema helminthaxis* Huisman & Kraft (Huisman 2006), further emergence of rare species observations could reasonably be expected over time. The recent discovery of *Cryptonemia wilsonii* in the Tamar Estuary stands as an example of a new record of a rare species in waters between the substantially disjunct localities of Port Phillip Heads and south-east Tasmania. Along with the two species having new southerly records (*Dasya hapalathrix* from Port Davey and *Herposiphonia pectinella* from the Tamar Estuary), plus the novel species (*Entwisleia bella* from Blackmans Bay), these records serve to inspire more comprehensive algal surveys or collecting efforts from these particular environments.

For the previously identified centres of algal rarity of Ninepin Point MPA and Port Phillip Heads (identified in Chapter 2, Table 2.4) the small numbers of rare species observed in field data were at variance with known records (9 and 23 respectively). Historical populations can be difficult to relocate in the field, particularly in a sub-marine environment where constraints of search time prevail. Errors of observation in the form of 'false negatives' are possible, in which a population may be present but not observed. The relatively small number of surveys undertaken in the current project appeared to be a serious limitation in detectability of rare macroalgae *in situ*.

5.4.2 Species richness and range extensions

Further information about species diversity found at the UVC survey site are included here, in as much as they relate to overall species diversity.

The Western Australian sites surveyed returned high levels of species richness (>30 spp), reflective of descriptions in previous reports (Huisman et al. 1998, Goldberg and Collings 2006). The area including Rottnest I and nearby Pt Peron are rich with macroalgae and renowned for high levels of local endemism (Huisman and Walker 1990, Huisman 1993, Huisman et al. 1999, Phillips 2001, Goldberg and Collings 2006). No explanation can be offered as to why so few rare species (one, at Green I) were observed during the Rottnest I surveys. Replication of surveys would likely improve the chances of success in relocating known rare species populations. The Cosy Corner site (UVC survey no. 110) on a limestone reef in WA's far southwest also proved rich in macroalgae, similar to the findings of Kendrick *et al.* (1999) and Wernberg *et al.* (2003) for nearby Hamelin Bay. At Waychinicup Inlet on the south coast of WA, a short-term but thorough study revealed a benthic flora of 40 taxa that display strong distribution patterns according to their distance from the river mouth, as well as habitat either on the sea floor or on vertical rock walls (Phillips and Avery 1997). The observation of 24 species from the single UVC survey in the present study (survey no. 106) represented more than half of previously reported species for this site.

Of the sites surveyed in Victoria those in the vicinity of Port Phillip Heads (Lonsdale Wall, Queenscliff, Portsea Hole and Popes Eye) returned results of low species richness, markedly at variance with the renowned richness of the general area (Ducker 1993). The richness of benthic algae in this area has possibly been adversely affected by recent dredging and blasting activities across the shipping channel at The Heads (Edmunds et al. 2009). The record of *Halopteris novae-zelandiae* Sauvageau from Lonsdale Wall is of particular interest because it represents the first mainland Australian record for this species. The site lies adjacent to a major shipping route, so *H. novae-zelandiae* likely represents either an introduced species (from New Zealand) or a notable range extension, with the next nearest and only other Australian record from Waterfall Bay in south-east Tasmania.

Further eastward in Westernport Bay, the algal flora at Crawfish Rock was locally regarded as rich (138 species recorded in 1971) but by 2006 a substantial loss in species diversity had occurred, with 66% of algal species being lost due to increased turbidity and sedimentation in that part of the bay (Shepherd et al. 2009). Shepherd *et al.* (2009) observed algal growth only to 4 m in depth. In the present study, algal growth was observed to at least 7 m deep and several species previously unreported for the site were recorded. *Dictyopteris nigricans* Womersley, *Scaberia agardhii* Greville, *Chondria harveyana* (J. Agargh) De Toni, *Platysiphonia victoriae* (Harvey ex J. Agardh) Womersely & Shepley, *Sporochnus apodus* Harvey and *Encyothalia cliftonii* Harvey can now be added to the clearly dynamic assemblage of local flora.

In Tasmania rare species were found at sites in the north (Tamar Estuary), the south-east (Derwent & Huon Estuaries and D'Entrecasteaux Channel) and the southwest (Kelly Basin, Port Davey). These areas represent mouths of four of the five major estuary systems (of a total of 113) in Tasmania that are affected by periodic changes in salinity and light attenuation. The lower Huon Estuary (Huon Pt, Huon I, Butts Reef, Charlotte Cove Light, Ninepin Pt and Arch Rock) appears to be a particularly rich area and has already been thus recognised, in part, by the proclamation (SOE 2009), and subsequent extension of a marine protected area (RPDC 2008) at Ninepin Pt. A soon-to-be proposed new genus and species from the vicinity (G.W. Saunders pers. comm.) strengthens the high biodiversity status of the area.

The number of rare species observed in the lower Derwent Estuary, including a proposed new genus and species (see Chapter 6) also draws attention to south-east Tasmania as a centre of rarity, with rare species generally growing in the near-shore rocky reef habitats rather than on sand/silt seafloor substratum. The recent observations of *Aeodes nitidissima* J. Agardh were particularly noteworthy in the low-diversity areas of the mid–upper Derwent Estuary. In February 2010 up to 10 cm-thick layers of dried *Aeodes* 'wrack' were observed in the vicinity of the lower Derwent Bridge (Barrett 2011 pers. obs.). Subtidally the observed plants were of pale brownish colour with a pink-red basal portion and were found locally abundant in the Derwent Estuary (TAS) forming up to 10% of total substratum cover at several low algal biodiversity sites (Barrett et al. 2010). To date there has been only one observation of this plant outside this river estuary (nearby, along the coast of the Tinderbox Peninsula). This species was originally described from New Zealand, where plants have been described as "on rock, low intertidal to subtidal on open coasts" with plants from exposed sites being dark red, tough and lacerated, whereas plants from more sheltered waters are of "smooth, rounded outline and are generally thinner and pinker in colour" (Adams 1994). In Tasmania *A. nitidissima* possibly represents an introduced species rather than a naturally occurring one and it now appears to be well established in the Derwent Estuary.

Overall the emergence of new range extensions for both rare and non-rare macroalgae should offer no surprise. However, it is impossible to determine if these range extensions are the results of increased search effort by a skilled collector or as consequences of species range-shift in response to changes in climate or habitat conditions. Geographical retreat of seaweed has been inferred by data analysis of both herbarium datasets (Wernberg et al. 2011b) and field surveys (Phillips and Blackshaw 2011) but comprehensive and, perhaps even more importantly, *long-term* monitoring of biota will always be useful. Herbarium or museum records represent sources of valuable historical information, even if they rarely contain information regarding local abundance. Undoubtedly a combination of both historical data and comprehensive field surveys will provide extra rigour to any further studies of macroalgal range-shifts.

5.4.3 Herbarium data and field observations

A simple comparison of the proportion of rare algae recorded in the AVH data (142 of 1487 = 9.56%) to that of the current field UVC surveys (10 of 489 = 4.89%) supports the robust nature of the historical AVH dataset. Strong broad-scale patterns emerge even though the geocode resolution of many of the pre-GPS (Global Positioning System) records in the AVH is likely to be relatively coarse — to kilometres, or even tens of kilometres for very old records. Many localities of the new field observations represent genuine species range-extensions (e.g. *Pterothamnion aciculare* from Southport).

The valuable historical records within the AVH data have been analysed for various studies including research on bioregional provinces (Crisp et al. 2001, Waters et al. 2010), biogeography of macroalgae (Gurgel 2011), retreat of seaweeds from ocean warming (Wernberg et al. 2011b) and seaweed population demise (Johnson et al. 2011, Phillips and Blackshaw 2011). Additional records or specimens held in unregistered collections are not easily accessed and represent regrettable omissions from such research, including the current project. The value of maintaining verifiable evidence for species identification (voucher specimens or photos) cannot be overestimated. Even though this present work was focussed on rare species, all species observed at each UVC survey site were recorded (Appendix 3) and representative material was processed as voucher specimens.

Even though the UVC surveys were not comprehensive in terms of seasonality or number of individual collections, the positive observations that were made offer encouragement for future targeted studies of rare marine macroalgae. Collectively the data are similar in scope to those obtained in other single-season floristic surveys, such as Macquarie Island (Ricker 1987) and Norfolk Island (Millar 1999). No one study can ever be regarded as a final assessment; over time each adds further information to the knowledge bank.

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Chapter 6: *Entwisleia bella* gen. et sp. nov. a novel colaconematoid red alga from southern Tasmania representing a new family of unknown ordinal classification

Acknowledgement is made to Gerald T. Kraft, University of Melbourne, for light micrographs of reproductive features (Figures 6.3c–f, 6.4c–e, 6.5a–j, 6.6a–f) and contributions to the discussion on taxonomic affiliation of the new species.

6.1 Introduction

The cool temperate waters of the southern hemisphere continue to reveal hidden secrets of marine biodiversity. South-east Tasmania (IMCRA meso-scale Bruny Bioregion (IMCRA 2006)) is proving to be an area of great biological interest not only because of unusually large numbers of range-restricted endemic marine biota (Edgar et al. 2004), but because the general region may represent the southernmost refuge for organisms whose populations appear to be migrating southwards in response to changes in climate and ocean environments (Wernberg et al. 2011b). This region has proved to be particularly well endowed with recent discoveries, particularly in subtidal habitats that have been only sporadically collected.

Within the red algal Division Rhodophyta, several species have been recently described from this region, including *Crouania brunyana* Wollaston (Wollaston and Womersley 1998), *Pseudohalopeltis tasmanensis* G.W. Saunders and *Halopeltis cuneata* (Harvey) G.W. Saunders (Saunders and McDonald 2010). Recent collections made in the course of research for the algal section of the Barcode of Life project headed by G.W. Saunders have revealed a wealth of both cryptic and morphologically distinctive species, the taxonomic status and phylogenetic positions of which are now strongly supported by molecular data.

A current finding has been a striking element of the sublittoral flora at a locality in the lower Derwent Estuary where the initial discovery was made, and the plant's seasonality, distribution and community structure was charted over the past three years. Particularly intriguing features of this organism were its thallus architecture and male and female reproductive structures, as they all immediately suggested strong similarities to the exclusively freshwater genus *Batrachospermum.* Although initial molecular analyses have failed to support our preliminary proposal, the anatomy of the alga remains startlingly *Batrachospermum*-like. The entity does however represent a new genus, family and possibly even a new order in the same large lineage that includes the *Thorea*, *Batrachospermum* and *Lemanea* lines of exclusively freshwater macrophytes, and members of the marine family Colaconemataceae (order Colaconematales).

A new taxon *Entwisleia bella* sp. nov. (family Entwisleiaceae fam. nov.) is described, based on both molecular and morphological features. Molecular analyses that will strengthen the proposal at species, genus and family levels have proved particularly challenging and are still underway (G.W. Saunders pers. comm.). The morphology and habitat data are presented here.

6.2 Materials and methods

Material was first photographed *in situ* and collected in February 2010 and despite continuous target searching over the following 12 months further material was not found again until February 2011. Twenty-five vouchered specimens were the sole outcome of three years of collection effort. Type (female material) and voucher collections are currently being accessed into the herbaria HO, UNB and MELU. Abbreviations for herbaria follow Holmgren *et al* (1981).

Initial examination of material was conducted immediately following collection, on board the dive vessel, and subsequently followed by laboratory-based light-microscopy and preparation of herbarium-pressed voucher specimens. Anatomical studies were made from fresh, herbarium-pressed and liquid-preserved specimens. Fragments of material were stained in a 1% aniline blue solution and prepared as permanent slide mounts in a 20-40% solution of Karo® corn syrup acidified by addition of a small amount of 1N HCL. Other fragments were preserved in 5% Formalin-seawater and also retained as vouchered material. Underwater photographs were taken with a Canon Powershot G10 camera with dedicated underwater housing. Low magnification photomicrographs were taken with a Leica MZ 7.5 stereomicroscope equipped with digital camera. High magnification photomicrographs were taken with a Zeiss Axioskop light microscope with MRc-5 digital camera (Zeiss, Oberkochen, Germany) digital camera and images processes using Adobe® Photoshop CS4 Extended Version 11.0.1.

6.3 Results

6.3.1 Morphological and taxonomic observations

Taxonomic results: the suite of anatomical features that this organism displays strongly indicates the uniqueness of this alga at the family, genus and species levels. The following new taxa are thus proposed:

Entwisleiaceae G.W. Saunders & G.T. Kraft, fam. nov.

Description: Thalli uniaxial; central axial cells ringed distally by numbers of periaxial cells bearing lax cortical fascicles. Carpogonial branches borne on periaxial and distal fasicle cells and, when present, cells of adventitious filaments arising from descending rhizoids. Presumed fertilization resulting in multiple gonimoblast initials cut off directly from the carpogonium; carposporangia terminal on surfaces of compact carposporophytes.

Entwisleia F.J.Scott, G.W.Saunders & G.T.Kraft, gen. nov.

Description: Thalli flaccid, mucoid; central-axial cells tightly jacketed by a lax layer of downgrowing rhizoids derived from periaxial cells, the rhizoids giving rise perpendicularly to adventitious cortical filaments that fill in between the nodal facsicles. Carpogonial branches bearing simple to richly branched adventitious laxly involucral filaments from subhypogynous cells; divisions of the fertilized carpogonium vertical; spermatangia sessile, borne on distal mother cells of cortical fascicles and adventitious cortical filaments arising from rhizoidal filaments.

Etymology: Named in honour of Dr Tim Entwisle, current Director of Conservation, Living Collections and Estates, Kew Gardens, who contributed so much to the current knowledge of algae of Australia, in particular the red algal Order Batrachopermales and genus *Batrachospermum* to which the new genus bears a striking morphological resemblance, and is critically compared.

Entwisleia bella F.J.Scott, G.W. Saunders & G.T. Kraft, sp. nov.

Description: Thalli flaccid, caespitose, erect, to 8.0 cm in length, single or in clusters from fibrous discoid holdfasts. Axes terete or nodulose, radially branched to 2-6 orders.

Periaxial cells 3-8. Cystocarps globular to somewhat compressed, 80-105 µm in diam.; carposporangia undivided, 5.5-9.0 µm in length.

Etymology: besides being a beautiful plant, the Italian species epithet also pays homage to the first author's Sicilian great-grandfather, who settled in Queenscliff, Victoria, on Bass Strait to the north of Tasmania. Early experiences at Queenscliff strongly influenced her devotion to exploring and studying the marine environment.

Holotype: FJS 6508;, female material, from -6 m, epilithic on near-horizontal rocky reef (Fig. 6.1a).

Type locality: "The Blowhole" (42^{o} 58′ 19″ S; 147^{o} 20′ 25″E), Blackmans Bay, Derwent Estuary, Tasmania (leg. F.J. Scott,& I.M. Mitchell, 26 January 2012).

Distribution: known only from the type locality of Blackmans Bay, Tasmania.

Material Examined: Blackmans Bay Blowhole, Derwent Estuary, Tasmania. -7.2 m, epilithic on near-horizontal rocky reef, (*F.J.Scott, FJS 5425*, 11 Feb 2010); -7 to -8.4 m, epilithic (*FJ.Scott, FJS 6082 cystocarpic*, 4 Feb 2011); -7 to -8 m, epilithic (*F.J.Scott, FJS 6088 cystocarpic, 6089 spermatangia, 6090–6093 cystocarpic, 6095 cystocarpic*, 4 Feb 2011); -7 to -7.5 m, epilithic (*F.J.Scott, FJS 6096–6098* young cystocarpic, 12 Feb 2011); -6.5 to -8 m, epilithic (*I.M.Mitchell, FJS 6116–6117 cystocarpic,* 17 Feb 2011); -7 to -8.7 m, epilithic *(F.J.Scott, FJS 6118–6119, 6121–6122 cystocarpic, 6120 male & female (?dioecious),* 17 Feb 2011); -5.5 to -6.5 m, epilithic *(F.J.Scott, & I.M.Mitchell, FJS 6506–6509*, *cystocarpic*, 26 Jan 2012); -6 m, epilithic *(F.J.Scott, & I.M.Mitchell, FJS 6512–6513*, *cystocarpic*, 9 Feb 2012).

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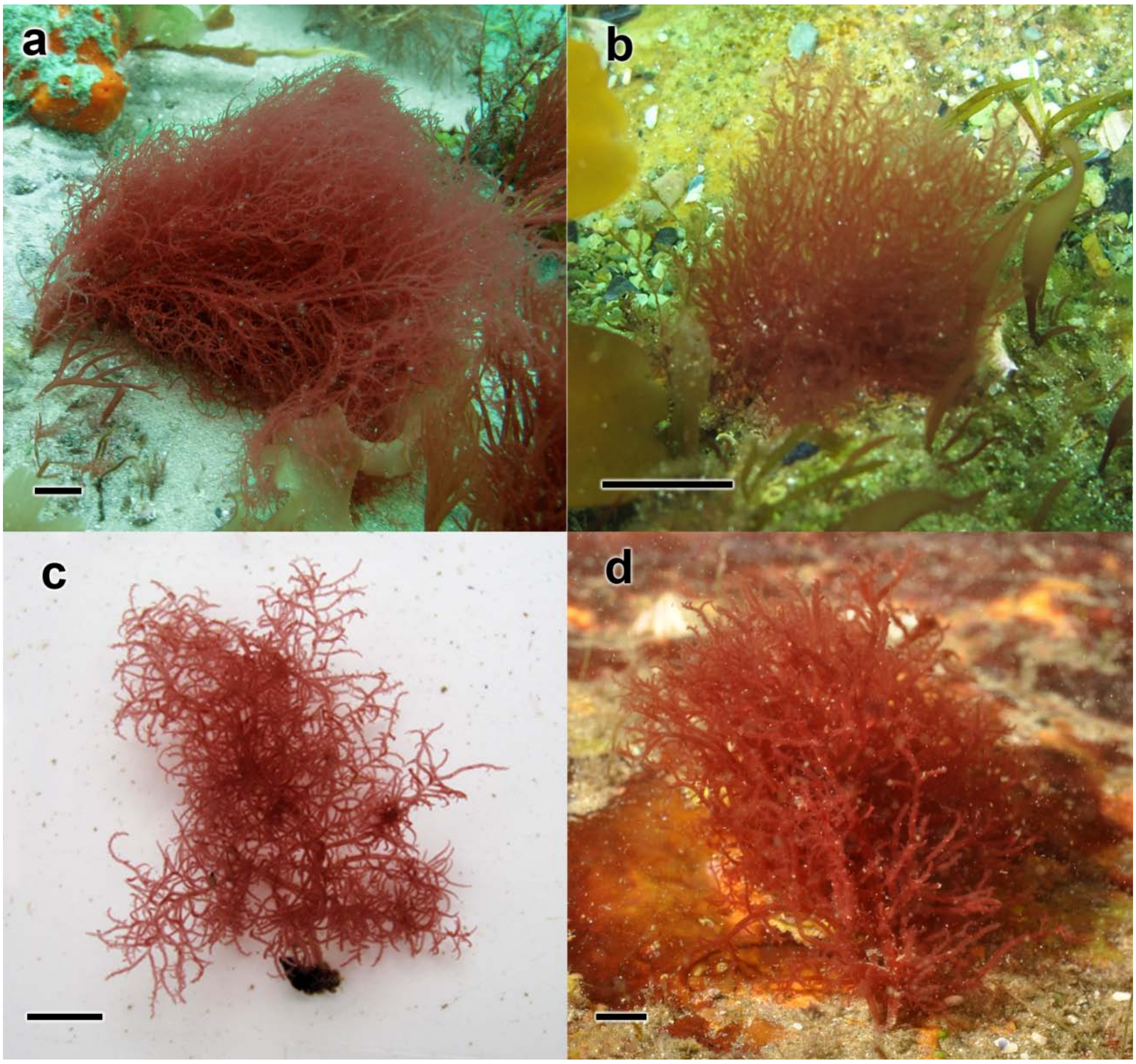

Figs 6.1a–d *Entwisleia bella* F. Scott, G. Kraft & G.W.Saunders, gen. et sp. nov. a) FJS 6508 (GWS 015666, 015667) HOLOTYOE *in situ*, b) FJS 5425 *in situ*, c) FJS 6119 wet specimen from which permanent microscope slides were made, d) FJS 6512 (GWS 015674) *in situ*. Scale bars = 1 cm.

Habit: The plant thallus is upright, 1–13 cm in high, of mid- to pale red colour, with 1–several percurrent axes arising from a thin crustose holdfast attached to the substratum (Figs 6.2a–d). Plants are flaccid, mucoid, and adhere closely to paper upon drying. Axes are terete, moniliform to continuous in outline, to 1 mm diameter near the base and tapering distally to a bluntly rounded apex (Fig. 6.2f). Axes are sometimes subdichotomously divided, but always bearing 2–4 orders of irregularly pinnate distal branching, with branches often tufted towards the apex.

Vegetative features: Structure uniaxial; apical cell rounded, 2–3 µm diam., 5–8 µm long, rarely exserted, transversely divided (Fig. 6.2e), giving rise to an initial series of rectilinear cells before branching of central axial cells sets in (Fig. 6.2f); axial cells stout, in upper parts 20–25 µm in diam., 20–40 µm long (L/D 1.5–2), in mid-parts 60–80 µm in diam., 300–400 µm long (L/D 4–5) (Fig. 6.2g). Axial cell row with regular whorls of branched determinate laterals (primary fascicles) borne on the distal end of each axial cell (Fig. 6.2h); fascicles to 220 µm long, with 8–10 cell storeys, branching 1–3 times; cells, elongate or obovoid, 2.5–4 µm in diam., 7–10 µm long (L/D 2–4). Axes are 100–130 µm wide in distal parts, 200–270 µm wide in second- and third-order laterals, and 400–600 µm wide in proximal parts.
Early development of lateral fascicles results in the cutting off of from 3-8 periaxial cells in apparently no precise order around the distal poles of central-axial cells, which are 15–25 µm in diam. before formation of periaxial cells and reach 35–110 µm in diam. by 100–450 µm in length below. The cortical fascicles reach 220 µm and 8–10 elongate/ovoid cells in length; most terminal cells in many axes end in a colorless hair to 300 µm in length (Fig. 6.2f), and most interior cells subtend a pseudodichotomy (Fig. 6.2h). Cortical fascicles and adventitious filaments densely clothe the central-axial filament (Fig. 6.3a), the central-axial cells prominently visible through the jacketing cortication (Fig. 6.3b).

Within 15–25 cells (a few mm) of the tips of axes the periaxial cells initiate proximally directed rhizoids that soon deeply embed the axial row in broadly rounded tips (Figs 6.2f, 6.2h, 6.3a–d); rhizoids 5–8 µm in diam. tightly adhere to the surfaces of the central-axial cells and initiate perpendicular laterals (Fig. 6.3c) that corticate the axes between the periaxial fascicles (Fig. 6.3d). Downgrowing rhizoids predominate, but are later added to by distally directed rhizoids arising on the same periaxial cells (Fig. 6.3d). Adventitious corticating filaments tend to be sparingly and distally branched (Figs

6.3e–f), although they eventually reach the same lengths as periaxial fascicles and are composed of similarly shaped or somewhat more rectilinear cells (Fig. 6.3e). When periaxial cells subtend in indeterminate lateral (Fig. 6.3e), this is signaled by the issuing of rhizoidal filaments from the bases of its own periaxial cells (Fig. 6.3e). Cross-sections of axes show the rhizoidal filaments closely appressed to the cuticle of the central-axial cells and producing perpendicular filaments with cells about half the diameter of fascicle cells (Fig. 6.3f). Surface view of a typical branch is composed of a mixture of whorl-branchlets and adventitious cortical filaments.

Gametophytes: Reproductive gametophytic thalli are dioecious, the spermatangial gametophytes built and branching similarly to the female gametophytes.

Male gametophyte: The branches are of annulate or moniliform appearance (Fig. 6.4a). The spermatangial clusters are borne on the distal 2–3 cells of both adventitious and non-adventitious cortical filaments (Fig. 6.4b), in pairs or threes on axial and lateral cells (Figs 6.4c–d). Spermatangia colourless, rounded, and 1.5–2.5 µm in diam., and are sessile laterally and apically the on terminal cells of cortical filaments (Fig. 6.4e).

Carpogonial and cystocarpic development: Carpogonial branches and cystocarps in various stages were plentiful in the material examined, occurring on both fascicles and adventitious filaments. Carpogonial branches are straight or curved, 5–8 celled, borne on periaxial cells or the basal cells of adventitious cortical filaments (Figs 6.5a–b, 6.5e). The carpogonium is sessile on terminal cell of carpogonial branch, which is straight or curved, 40–75 µm long, 2–3 µm in diam. at the base, and with a trichogyne of 1.5–2.5 µm diam. and to 65 µm long (Figs 6.5c, 6.5e). The hypogynous cell and subhypogynous cells initially bear a single globose lateral (Fig. 6.5b), and extended filaments are borne on most subsequent proximal cells (Figs 6.5c, 6.5e). The hypogynous cell soon bears a pair of distinctive, typically downwardly-pointing laterals tending to arch towards the thallus interior (Figs 6.c–e). Adventitious lateral cells issue from the hypogynous, sub-hypogynous and even more proximal carpogonial branch cells, although they grow out into uniseriate unbranched or distally branched filaments only on sub-hypogynous cells (Fig. 6.5d).

After presumed fertilization of the carpogonium nucleus and swelling of the base of the carpogonium (Fig. 6.5f), primary gonimoblast initials arise from longitudinal divisions of the carpogonium, upon the cutting off of the first gonimoblast initial by a vertical septum (Fig. 6.5g). This is followed by a second (Fig. 6.5h), and ultimately three (Fig.

6.5i) or more gonimoblast initials as the trichogyne withers and disappears. As the carposporophyte matures, the subtending filaments borne on carpogonial-branch cells branch pseudodichotomously or unilaterally forming a lax involucre (Fig. 6.6a) or may remain relatively simple (Fig. 6.6b). No fusion cell (post-fertilization fusion of the carpogonial branch) forms, the carposporophyte expanding into a tight cluster (Fig. 6.6c) by repeated division of the gonimoblasts and differentiating across the surface into an outer layer of obovoid carposporangia (Fig. 6.6d). Regeneration of new sporangia within walls vacated by carpospores was not seen.

Carposporophytes: The carposporophytes are globose to somewhat compressed (Figs 6.6c–f), 80–105 µm in diam., comprised of clusters carposporangial filaments (Fig. 6.6d). The carposporangia develop terminally on the carposporangial filaments to form the outer surface of the cystocarp. Carposporangia are elongate, distally rounded, 2–3 µm in diam., 6–9 µm long. Carpogonial branches with mature cystocarps are often borne directly on periaxial cells, either singly (Figs 6.6a, 6.5e) or in pairs (Fig. 6.6f).

Tetrasporophytes: Tetrasporophytes are unknown.

Figs 6.2a–h *Entwisleia bella* F. Scott, G. Kraft & G.W.Saunders, gen. et sp. nov. Habit and vegetative features. a, b, d: FJS 5425; c, f, h: FJS 6119 (c, f, slide B; h, slide D); e: 6120 (slide C).

6.2a. *In situ* habit of cluster of gametophytes (FS 5425) growing with *Carpoglossum confluens* (arrow), a southeastern-Australian endemic genus and species of Fucales.

6.2b. Herbarium-pressed cystocarpic specimen (FS 5425).

6.2c. Wet-habit of the two to four orders of irregularly pinnate distal branching.

6.2d. Wet-habit of the base of a robust female gametophyte, the primary axis anchored by a thin crustose holdfast (arrow).

6.2e. A rare instance of an exserted transversely dividing apical cell (arrow).

6.2f. The bluntly rounded, scarcely tapering apices of primary laterals on a cystocarpic thallus, the apical cells of the central axes not evident and virtually every cortical filament ending in a hair.

6.2g. A typical axial filament of a primary lateral in which the closely spaced rectilinear subapical cells (arrows) of the central-axial filament are deeply embedded within the surrounding cortical filaments.

6.2h. Whorls of determinate laterals encircling the distal poles of central-axial cells, with downgrowing rhizoidal filaments (arrows) being initiated on the periaxial cells.

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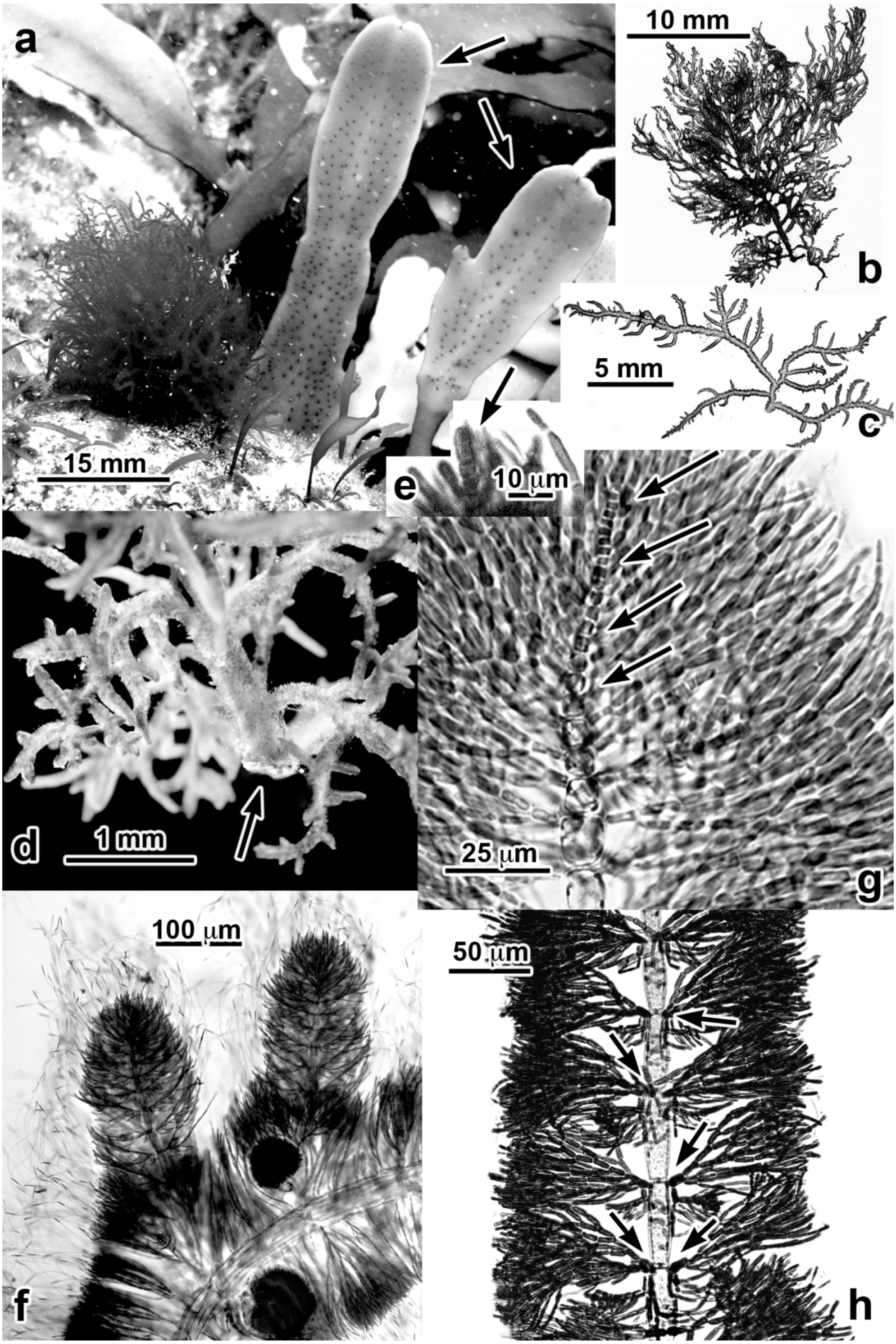


Figs 6.2a–h *Entwisleia bella* F. Scott, G. Kraft & G.W.Saunders

Figs 6.3a–f *Entwisleia bella* F. Scott, G. Kraft & G.W.Saunders, gen. et sp. nov. Vegetative features. a, b, f: FJS 5425; c, d: FJS 6119 (c, slide D; d, slide B); e: FJS 6120 (slide B). (*Figs 6.3c–f by Gerald T. Kraft*)

6.3a. Surface view of mature cystocarpic axes uniformly composed of a uniform mixture of whorl-branchlets and adventitious cortical filaments.

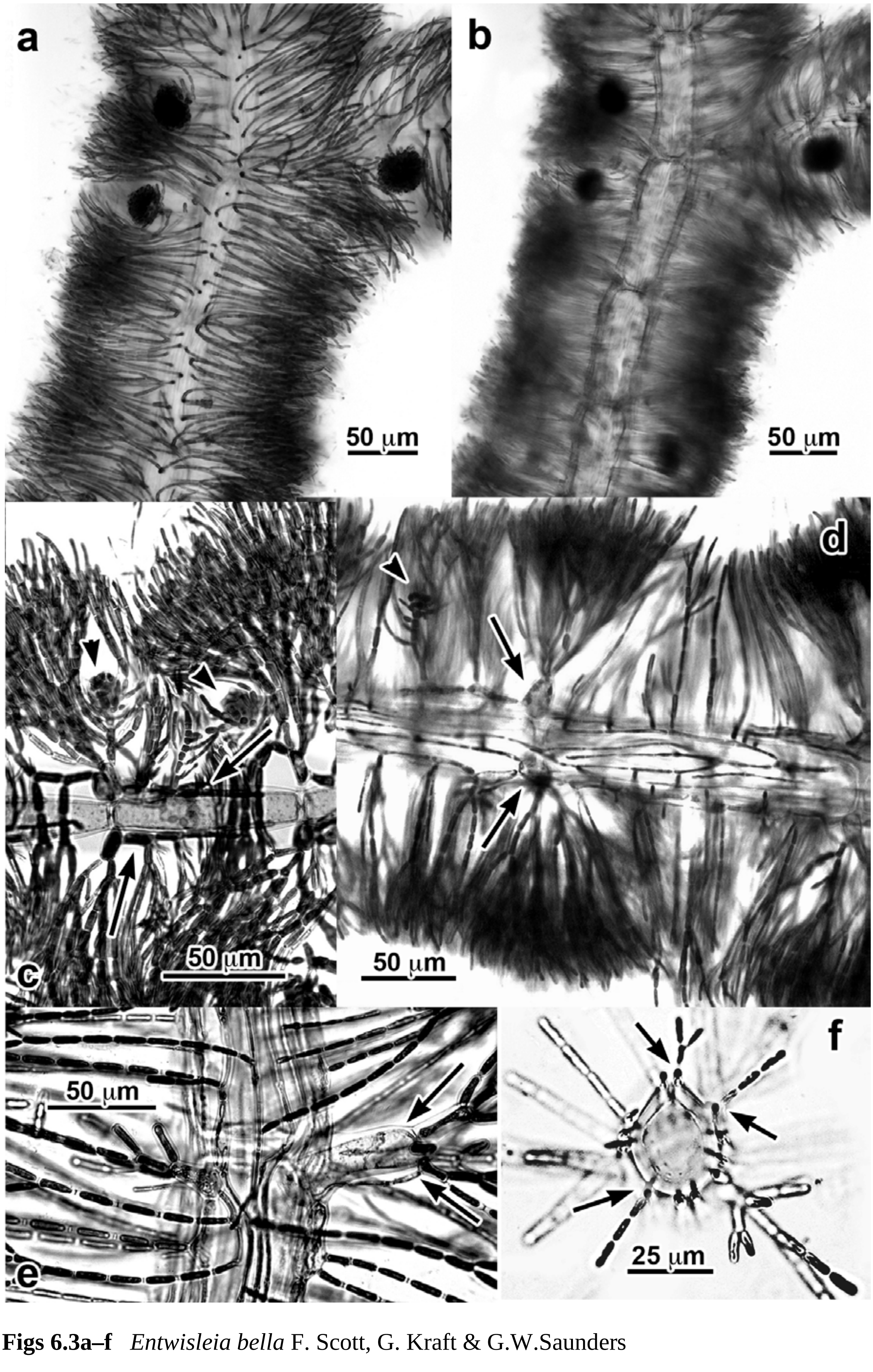
6.3b. The axes of Fig. 11, the focus on the stout cells of the central axial filament.

6.3c. Early axial development in which the cortex is largely made up of fascicles borne on periaxial cells that are also producing downwardly growing rhizoids (arrows). Two immature carposporophytes (arrowheads) terminate carpogonial braches borne on periaxial cells.

6.3d. Periaxial cells (arrows) initiating a monolayer of corticating rhizoids that produce adventitious cortical filaments, one of which underpins an early gonimoblast (arrowhead).

6.3e. Detail of a periaxial cell (arrow) surrounded by numbers of adventitious filaments borne on corticating rhizoids.

6.3f. Cross section of an axis, the cuticle of the central-axial cell surrounded by rhizoids bearing adventitious cortical filaments (arrows).



Figs 6.3a–f *Entwisleia bella* F. Scott, G. Kraft & G.W.Saunders

Figs 6.4a–e *Entwisleia bella* F. Scott, G. Kraft & G.W.Saunders, gen. et sp. nov. Male-gametophyte features. a, c-e: FJS 6120 (c–e: slide A); b: FJS 5425 (slide B). (*Figs 6.4a–e by Gerald T. Kraft*)

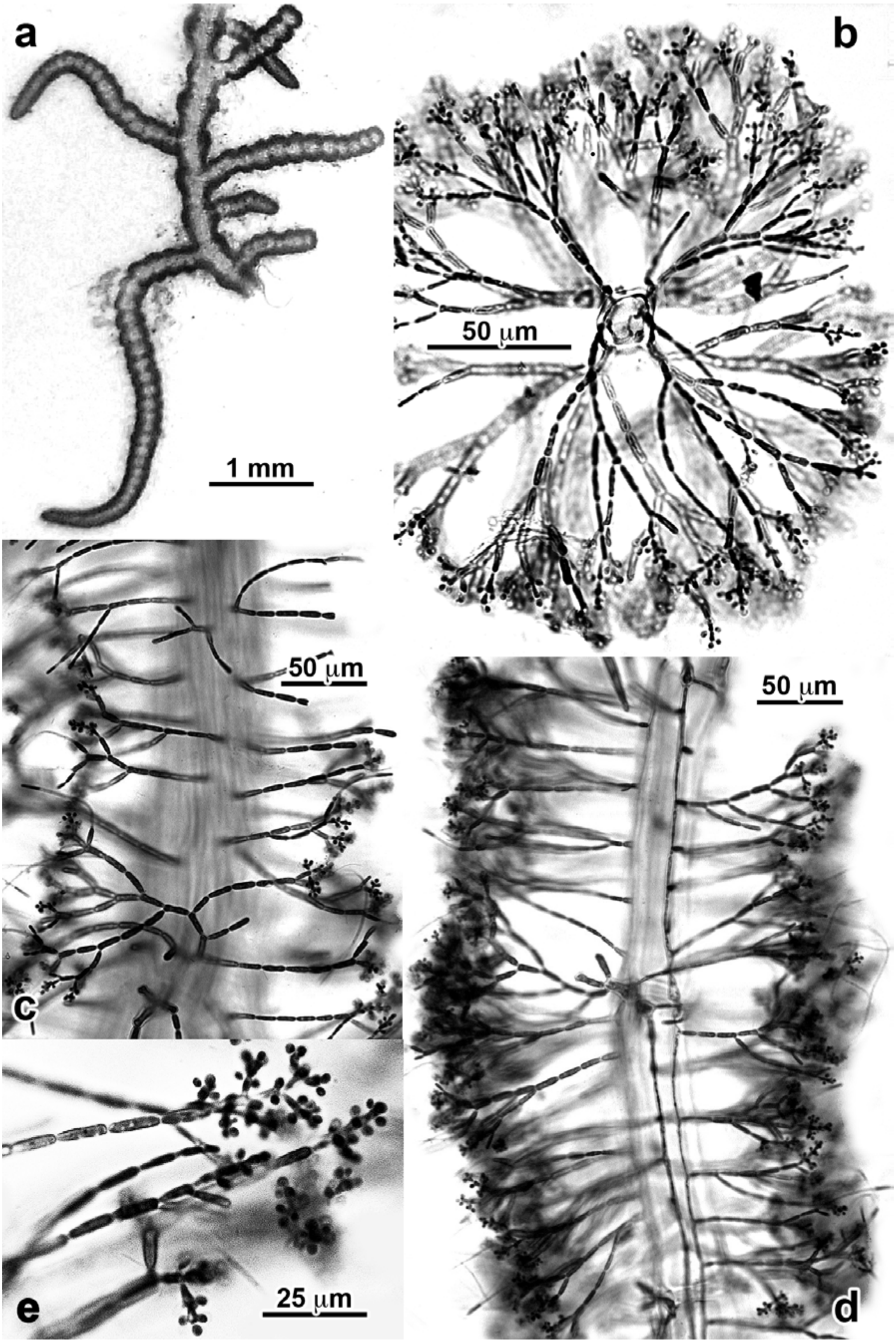
6.4a. The annulate habit of liquid-preserved portion of a mature spermatangial thallus.

6.4b. Cross-section of a reproductive axis, the spermatangial clusters borne distally on both adventitious and non-adventitious cortical filaments.

6.4c. Surface view of fecund male reproductive axis.

6.4d. Detail of axis and cortical filaments with terminal spermatangia.

6.4e.Detail of spermatangia sessile on the terminal two or three cells of cortical filaments.



Figs 6.4a–e *Entwisleia bella* F. Scott, G. Kraft & G.W.Saunders

Figs 6.5a–j *Entwisleia bella* F. Scott, G. Kraft & G.W.Saunders, gen. et sp. nov. Carpogonial, zygote and early carposporophyte features. a, c: FJS 6120 (slide C); b, d–j: FJS 6119 (b, slide B; d, g: slide D; e: slide C; f, h–j: slide A). (*Figs 6.5a–j by Gerald T. Kraft*)

6.5a. Early stage in development of an eight-celled carpogonial branch on the basal cell of an adventitious cortical filament, the four cells subtending the carpogonium each bearing a single-celled lateral.

6.5b. Hypogynous and subhypogynous cells of an unfertilized carpogonial branch, each bearing a single globose lateral and with extended filaments borne on most subsequent proximal cells.

6.5c. A mature carpogonial branch, with a typically downwardly directed pair of laterals issuing from the hypogynous cell.

6.5d. A five-celled carpogonial branch with a pair of reflexed two-celled laterals initiated from the hypogynous cell.

6.5e. A seven-celled carpogonial branch with compact clusters of cells from the two immediately subtending cells of the carpogonium and unbranched single laterals on the basal three cells.

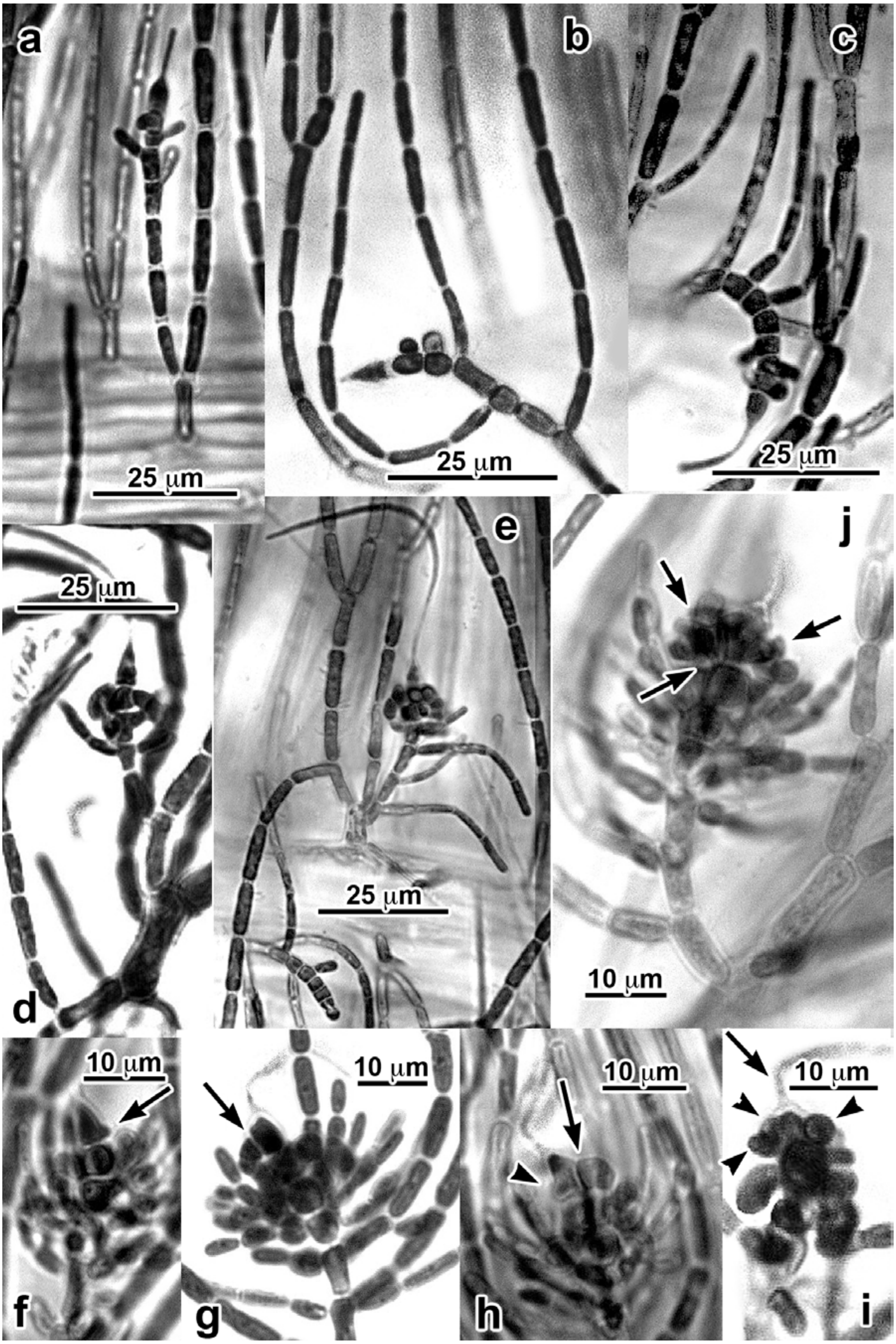
6.5f. A lateral bulge at the base of an apparently fertilized carpogonium (arrow) that signals the first differentiation of the presumed zygote.

6.5g. A longitudinal division of the carpogonium (arrow) resulting in the first gonimoblast initial.

6.5h. The vertical cross-wall separating the primary gonimoblast initial (arrow) from one side of the presumably fertilized carpogonium and the bulging primordium (arrowhead) of the second gonimoblast initial on the other.

6.5i. A carpogonium with remnant trichogyne (arrow) surrounded by a collar of primary gonimoblast initials (arrowheads).

6.5j. A horizontally spreading plate of gonimoblast cells (arrows) borne on unfused subtending cells of the carpogonial branch.



Figs 6.5a–j *Entwisleia bella* F. Scott, G. Kraft & G.W.Saunders

Figs 6.6a–f *Entwisleia bella* F. Scott, G. Kraft & G.W.Saunders, gen. et sp. nov. Mature cystocarp features. a, 37: FJS 6119 (Fig. a: slide D; Fig. f: slide B); b–d: FJS 5424 (slide A); e: 6120 (slide A). (*Figs 6.6a–f by Gerald T. Kraft*)

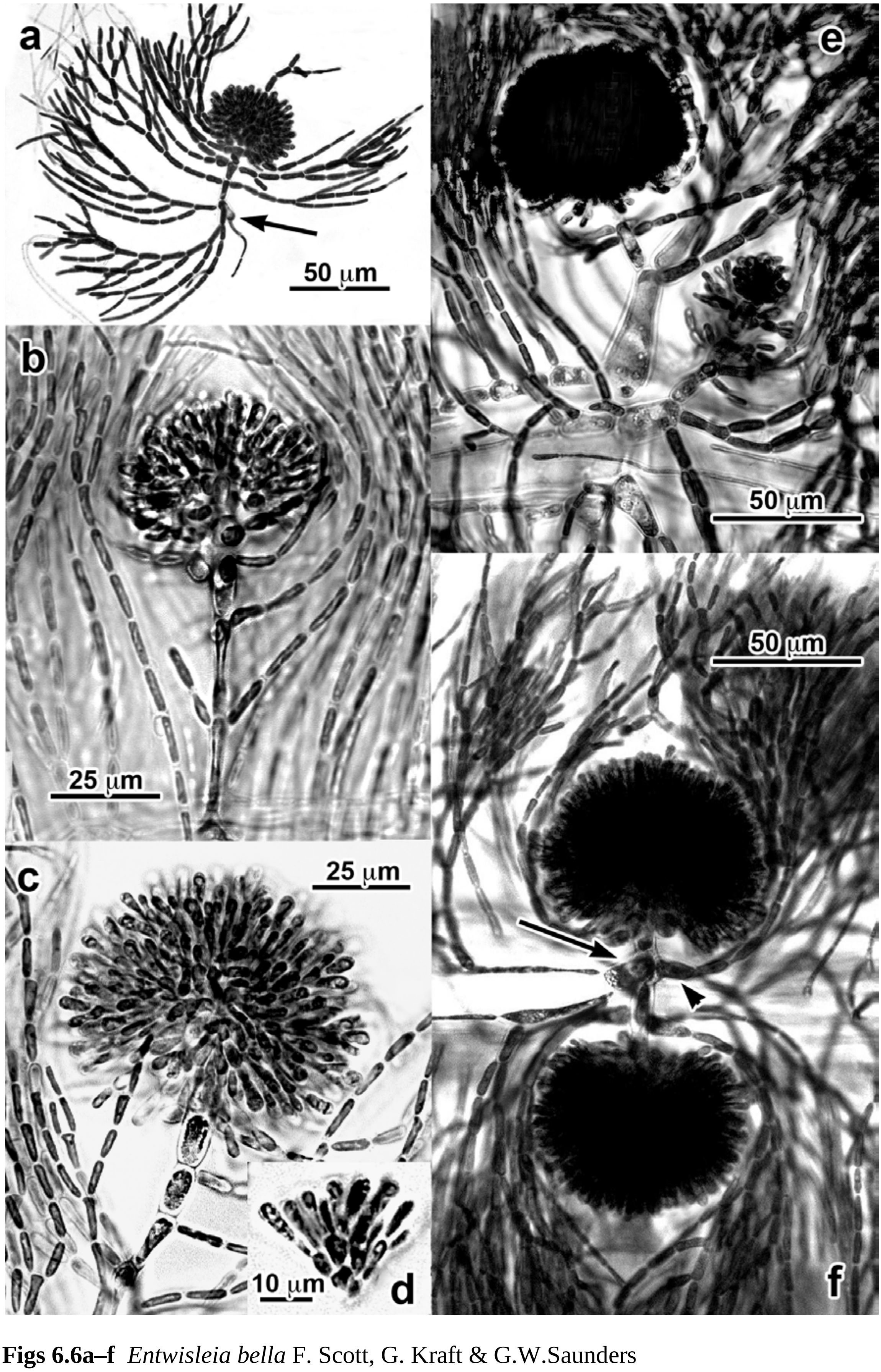
6.6a. An excised mature cystocarp, its carpogonial branch borne on a periaxial cell to which a rhizoid (arrowhead) and two proximally unilaterally branched cortical filaments are attached, the laterals on carpogonial-branch cells more regularly subdichotomous throughout and forming a lax involucre around the carposporophyte.

6.6b–c. Early formation of carposporangia at the surfaces of cystocarps terminating the unfused cells of carpogonial branches.

6.6d. Detail of the surface and interior cells of carposporangial filaments of the cystocarp of Fig. 6.6c.

6.6e. Mature and young cystocarps borne on carpogonial branches attached to separate periaxial cells at an axial node.

6.6f. A pair of nearly equally developed mature cystocarps borne with cortical filaments (arrowheads) on a common periaxial cell (arrow).



Figs 6.6a–f *Entwisleia bella* F. Scott, G. Kraft & G.W.Saunders

Table 6.1. Comparison of morphological features within family Entwisleiaceae and those within family Batrachospermaceae (Batrachospermales) (Entwisle and Foard 2007), family Thoreaceae (Thoreales) (Müller et al 2002; Entwisle & Foard 2007), familyLiagoraceae (Nemaliales) (Huisman 2006), and family Colaconemataceae (Colaconemataceae) (Harper & Saunders 2003; Wynne & Schneider 2008).

	order unknown Entwisleiaceae	**Batrachospermales Batrachospermaceae**	**Thoreales Thoreaceae**	**Nemaliales Liagoraceae**	**Colaconematales Colaconemataceae**
Gametophyte	Dioecious (also monoecious ?)	Monoecious or dioecious	Dioecious	Monoecious or dioecious	Where known, sexual life histories triphasic
Gametophyte morphology	Uniaxial, with regular whorls of determinate laterals (fascicles)	Uniaxial, with regular whorls of determinate laterals (fascicles)	Multiaxial, with determinate lateral assimilatory filaments	Multiaxial; cortical filaments loosely arranged	Uniseriate
Axial filaments	Axial cell stout, elongate; periaxial cells giving rise to branched assimilatory filaments 8-18 (-30) cell storeys, as well as descending rhizoids that also bear branched adventitious filaments	Axial cells broad; periaxial cells usually 4-6; rhizoidal filaments usually adhering to axial filament; lateral 'secondary' fascicles absent to common	Medulla of longitudinal filaments and bearing branched assimilatory filaments 8-18 (-30) cell storeys, forming the cortex	Medulla of longitudinal filaments and bearing anticlinal subdichotomously to trichotomously branched assimilatory filaments forming the cortex	Filamentous
Habitat	Marine	Freshwater	Freshwater	Marine	Marine
Spermatangia	Borne on spermatangial mother cells, on terminal 2-3 cells of fascicles	Borne on terminal cells of fascicles or on specialized filaments	Clustered on specialized filaments	Borne on spermatangial mother cells on outer cortical cells or in whorls on mid-cortical cells	Borne on cells of distal branches
Carpogonial branches	Borne laterally on periaxial cells or cortical filaments, 3-8 celled, straight or curved; trichogyne thin, straight or curved; lateral filaments arise from proximal cells of carpogonial filament; hypogynous cell bears distinctive reflexed laterals	Variously differentiated from vegetative fascicles, 3–31 celled, straight, curved or twisted; trichogyne swollen, generally broader than base of carpogonium; lateral filaments arise from proximal cells of carpogonial filament	Borne laterally on cortical filaments 1-few-celled; trichogyne linear and elongate	Borne either laterally (*Liagora*) or terminally (*Nemalion*) on cortical filaments, 3- to many-celled, either straight with lower cells having the appearance of cortical cells, or curved and composed primarily of modified cells	Absent; carpogonia are sessile

Gonimoblast filaments	Arise from longitudinal division of carpogonium; filaments ?determinate	determinate or indeterminate; 1–12 cell storeys *Batrachospermum*)	?division of carpogonium; filaments indeterminate	Arise from transverse division of carpogonium, with only the upper cell producing gonimoblasts; filaments	
Cell fusion of carpogonial branch cells	Appears to be absent	?	Appears to be absent	Appears to be absent	
Carposporo-phytes	Borne within the thallus; develops directly from the carpogonium; with branched gonimoblast filaments and terminal carposporangia	Usually borne within thallus, often of definite shape; gonimoblast filaments determinate and/or indeterminate; carposporangia single from a terminal cell	Develops directly from the carpogonium	Within the inner cortex, not protuberant, non-ostiolate, with branched gonimoblast filaments and terminal carposporangia	Develops directly from the carpogonium
Involucre surrounding carposporo-phyte	Present; lax; formed by subdichtomous branching of the filaments that arise from proximal carpogonial branch cells	?	?	Present; formed from coalescence of secondary assimilatory filaments	Absent
Chantransia phase	Unknown	Present; meiotic tetraspores formed	Present; cushion-like; monosporangia present (some reports may be misinterpreted carposporangia)	Absent	Asexual reproduction primarily by monosporangia; but monosporangia apparently absent in some species
Tetrasporo-phytes	unknown	Absent	?	(Where known) filamentous, tetrasporangia cruciate	Apparently absent
Pit plug cap membranes		Absent (Two cap membranes present in some other families; inner is thin; outer is typically domed and 10-15 times wider than inner)	Two present; inner is thin and electron translucent; outer is more electron dense and typically plate-like, or if domed, only 1-4 times wider than inner		

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6.3.2 Distribution and habitat

This species is known only from Blackmans Bay (western shore of the lower Derwent Estuary, Tasmania) (Fig. 38) and occurs between 5 and 8 metres deep, scattered sparingly on sandstone reef flats dusted or shallowly covered by sand. Individuals are attached to rock or shell, conspicuously associated with the Tasmanian endemic fucoid *Carpoglossum confluens* (R. Brown ex Turner) Kuetzing, the native *Tsengia feredayae* (Harvey) Womersely & Kraft, and mixed algal turf. Year-round continuous searching suggests that plants appear in summer, become reproductive and most abundant in January and February,, then wane such that gametophytes decline to rudimentary numbers or are not present during the winter months. Intensive target-searching also failed to reveal any signs of a possible C*hantransia* phase, as exists in some members of one of the putatively nearest orders, such as the Batrachospermales.

The site is subject to moderate seas and ocean swell and the near-flat reefs appear to be often scoured by sand. Low profile sponges, anemones, mixed algal turf, the brown algae *Carpoglossum confluens*, *Ecklonia radiata* (C. Agardh) J. Agardh, *Dictyopteris muelleri* (Sonder) Reinbold, *Cladostephus spongiosus* (Hudson) C. Agardh, *Bellotia eriophorum* Harvey, *Cystophora moniliformis* (Esper) Womersley & Nizamuddin, *Sargassum* spp, and the red algae *Rhodoglossum gigartinoides* (Sonder) Edyvane & Womersley, *Hemineura frondosa* (Harvey), and *Plocamium angustum* (J. Agardh) J.D. Hooker & Harvey, comprise the biotic community on the substrates near to where *Entwisleia* occurs. Nearby (inshore), the high-profile reef structure supports a complex biological community structured by large boulders with many vertical surfaces and the canopy-forming species *Ecklonia radiata* and *Lessonia corrugata* Lucas. A large number of species is known to occur in the general area and underwater visual census (UVC) surveys for Blackmans Bay (north and south reefs) during 2009–2011 resulted in a record of 99 macroalgae (see Appendix A3).

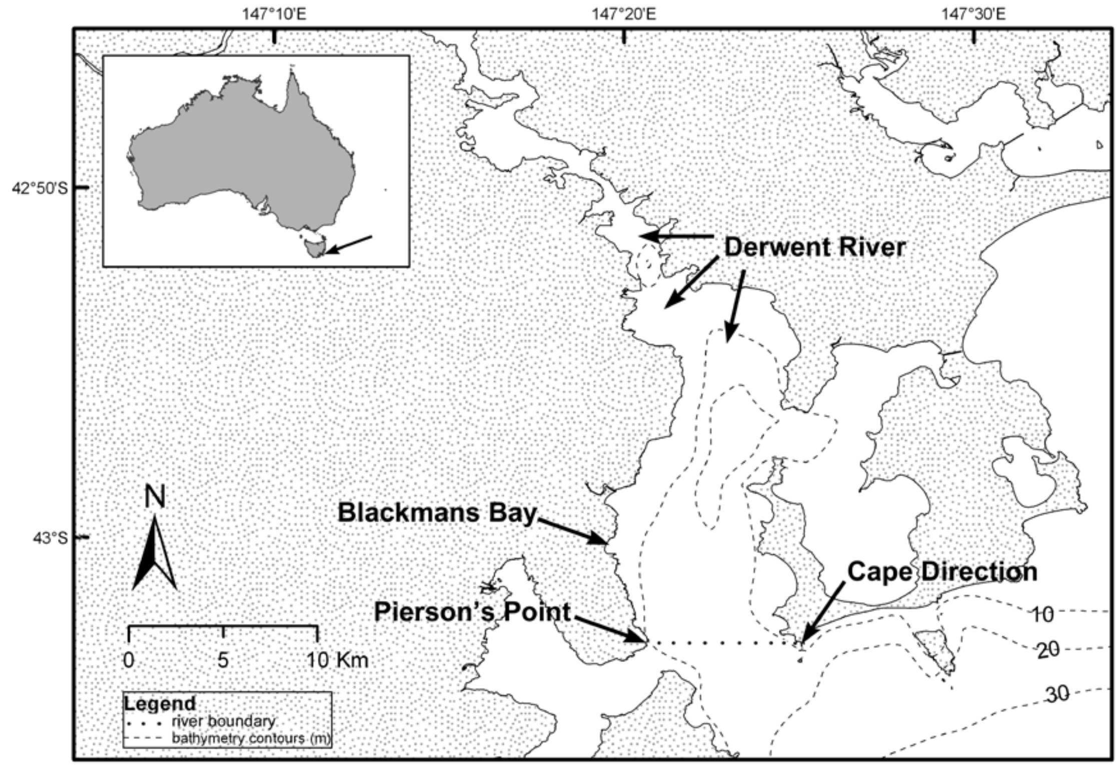

Fig. 6.7 Type locality of *Entwisleia bella*; Blackmans Bay and vicinity, south east Tasmania.

6.4 Discussion

6.4.1 Morphology

The habit and morphology of *Entwisleia* initially suggested various affinities with either members of the freshwater family Batrachospermaceae (Batrachospermales) and family Thoreaceae (Thoreales) or the marine family Liagoraceae (Nemaliales) and family Colaconemataceae (Colaconematales), to which the new species is compared (Table 6.1). However, *Entwisleia* is well separated from known red algal orders based on characteristics of a marine habitat, uniaxial thallus construction, a cortex made up of both whorled fascicles and adventitious lateral branches arising from the rhizoids, and the distinctive downward-pointing laterals present on the hypogynous cell (of the female gametophytes). With respect to construction and morphology *Entwisleia* is quite unlike those uniaxial taxa within the orders Gelidiales and Bonnemaisoniales.

The new genus bears a strong resemblance in the field to *Dudresnaya australis* J. Agardh *ex* Setchell (Robins and Kraft 1985) with which it was sometimes confused, but differs internally and reproductively, not least of which is *Dudresnaya* producing gametophytes and tetrasporophytes with similar morphologies and zonate tetrasporangia. Another unrelated genus that has species habit and textures similarities to *Entwisleia* is *Ganonema*, illustrated by Huisman (2006) in his figures 14 and 16, and indeed the new collections would have strongly suggested alliances with the Liagoraceae were it not for the fact that all members of that family are multiaxial. This leaves the extraordinary resemblance of plants to those of the freshwater genus *Batrachospermum* which Entwisle *et al.* (2007) illustrate in their figures 2–3 showing Australian members with axial, fascicle and corticating rhizoidal structures, carpogonial branches borne on periaxial cells bearing numerous sterile laterals from hypogynous and sub-hypogynous cells (their figures 4–5), and globular cystocarps (their figures 2C, 3D) very similar to those of *Entwisleia*.

Planned molecular and ultrastructure studies may further elucidate the phylogenetic placement of the new family and its relationship to morphologically similar taxa. Its close allegiance to the currently monogeneric order Colaconematales (Harper and Saunders 2002a, Wynne and Schneider 2008) is based on morphological characters and early results of molecular LSU and SSU DAN sequence data (Saunders pers. comm.). Within the closely related order Acrochaetiales (in which *Colaconema* was formerly placed) the holdfast and plastid features that were used to demarcate genera are problematic, and more reliance is being placed on the combination of molecular phylogenies and morphological features to now delineate genera.

6.4.2 Habitat and planned extension of study

The morphology of the Derwent estuary is that of a drowned river valley formed between 6,500 and 13,000 years ago, after which sea level rose ~60 metres to near its current level (Green and Coughanowr 2003). Blackmans Bay is in the outer estuary region some 6 km from the generally accepted seaward boundary between Piersons Point and Cape Direction (Fig. 6.7). The northern end of the bay where the plants were found has steep bluffs of Permian mudstone layered with strong vertical fissures. The adjacent subtidal reefs, topped with scattered boulders and debris from former rockfalls, grades gently into sand within some 50 m of the shore. Situated within the IMCRA (Interim Marine and Coastal Regionalisation for Australia) Bruny Bioregion (IMCRA 2006), the Derwent estuary is of a slat wedge type, with freshwater surface flow heading downstream and marine flow in the bottom waters, heading upstream (Herzfeld et al. 2005). The tidal behaviour is predominantly of diurnal mixed character and with a tidal range of ~0.5 m (neap tides) to ~1 m (spring tides). In the Blackmans Bay area, late summer conditions at -7 m typically include water temperatures of 16–17°C, surface-water salinity of 28–32 psu (certainly higher at -7m, where plants occur), and water current velocity of 0.1–0.2 ms^{-1} (Herzfeld et al. 2005, Wild-Allen et al. 2009).

Near to the collecting site is a seasonal rivulet/stormwater drain and although “rainfall is usually distributed relatively evenly throughout the year, with a mean minimum of 40 mm in February and a mean maximum of 63 mm in October” (Green and Coughanowr 2003) the area can be subject both to high rainfall plume events that typically elevate nitrate concentrations adjacent to such stormwater drains. The incoming tide flows in along the western shore of the Derwent River and flows out along the eastern shore (due to the influence of the Coriolis force), thus Blackmans Bay is more like to be of generally higher salinity than the eastern shore locations (I. Mitchell pers. comm.). In addition, particularly during summer periods of southerly winds and ocean-swell (to 2–3 m), turbulent water conditions at the site can adversely affect the benthos and certainly curtails survey activities. A particularly strong weather event in March 2011 resulted in the reefs on which *Entwisleia* had been found being buried under extensive ridges of 20-40 cm sand and rubble. Partial re-exposure of these reefs was not evident until January 2012, during which further observations and collections of the species were made.

The Blackmans Bay area is an established outer suburb of the city of Hobart and is a popular location for sailors, surfers and divers as the weather dictates. Approximately 1.5 km downstream from the collecting site at Blackmans Bay Blowhole is a substantial sewerage treatment plant, and, with an average discharge of 1.64 ML/y some 600 m offshore, no doubt bathing the surrounding area with water of elevated nutrient load. Approximately 1 km further downstream from the sewerage plant is the northern boundary for the recently-extended Tinderbox Marine Reserve, a state marine protected area with declared management objectives including the preservation of biodiversity (DPIWE 2000).

Estuaries in a pristine state are considered to be amongst the most productive environments on earth, typically dominated by species that rarely occur abundantly in fully marine or freshwater systems (Edgar et al. 2000). Despite varying degrees of anthropogenic degradation, a high percentage of Tasmanian estuarine habitats (almost 80%) have been classified as having high conservation value (SOE 2009). The Derwent Estuary is typically stratified for much of the year due to reasonably constant freshwater supply and contains the only known habitats of several marine species such as the red alga *Pterothamnion aciculare* (Wollaston) Athanasiadis & Kraft (Womersley 1998), hydrozoan *Csiromedusa medeopolis* Gershwin & Zeidler (2010) and the Critically Endangered spotted handfish *Brachionichthys hirsutus* Lacépède (Edgar 2008). Without further study it is difficult to determine whether *Entwisleia bella*, occurring as it does at depth and near the seaward margin of the estuary, is influenced by changes in salinity caused by freshwater input from the Derwent River or the nearby Blackmans Bay Rivulet.

To date the collections essentially represent a single-population severely range-restricted species, possibly as a neoendemic or as an old species presumably existing only in a riverine/estuarine habitat of a glacial refuge. *In situ*, even for trained observers, this new species has proven extremely difficult to distinguish from *Naccaria naccarioides* (J. Agardh) Womersely & I.A. Abbott, *Crouania brunyana* Wollaston, *Ptilocladia gracilis* (J. Agardh) Womersley, and (young plants of) *Dudresnaya* *australis* J. Agardh *ex* Setchell, all of which occur at the site and are similar in size, colour, flaccid habit and seasonality to *Entwisleia bella*.

Careful observations of the strata and habitat from which *Entwisleia* is known have been made over three years, enabling a mental model of its environment to be developed and used as a guide for target-searching in similar areas. An interesting observation made independently by the (only) two collectors is that the immediate vicinity of *Entwisleia* plants is often devoid of other algae, suggestive of possible allelopathic properties of the plant. In the search for new populations, sites within 5 km of the type locality have been surveyed but no additional sightings have been made. Failure to detect further populations could conceivably be due to the following; plants having sparse, clustered or extremely seasonal population; a lack of methodical survey; real-world limits (time and funding) to the implementation of more widespread surveys. Target searches are planned for future seasons at the type locality as well as in similar habitats.

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Chapter 7: General discussion and implications

7.1 Rare species

Rare species list

By interrogating data-based herbarium records I have collated a list of one hundred and forty-two putatively rare marine algae endemic to southern Australia, comprising ~10% of the known flora of these temperate coasts. The rare species met the defined criterion of occurring at five or fewer localities and together represent a important update to an earlier work, the *Overview of the Conservation Status of Marine Macroalgae* (Cheshire et al. 2000) in which rare species numbered one hundred and eighty-two. The twelve-year gap between the documents facilitates an historical perspective to our knowledge of rare macroalgae. Notwithstanding the possibility of extinctions or new discoveries, this apparent diminution of the number can be partly explained by rare species either having recently been found in abundance (e.g. *Schizoseris hymenena*), found over a broader range (e.g. *Dasya hapalathrix*), or having undergone taxonomic reclassification that disqualifies them from the definition (e.g. *Rhodymenia halymenioides*, now considered a synonym of the non-rare *Halopeltis cuneata*). Because there are gaps in our knowledge of rare species distributions and ecology, the numbers are expected to change.

I have ascertained that macroalgal rarity is not restricted to functional or taxonomic groups, even though data showed evidence of a bias in thallus size (>60% of rare macroalgae are less than 10 cm high) and in thallus functional form (39% are filamentous, 32% are coarsely-branched). Instances of rare species being closely-related usually reflect specific research interest with a focus on a particular taxonomic group (e.g. *Antithamnion*, *Callithamnion*) or a functional group (e.g. epiphytic brown algae including species of *Sphacelaria*, *Myriactula*, *Myrionema*, *Elachista*, *Strepsithalia*).

Mapping algal rarity for the first time has been accomplished due to access to geographical information of records in the Australian Virtual Herbarium. The distribution maps presented in Chapter 2 offered a starting point for subsequent analyses in which the validity of the patterns of distribution was tested. As skilled biologists recognise little-known species in a field situation, any lodgement of such voucher material into a registered herbarium enables our concepts of rarity and the distributions of rare species to be revised. This reinforces the value of herbarium resources when investigating specific groups of taxa such as rare macroalgae, in being able to access collection data and examine original voucher specimens.

Categorisation of rare macroalgae

Because concepts fundamental to marine conservation management include geographic range, habitat specificity and local abundance of species, the “seven forms of rarity” scheme described by Rabinowitz (1981) is still a useful guide when classifying species for conservation purposes. Clearly some of the putative rare species can fit into this rarity framework (Table 7.1) even if the paucity of data for majority of the 142 rare species prevents such classification. *Palmoclathrus stipitatus* has a range of 792 km and is only known from deep water, but in such localities may be common, and collections have been from drift and from 45-60 m deep (Womersley 1984). *Ceramium lenticulare* has a range of 1214 km and has been found growing on rocks, a pipeline, as well as epiphytically on *Tsengia feredaye*, and *Rhabdonia verticillata* in eulittoral pools to habitats at 14 m deep. *Ganonema helminthaxis* is known from two collections only, both from the type locality and habitat (Huisman 2002). The brown *Scoresbyella profunda* is often regarded as a rare species of broad range, but confined to deep water.

GEOGRAPHIC RANGE →	Large range		Small range	
HABITAT SPECIFICITY →	**Wide**	**Narrow**	**Wide**	**Narrow**
LOCAL POPULATION SIZE ↓ **Large, dominant somewhere**	COMMON Locally abundant over a large range in several habitats *Dictyota dichotoma*	PREDICTABLE Locally abundant over a large range in a specific habitat *Palmoclathrus stipitatus*	UNLIKELY Locally abundant in several habitats but restricted geographically *Schizoseris hymenena*	ENDEMICS Locally abundant in a specific habitat but restricted geographically *Rhipiliopsis multiplex*
Small, non-dominant	SPARSE Constantly sparse over a large range in several habitats *Ceramium lenticulare*	Constantly sparse in a specific habitat but over a large range *Scoresbyella profunda*	Constantly sparse & geographically restricted in several habitats *Schizoseris tasmanica*	Constantly sparse & geographically restricted in a specific habitat *Ganonema helminthaxis* *Pterothamnion aciculare*

Table 7.1 The "seven forms of rarity" scheme of Rabinowitz (1981) based on geographic range, habitat specificity and local population size, tabulated with examples of temperate Australian marine macroalgae.

The current limitations of knowledge of both distribution and abundance of rare macroalgae hinder the assignment of most of these species to the formal conservation categories used for conservation management. Comprehensive surveys for rare species are needed to collect data sufficient to nominate them for an extinction risk category (other than the 'Data Deficient' or 'Not Evaluated' categories) of the International Union for the Conservation of Nature (IUCN 2006) (Table 7.2). However, it should be noted that there are apt to be limitations in trying to apply the IUCN terrestrial criteria, categories, and methods of scrutiny/monitoring to aquatic biota that are largely out of sight. In practice a realistic approach for marine macroalgae would be to focus on specific geographic areas and targeting the identified 'centres of rarity', in order to make use of the finite resources available for marine conservation and the optimal use of such resources.

Category	Description
Extinct	there is no reasonable doubt that the last individual has died
Extinct in the wild	when a species is known only to survive in cultivation, in captivity or as a naturalised population (or populations) well outside the past range
Critically endangered	This category reflects an “extremely high” risk of extinction in the wild in the immediate future
Endangered	has a “very high” risk of extinction in the near future
Vulnerable	has a “high” risk of extinction in the medium-term future
Conservation Dependent	reflects the fact that the species relies on an existing conservation program to remain out of one of the “threatened” categories above
Near Threatened	close to being “vulnerable”
Least Concern	the category into which taxa in least danger are placed
Data Deficient	indicates that quantitative data sufficient for assignation of category are not available
Not Evaluated	for those species not assessed against the criteria

Table 7.2 International Union for the Conservation of Nature Red List Threatened Categories (after IUCN 1994).

7.2 Centres of rarity and safeguarding of rare species

Through mapping the AVH data I have identified ‘centres of rarity’ and tested the validity of the apparent rarity. The six centres of rarity were Rottnest I WA, King George Sound WA, Eucla WA, Fowlers Bay SA, Port Phillip Bay VIC and D’Entrecasteaux Channel TAS. Recognizing such centres of rarity draws attention to implications for conservation area policy and practice, particularly with respect to maximising the preservation of species diversity.

Sanctuary status (“no-take”) marine protected areas (MPAs) are the only areas that afford full protection. They help safeguard rare species although they are not enough in themselves to ensure the species’ futures. Fifty rare marine macroalgae were recorded from sites within sanctuary zones of existing MPAs of southern Australia (Table 7.3). For virtually all species there are inadequate data to verify whether they still occur within these sanctuary zones, so they cannot be confirmed as adequately safeguarded. Six species (*Balliella hirsuta* Huisman, *Callithamnion perpusillum* P.C. Silva, *Callithamnion crispulum* Harvey, *Ganonema helminthaxis* Huisman & Kraft, *Gloiophloea rosea* (J.Agardh) Huisman & Womersley, and *Gymnothamnion nigrescens* (J.Agardh) Athanasiadis) are still known only from single collections.

Currently there are ten sanctuary zones in Tasmania, twelve in Victoria, and twelve in southern WA, in which rare macroalgae have been recorded (Table 7.3). Within the identified centres of rarity listed above, five sanctuary zones currently exist at Rottnest I (Little Armstrong Bay, Mary Cove, Little Salmon Bay, Kingston Reef, and the West End demersal sanctuary), one in Victoria (Port Phillip Heads), and two in south-east Tasmania (Tinderbox and Ninepin Pt). Currently no sanctuary zones have been declared for South Australia, although proposals are under consideration.

Tasmania (10 sanctuaries)	**Western Australia (12 sanctuaries)**	**Victoria (12 sanctuaries)**
Crouania brunyana	*Amansia mamillaris*	*Acrothamniopsis eliseae*
Cryptonemia wilsonii	*Balliella hirsuta*	*Callithamnion multifidum*
Dasya hapalathrix	*Callithamnion crispulum*	*Chondria foliifera*
Halothrix ephemeralis	*Callithamnion multifidum*	*Chondria hieroglyphica*
Interthamnion attenuatum	*Callithamnion perpusillum*	*Cryptonemia digitata*
Macrothamnion acanthophorum	*Caulerpa ellistoniae*	*Cryptonemia wilsonii*
Macrothamnion pectenellum	*Dilophus crinitus*	*Dasya atactica*
Pterothamnion manifestum	*Dotyophycus abbottiae*	*Dasya hapalathrix*
Schizoseris perriniae	*Ganonema helminthaxis*	*Dasya wilsonis*
Schizoseris tasmanica	*Kallymenia spinosa*	*Dipterosiphonia australica*
	Papenfussiella extensa	*Elachista claytoniae*
	Platyclinia ramosa	*Erythronaema ceramioides*
	Predaea huismanii	*Faucheopsis coronata*
	Rhipiliopsis multiplex	*Ganonema codii*
	Sphacelaria chorizocarpa	*Gloiophloea rosea*
		Gymnothamnion nigrescens
		Herposiphonia pectinella
		Hormophora australasica
		Kallymenia rubra
		Lithothamnion indicum
		Macrothamnion acanthophorum
		Macrothamnion pectenellum
		Myrionema ramulans
		Nereia lophocladia
		Nitophyllum fallax
		Phitymophora hypoglossum
		Platyclinia crenulata
		Pterocladiella minima
		Schizoseris hymenena
		Vaucheria glomerata

Table 7.3 Rare macroalgae recorded from marine sanctuary zones in southern Australia. Currently no sanctuary zones exist in South Australia with rare macro-algae known within their boundaries.

From the viewpoint of conservation management of a marine park network that meets Australia's national and international obligations for marine protection, the design principles applied for selecting species, ecosystems or areas for conservation are either biophysical, or relate to community interactions for multiple-use marine protected areas. They can include:

- precautionary principle; a risk management tool requiring action in areas of incomplete scientific knowledge;
- adequacy principle; providing for both ecosystem integrity and the viability of whole populations of species so that biodiversity is safeguarded;
- comprehensiveness principle;
- representativeness principle;
- resilience and vulnerability principle; providing for biota vulnerable to disturbance, or low capacity to recover from pressure;
- ecological importance principle; concentrating on species of high ecological importance;
- connectivity of marine park networks principle; contributing to protected corridors across the land–sea interface; and spreading the risk that may exist in isolated MPAs;
- complementing existing management principle; accommodating ongoing management;
- consideration of the full diversity of marine park uses;
- consideration of cultural heritage;
- ensuring ease of identification, compliance and enforcement;
- provision for education, appreciation and recreation.

The importance of rare, range-restricted and endemic species is generally accepted in the siting of protected areas, particularly in relation to the adequacy and representativeness principles (Roberts et al. 2003). With respect to the current work on rare macroalgae, future research could include comprehensive macroalgal surveys of the existing MPAs, both to confirm rare species occurrence, and to gather ecological data required by conservation managers to address the marine park design principles. For marine algae this includes information about occurrence, habitat, seasonality, life history phases, dispersal and any discernible threats – data that are presently often anecdotal or nonexistent (Brodie et al. 2009). Such a 'near absence of empirical studies' for marine biota in general (Edgar 2011), highlights the broadscale deficiencies in trying to address the adequacy principle.

In their study of MPAs of the southern African coast, Anderson *et al.* (2009) demonstrated the usefulness of reliable species-level distribution data for marine conservation planning. Although their study did not include rare species (species that are extremely uncommon at any locality) they concluded that the eight MPAs were well-sited along the coast and captured (conserved) the full biogeographic ranges of seaweeds.

7.3 Environmental domains that favour rare species

There are particular environments and distinct environmental extremes that favour high proportions of rare species. Extremes of sand substratum, nitrate, phosphate, and chlorophyll-*a* were found to be associated with high proportions of rare species. Overall, the analyses suggested that rare species are predominantly associated with low-nutrient environments (low phosphate, nitrate and chlorophyll-*a*) or a high level of wave exposure (high sand substrate), whereas highly productive waters appear to be bereft of rare species. Other biotic or abiotic variables may prove useful in future analyses. For example, fetch-based exposure indices have been used for quantifying exposure on shallow reefs and were significant predictors of algal patterns, explaining up to 37% of the variance associated with the occurrence and cover of algal genera (Hill et al. 2010).

There are implications for policy and planning of conservation areas in the present work, considering that comprehending and predicting patterns of biodiversity is becoming an important tool for agencies responsible for conservation management (Guisan et al. 2006, Franklin 2010). Site and habitat conservation may be the ultimate means to safeguard species that are intrinsically rare, whereas species that are rare due to extrinsic or anthropogenic causes (pollution, overexploitation, physical alteration of habitat, alien species, climate change) require a conservation approach that addresses the specific threat(s).

Given opportunity and resources to survey regions traditionally difficult for submarine access, either by direct or remote observation and sampling, there are still chances to find rare or new species in remote habitats, unique environments or extreme environments. Such work may also show that species thought to be rare are in fact common. An important future direction for investigating rare species rests in empirical studies—validating occurrence, abundance and seasonality of algae—which would allow more accurate models of species distributions and centres of rarity given that such models would then be based on more comprehensive data than are currently available.

7.4 Field studies and novel find

Field studies

Through the field survey component of the study (111 underwater visual censuses) I have verified specific sites of rare species occurrence. Of the 489 species recorded in the survey, I found sixteen rare species and verified three records from previously known sites, as well as seven from new sites that represent range extensions. Not being able to re-locate rare species at locations from which they are previously known cannot be interpreted as their disappearance from the area. It is more likely that, through happenstance, rare species were not encountered during survey time or that plants were present at the sites only in a microscopic life-history phase, beyond detectability.
The range extensions reported in the current study certainly add to the overall knowledge bank of macroalgal species distributions. It is impossible to determine if these range extensions are consequences of species range-shift in response to changes in climate or habitat conditions, because of the paucity of baseline distribution data. This paucity of data should however in no way detract from the institutional strengths of museums, herbaria, zoological and botanical gardens, and the information they currently hold (Hardwick et al. 2011). Certainly the underwater surveys have contributed to the records of rare species, in some cases (e.g. *Amansia mamillaris, Cryptonemia wilsonii*) filling in gaps of otherwise disjunct populations.

The areas I recommend for comprehensive algal survey are the ‘centres of rarity’ and in environments considered rare or extreme (as identified in Chapters 3 & 4). Because of the high proportions of rare species occurring around Port Phillip Heads VIC, and the D’Entrecasteaux Channel TAS, I speculate that coastal embayments and large estuarine systems with similar features to these two areas, for example Port Davey TAS, American River SA and Walpole–Nornalup Inlet WA are likely additional habitats for rare species, and worthy of comprehensive algal survey.

Novel find

The discovery a novel taxon (*Entwisleia bella* gen. et sp. nov.) contributes to our knowledge of local flora of the Derwent Estuary, south east Tasmania. In both the Derwent and nearby Huon Estuaries there are sandy seagrass habitats as well as high-profile reefs that support rich and complex biological communities and the regions are highly productive and have high conservation value (SOE 2009).

Entwisleia has morphological similarities to both freshwater and marine red algae and its discovery represents an interesting discovery that may resolve some phylogenetic questions in the red algae, due to morphological similarities to various members of the Orders Colaconematales, Balliales, Batrachospermales and Nemaliales.

Morphological study of algal vegetative and reproductive structure has been the primary approach for resolving relationships among genera and families of red algae. Yet there is a heavier reliance on genetic tools for molecular-assisted alpha taxonomy (Garbary and Gabrielson 1990, Saunders 2005a, Verbruggen et al. 2010). Further research using a molecular approach to elucidate the ordinal placement of the new entity is currently underway (G.W. Saunders pers. comm.).

7.5 Concluding remarks

Further work is required to appropriately understand the distribution of southern Australian rare marine algae. The novel find of *Entwisleia* highlights the huge data deficiencies that remain in the distributions of rare species and phylogeny of specific algal groups (e.g. the “primitive” red algae). The gap between what is known of terrestrial and marine flora is so great that the modest survey work for this current thesis has revealed what is certainly a new family and probably a new order of algae. For this project I have been working on the known rare algae yet there are probably many more unknown rare species that represent a significant pool of biodiversity. My work has suggested where they might be found.

Specific ecological functions of rare or little-known algae are virtually unknown, but it is possible that they offer a degree of genetic biodiversity in coastal ecosystems that can act as a buffer to climate change response. Marine plants are more likely to be threatened by processes such as sedimentation, eutrophication, climate change, or invasive species than by fishing, although changes in fauna caused by fishing can affect algal species. To maximise protection efforts for marine macroalgae it is important to consider a wide range of anthropogenic causes that could affect rare species' or communities' health and longevity.

This study has been aimed at contributing one small step in the process of safeguarding rare macroalgae. Considerable further scientific study of life-history, ecology and distribution of rare marine flora is clearly needed to provide stronger protection of this subset of Australia's marine biodiversity, as is the application of novel and appropriate management actions.

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Appendix 1 (appendix for chapter 1)

Categories and criteria for extinction risk for Australian Commonwealth and State agencies.

AUSTRALIA

At the Commonwealth level threatened species may be placed in one of five categories which indicate their level of extinction risk. These were developed by the International Union for Conservation of Nature and Natural Resources (IUCN). At the Commonwealth level these species are listed in the *Environment Protection and Biodiversity Protection Act 1999.* The five categories or risk codes are listed in order of decreasing seriousness:

Extinct (ex)
Extinct In The Wild (ew)
Critically Endangered (cr)
Endangered (en)
Vulnerable (vu)

Extinct (EX): Where a species has not definitely been located in the wild for the past 50 years. A well known Tasmanian example is the thylacine. The last recorded, proven sighting was in 1936. Since then we have had many reported sightings, often dozens a year. However none of the thylacine sightings has been confirmed, so it is presumed extinct and under the IUCN category can be listed as officially extinct.

Extinct In The Wild (EW): This is when a species cannot be found living in the wild despite exhaustive surveys, but is still known to exist in captivity.

Critically Endangered (CR): In this case a species is in extreme danger of becoming extinct in the immediate future. A species is placed in this category if:

- it has undergone, is suspected to have undergone or is likely to undergo in the immediate future a very severe reduction in numbers;
- its geographic distribution is precarious for the survival of the species and is very restricted;
- the estimated total number of mature individuals is very low and (a) evidence suggests that the number will continue to decline at a very high rate or (b) the number is likely to continue to decline and its geographic distribution is precarious for its survival;
- the estimated total number of mature individuals is extremely low;
- the probability of its extinction in the wild is at least 50% in the immediate future.

Endangered (EN): A species at very high risk of becoming extinct in the near future. A species is placed in this category if:

- it has undergone, is suspected to have undergone or is likely to undergo in the immediate future a severe reduction in numbers;
- its geographic distribution is precarious for the survival of the species and is restricted;
- the estimated total number of mature individuals is low and (a) evidence suggests that the number will continue to decline at a high rate or (b) the number is likely to continue to decline and its geographic distribution is precarious for its survival;
- the estimated total number of mature individuals is very low;
- the probability of its extinction in the wild is at least 20% in the immediate future.

Vulnerable (VU): A species is facing a high risk of extinction in the medium term future. A species is placed in this category if:

- it has undergone, is suspected to have undergone or is likely to undergo in the immediate future a substantial reduction in numbers;
- its geographic distribution is precarious for the survival of the species and is limited;
- the estimated total number of mature individuals is limited and (a) evidence suggests that the number will continue to decline at a substantial rate or (b) the number is likely to continue to decline and its geographic distribution is precarious for its survival;
- the estimated total number of mature individuals is low;
- the probability of its extinction in the wild is at least 10% in the immediate future.

COSEMA

Overview of the Conservation Status of Australian Marine Macroalgae, and an associated website COSEMA (last updated 2002) (Cheshire, Collings et al. 2000). The report encompassed both microalgae and macroalgae based on distribution data and species information available up to 2000. The nominated categories of conservation status used in COSEMA were based on the number of known collecting localities, plus estimates of range.

Categories (& critera): VU = Vulnerable (recorded from 5 or fewer locations), VNR = Vulnerable with Narrow Range (recorded from 5 or fewer locations not more than 500 km apart), VPE = Vulnerable and Potentially Endangered (recorded from 5 or fewer locations not more than 500 km apart).

WESTERN AUSTRALIA

Wildlife Conservation Act 1950

Department of Environment and Conservation Threatened Flora Rankings
Current at December 2010

CR = Critically Endangered, EN = Endangered, VU = Vulnerable and EX = Presumed Extinct.

EPBC Rank lists status under the Commonwealth *Environment Protection and Biodiversity Conservation Act 1999.* Threatened fauna and flora may be listed in any one of the following categories as defined in Section 179 of the *Environment Protection and Biodiversity Conservation Act 1999* (EPBC Act), as follows:

(1) A native species is eligible to be included in the **extinct** category at a particular time if, at that time, there is no reasonable doubt that the last member of the species has died.

(2) A native species is eligible to be included in the **extinct in the wild** category at a particular time if, at that time:

(a) it is known only to survive in cultivation, in captivity or as a naturalised population well outside its past range; or
(b) it has not been recorded in its known and/or expected habitat, at appropriate seasons, anywhere in its past range, despite exhaustive surveys over a time frame appropriate to its life cycle and form.

(3) A native species is eligible to be included in the **critically endangered** category at a particular time if, at that time, it is facing an extremely high risk of extinction in the wild in the immediate future, as determined in accordance with the prescribed criteria.

(4) A native species is eligible to be included in the **endangered category** at a particular time if, at that time:

(a) it is not critically endangered; and
(b) it is facing a very high risk of extinction in the wild in the near future, as determined in accordance with the prescribed criteria.

(5) A native species is eligible to be included in the **vulnerable category** at a particular time if, at that time:

(a) it is not critically endangered or endangered; and
(b) it is facing a high risk of extinction in the wild in the medium term future, as determined in accordance with the prescribed criteria.

(6) A native species is eligible to be included in the **conservation dependent** category at a particular time if, at that time:

(a) the species is the focus of a specific conservation program the cessation of which would result in the species becoming vulnerable, endangered or critically endangered; or
(b) the following subparagraphs are satisfied:

(i) the species is a species of fish;
(ii) the species is the focus of a plan of management that provides for management actions necessary to stop the decline of, and support the recovery of, the species so that its chances of long term survival in nature are maximised;
(iii) the plan of management is in force under a law of the Commonwealth or of a State or Territory;
(iv) cessation of the plan of management would adversely affect the conservation status of the species.

(7) In subsection (6):

fish includes all species of bony fish, sharks, rays, crustaceans, molluscs and other marine organisms, but does not include marine mammals or marine reptiles.

Species listed as 'conservation dependent' and 'extinct' are not matters of national environmental significance and therefore do not trigger the EPBC Act.

SOUTH AUSTRALIA

A **species** is often defined as a group of organisms capable of interbreeding and producing fertile offspring. A **population** is all the organisms that both belong to the same species and live in the same geographical area. Many of our species are found nowhere else in the world; we call these species 'endemic'.

Threatened species are those plant and animal species considered to be at risk of extinction in the wild. There are different scales for how a species may be considered threatened:

- on a global scale
- on a national scale
- on a state scale
- on a regional and local scale.

In South Australia, threatened species are given formal legal recognition under the National Parks and Wildlife Act 1972 as Endangered, Vulnerable or Rare.

Regional Species Conservation Assessment Project

In South Australia, a Regional Species Conservation Assessment Project adopts the IUCN Red List Categories and Criteria

VICTORIA

Legend for Bioregional Conservation Status of Ecological Vegetation Classes (EVC)

Status		Criteria
Presumed Extinct	**X**	Probably no longer present in the bioregion (the accuracy of this resumption is limited by the use of remotely - sensed 1:100 000 scale woody vegetation cover mapping to determine depletion - grassland, open woodland and wetland types are particularly affected).
Endangered	**E**	Contracted to less than 10% of former range; OR Less than 10% pre-European extent remains; OR Combination of depletion, degradation, current threats and rarity is comparable overall to the above: 10 to 30% pre-European extent remains and severely degraded over a majority of this area; or naturally restricted EVC reduced to 30% or less of former range and moderately degraded over a majority of this area; or rare EVC cleared and/or moderately degraded over a majority of former area.
Vulnerable	**V**	10 to 30% pre-European extent remains; OR Combination of depletion, degradation, current threats and rarity is comparable overall to the above: greater than 30% and up to 50% pre-European extent remains and moderately degraded over a majority of this area; or greater than 50% pre-European extent remains and severely degraded over a majority of this area; or naturally restricted EVC where greater than 30% pre-European extent remains and moderately degraded over a majority of this area; or rare EVC cleared and/or moderately degraded over a minority of former area.
Depleted	**D**	Greater than 30% and up to 50% pre-European extent remains; OR Combination of depletion, degradation and current threats is comparable overall to the above and: greater than 50% pre-European extent remains and moderately degraded over a majority of this area.
Rare	**R**	Rare EVC (as defined by geographic occurrence) but neither depleted, degraded nor currently threatened to an extent that would qualify as Endangered, Vulnerable or Depleted.
Least Concern	**LC**	Greater than 50% pre-European extent remains and subject to little to no degradation over a majority of this area.

TASMANIA

Department of Primary Industry, Water and the Environment

http://www.dpiw.tas.gov.au/intertext.nsf/WebPages/RLIG-5433LB?open#TasmanianStatusAt the (Tasmanian) State level, threatened species may be placed in one of four categories which indicate their level of extinction risk. There are Guidelines for the listing of species under the Tasmanian *Threatened Species Protection Act 1995.* The four categories or risk codes are listed in order of decreasing seriousness:

Extinct (x): Those species presumed extinct.

Endangered (e): Those species in danger of extinction because long term survival is unlikely while the factors causing them to be endangered continue operating.

Vulnerable (v): Those species likely to become endangered while the factors causing them to become vulnerable continue operating.

Rare (r): Those species with a small population in Tasmania that are at risk.

Appendix 2 (appendix for Chapter 2)

Algal taxa excluded from the present study— comments on southern Australian marine macroalgae known from few records or from restricted habitats, excluded from current study; source of data Womersley (2005).
Size categories (Womersley 2005); ma = macroscopic; mi = minute; ep = epiphytic
Abundance at known locality (Womersley 2005); u = rare (or unknown); p = plentiful
Collections; Known collections (Womersley 2005); OLD = only records are 50+ years old, but not necessarily extinct or endangered
Reason for exclusion from current study (FJS); O/S = recorded from overseas (external to Australian continental plate); >5 = more than 5 localities now known; AE = accidental exclusion.

Taxon	**size**	**abund-ance**	**collections**	**reason for exclusion**
Bryopsis minor Womersley	ma	u	American River Inlet, Kangaroo I.; Port MacDonnell?	>5
Cladophora rhizocloniodea van den Hoek & Womersley	ma-ep	u	Nora Creina; Rottnest I.; West I.; Nelson; Warrnambool; Georgetown	>5
Uronema marinum Womersley	mi-ep	p	Coffin Bay; Rottnest I.	O/S
Urospora pencilliformis (Roth) Areschoug	mi	u	Eaglehawk Neck; Arctic; Antarctic	O/S
Colpomenia ecuticulata Womersley & Skinner	ma	p	Port MacDonnell	O/S
Discosporangium mesathrocarpum (Meneghini) Hauck	ma-ep	u	Grange; Glenelg	O/S
Gononema ramosum (Skottsberg) Kuckuck & Skottsberg	mi-ep	u	Safety Cove; Tasmania; Macquarie I.	O/S
Sargassum flindersii (intended Womersley 2004)	ma	u	West coast of Eyre Peninsula	(Synonym of *S. kendrickii*)
Scorsbyella profunda Womersley	ma	u	Isles of St Francis to Yorke Peninsula	AE
Sphacelaria spuria Sauvageau	ma-ep	u	Port Phillip	AE

Sphacella subtilissima Reinke	mi-ep	u	Pearson I.; Investigator Strait	O/S
Acrosymphyton taylorii Abbott	ma	u	Isles of St Francis	O/S
Acrosorium minus (Sonder) Kylin	ma	u	Fremantle and nearby	>5
Acanthophora dendroides Harvey	ma	u	Denial Bay (trop. Australia)	O/S
Anothrichium subtile Baldock	ma	u	Semaphore; Port Phillip; Botany Bay	AE
Anothrichium towinna Baldock	ma	u	Coffin Bay; Saunders Beach, Muston Kangaroo I	AE
Bornetia tenuis Baldock & Womersley	ma	u	Adelaide beaches; Victor Harbour; Port Phillip	O/S
Botryoglossum cartilagineum (Harvey & Greville) Papenfuss	ma	u	Head of the Great Australian Bight; Dongara	AE
Callithamnion pinnatum Womersley	ma	u	Port Phillip Heads; Warrnambool; Isles of St Francis	AE
Caloglossa ogasawarensis Okamura	ma	u	Port Adelaide; Garden Island	O/S
Ceramium wilsonii Womersley	ma	u	Port Phillip Heads	OLD
Chamaethamnion schizandra Falkenberg	mi-ep	u	Grange; Brighton (SA)	O/S
Chondria lanceolata Harvey	ma	u	Rottnest Is.; Scott Bay	>5
Chondria subsecunda Gordon-Mills & Womersley	am	u	Warrnambool; Port MacDonnell	AE
Cottoniella fusiformis Boergesen	ma	u	E Gulf St Vincent	O/S
Episporium centroceratis Moebius	mi-ep	u	Wanna	O/S
Gibsmithia womersleyi Kraft & Ricker ex Kraft	ma	u	Hopetoun; Esperance; Elliston	>5
Gigartina welhiae Sonder	ma	u	Pt Elliot; Portland; Pt Roadknight; Hobart	>5
Gracilariopsis lemanaeiformis (Bory) Dawson et al	ma	p	Robe	O/S
Gymnogongrus griffithsiae (Turner) Martens	ma	u	Vivonne Bay; Pennington Bay; Barwon Heads	O/S
Haraldia australica Womersley	ma	u	Muston; Rocky Point?	OLD

Heterostroma nereidiis Kraft & M.J.Wynne	ma	u	Elliston; Rottnest Is.	Widespread, but apparently rare
Hildenbrandia lecannellieri Hariot	ma	p	Cape Willoughby	O/S
Laurencia distochophila J.Agardh	ma	u	Wine Glass Bay	O/S
Lophosiphonia obscura (C.Agardh) Falkenberg	ma	u	Wallaroo (subtrop.)	O/S
Micropeuce proxima (Harvey) Womersley & M.J. Parsons	ma	u	King George Sound	OLD; assigned to *Micropeuce* with some doubt
Micropeuce sarcocaulon (Harvey) Kylin ex P.C.Silva	ma	u	Fremantle	OLD; assigned to *Micropeuce* with some doubt
Placophora binderi (J.Agardh) J.Agardh	ma	u	Elliston	O/S
Polysiphonia brevisegmata Womersley	mi	u	Elliston, Lord Howe I	O/S (LHI)
Polysiphonia propagulifera Womersley	ma	u	Troubridge Is.; Investigator Strait; Penneshaw	>5
Porphyra woolhousiae Harvey	ma-ep	u	Tasmania; St Kilda?; Mallacoota?	O/S
Porphyridium purpureum (Bory) Drew & Ross	mi-ep	u	West I.	O/S
Rhipidiothamnion secundum Huisman	ma	u	Port Phillip; Glenelg	>5
Scageliopsis patens Wollaston	mi	u	Semaphore to Port Noarlunga	>5
Solieria filiformis (Kuetzing) Gabrielson (as *S. tenera*)	ma	u	Hobsons Bay	O/S
Spongites yendoi (Foslie) Chamberlain	ma	u	Lorne	O/S
Trematocarpus affinis (J. Agardh) de Toni	ma	u	West I.	O/S

Womersley, H. B. S. 2005. Comments on marine benthic algal species known form single or very few records or from restricted habitats in southern Australia. Pages 1-6. State Herbarium, Plant Diversity Centre, Adelaide. unpublished.

Appendix 3 (appendix for Chapter 5– Field Data)

Raw data from Underwater Visual Census (UVC) surveys

- Survey number
- Site name
- MPA zones and status with respect to harvesting: FT = Full take, RT = Restricted take, NT = No take
- Survey date
- Site location (latitude, longitude, GDA 94)
- Survey depth (metres)

Data are in the form of presence only records (1 = seen; blank = not seen).

Rare species names are in bold type face and highlighted in grey.

Survey number	SITE NAME	MPA Zone	Full/Restricted/No Take	Date	Latitude	Longitude	depth (m)
1	Shepherds (1)	n/a	FT	18/11/2008	-43.08944	147.30101	11.2
2	NW Bay (near Gunpowder Jetty) (2)	n/a	FT	18/11/2008	-43.05753	147.31147	7.8
3	Bligh Pt (3)	n/a	FT	19/11/2008	-43.08396	147.32294	11
4	Tinderbox (4)	Sanctuary	NT	19/11/2008	-43.05688	147.33748	13.1
5	Nine Pin (5)	Sanctuary	NT	26/11/2008	-43.27912	147.18317	9.2
6	Charlotte Cove Light (6)	n/a	FT	26/11/2008	-43.27311	147.14354	7.5
7	Satellite I (7)	n/a	FT	8/12/2008	-43.32163	147.22935	6.1
8	Simpsons Pt (8)	n/a	FT	8/12/2008	-43.24900	147.28825	9.9
9	Southport (9)	n/a	FT	9/12/2008	-43.46099	146.99550	9.5
10	Partridge I (10)	n/a	FT	11/12/2008	-43.40293	147.10431	6.4
11	Huon Pt (11)	n/a	FT	11/12/2008	-43.28310	147.10087	6.6
12	Piersons Pt (12)	Sanctuary	NT	19/03/2009	-43.05204	147.34385	6.4
13	Lucas Pt (13)	n/a	FT	19/03/2009	-43.03831	147.33904	7.4
14	Tinderbox "central" (14)	Sanctuary	NT	20/03/2009	-43.05895	147.33257	6.3
15	Dennes Pt (15)	n/a	FT	20/03/2009	-43.06289	147.35082	5.7
16	Charlotte Cove (16)	n/a	FT	1/04/2009	-43.27219	147.14244	6.4
17	Nine Pin Pt (17)	Sanctuary	NT	1/04/2009	-43.28417	147.16668	4.7
18	Huon I (18)	n/a	FT	1/04/2009	-43.29370	147.14115	6.3
19	Outer Saddle Bight Port Davey (19)	Habitat	RT	21/04/2009	-43.31817	145.87360	10.5
20	Inner Saddle Bight SW (20)	Sanctuary	NT	21/04/2009	-43.31234	145.89600	9.4
21	Inner Saddle Bight SW (21)	Sanctuary	NT	22/04/2009	-43.31224	145.98644	10
22	South Whalers Pt (22)	Habitat	RT	22/04/2009	-43.30344	145.91704	11.1
23	Mutton Bird I (23)	n/a	FT	23/04/2009	-43.42191	145.96959	10.2
24	Mutton Bird I (24)	n/a	FT	23/04/2009	-43.41674	145.97122	6.1
25	West Pyramid Rock (25)	n/a	FT	25/04/2009	-43.29735	145.81958	11.4
26	Sharks Jaw Gulch (26)	n/a	FT	25/04/2009	-43.30943	145.84282	11.4
27	Norman Cove (27)	Habitat	RT	26/04/2009	-43.36957	145.93304	13.3
28	Spain Bay (28)	Habitat	RT	26/04/2009	-43.36115	145.95784	6.8
29	Milner Head (29)	Sanctuary	NT	26/04/2009	-43.32276	145.98651	6.8
30	South Channel Head (30)	Sanctuary	NT	27/04/2009	-43.32943	145.98819	6.2
31	Turnbull I (31)	Sanctuary	NT	27/04/2009	-43.33143	145.99562	8.3
32	Green Bluff (32)	n/a	FT	11/05/2009	-42.72018	148.01164	6.6
33	Painted Cliffs (33)	Sanctuary	NT	13/05/2009	-42.59235	148.05067	5.5
34	Okehampton (34)	n/a	FT	13/05/2009	-42.52454	147.96992	8
35	Karitane Bay east (35)	Habitat	RT	23/06/2009	-39.49284	147.34212	12.7
36	Karitane Bay east (36)	Habitat	RT	23/06/2009	-39.49501	147.33067	6.2
37	Dover I (37)	Sanctuary	NT	24/06/2009	-39.46529	147.28712	10.6
38	Dover I (38)	Sanctuary	NT	24/06/2009	-39.46529	147.28712	7.7
39	Erith I (39)	Sanctuary	NT	25/06/2009	-39.44466	147.30128	9.7
40	Dover I isthmus (40)	Sanctuary	NT	25/06/2009	-39.46482	147.29480	9.2
41	Hogan I (41)	n/a	FT	26/06/2009	-39.21919	146.99583	11.7
42	Hogan I (42)	n/a	FT	26/06/2009	-39.21913	146.99231	8.3
43	Tunnel Beach (43)	n/a	FT	27/06/2009	-39.22600	146.97958	10.9
44	Tunnel Beach (44)	n/a	FT	27/06/2009	-39.22600	146.97958	6.8
45	East I (45)	n/a	FT	27/06/2009	-39.21384	147.02145	5.5
46	Erith I north (46)	Sanctuary	NT	28/06/2009	-39.44375	147.28526	10.4
47	Erith I north-west (47)	Sanctuary	NT	28/06/2009	-39.44364	147.27716	6.4
48	Jetty Bay (48)	Sanctuary	NT	30/06/2009	-39.46922	147.31026	7.2
49	North East I (49)	Habitat	RT	29/06/2009	-39.44680	147.37689	10
50	Green I (50)	Sanctuary	NT	24/07/2009	-32.01774	115.49950	13.3
51	The Count (51)	Recreation	RT	24/07/2009	-32.01458	115.55802	7.2
52	Eagle Bay (52)	Recreation	RT	25/07/2009	-32.01805	115.45234	5.1
53	Little Parakeet Bay (53)	Sanctuary	NT	25/07/2009	-31.98888	115.51793	7.7
54	Crystal Palace (54)	Recreation	RT	26/07/2009	-32.02539	115.54514	17.1
55	Pocillopora Reef (55)	Sanctuary	NT	26/07/2009	-32.02446	115.52979	12.3
56	Green Island Wall (56)	Sanctuary	NT	27/07/2009	-32.02472	115.50535	10.5

Survey number	Acanthophora dendroides	Acrocarpia paniculata	Acrocarpia robusta	Acrosorium ciliolatum	Acrotylus australis	Aeodes nitidissima	Aglaothamnion obstipum	**Amansia mamillaris**	Amphibolis antarctica	Amphibolis griffithii	Amphiroa anceps	Amphiroa foliacea	Amphiroa gracilis	Anotrichium crinitum	Anotrichium elongatum	Anotrichium tenue	Anotrichium (FJS 5357 sp. inc	**Antithamnion biarmartum**	Antithamnion delicatulum	Antithamnion gracilentum	Antithamnion hanoviodes	Antithamnion pectinatum	Antithamnion pinnafolium
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Survey number	Callipsygma wilsonis	Callithamnion caulescens	Callithamnion violaceum	Callithamnion (FJS 6502 sp. i	Callophycus harveyanus	Callophycus laxus	Callophycus oppositifolius	Callophyllis cervicornis	Callophyllis lambertii	Callophyllis rangiferina	Camontagnea oxyclada	Capreolia implexa	Carpoglossum confluens	Carpomitra costata	Carpopeltis phyllophora	Carpothamnion gunnianum	Caulerpa annulata	Caulerpa brownii	Caulerpa cactoides	Caulerpa distichophylla	Caulerpa flexilis	Caulerpa flexilis var. muelleri	Caulerpa geminata
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Survey number	Caulerpa hedleyi	Caulerpa hodgkinsoniae	Caulerpa longifolia	Caulerpa obscura	Caulerpa racemosa	Caulerpa racemosa var. laetiv	Caulerpa remotifolia	Caulerpa scalpelliformis	Caulerpa sedoides f. geminat	Caulerpa simpliciuscula	Caulerpa trifaria	Caulerpa vesiculifera	Caulocystis cephalornithos	Caulocystis uvifera	Ceramium cliftonianum	Ceramium excellens	Ceramium flaccidum	**Ceramium lenticulare**	Ceramium macilentum	Ceramium monocanthum	Ceramium pusillum	Ceramium rubrum	Ceramium tasmanicum
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Survey number	Chaetomorpha aerea	Chaetomorpha coliformis	Chaetomorpha megalonium	Champia insignis	Champia stipitata	Champia viridis	Champia zostericola	Cheilosporum sagittatum	Chlorodesmis baculifera	Chondria angustissima	Chondria curdieana	Chondria harveyana	Chondria incrassata	Chondria subfasiculata	Chondria succulenta	Chordaria cladosiphon	**Cirrulicarpus polycoelioides**	Cladophora bainesii	Cladophora billardierii	Cladophora feredayi	Cladophora lehmanniana	Cladophora prolifera	Cladophora vagabunda
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Survey number	Cladosiphon filum	Cladosiphon vermicularis	Cladostephus spongiosus	Cladurus elata	Chlanidophora microphylla	Codiophyllum decipiens	Codiophyllum flabelliforme	Codium apiculatum	Codium australicum	Codium dimorphum	Codium duthiae	Codium fragile	Codium galeatum	Codium harveyi	Codium lucasii	Codium mamillosum	Codium pomoides	Codium spinescens	Codium spongiosum	Coeloclonium tasmanicum	Coeloclonium verticillatum	Colpomenia peregrina	Colpomenia sinuosa
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Survey number	Corallina officinalis	Corynomorpha prismatica	Craspedocarpus blephicarpus	Craspedocarpus ramentaceus	Crouania mucosa	cc Crustose coralline algae	Cryptonemia kallymenioides	**Cryptonemia wilsonii**	Curdiea angustata	Curdiea irvineae	Curdiea obesa	Cutleria multifida	Cystophora congesta	Cystophora expansa	Cystophora grevillei	Cystophora monilifera	Cystophora moniliformis	Cystophora pectinata	Cystophora platylobium	Cystophora racemosa	Cystophora retorta	Cystophora retroflexa	Cystophora siliculosa
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Survey number	Cystophora subfarcinata	Cystophora torulosa	Cystophora xiphocarpa	Cystoseira trinodis	Dasya ceramioides	Dasya clavigera	Dasya crescens	Dasya divergens	Dasya haffiae	Dasya naccarioides	Dasya villosa	Dasyclonium harveyanum	Dasyclonium incisum	Dasythamniella latissima	Dasythamniella plumigera	Delisea elegans	Delisea hypneoides	Delisea plumosa	Delisea pulchra	Derbesia tenuissima	Desmarestia ligulata	Deucalion levringii	Dicranema revolutum
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Survey number	Dictyomenia harveyana	Dictyomenia sonderi	Dictyomenia tridens	Dictyopteris acrostichoides	Dictyopteris muelleri	Dictyopteris nigricans	Dictyopteris plagiogramma	Dictyosphaeria seriecea	Dictyota dichotoma	Dictyota dichotoma var. intrica	Dictyota diemensis	Dictyota furcellata	Dictyota prolifera	Dilophus gunnianus	Distromium flabellatum	Ditria expleta	Durvillaea potatorum	Echinothamnion hookeri	Echinothamnion hystrix	Ecklonia radiata	Ectocarpos siliculosa	Elachista orbicularis	Encyothalia cliftonii
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Survey number	Enteromorpha compressa	Epiglossum proliferum	Epiglossum smithiae	Epiphloea bullosa	Erythroclonium muelleri	Erythroclonium sonderi	Erythrotrichia carnea	Erythrymenia minuta	Euptilota articulata	Exallosorus olsenii	FS 5394 (red sp. indet.)	**FS 5425 (Entwisleia bella)**	FS 5640 (red. sp. indet.)	FS 5811 (red sp. indet.)	FS 5872 (indet red)	FS 6055 (indet red)	FS 6145 (indet red)	FS 6449 (indet red)	FJS 6465 (indet green)	Galaxaura marginata	Galaxaura obtusata	Ganonema farinosum	Glaphrymenia pustulosa
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Survey number	Gelidium apserum	Gelidium australe	Gelidium crinale	Gelidium pusillum	Gelinaria ulvoidea	Gigartina muelleriana	Gigartina pinnata	Gigartina recurva	Glaphrymenia pustulosa	Gloiocladia australis	Gloiocladia halymenioides	Gloioderma polycarpum	Gloiophloea sciniaioides	Gloiosaccion brownii	Glossophora nigricans	Gracilaria cliftonii	Gracilaria preissiana	Gracilaria ramulosa	Gracilaria secundata	Grateloupia filicina	Grateloupia intestinalis	Grateloupia pectinata	Grateloupia (FS 5427 sp. inde
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Survey number	Grateloupia (FS 5640 sp. inde	Griffithsia crassiuscula	Griffithsia gunniana	Griffithsia monilis	Griffithsia teges	Halicnide similans	Halimeda cuneata	Haliptilon roseum	Halopeltis australis	Halopeltis cuneata	**Halopeltis cuneata**	Halopeltis prostrata	Halopeltis verrucosa	Halophila australis	Halophila ovalis	Haloplegma preissii	Halopteris novae-zelandiae	Halopteris paniculata	Halymenia floreseia	Halymenia kraftii	Halymenia muelleri	Halymenia plana	Haraldophyllum (FS 5658 sp.
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Survey number	Hemineura frondosa	Hennedya crispa	Herposiphonia calothrix	**Herposiphonia pectinella**	Herposiphonia versicolor	Heterodoxia denticulata	Heterosiphonia australis	Heterosiphonia gunniana	Heterosiphonia microcladioide	Heterosiphonia muelleri	Heterozostera tasmanica	Hincksia mitchellae	Hincksia sordida	Hormosira banksii	Hydroclathrus clathratus	Hymenena affinis	Hymenena multipartita	Hymenocladia usnea	Hypnea charoides	Hypnea musciformis	Hypnea pannosa	Hypnea ramentacea	Hypnea valentiae
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Survey number	Hypoglossum armatum	Hypoglossum heterocystideur	Inkyuleea mariana	Jania micrarthrodia	Kallymenia cribrosa	Laurencia arbuscula	Laurencia botryoides	Laurencia brongniartii	Laurencia clavata	Laurencia elata	Laurencia filiformis	Laurencia forsteri	Laurencia majuscula	Laurencia tasmanica	Lenormandia marginata	Lenormandia muelleri	Lenormandia pardalis	Leptophyllis conferta	Leptosomia rosea	Lessonia corrugata	Liagora wilsoniana	Lobophora variegata	Lobospira bicuspidata
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Survey number	Lomentaria australis	Lophothalia hormoclados	Macrocystis angustifolia	Macrocystis pyrifera	**Macrothamnion pectenellum**	Malaconema roeanum	Martensia elegans	Martensia fragilis	Mastophoropsis canaliculata	Medeiothamnion protensum	Medieothamnion (FS 5327 sp	Melanema dumosum	Melanthalia abscissa	Melanthalia coccinna	Melanthalia obtusata	Mesophyllum incisum	Metagoniolithon chara	Metagoniolithon radiatum	Metagoniolithon stelliferum	Metamastophora flabellata	Microcoleus lyngbyaceus	Mychodea acanthymenia	Mychodea aciculare
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Survey number	Mychodea carnosa	Mychodea disticha	Mychodea marginifera	Myriogramme gunniana	Neurymenia fraxinofolia	Nitophyllum crispum	Nitospinosa tasmanica	Nizymenia australis	Nizymenia conferta	Ochmapexus minimus	Padina elegans	Padina gymnospora	Peltasta australis	Perithalia caudata	Petalonia fascia	Peyssonnelia capensis	Peyssonnelia novae-hollandia	Phacelocarpus alatus	Phacelocarpus apodus	Phacelocarpus complanatus	Phacelocarpus peperocarpos	Phitymophora amansioides	Phloiocaulon spectabile
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Survey number	Phyllospora comosa	Phymatolithon masonianum	Platoma foliosa	Platysiphonia delicata	Platysiphonia victoriae	Platythalia angustifolia	Plocamium angustum	Plocamium cartilagineum	Plocamium costatum	Plocamium dilatatum	Plocamium leptophyllum	Plocamium mertensii	Plocamium patagiatum	Plocamium priessianum	Pollexfenia lobata	Polycoelia laciniata	Polyopes constrictus	Polyopes tasmanicus	Polyopes tenuis	Polysiphonia blandii	Polysiphonia brodiei	Polysiphonia crassiuscula	Polysiphonia decipiens
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Survey number	Polysiphonia infestans	Polysiphonia scopulorum	Polysiphonia subtilissima	Porphyra columbina	Porphyra lucasii	Porphyra woolhousiae	Posidonia australis	Posidonia sinuosa	Pterocladia capillacea	Pterocladia lucida	**Pterothamnion aciculare**	Pterothamnion (FS 5336 sp. i	Ptilocladia australis	Ptilocladia crouanioides	Ptilonia australasica	Ptilophora prolifera	Ptilothamnion subsimplex	Punctaria latifolia	Rhabdonia coccinea	Rhiplia (sp. indet)	**Rhipiliopsis multiplex**	Rhodoglossum gigartinoides	Rhodopeltis australis
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Survey number	Rhodopeltis borealis	Rhodophyllis gunnii	Rhodophyllis membranacea	Rhodophyllis multipartita	Rhodophyllis volans	Rhodymenia leptophylla	Rhodymenia obtusa (correct)	Sarcodia marginata	Sarcothalia radula	Sarcotrichia dolichocystidea	Sargassum decipiens	Sargassum decurrens	Sargassum distichum	Sargassum fallax	Sargassum heteromorphum	Sargassum lacerifolium	Sargassum linearfolium	Sargassum paradoxum	Sargassum sonderi	Sargassum spinguligerum	Sargassum verruculosum	Sargassum vestitum	Scaberia agardhii
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Survey number	**Schizoseris hymenena**	**Schizoseris perrinae**	Schizymenia dubyi	Scinaia tsingalensis	Scytothalia dorycarpa	Seirococcus axillaris	Shepleya australis	Solieria robusta	Sonderopelta coriacea	Spermothamnion cymosum	Sphacelaria reinki	Spongoclonium brownianum	Sporochnus apodus	Sporochnus comosus	Sporochnus radiciformis	Sporochnus stylosus	Spyridia filamentosa	Spyridia tasmanica	Stenogramme interrupta	Stictsiphonia intricata	Struvea plumosa	Stylonema alsidii	Stypopodium flabellatum
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Survey number	Synarthrophyton patena	Thamnoclonium dichotomum	Thuretia quercifolia	Trematocarpus coccinus	Tricleocarpa cylindrica	Trithamnion vulgare	Tsengia feredayae	Tsengia laingii	Tsengia (FS 6472 sp. indet.)	Tylotus obtusatus	Ulva intestinalis	Ulva rigida	Ulva taeniata	Undaria pinnatifida	Veleroa adunca	Ventricaria ventricosa	Wollastoniella myriophylloides	Wrangelia nobilis	Wrangelia (FS 5649 sp. indet.	Xiphophora chondrophylla	Xiphophora gladiata	Zonaria angustata	Zonaria spiralis
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Survey number	Zonaria turneriana	Zostera muelleri	Zymergia chondriopsidea	**No. RARE spp per site**	**No. ALL spp per site**
1				**0**	**29**
2				**0**	**31**
3	1			**2**	**40**
4				**0**	**33**
5	1			**0**	**46**
6				**0**	**40**
7				**1**	**33**
8	1			**0**	**25**
9	1			**1**	**48**
10	1			**0**	**34**
11	1			**0**	**23**
12	1			**1**	**34**
13				**0**	**42**
14	1			**1**	**38**
15				**1**	**32**
16				**0**	**36**
17				**0**	**38**
18	1			**1**	**52**
19				**0**	**35**
20	1			**0**	**28**
21				**0**	**43**
22				**0**	**34**
23				**0**	**38**
24	1			**0**	**37**
25				**0**	**31**
26				**0**	**27**
27				**1**	**31**
28	1			**0**	**22**
29				**0**	**28**
30				**0**	**28**
31	1			**0**	**28**
32	1			**0**	**30**
33	1			**0**	**36**
34	1			**0**	**31**
35				**0**	**35**
36				**0**	**18**
37				**0**	**38**
38				**0**	**24**
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40				**0**	**33**
41	1			**0**	**28**
42				**0**	**36**
43				**0**	**22**
44				**0**	**11**
45	1			**0**	**24**
46	1			**0**	**40**
47				**0**	**18**
48				**0**	**26**
49	1			**0**	**37**
50	1			**1**	**24**
51	1			**0**	**34**
52	1			**0**	**24**
53				**0**	**52**
54	1			**0**	**34**
55	1			**0**	**39**
56	1			**0**	**22**

Survey number	SITE NAME	MPA Zone	Full/Restricted/No Take	Date	Latitude	Longitude	depth (m)
57	Fish Hook Bay (57)	Demersal	RT	27/07/2009	-32.02468	115.45157	12.3
58	Bunker Bay (58)	n/a	FT	29/07/2009	-33.53709	115.03221	2
59	Trywork Reef (59)	n/a	FT	13/11/2009	-42.94022	147.40892	5.1
60	Gellibrand's Grave (60)	n/a	FT	13/11/2009	-42.96646	147.40373	7.3
61	Alum Cliffs central (61)	n/a	FT	14/11/2009	-42.96453	147.34142	5.8
62	Maning Reef (62)	n/a	FT	14/11/2009	-42.90611	147.34470	2.5
63	Hales Farm (63)	n/a	FT	15/11/2009	-43.04371	147.34192	9.1
64	Gypsy Shoal (64)	n/a	FT	15/11/2009	-42.94961	147.41687	12.1
65	Soldiers Rocks South (65)	n/a	FT	25/11/2009	-43.01334	147.33089	4.5
66	Blackmans Bay (66)	n/a	FT	25/11/2009	-43.01720	147.33247	7.2
67	George III Reef (67)	n/a	FT	21/01/2010	-43.50742	146.98469	11.6
68	The Grange (68)	n/a	FT	10/02/2010	-42.93326	147.36162	3.9
69	Crayfish Point (69)	Fisheries	RT	10/02/2010	-42.95207	147.35603	4.6
70	Tranmere Pt (70)	n/a	FT	10/02/2010	-42.93042	147.40926	4.4
71	Alum Cliffs (71)	n/a	FT	11/02/2010	-42.96660	147.34175	7.6
72	Blackmans Bay blowhole (72)	n/a	FT	11/02/2010	-42.99837	147.32967	7.1
73	Battery Point (73)	n/a	FT	11/02/2010	-42.88971	147.33942	2.9
74	White Rock South Arm (74)	n/a	FT	12/02/2010	-42.97745	147.39230	5.2
75	Cornelian Bay (75)	n/a	FT	16/02/2010	-42.85181	147.32785	2.2
76	Geilston Bay (76)	n/a	FT	16/02/2010	-42.84532	147.33737	2.9
77	Montague Bay (77)	n/a	FT	16/02/2010	-42.86165	147.35025	4.6
78	Rosny Point Nth (78)	n/a	FT	16/02/2010	-42.87378	147.35132	3.1
79	Ninepin Pt (79)	Sanctuary	NT	11/03/2010	-43.28409	147.16743	5.6
80	Huon I (80)	n/a	FT	12/03/2010	-43.29404	147.14168	7.1
81	Butts Reef (81)	n/a	FT	15/03/2010	-43.27588	147.12712	7.5
82	Butts Reef (82)	n/a	FT	16/03/2010	-43.27466	147.12695	10.5
83	Garden I (83)	n/a	FT	16/03/2010	-43.26229	147.13287	7.5
84	Spring Bay (84)	n/a	FT	27/04/2010	-42.58376	147.916	7
85	Point Holme (85)	n/a	FT	27/04/2010	-42.5532	147.94638	6
86	Okehampton (86)	n/a	FT	30/04/2010	-42.52401	147.96925	6.1
87	Ile du Nord (87)	n/a	FT	30/04/2010	-42.56167	148.06781	6.5
88	Darlington Jetty (88)	Sanctuary	NT	3/05/2010	-42.57632	148.06232	5.5
89	Magistrates Pt (89)	Sanctuary	NT	3/05/2010	-42.58691	148.05179	6.2
90	Point Leseuer (90)	Sanctuary	NT	5/05/2010	-42.66105	148.00744	5.8
91	Return Point (91)	Sanctuary	NT	5/05/2010	-42.62899	148.02459	6.2
92	Barrel Rock (92)	n/a	FT	12/05/2010	-41.06596	146.79179	5.6
93	Pilots Bay (93)	n/a	FT	12/05/2010	-41.06654	146.79665	2.7
94	Kelso Bay (94)	n/a	FT	13/05/2010	-41.10954	146.80394	2.9
95	Arch Rock (95)	Sanctuary	NT	17/05/2010	-43.28744	147.17945	8.8
96	Queenscliff (96)	n/a	FT	25/06/2010	38.26778	144.66778	2.5
97	Pope's Eye (97)	Sanctuary	NT	26/06/2010	-38.27667	144.69944	10.9
98	Portsea Pothole (98)	Sanctuary	NT	27/06/2010	-38.31140	144.71085	16.4
99	Lonsdale Wall (99)	Sanctuary	NT	27/06/2010	-38.29125	144.63042	25
100	Flinders (100)	n/a	FT	29/06/2010	-38.47578	145.025	4.7
101	Crawfish Rock (101)	Sanctuary	NT	3/07/2010	-38.26995	145.29695	7
102	Huon Pt (102)	n/a	FT	14/07/2010	-43.2836	147.1012	7.7
103	Ninepin Pt (103)	Sanctuary	NT	14/10/2010	-43.28422	147.16733	7.9
104	Waychinicup Inlet (104)	Recreation	RT	28/10/2010	-34.89278	118.33352	2
105	Thompson Bay (105)	Recreation	RT	15/11/2010	-32.00013	115.54622	2
106	Ricey Beach (106)	n/a	FT	17/11/2010	-32.00032	115.4888	2
107	Point Peron (107)	Special	RT	20/10/2010	-32.27142	115.68721	3
108	Two Peoples Bay (108)	n/a	FT	30/10/2010	-34.97174	118.18186	2
109	Canal Rocks (109)	n/a	FT	22/11/2010	-33.66951	114.9955	3
110	Cosy Corner (110)	n/a	FT	24/11/2010	-34.25767	115.02658	6
111	Tinderbox (111)	n/a	FT	18/01/2011	-43.02661	147.33545	8.2
	Count of sites at which individual species was recorded						

Survey number	Acanthophora dendroides	Acrocarpia paniculata	Acrocarpia robusta	Acrosorium ciliolatum	Acrotylus australis	Aeodes nitidissima	Aglaothamnion obstipum	**Amansia mamillaris**	Amphibolis antarctica	Amphibolis griffithii	Amphiroa anceps	Amphiroa foliacea	Amphiroa gracilis	Anotrichium crinitum	Anotrichium elongatum	Anotrichium tenue	Anotrichium (FJS 5357 sp. inc	**Antithamnion biarmartum**	Antithamnion delicatulum	Antithamnion gracilentum	Antithamnion hanoviodes	Antithamnion pectinatum	Antithamnion pinnafolium
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Survey number	Antithamnion (FJS 6135 sp. ir	Antrocentrum nigrescens	Apjohnia laetivirens	Apoglossum spathulatum	Areschougia congesta	Areschougia stuartii	Arthrocardia anceps	Arthrocardia flabellata subsp.	Arthrocardia wardii	Asparagopsis armata	Asparagopsis taxiformis	Austronereia australis	Ballia callitrica	Batracytrichia quoyi	Bellotia eriophorum	Betaphycus speciosum	Botryocladia leptopoda	Botryocladia sonderi	Brongiartella australis	Bryopsis australis	Bryopsis gemellipara	Bryopsis macraildii	Bryopsis plumosa
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Survey number	Callipsygma wilsonis	Callithamnion caulescens	Callithamnion violaceum	Callithamnion (FJS 6502 sp. i	Callophycus harveyanus	Callophycus laxus	Callophycus oppositifolius	Callophyllis cervicornis	Callophyllis lambertii	Callophyllis rangiferina	Camontagnea oxyclada	Capreolia implexa	Carpoglossum confluens	Carpomitra costata	Carpopeltis phyllophora	Carpothamnion gunnianum	Caulerpa annulata	Caulerpa brownii	Caulerpa cactoides	Caulerpa distichophylla	Caulerpa flexilis	Caulerpa flexilis var. muelleri	Caulerpa geminata
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Survey number	Caulerpa hedleyi	Caulerpa hodgkinsoniae	Caulerpa longifolia	Caulerpa obscura	Caulerpa racemosa	Caulerpa racemosa var. laetiv	Caulerpa remotifolia	Caulerpa scalpelliformis	Caulerpa sedoides f. geminat	Caulerpa simpliciuscula	Caulerpa trifaria	Caulerpa vesiculifera	Caulocystis cephalornithos	Caulocystis uvifera	Ceramium cliftonianum	Ceramium excellens	Ceramium flaccidum	**Ceramium lenticulare**	Ceramium macilentum	Ceramium monocanthum	Ceramium pusillum	Ceramium rubrum	Ceramium tasmanicum
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Survey number	Chaetomorpha aerea	Chaetomorpha coliformis	Chaetomorpha megalonium	Champia insignis	Champia stipitata	Champia viridis	Champia zostericola	Cheilosporum sagittatum	Chlorodesmis baculifera	Chondria angustissima	Chondria curdieana	Chondria harveyana	Chondria incrassata	Chondria subfasiculata	Chondria succulenta	Chordaria cladosiphon	**Cirrulicarpus polycoelioides**	Cladophora bainesii	Cladophora billardierii	Cladophora feredayi	Cladophora lehmanniana	Cladophora prolifera	Cladophora vagabunda
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Survey number	Cladosiphon filum	Cladosiphon vermicularis	Cladostephus spongiosus	Cladurus elata	Chlanidophora microphylla	Codiophyllum decipiens	Codiophyllum flabelliforme	Codium apiculatum	Codium australicum	Codium dimorphum	Codium duthiae	Codium fragile	Codium galeatum	Codium harveyi	Codium lucasii	Codium mamillosum	Codium pomoides	Codium spinescens	Codium spongiosum	Coeloclonium tasmanicum	Coeloclonium verticillatum	Colpomenia peregrina	Colpomenia sinuosa
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Survey number	Corallina officinalis	Corynomorpha prismatica	Craspedocarpus blephicarpus	Craspedocarpus ramentaceus	Crouania mucosa	cc Crustose coralline algae	Cryptonemia kallymenioides	**Cryptonemia wilsonii**	Curdiea angustata	Curdiea irvineae	Curdiea obesa	Cutleria multifida	Cystophora congesta	Cystophora expansa	Cystophora grevillei	Cystophora monilifera	Cystophora moniliformis	Cystophora pectinata	Cystophora platylobium	Cystophora racemosa	Cystophora retorta	Cystophora retroflexa	Cystophora siliculosa
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Survey number	Cystophora subfarcinata	Cystophora torulosa	Cystophora xiphocarpa	Cystoseira trinodis	Dasya ceramioides	Dasya clavigera	Dasya crescens	Dasya divergens	Dasya haffiae	Dasya naccarioides	Dasya villosa	Dasyclonium harveyanum	Dasyclonium incisum	Dasythamniella latissima	Dasythamniella plumigera	Delisea elegans	Delisea hypneoides	Delisea plumosa	Delisea pulchra	Derbesia tenuissima	Desmarestia ligulata	Deucalion levringii	Dicranema revolutum
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Survey number	Dictyomenia harveyana	Dictyomenia sonderi	Dictyomenia tridens	Dictyopteris acrostichoides	Dictyopteris muelleri	Dictyopteris nigricans	Dictyopteris plagiogramma	Dictyosphaeria seriecea	Dictyota dichotoma	Dictyota dichotoma var. intrica	Dictyota diemensis	Dictyota furcellata	Dictyota prolifera	Dilophus gunnianus	Distromium flabellatum	Ditria expleta	Durvillaea potatorum	Echinothamnion hookeri	Echinothamnion hystrix	Ecklonia radiata	Ectocarpos siliculosa	Elachista orbicularis	Encyothalia cliftonii
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	22	1	2	1	39	1	2	2	30	1	18	12	1	1	12	1	11	10	17	83	9	3	1

Survey number	Enteromorpha compressa	Epiglossum proliferum	Epiglossum smithiae	Epiphloea bullosa	Erythroclonium muelleri	Erythroclonium sonderi	Erythrotrichia carnea	Erythrymenia minuta	Euptilota articulata	Exallosorus olsenii	FS 5394 (red sp. indet.)	**FS 5425 (Entwisleia bella)**	FS 5640 (red. sp. indet.)	FS 5811 (red sp. indet.)	FS 5872 (indet red)	FS 6055 (indet red)	FS 6145 (indet red)	FS 6449 (indet red)	FJS 6465 (indet green)	Galaxaura marginata	Galaxaura obtusata	Ganonema farinosum	Glaphrymenia pustulosa
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	1	1	1	2	1	1	1	8	28	22	1	1	1	1	1	1	1	1	1	5	4	1	3

Survey number	Gelidium apserum	Gelidium australe	Gelidium crinale	Gelidium pusillum	Gelinaria ulvoidea	Gigartina muelleriana	Gigartina pinnata	Gigartina recurva	Glaphrymenia pustulosa	Gloiocladia australis	Gloiocladia halymenioides	Gloioderma polycarpum	Gloiophloea sciniaioides	Gloiosaccion brownii	Glossophora nigricans	Gracilaria cliftonii	Gracilaria preissiana	Gracilaria ramulosa	Gracilaria secundata	Grateloupia filicina	Grateloupia intestinalis	Grateloupia pectinata	Grateloupia (FS 5427 sp. inde
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Survey number	Grateloupia (FS 5640 sp. inde	Griffithsia crassiuscula	Griffithsia gunniana	Griffithsia monilis	Griffithsia teges	Halicnide similans	Halimeda cuneata	Haliptilon roseum	Halopeltis australis	Halopeltis cuneata	**Halopeltis cuneata**	Halopeltis prostrata	Halopeltis verrucosa	Halophila australis	Halophila ovalis	Haloplegma preissii	Halopteris novae-zelandiae	Halopteris paniculata	Halymenia floreseia	Halymenia kraftii	Halymenia muelleri	Halymenia plana	Haraldophyllum (FS 5658 sp.
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Survey number	Hemineura frondosa	Hennedya crispa	Herposiphonia calothrix	**Herposiphonia pectinella**	Herposiphonia versicolor	Heterodoxia denticulata	Heterosiphonia australis	Heterosiphonia gunniana	Heterosiphonia microcladioide	Heterosiphonia muelleri	Heterozostera tasmanica	Hincksia mitchellae	Hincksia sordida	Hormosira banksii	Hydroclathrus clathratus	Hymenena affinis	Hymenena multipartita	Hymenocladia usnea	Hypnea charoides	Hypnea musciformis	Hypnea pannosa	Hypnea ramentacea	Hypnea valentiae
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Survey number	Hypoglossum armatum	Hypoglossum heterocystideur	Inkyuleea mariana	Jania micrarthrodia	Kallymenia cribrosa	Laurencia arbuscula	Laurencia botryoides	Laurencia brongniartii	Laurencia clavata	Laurencia elata	Laurencia filiformis	Laurencia forsteri	Laurencia majuscula	Laurencia tasmanica	Lenormandia marginata	Lenormandia muelleri	Lenormandia pardalis	Leptophyllis conferta	Leptosomia rosea	Lessonia corrugata	Liagora wilsoniana	Lobophora variegata	Lobospira bicuspidata
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Survey number	Lomentaria australis	Lophothalia hormoclados	Macrocystis angustifolia	Macrocystis pyrifera	**Macrothamnion pectenellun**	Malaconema roeanum	Martensia elegans	Martensia fragilis	Mastophoropsis canaliculata	Medeiothamnion protensum	Medieothamnion (FS 5327 sp	Melanema dumosum	Melanthalia abscissa	Melanthalia coccinna	Melanthalia obtusata	Mesophyllum incisum	Metagoniolithon chara	Metagoniolithon radiatum	Metagoniolithon stelliferum	Metamastophora flabellata	Microcoleus lyngbyaceus	Mychodea acanthymenia	Mychodea aciculare
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Survey number	Mychodea carnosa	Mychodea disticha	Mychodea marginifera	Myriogramme gunniana	Neurymenia fraxinofolia	Nitophyllum crispum	Nitospinosa tasmanica	Nizymenia australis	Nizymenia conferta	Ochmapexus minimus	Padina elegans	Padina gymnospora	Peltasta australis	Perithalia caudata	Petalonia fascia	Peyssonnelia capensis	Peyssonnelia novae-hollandia	Phacelocarpus alatus	Phacelocarpus apodus	Phacelocarpus complanatus	Phacelocarpus peperocarpos	Phitymophora amansioides	Phloiocaulon spectabile
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Survey number	Phyllospora comosa	Phymatolithon masonianum	Platoma foliosa	Platysiphonia delicata	Platysiphonia victoriae	Platythalia angustifolia	Plocamium angustum	Plocamium cartilagineum	Plocamium costatum	Plocamium dilatatum	Plocamium leptophyllum	Plocamium mertensii	Plocamium patagiatum	Plocamium priessianum	Pollexfenia lobata	Polycoelia laciniata	Polyopes constrictus	Polyopes tasmanicus	Polyopes tenuis	Polysiphonia blandii	Polysiphonia brodiei	Polysiphonia crassiuscula	Polysiphonia decipiens
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Survey number	Polysiphonia infestans	Polysiphonia scopulorum	Polysiphonia subtilissima	Porphyra columbina	Porphyra lucasii	Porphyra woolhousiae	Posidonia australis	Posidonia sinuosa	Pterocladia capillacea	Pterocladia lucida	**Pterothamnion aciculare**	Pterothamnion (FS 5336 sp. i	Ptilocladia australis	Ptilocladia crouanioides	Ptilonia australasica	Ptilophora prolifera	Ptilothamnion subsimplex	Punctaria latifolia	Rhabdonia coccinea	Rhiplia (sp. indet)	**Rhipiliopsis multiplex**	Rhodoglossum gigartinoides	Rhodopeltis australis
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Survey number	Rhodopeltis borealis	Rhodophyllis gunnii	Rhodophyllis membranacea	Rhodophyllis multipartita	Rhodophyllis volans	Rhodymenia leptophylla	Rhodymenia obtusa (correct)	Sarcodia marginata	Sarcothalia radula	Sarcotrichia dolichocystidea	Sargassum decipiens	Sargassum decurrens	Sargassum distichum	Sargassum fallax	Sargassum heteromorphum	Sargassum lacerifolium	Sargassum linearfolium	Sargassum paradoxum	Sargassum sonderi	Sargassum spinguligerum	Sargassum verruculosum	Sargassum vestitum	Scaberia agardhii
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Survey number	**Schizoseris hymenena**	**Schizoseris perrinae**	Schizymenia dubyi	Scinaia tsingalensis	Scytothalia dorycarpa	Seirococcus axillaris	Shepleya australis	Solieria robusta	Sonderopelta coriacea	Spermothamnion cymosum	Sphacelaria reinki	Spongoclonium brownianum	Sporochnus apodus	Sporochnus comosus	Sporochnus radiciformis	Sporochnus stylosus	Spyridia filamentosa	Spyridia tasmanica	Stenogramme interrupta	Stictsiphonia intricata	Struvea plumosa	Stylonema alsidii	Stypopodium flabellatum
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107								1													1		
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110					1										1								
111														1									
	1	2	2	1	5	8	1	2	38	1	1	1	1	13	2	1	1	3	17	1	1	1	4

Survey number	Synarthrophyton patena	Thamnoclonium dichotomum	Thuretia quercifolia	Trematocarpus coccinus	Tricleocarpa cylindrica	Trithamnion vulgare	Tsengia feredayae	Tsengia laingii	Tsengia (FS 6472 sp. indet.)	Tylotus obtusatus	Ulva intestinalis	Ulva rigida	Ulva taeniata	Undaria pinnatifida	Veleroa adunca	Ventricaria ventricosa	Wollastoniella myriophylloides	Wrangelia nobilis	Wrangelia (FS 5649 sp. indet.)	Xiphophora chondrophylla	Xiphophora gladiata	Zonaria angustata	Zonaria spiralis
57					1							1											
58																							
59												1											
60		1										1											
61							1					1											
62												1											
63		1																					
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68							1					1	1	1									
69				1			1					1		1									
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80		1					1					1	1									1	
81	1						1	1					1								1		
82		1					1											1		1		1	
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107												1											
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110								1				1											
111												1		1									
	28	22	2	6	2	1	23	3	1	2	1	62	10	13	1	1	1	3	1	14	18	15	1

Survey number	Zonaria turneriana	Zostera muelleri	Zymergia chondriopsidea	**No. RARE spp per site**	**No. ALL spp per site**
57	1			**0**	**38**
58				**0**	**20**
59				**1**	**19**
60				**0**	**29**
61	1			**0**	**36**
62			1	**0**	**10**
63				**2**	**34**
64				**0**	**9**
65	1			**0**	**30**
66	1			**2**	**47**
67	1			**0**	**22**
68				**0**	**33**
69				**0**	**35**
70				**0**	**13**
71	1			**1**	**43**
72				**2**	**45**
73				**0**	**9**
74	1			**0**	**38**
75				**0**	**8**
76				**0**	**4**
77				**0**	**7**
78				**0**	**10**
79	1			**1**	**45**
80	1			**0**	**47**
81	1			**0**	**46**
82	1			**0**	**39**
83				**0**	**38**
84	1			**0**	**34**
85	1			**0**	**22**
86	1			**0**	**28**
87	1			**0**	**21**
88	1			**0**	**31**
89	1			**0**	**20**
90	1	1		**0**	**15**
91	1			**0**	**30**
92				**0**	**34**
93				**0**	**17**
94				**2**	**26**
95	1			**0**	**39**
96	1			**0**	**18**
97	1			**1**	**36**
98	1			**1**	**23**
99				**0**	**17**
100	1			**0**	**35**
101				**0**	**29**
102				**1**	**40**
103	1			**0**	**32**
104	1			**0**	**24**
105				**0**	**29**
106				**0**	**42**
107				**0**	**34**
108				**0**	**22**
109				**0**	**31**
110	1			**1**	**49**
111	1			**0**	**35**
	54	1	1		