Lauwa

ESTUARINE & COASTAL SCIENCES ASSOCIATION (ECSA)

SEAWEED IDENTIFICATION WORKSHOP

Heriot-Watt University, Edinburgh, Scotland, 7th-11th April 2008

General Handouts (revised for 2008)

This booklet contains general information about the workshop, general background information on algae and seaweeds, information on how to search shores for seaweeds and how to identify them, notes on local algae and maps of field sites. Additional handouts will be available during the week with illustrations for specific lectures. Those of you who have been to a previous workshop should note that some parts of this booklet have been updated form the ones used in previous years.

Contents

Welcome to Heriot-Watt University

This is the 8th oldest university in Britain as it can trace its roots back to 1821 when the Watt Institution and School of Arts was founded. At that time arts meant natural science and its application to engineering, so we have always been a technological institution. Effectively we were an early mechanics' institute. The college was a pioneer in various ways, for example being one of the first to allow women to graduate in the later 19th century. The life sciences started out in the 19th century as botany and microbiology teaching in the Chemistry Department to the staffs of the numerous breweries in Edinburgh at that time. In the early 20th century Heriot-Watt College became a Scottish Central Institution i.e. a tertiary education establishment, similar to a University, but funded directly by the Scottish Office, with degree equivalent qualifications of AHWC and FHWC, respectively equivalent to BSc and PhD. Along with the other major Scottish technological college, the Royal College of Science and Technology in Glasgow which became Strathclyde University, Heriot-Watt was given full University status in the major university expansion of the early 1960's when the number of universities in the UK doubled from 26 to 52 (compare that with over 200 now!). In the early 70's the biological sciences expanded massively and complemented the brewing and biochemistry that then existed with new degrees in microbiology and marine biology. The latter was part of a massive marine development in the university which also saw establishment of a an Offshore Engineering Department and an Institute of Offshore Engineering (IOE) which became one of the best known and largest environmental consultancies serving the oil industry, employing nearly 130 people at its peak, with bases in Edinburgh, Aberdeen, Plymouth and Orkney. Sadly the University saw fit to sell off this Institute's various spin-off companies 13 years ago and to close the Institute, as the management and business side of the university has expanded. Nonetheless the marine biology and its pioneering marine resources MSc continues to thrive in the School of Life Sciences and a management buyout of the biological environmental part of one of the privatised companies has returned a company to the campus (ERT Scotland Ltd) which embodies what was at the heart of the success of IOE in the 1970's.

We moved to the Riccarton campus in stages between 1969 and 1996 gradually relinquishing what had become increasingly cramped city centre accommodation. This was made possible by the generous gift of the Riccarton estate to the University by the then Midlothian County Council. The estate had been the home of the Gibson-Craig family, with the house on the site of the present library, looking out over what is now the sunken garden as its lawn. In the 2nd world war the house was requisitioned as a war hospital and fell into disuse afterwards. It has given us a marvellous spacious campus which has been developed along a master plan giving a sense of coherence. It also allowed space for us to develop Britain's first research park on a university campus, another pioneering development. This is now home to 60 companies including SEPA and ERT who have delegates at this workshop.

The building we are in opened in 1989 when the Biological Sciences Department vacated the original city centre site in Chambers Street. It includes the International Centre for Brewing & Distilling, mirroring its origins in the century before last, and a marine research aquarium reflecting its more recent successes. The latter is complemented by our own research vessel berthed in Loch Creran, north of Oban. Broader marine management and planning studies continue in the International Centre for Island Technology, our Orkney Campus, which was originally established by IOE and has survived the changes to be recently reborn as a renewables centre.

We welcome you to this University and hope that you will enjoy the excellent grounds of the campus – if you get time off from the seaweeds. Ask at the James Watt Centre Reception for various interpretative leaflets including the tree trail. The Gibson-Craigs planted many overseas species.

Aims of the workshop

The purpose of this workshop is to give you the ability to use the professional literature for seaweed identification. This means that you need background lectures on what algae are and on the background biology of algae sufficient to understand such professional works. In addition you need introduction to what are the professionals' literature for identification and endless practice in using it. Our own experience is that there is no substitute for practice. That is why we are spending so little time on the shore compared with that in the lab. You will learn the importance of painstaking examination under the microscope. This is not a course on the Water Framework Directive (WFD). However, the WFD will require some agency staff and consultants to be taxonomically very able with seaweeds so the course is timely. Most of the tutors are the seaweed specialist members of the Marine Plants Task Team for UK and RoI for devising classification tools for the WFD. Therefore we can give you a particularly good idea of what skills will be needed in shore searching and identification for the implementation of shore classification which is now underway. However it is important to realise that UK and RoI are still developing tools. Therefore nothing we say should be taken as a statement of official policy. We will be able to give you practice, if you wish at part of a possible WFD type survey on the second field visit and this will aid tool development rather than be a statement of what tools will actually be developed. The real emphasis is on acquiring good pure biological skills with seaweeds.

The approach is meant to be accessible to the intelligent amateur as well as to the professional. It is also meant to allow people to proceed at different paces according to previous experience and ability. We achieve this by a short series of basic lectures and a lot of lab time in which people can proceed at their own pace. There are five tutors and two demonstrators so don't be afraid to ask for help no matter whether it is really basic or is complex. There is no examination. However a Certificate of Completion of the Course can be issued at the end on request, if you have completed the whole course.

Provisional list of participants

TUTORS		*PARTICIPANTS:*	
Clare Scanlan	SEPA	Nuala McQuaid	EHS(NI)
Emma Wells	Wells Marine	Charmaine Blake	EHS(NI)
Martin Wilkinson	HWU	Siobhan McMenamin	EHS (NI)
Ian Tittley	NHM	Nikki Chapman	JNCC
		Sarah Holt	SEPA
		Kirsten Gray	SEPA
LOCAL STAFF AND STUDENTS:		Laura Bush	SEPA
Rosie Foster	MSc student HWU	Lee Heaney	SEPA
Dan Harries	Diving Officer HWU	Myles O'Reilly	SEPA
Margaret Stobie	Chief marine biology technician HWU	Mhairi Wilson	SEPA
Colin Trigg	PhD student HWU	Becky Boyd	SWT
		Liz Morris	Marine Ecological Solutions
		Sue Brown	CEH

Provisional Timetable

Monday		
1400	F48	Introduction Lectures 1 and 2 and briefing for field visits
	F35	Introduction to laboratory examination of seaweeds - a range of common species is provided which have been specifically chosen to heighten microscopic examination skills
Tuesday		
0730		Breakfast
0900	F35	Lab work – a large variety of specimens, intertidal and sublittoral, is provided from the Forth and from Loch Creran, near Oban to suite all levels of expertise and training
1230	F48	Lunch
1315	F48	Lectures 3 and 4
1500	F35	Continue work up of material in lab into evening if desired
Wednesday		
0730		Breakfast
0830		Depart Riccarton for field work* LW 1120 0.6m
1230	F48	Lunch
1315	F48	Specialist tutorial on green seaweeds using the new book
1415	F35	Lab workup of specimens from field visit continuing into evening if desired
1630	F48	Briefing for tomorrow's field visit then continue with lab work if desired
Thursday		
0730		Breakfast
0830		Depart Riccarton for field work* LW 1202 0.8m
1300	F48	Lunch
1330	F48	Initial debriefing about today's shore work
1400	F35	Work up material from field visits
1930		Workshop banquet at Zizzi's, Queensferry Street, Edinburgh. Easily reached by taking 25 bus to Queensferry Street (every 10 mins, £1). Note that owing to tramway works the 25 currently runs into the city from Haymarket via Melville Street and Queensferry Street rather then Shandwick Place but returns via Lothian Road, Western Approach Road and Morrison Street. Participants might like to leave together on an early bus for a pre-dinner drink in Mathers' Bar, Queensferry Street. We can arrange this on the day.
Friday		
0730		breakfast
0900	F35	Continue work up of specimens from field visits (possible optional visit to upper Almond estuary for those interested in upper estuarine species not seen at the Peffer Burn, if time permits)
1230	F48	final discussion
1300	F48	lunch
Afternoon	F35	participants free to leave after 1230 discussion or to stay – informal lab work may be available until 1700

* One days field work will be at Dunbar or other rich East Lothian shore nearby. We will stop on way at salt marsh and small estuary of Peffer Burn at Aberlady Bay. The other day we will go to a shore which may be less rich and/or recovering from pollution but will give practise at describing such shores

Phytobenthos – An Introductory Overview

(Taken from M. Wilkinson 2001. Phytobenthos. In: *Encyclopaedia of Ocean Sciences.* (J.H.Steele, K.K.Turekian & S.A.Thorpe, eds.). Academic Press. 2172-2179). This encyclopaedia is strongly recommended for short essays on virtually every aspect of marine science).

These introductory notes will complement the lectures so please read them outside the class times.

What is phytobenthos?

"Phytobenthos" means plants of the seabed, both intertidal and subtidal, and both sedimentary and hard. Such plants belong almost entirely to the algae although seagrasses, which form meadows on some subtidal and intertidal areas, are flowering plants or angiosperms. Algae of sedimentary shores are usually microscopic, unicellular or filamentous, and are known as the microphytobenthos or benthic microalgae. Marine algae on hard surfaces can range from microscopic single-celled forms to large cartilaginous plants. Some use the term "seaweed" for macroscopic forms while others also include the smaller algae of rocky seashores. This account is concerned with the nature, diversity, ecology and exploitation of the marine benthic algae. Other plants of the shore are dealt with elsewhere in this Encyclopaedia as salt-marshes, mangroves and seagrasses.

What are algae?

Algae were regarded as the least highly evolved members of the plant kingdom. Nowadays most classifications either regard the microscopic algae as protists, while leaving the macroscopic ones in the plant kingdom, or regard all algae as protists. This distinction is not important for an understanding of the ecological role of these organisms so they will all be called plants in this review. The fundamental feature that algae share in common with the rest of the plant kingdom is photoautotrophic nutrition. In photosynthesis they convert inorganic carbon (as carbon dioxide, carbonate or bicarbonate) to organic carbon using light energy. Thus they are primary producers, which act as the route of entry of carbon and energy into food chains. They are not the only autotrophs in the sea. Besides the other non-algal plant communities mentioned earlier, there are chemoautotrophs in hydrothermal vent communities, which use inorganic reactions rather than light as the energy source, and some bacteria are photosynthetic. However, algae are responsible for at least 95% of marine primary production. Algal photosynthesis uses chlorophyll-*a* as the principal pigment that traps and converts light energy to chemical energy (although many accessory photosynthetic pigments may also be present) and water is the source of the hydrogen that is used to reduce inorganic carbon to carbohydrate. Oxygen is a by-product so the process is called oxygenic photosynthesis. Broadly the same process occurs throughout the plant kingdom. Those true bacteria that are photosynthetic use alternative pathways, pigments and hydrogen donors, e.g. hydrogen sulphide.

One group of organisms falls between the algae and the bacteria – the cyanobacteria, until recently regarded as blue-green algae. These perform oxygenic photosynthesis and have similar photosynthetic pigments to algae, but their cell structure is fundamentally different. In common with the bacteria they have the more primitive, prokaryotic cell structure, lacking membrane-bound organelles and organised nuclei. Algae have the more advanced and efficient eukaryotic cell structure, with membrane-bound organelles and defined nuclei, in common with all other plants and animals. Blue-greens also have some physiological affinities with bacteria, particularly nitrogen fixation. This means that they can use elemental nitrogen as a source of nitrogen for biosynthesis of various organic nitrogen compounds, starting from the simple organic compounds formed in photosynthesis. Algae and other plants have lost this ability and require to absorb fixed nitrogen, combined inorganic nitrogen as nitrate and ammonium ions, from solution in seawater. Despite internal cellular differences, blue-greens have similar overall morphology to smaller algae and live indistinguishably in algal communities as primary producers. They will therefore be included with algae in this review.

Algae are therefore similar to the "true" plants in having oxygenic photosynthesis. They are distinguished from the rest of the plant kingdom only on a rather technical botanical point. Algae have simpler reproductive structures. In all the higher plant groups the reproductive organs are surrounded by walls of sterile cells (i.e. cells that are not gametes or spores) that are formed as a specific part of the reproductive organ. This does not occur in algae. Even in the highly complex large brown seaweeds with apparently complex reproductive structures, the gametangia, which produce eggs and sperm, enclosed within complex reproductive structures, have only membranous walls rather than cellular walls.

Diversity of algae

Algae as defined in the previous section include a large diversity of organisms from microscopic single-celled ones, as little as about 2μm in diameter, to the complex giant kelp nearly 70m long, the largest plant on Earth. We can make sense of this diversity in three ways:

- Structural diversity
- Habitat diversity
- Taxonomic classification

Structural diversity of algae

The simplest algae are single-cells, which can vary in size from about 2μm to 1mm. They can be non-motile, lacking flagella, or motile by means of flagella. An interesting intermediate situation is in the diatoms which lack flagella but are nonetheless motile by gliding over surfaces. Unicells can differ in the presence of external sculpturing and the number and orientation of flagella on each cell.
Colonies are aggregations of single cells which can also be flagellate or non-flagellate. The simplest truly multicellular algae are filamentous, i.e. hair-like, chains of cells. These can be branched or unbranched and may be only one cell in thickness (uniseriate) or more than one cell in thickness (multiseriate). Heterotrichy is an advanced form of filamentous construction in which two separate branched systems of filaments may be present on one plant – a prostrate system which creeps along the substratum and an erect system which arises into the seawater medium from the prostrate system.
The larger more advanced types of seaweeds can be traced in origin to modifications of the heterotrichous system. Reduction of one of the two filament systems and elaboration of the other can give rise either to encrusting forms (erect reduced, prostrate elaborated) or to erect plants in which the prostrate system only forms the attachment organ or holdfast. Three further modifications give rise to a wide diversity of large cartilaginous (leathery), foliose (leaf-like) and complex filamentous seaweeds. These three modifications are:

- Presence of meristems – localised areas where cell division is concentrated – which may be apical, at the growing tips of branches, or may be intercalary, located along the length of the plant (in simpler algae growth is diffuse with cell division occurring anywhere in the plant, not localised to meristems).

- Pseudoparenchyma formation – aggregation of many separate filaments together to make a massive plant body, as opposed to true parenchyma formation, where massive tissues result only from multiplication of adjacent cells. This is a different use of the term parenchyma from that in higher plants where it means an unspecialised type of cell which acts as packing tissue.

- The occurrence of two or more phases of growth, which may or may not differ in pattern (pseudoparenchymatous or truly parenchymatous) and may involve formation of a secondary lateral meristem. Various phases of growth can give rise to the different tissues seen in cross-sections of seaweeds which may help in giving the ability to bend in response to water motion and wave action, without breaking.

Some seaweeds are able to secrete calcium carbonate so that they appear solid. Red calcareous species appear pink and are common throughout the world while green calcareous forms are commoner in the tropics and sub-tropics. Calcareous encrusting red algae form a pink calcareous coating on the rock surface which can be mistaken by the non-specialist for a geological feature.

The structure of a kelp plant illustrates the life of seaweeds. The plant is attached to the rock surface by a holdfast, which is branched and fits intimately to the microtopography of the rocks. From the holdfast arises the stipe, a stem-like structure which supports the frond in the water column. The frond is a wide flat area which gives a high surface area to volume ratio for light, carbon dioxide and nutrient absorption. Superficially there is a resemblance to the roots, stem and leaves of higher plants but there is no real equivalence because of the different life style. The holdfast is not an absorptive root system and does not penetrate the substratum, unlike roots penetrating the soil, since the seaweed can obtain all its requirements by direct absorption over its surface. The stipe is not a stem containing transport systems, as in higher plants, since these are not needed, again because of direct absorption. Similarly the frond does not have the complex structure of leaves with gas exchange and water retention organs such as stomata. Seaweeds do not have resistant phases such as seeds. Development is direct from spores or zygotes.

A seaweed, such as a kelp, can be viewed as a chemical factory taking in light nutrients and inorganic carbon from the water and converting them to organic matter. This production can be going on even when the plant does not seem to be increasing in size. The formation of new organic matter is then balanced by the loss of decaying tissue from the tip of the plant and by organic secretions from the frond. Both of these will be contributing to hetrotrophic production in the kelp's ecosystem.

Habitat diversity of benthic algae

Microphytobenthos in sedimentary shores can be distinguished according to whether they are epipsammic (attached to sand particles) or epipelic (between mud particles). They are mainly unicellular forms – diatoms, euglenoids and blue-greens in estuarine muds; diatoms, dinoflagellates and blue-greens in sand. Many show vertical migration within the top few mm of the sediment, photosynthesising when the tide is out and burrowing before the return of the tide so that some escape being washed away. This is not 100% effective so that resuspended microphytobenthos can be a significant proportion of apparent phytoplankton in some estuaries. Diatoms migrate by gliding motility while euglenoids do so by alternate contraction and relaxation of the cell shape (metaboly). In estuaries, which may be turbid environments where photosynthesis by submerged plants may be reduced, and large expanses of intertidal mud flats may be available, microphytobenthos could be important primary producers which have been underestimated because they are not visually obvious. They may also help to stabilise sediments by the mucus secretions which keep them from desiccation when on the mud surface.

Seaweeds don't just grow attached to hard surfaces such as bedrock, boulders and man-made structures. In Britain, a habitat-diverse, open coast shore is likely to have 70-100 species of seaweed present out of a British total of about 630 species. Such a high total on a shore is only realised because of many habitat variations that harbour the more microscopic species.

Most seaweeds have smaller species that grow attached to them as epiphytes. In turn they have even smaller species attached and this may continue for several orders down to very small microscopic plants. Endophytes are microscopic algae that grow between the cells within the tissues of larger ones. Epizoic algae grow attached to animals and endozoic forms grow inside animals, usually in skeletal parts. These include algae that penetrate calcareous substrata i.e. shell-boring algae – red, green and blue-green forms that bore through mollusc and barnacle shells and coral skeletons. They also include forms that inhabit proteinaceous animal skeletons – red and green filamentous species in skeletons of hydroids and bryozoans, and filamentous green seaweeds, mainly *Tellamia*, in the periostracum of periwinkles. Some of the shell-boring algae are also endolithic, boring through chalk rocks and so possibly aiding coastal erosion. Finally there are endozoic algae that live in soft parts of benthic animals. Zooxanthellae are non-motile dinoflagellate unicells in coral polyps, where they contribute to the high productivity of coral reefs, and unicellular blue-greens live in the tissues of some sea-slugs.

Taxonomic classification of the algae

Algae are classified into a number of divisions of the plant kingdom (equivalent to phylum), varying in number from about 8 to 16 depending on author. Distinction is based on fundamental cellular and biochemical features and so is independent of the form of the plant. Each division can contain a range of forms, from unicellular to complex multicellular, although in many divisions the unicellular and colonial forms predominate. General features used to distinguish the divisions are:

- The range of accessory photosynthetic pigments present in addition to chlorophyll-*a* (other chlorophylls, carotenoids and biloproteins).
- The secondary more soluble components of the cell wall present in addition to the main fibrillar component
- The chemical nature of the insoluble storage products resulting from excess photosynthesis
- The presence, fine structure, number and position of flagella on vegetative cells of flagellate organisms or on flagellate reproductive bodies of larger species.
- Specialised aspects of cell structure, peculiar to particular divisions, such as the silica frustules, which encase diatom cells.

The three biochemical features above are relatively uniform in the higher plants, compared with the algae, and similar to those of one algal division, Chlorophyta (green algae). This suggested origin of land plants occurred from only this one division, although this is now contested. At a fundamental level the algae are therefore much more diverse than the higher plants. Characteristics for each division can be found in several of the references listed at the end.

The seaweeds are the macroscopic marine algae in the divisions Chlorophyta (green), Phaeophyta (brown) and Rhodophyta (red algae). Greens are mainly foliose and filamentous seaweeds. Browns have no unicellular forms and include the very large complex and leathery forms such as kelps and rockweeds. Reds include a wide range of heterotrichous forms forming a wide diversity of complex foliose and filamentous forms.

Seaweed life cycles

Most seaweeds have more than one phase in their life cycle. They have generally the same pattern as higher plants where a sexually reproducing gametophyte generation gives rise to an asexually reproducing sporophyte generation and vice-versa. There is not always an obligate alternation as in higher plants and there is much more diversity in the nature of the different phases in algae, with some red algae even having a third generation. Some only have one generation. In some cases this may reflect lack of experimental culture which is necessary for life cycle determination.

The simplest life cycle with two phases is termed isomorphic where the gametophyte and sporophyte are morphologically identical. Many common green seaweeds are like this e.g. *Ulva* and *Enteromorpha.* Life cycles with morphologically different phases are heteromorphic. An example is kelp plants which have a massive leathery sporophyte which alternates with a microscopic filamentous gametophyte.

In many cases the two generations in a heteromorphic life cycle may have been known since the 19th Century by separate names from before the life cycle was determined in culture. For example, the various species of the red seaweed, *Porphyra,* alternate with a filamentous shell-boring sporophyte formerly known as *Conchocelis rosea.*

Life cycles can be under environmental control. In some *Porphyra* species the change between generations is controlled by daylength, bringing about an annual seasonal life cycle. In some simpler life cycles, individual generations may be able to propogate themselves so that the full life cycle is not seen. This can be environmentally controlled so that, for example, in Europe there is a change with latitude of the relative proportions of the sexual and asexual generations of the brown filamentous seaweed, *Ectocarpus,* connected with latitudinal variation of sea temperature.

The validity of laboratory cultures of phytobenthos

Experimental culture is needed to determine life cycles. It is difficult to simulate all environmental conditions. Wave action and water flow are not usually simulated in the numerous batch culture dishes needed for replicated ecological experiments. Artificial light sources are unlike daylight in spectral composition and intensity, yet light quality may control photomorphogenesis in plants. It is therefore possible that laboratory culture could give false results. Two examples are given below.

The red seaweeds *Asparagopsis armata* and *Falkenbergia rufulanosa*, originally described as separate species, are phases in the same life cycle. During the 20th Century they have been spreading their geographical limit northwards in Europe from the Mediterranean to northern Scotland. Populations in Britain are rarely seen with reproductive organs but have a mode of attachment to the rock surface that suggests they were produced by vegetative reproduction. The two phases seem to have spread independently in Britain although in culture they could be made to participate in the same life cycle. This reflects a wider phenomenon in red seaweeds where, going north and south from the centre of geographical distribution, reproductive potential declines.

In ecological experiments aseptic conditions are often not used, to the surprise of microbiologists. This lack of sterility may be desirable. For example, the green foliose seaweed, *Monostroma*, develops abnormally as a filamentous form in aseptic culture because of the need for growth factors from contaminating bacteria. These examples are not meant to decry culture experiments but to counsel their critical interpretation.

Seaweed ecology

Seaweeds are present on all rocky shores but are more obvious where wave action is less. On temperate shores intertidal zones are generally dominated by brown fucoid seaweeds (wracks or rockweeds), while the shallow subtidal is occupied by a kelp forest formed of large laminarian seaweeds. A variety of red, green and brown seaweeds forms an understorey.

Some general rules can be exemplified by consideration of shores in north-west Europe. Firstly consider intertidal rocky shores. The number of species is greatest at the lower tidal levels and declines with increasing intertidal height. Shores sheltered from wave action show the greatest cover and biomass of seaweeds. Shores exposed to very strong wave action tend to be dominated by sessile animals rather than seaweeds. Most shores are intermediate in wave action and tend to have a mosaic distribution of organisms, at least on lower and mid-shore. This may include patches of grazing animals interspersed with patches of different seaweed communities. The mosaic may make it hard to see a zonation of organisms with height on the shore. On very sheltered shores there may be a very obvious zonation of large brown seaweeds, in order of descending height on the shore: *Pelvetia canalicaulata, Fucus spiralis, Fucus vesiculosus* and *Ascophyllum nodosum, Fucus serratus, Laminaria digitata.* (Similar zonations, but with different species, may occur on temperate shores outside north-west Europe). Clear-cut zonations with visually dominant species can give a false impression that discrete communities exist at different tidal heights. Understorey species also have zones but their boundaries do not coincide with the larger species so as not to give sharply delimited communities.

With increase in wave action there is change of species e.g. in fucoids *Fucus serratus* is replaced by *Himanthalia elongata* and in laminarians *Laminaria digitata* is replaced by *Alaria esculenta.* Some species change form with wave action e.g the bladder wrack, *Fucus vesiculosus*, loses its bladders (such morphological plasticity is a common feature confusing seaweed identification). With increased wave action zones increase in breadth and height on shore. All these features can be incorporated in biologically defined exposure scales for the comparative description of rocky shores, which place shores on a numerical exposure scale. This facilitates the comparison of similar shores in pollution monitoring studies to ensure that differences along a pollution gradient are due to human disturbance rather than to wave action.

Rock pools interrupt the gradient of conditions with height on shore. They provide a constantly submerged environment, like the subtidal one, but which is of limited volume and so undergoes physicochemical fluctuations while the tide is out, unlike the open sea. There is a corresponding zonation of dominant seaweed types in rock pools. On the lower shore they are characterised by sublittoral species and on the mid shore they include species restricted to pools such as *Halidrys siliquosa.* Upper shore pools, where salinity fluctuates, have few species and are characterised by euryhaline opportunists such as *Enteromorpha* spp.

Intertidal zonation is only partly due to the desiccation and salinity tolerance of the seaweeds. Such factor tolerance is particularly important on the upper shore where conditions are most harsh for a marine organism and so few species are present, with few biotic interactions. On mid and lower shores biotic factors are important in determining species boundaries. Grazing by limpets and periwinkles on smaller algae, and on the microscopic germlings of larger ones, is important as is biological competition, which narrows down species occurrence to less than their tolerance range.

Subtidally a zonation may also be seen with dense kelp forest, with a large variety of understorey species in the shallowest water, below which is a kelp park with only scattered plants. Below the kelp depth limit may be a red algal zone to the photic depth limit where light becomes insufficient for positive net photosynthesis. Important factors again are both physical and biotic. Light tolerance plays a role but in shallowest waters, where plant density is greatest, competition is important and zone limits may be set by grazers, this time by sea urchins rather than limpets.

There is an old view that accessory pigment differences between green, brown and red seaweeds equip them to dominate at different depths according to which different spectral quality of light penetrates. This is an oversimplification. Deeper growing plants are shade plants with lower overall light requirements and can be of any colour group.

Distribution into estuaries along a generally decreasing salinity gradient is another modifying factor like wave action. Colonisation of hard surfaces by phytobenthos in estuaries is largely by marine species with species number declining going upstream. This occurs by selective attenuation firstly of red, then of brown species. Estuaries have broadly two algal zones: an outer one with fucoid dominated shores, which are a species-poor version of a sheltered open coast shore, and an inner zone dominated by filamentous mat-forming algae, principally greens and blue-greens.

There can be a successional sequence in which a bare area of shore is successively colonised, starting with unicells, with increasingly larger and more complex algae. Patches in a mosaic distribution may be at different stages in such a sequence. The succession involves contrasting types of seaweed as shown below:

	Opportunist species early in succession e.g foliose and filamanetous green algae	Late successional species e.g. large cartilaginous plants such as fucoids
Morphology	Simple	Complex
Size	Smaller	Larger
Growth rate	Faster	Slower
Life span	Shorter	Longer
Reproduction	All year round	Likely to have seasons
Environmental tolerance	Very wide but not precise adaptation to a specific niche	Narrower but good adaptation to a specific niche

Although opportunists are good at colonising bare rock, in a stable environment they are eventually replaced by more precisely adapted late successional species.

Various conditions may favour unusual abundance of opportunists. Mistaken conclusions about effects of effluent discharges can be reached by environmentalists who do not realise that there are both natural and man-made causes. Opportunist domination of rocks is favoured naturally by sand scour and they may have natural summer outbursts in temperate climates. Pollution, particularly by sewage-derived nutrients, may favour opportunist domination. On tidal flats, "green tides" may occur where the mudflat is completely covered by thick opportunist mats. This can induce anoxia and ammonia release beneath the mat so inhibiting benthic invertebrate populations and interfering with bird-feeding on tidal flats.

Uses of seaweed

Benthic macroalgae are an important biological resource. Their principal uses are human food, animal feeds, fertiliser and industrial chemicals.

In the west human seaweed consumption is small compared with the east. One of the most valuable fisheries listed by the Food and Agriculture Organisation (FAO) is a seaweed, *Porphyra*, used extensively for human consumption in Japan. In the west human consumption is more a health food market with beneficial effects ascribed to high trace element content, because of the high bioaccumulation activity of many seaweeds, but this remains to be rigorously tested.

Aqueous extracts of such seaweeds as fucoids and kelps are used as commercial and domestic fertilisers. Beneficial effects have been claimed in horticulture such as increased growth, faster ripening and increased fruit yield. Effects are usually ascribed to trace element or plant hormone (usually cytokinin) content.

Various high value fine chemicals, such as pigments, can be obtained from seaweeds but the main seaweed chemical industry is extraction of phycocolloids. These are secondary cell wall components of red and brown seaweeds, which have gel-forming and emulsifying properties in aqueous solutions. This gives them hundreds of industrial applications ranging from textile printing to ice cream manufacture. The chemicals concerned are all macromolecular carbohydrates, principally alginates from brown seaweeds and agars and carrageenans from red seaweeds. Alginate is not a single substance but a biopolymer with considerable possibility for structural variation. It is a linear structure of repeating sugar units of two kinds, mannuronic acid (M units) and guluronic (G units). Different alginates vary in the ratio of M and G units and in chain length (total number of units). Structural differences confer different gel-forming and emulsifying properties making different alginates suitable for different industrial applications. In turn different alginate structures are found in different species so that different seaweeds are required for different applications.

Ensuring supplies of commercial seaweeds

Seaweeds can be harvested from natural populations or farmed in the sea. The approach may depend on the value of the product. In the west harvesting is preferred for phycocolloids . Despite the wide industrial application they are low value products and so will not support the high labour costs needed for cultivation. By contrast alginate is successfully produced from farmed kelps in China, where labour costs are lower, and *Porphyra* can be farmed for human consumption in Japan because of its high value.

Sustainable harvesting should consider the ability of the seaweed resource to recover. Mechanised *Macrocystis* (giant kelp) harvesting in California is sustainable yet productive because of the growth pattern of the plant. It grows to almost 70m long and cropping of the distal few metres by barges floating over the forest canopy allows numerous meristems to remain intact so growth continues. By contrast *Laminaria hyperborea* harvesting in Norway is more destructive because the desired alginate is in the stipe of the plant (the supporting "stem"). Harvesting by kelp dredges, large bags with cutters at the front end towed over the seabed on skis just above the rock surface, cuts plants off just above the holdfast, so that the meristematic area is harvested. Sustainability of the *Laminaria* forest is based on the vegetation structure. There are different layers of plants. The dredge takes only the large canopy-forming plants with tough, non-yielding stipes. The smaller plants bend rather than breaking and so survive harvesting. With the absence of the canopy they receive more light and so grow quickly to replace the harvested plants. The forest biomass is regenerated in 3 years so the Norwegian Government licences areas of the seabed for harvesting not less than every 4 years. The regenerated kelp is better for alginate extraction as it is not contaminated by epiphytes. However the sustainability of the kelp forest biodiversity is separate from commercial yield. It is a diverse ecosystem with many invertebrates in the kelp holdfasts, as well as diverse seabed fauna and flora, and pelagic species sheltered by the forest. The diversity of this had not recovered after much more than 4 years so the licencing system does not conserve the full ecosystem.

There are biotic considerations in protecting the phytobenthic resource. In the early 1970's decline of the sea otter population off California allowed its prey, a sea urchin which was a kelp grazer, to increase. This hindered natural regeneration of the forest, which was already declining due to sewage pollution from Los Angeles. Recovery required manual transplantation. Various species of sea urchin are amongst the most voracious subtidal grazers. Another one, *Strongylocentrotus*, was able to create barren areas of seabed off the Canadian coast where *Laminaria longicruris* had been harvested, preventing regeneration.

Farming of seaweed can require knowledge from laboratory culture of environmental tolerances and the factors controlling life-cycles. This allows manipulation of stocks in seawater tanks on land under controlled conditions to produce reproductive bodies. These can be used to seed ropes, nets canes or other substrata which are then planted out into sheltered sea areas for ongrowing. This increases the habitat area for attachment in the sea, so increasing yield. In the case of *Porphyra* in Japan, such manipulation of environmental conditions allows up to 5 generations per year from an area of coast where natural seasonal changes would only give one. It is not practical to grow the plants entirely on land in environmentally controlled seawater tanks because of the high cost of the facilities. But it is feasible to retain a small stock of, for example, shells infected with the *Conchocelis*-phase of *Porphyra* from which spores can be obtained on demand by manipulation of daylength and temperature. The technology exists to cultivate seaweeds entirely in land-based tanks should the economics be favourable in the future. For example, there are different genetic strains of *Chondrus crispus*, whose carrageenan yield and type can be controlled by nutrient and salinity conditions. Such tank culture may be useful in the future to produce high value fine chemicals for medical applications.

Seaweeds are the most obvious type of plant in the sea and are the main component of the phytobenthos but other algae and other marine plants are described elsewhere in this Encyclopaedia.

Further reading

- Guiry MD and Blunden G (eds) (1991) *Seaweed Resources in Europe: Uses and Potential.* Chichester: Wiley.

- Hoek C van den, Mann DG and Jahns HM (1995) *Algae: An Introduction to Phycology.* Cambridge: Cambridge University Press.

- Lembi CA and Waaland JR (eds) (1988) *Algae and Human Affairs.* Cambridge: Cambridge University Press.

- Lobban CS and Harrison PJ (1997) *Seaweed Ecology and Physiology.* Cambridge: Cambridge University Press.

- Luning K (1990) *Seaweeds: Their Environment, Biogeography and Ecophysiology.* New York:Wiley.

- South GR and Whittick A (1987) *Introduction to Phycology.* Oxford: Blackwell Scientific Publications.

Making a full seaweed list for a seashore – collecting and identifying species

Don't make the mistake of thinking that identifying seaweeds is not a glamorous enough task for modern marine biology. Many universities are failing to train students to be able to cope with biodiversity or to carry out scientifically respectable surveys as consultants. Pressing seaweeds to make a herbarium is not just a simple handicraft. It provides a more or less permanent record of what was found. Now that we have environments recovering from pollution we need to see what was there before the pollution in order to gauge the recovery. This means that we need to use 19th Century species lists but because many old records are suspect the herbarium records enable us to verify them. Instructions on pressing seaweeds are given later.

How to collect seaweeds for a full species list to assess species richness

Average from single surveys ~70 on rich shore.

A rich shore may have as many as 100 species. This large species number will only be found if the shore is searched thoroughly. The following all need to be considered:

- Only attached species to be collected (drift may be from elsewhere)
- Full range of subhabitat types to be sampled:
    - Rockpools, crevices, couloirs, ledges, overhangs and caves
    - Upper shore rocks and freshwater seepage for Chlorophyta mats
    - Under canopy algae for small, fine filamentous forms
    - Turfs of mixed filamentous species
- Epiphytes on particular algal species (while some may be visible to the naked eye some can only be found by microscopic examination of common species which might otherwise not be collected) including but definitely not restricted to:
    - *Elachista* spp. and *Ulothrix* spp. on *Fucus*
    - *Litosiphon* spp. on *Alaria* and *Chorda.*
    - Encrusting Corallines on *Polyides*
    - Many small epiphytes on various filamentous species such as *Cladophora*
    - Red epiphytes on kelp stipes
- Endophytes in particular algal species, including but not restricted to:
    - *Chlorochytrium* spp. in a variety of host species
    - *Myrionema strangulans* in *Palmaria* and *Enteromorpha* spp.
    - Variety of Chlorophyta, Phaeophyta and Rhodophyta spp. in *Cladophora, Polysiphonia and Ceramium*
    - Many small filamentous epiphytes in gelatinous red and brown algae and particularly in decaying distal portions of *Dumontia* and *Chorda*
- Epizoans on particular animal species e.g.
    - *Audouinella spp.* on hydroids
    - *Ralfsia* on Limpet shells
- Endozoans in particular animal species (shell-borers may need the shell dissolving to find them) e.g.
    - *Audouinella spp., Melobesia* and *Epicladia* in/on hydroids
    - *Tellamia spp* in *Littorina littoralis.*
    - Blue-green species, reproductive phases and Chlorophyta spp. boring in various periwinkle, limpet and mussel shells
- Epilithic encrusting species on rock surfaces e.g.
    - Encrusting corallines such as *Lithothamnion, Phymatolithon.*
    - Other encrusters such as *Hildenbrandia* and *Ralfsia*

Collections should include sufficient of each plant to show all features needed for identification. Sometimes the basal attachment organ is very important so make sure you get this. Reproductive structures can also be very important. Beware of imagining that you can identify more on sight in the field than is reasonable. Most

e.g. greens.

filamentous forms need microscopic examination in the lab to determine which species they are. Green mats that look the same to the untutored eye can be very different from each other. Examination of mats often reveals many subordinate species. If you are to find epiphytes and endophytes you will need to take material for microscopic examination of species that you can identify in the field and therefore might not bother to collect. Even *Fucus* spp can be difficult. Don't accept just the superficial characters – *F.spiralis* is not always spiral, *F.vesiculosus* is not always vesiculate. Use the full range of features and remember that they may hybridise.

Identification

Keys are fabrications of Man designed to help identification. Use them if they help you. But it is very difficult to write infallible keys – I know, I have tried! They may lead you badly astray. This has two consequences. (1) you must confirm any identifications, which have been made using only a key, by referring to full descriptions and detailed drawings or photos in reference works (not laymen's guides to the shore!) (2) you may identify by looking at pictures in guides but again you need to confirm as above. You must consult the separate handout to choose keys and guides for seaweed identification.

Microscopic examination is usually necessary to identify all larger filamentous species and to find and identify the smaller ones that may live inside or attached to larger ones. Encrusting forms often need to be scraped of the rock surface for microscopic examination. Dissecting microscopes will sometimes suffice for looking at the general arrangement of plants but where you need to see cell detail (most filamentous species) you must use a compound microscope.

Beware that there are things that are commonly confused with seaweeds in field collections, often when observed under the microscope:

- Decaying remains of higher plant tissues, especially spiral lignin thickening off xylem vessels, which can be confused with the spiral filamentous cyanobacterium, *Spirulina*
- Leaves of bryophytes which may look like foliose green algae except that they have many discoid chloroplasts per cell
- Coloured or translucent man-made or natural fibres which can be confused with filaments
- Fine colourless hairs on filamentous algae may be chains of filamentous bacteria
- Single celled epiphytic diatoms on stalks
- Small animals like a funnel on the end of a retractile stalk which is attached epiphytically to other seaweeds especially in polluted places – vorticellids
- Colonies of hydroids and bryozoans which have a plant like appearance until examined microscopically showing that they are colonial animals

Range of Forms

Seaweeds belong mainly to three colour divisions of the algae – green (Chlorophyta), brown (Phaeophyta) and red (Rhodophyta). Beware that some may have their colour masked by an excess of other pigments – the red Porphyra usually looks brown, brown fucoids may sometimes appear green, blue-greens can vary their colour (chromatic adaptation) to suit the colour of incident light so that the same species may appear turquoise, green, black, brown or even purple.

There is an amazing range of seaweed forms some of which can only be found by detailed field searching or searching under the microscope.

Unicellular forms – some attached to rocks and large (up to 1mm) and maybe forming a green stratum on the rocks. May be species in their own right or may be phases in life cycles of other species

- Colonial forms
- Filaments
  - o branched or unbranched — regular, irregular, pinnate (feather), alternate
  - o uniseriate (one cell thick) or multiseriate (> 1 cell thick)
  - o macroscopic or microscopic
  - o free-living on rock or endophytic, endozoic, epiphytic
- Pseudoparenchymatous forms (growing by aggregation of filaments) or parenchymatous (growing by cell division in 2 or more planes): → Macroscopic forms
  - o Tubular (Enteromorpha traditionally)
  - o Foliose (traditionally Ulva morphology)
- Encrusting forms
- Coenocytic forms (made up of acellular filaments like fungal hyphae)
- Multinucleate-segmented forms (made up of mutinucleate segments which resemble large cells).
- Large cartilaginous forms

Special features that need to be considered in making identifications include:

- Existence and positions of meristems (areas of active mitosis). Growth may be diffuse (cells divide throughout the plant) or localised to meristems. Meristems may be apical (at the distal end), lateral or intercalary (somewhere in the middle of the plant). Apical meristems on filaments may appear as very large apical (at distal tip of filament) cells (enlarged in preparation for division) with cells half the size (already divided into two) immedaiately behind them going down the filament.

  cells small at meristem, increasing in size as move away

- Phases of growth – many seaweeds have more than one phase of growth resulting in the formation of internal tissue differentiation – e.g. cortex and medulla with different cells type in each – visible only under microscopic examination

- Chloroplast morphology in cells (compound microscopic examination) may be
  - o Parietal – forming a cylinder around the cell inside the cell wall
  - o Axile – passing through the middle of the cell cavity
  - o Simple – a non-perforated plate or cylinder
  - o Band shaped – a girdle almost completely encircling the cell
  - o Discoid – often may discs per cell
  - o Reticulate – a network – sometimes made up of lots of filaments of chloroplast material or sometimes formed by lots of perforations and lobes on a parietal cylinder

- Pyrenoids –centre of formation of storage product in the chloroplast –stains blue-black with iodine in potassium iodide in green algae because starch ids the storage product but won't stain with iodine in other colour groups which do not store starch ↳ imp in some green algae to speciate as these store starch (red algae however don't).

- Branching pattern:
  - o irregular
  - o alternate
  - o opposite
  - o secund (all on one side like a comb)

- Presence of reproductive structures

- Apparent encrusting forms may sometimes be basal portions of erect plants e.g. some encrusting calcareous forms may just be expanded basal portions of Corallina, some non-calcareous red ones may be bases of Mastocarpus

Citing of names

You must always give the full binomial (genus and species) name. On herbarium sheets, and on the first mention in a scientific paper, you must append the nomenclatural authorities after the name. This tells the observer or reader whose concept of that species you are using. In Britain we have check-lists of the currently accepted species names with their current nomenclatural authorities. Details of currently used and past check-lists are given in a later section on the use of check-lists.

Always speciate if at all possible
↳ not case in certain taxa in RBL.

Checklist Book
can be downloaded
from website (BPS).
free of charge!

Books and Keys for the Identification of Marine and Estuarine Benthic Algae

This list gives many more references than are needed for the basic identification of seaweeds. References 1 to 15 in the list is the basic set of identification works for seaweeds (with the addition of a check-list and/or seaweed atlas of the British Isles – see later section of this booklet on checklists). There is no specific key to estuarine algae so more detail is given on specialist keys that cover algae found in the upper reaches of estuaries. Most estuarine species can be identified with works for marine algae, although there are some works, in German, on the Baltic Sea which are particularly useful.

Remember that keys are artificial creations of man and are fallible. There is no intrinsic merit in using a key when you can more easily make an identification by scanning through the pictures in a work. But you must always cross-check any identification reached that way with written descriptions and any identification reached using a key should be cross-checked with illustrations. If there is any uncertainty, then cross-check with more than one source.

Identification of Seaweeds

Seaweeds can be identified to genus level using the following key:

1.Jones, W.E. 1962. A key to the genera of the British seaweeds. *Field Studies*, 1 (4), 1-32.

Easier to use than the genus key in Newton (see below) but still requires Newton or other works to confirm identifications or to take them to species level. It's not suggested as a standard way of beginning but to resolve problems when other methods fail.

Particularly useful keys to the red and brown seaweeds that will meet many needs are:

* **2. Hiscock, S. 1979. A field key to the British brown seaweeds (Phaeophyta). *Field Studies*, 5, 1-44.**
↳ all microscopic omitted

* **3. Hiscock, S. 1986. A field key to the British red seaweeds (Rhodophyta). Field Studies Council Occasional Publications no 13.**

These are easier to use than Jones or Newton. Beware that the brown one really is a field key and does not contain many smaller species – it only has the macroscopic ones and the drawings are not as good as in the red key. You will need specialist works for the small browns. The red one is more comprehensive and has excellent drawings - probably the best published drawings available for many of the reds!

There is no general field key to the green seaweeds of Britain as a whole, comparable with those of Hiscock. There is however a regional key which can be used reasonably well throughout Britain:

4. Clokie, J.P. and A.D. Boney. 1980. Key to the green algae of the Firth of Clyde. *Scottish Field Studies* 1980.

We have unpublished trial keys to all three of the seaweed groups - a set of keys, illustrations and descriptions of browns by Ian Tittley; keys to greens and browns by Ian Tittley; and separate keys to genera and species within genera of browns by Geoge Russell. The brown ones are the only complete up-to-date keys which cover the whole of the British browns and do make up for the lack of coverage in the Seaweeds of the British Isles series. We cannot cite formal references to these keys because they are unpublished typescripts written in preparation for works which have not yet been published. We thank the authors for their use.

Normally you should avoid laymen's guides such as "Collin's Pocket Guide" or the "Hamlyn Guide to the Seashore". They are very misleading and incomplete where seaweeds are concerned. However one layman's book is very good:

5. Dickenson, C.I. 1963. *British Seaweeds.* Kew Series, London, Eyre & Spottiswoode.

It doesn't have all the microscopic species but for the macroscopic ones it is surprisingly good. Unfortunately it is now out of print but it is in many local libraries and secondhand copies can be found at www.abebooks.co.uk

The only complete standard professional work covering all the British seaweeds in one volume is:

6. Newton, L., 1931. *A Handbook of the British Seaweeds.* London British Museum (Natural History).

The nomenclature in Newton is out of date, the keys to genera are difficult to use, the illustrations are not always helpful and the notes on distribution of species etc. may be misleading, but some of the keys to species within the genera are useful. When compiled it was a great achievement but now needs updating. It is a really useful book when you have some experience but must be used with great caution until then. Second hand copies are often available at £20 to £30 from www.abebooks.co.uk

The nomenclatural problems in Newton can be overcome, at least partly, by correcting identifications in accordance with a recent check-list (see later section of this booklet on the use of check-lists).

For scientific acceptability all seaweed names should be cited in accordance with a standard check-list wherever possible. See the later section of these notes on the check-lists now available.

The other objections to Newton can be overcome by the use of additional works. The ***Seaweeds of the British Isles*** is a series of very detailed identification works being published by the Natural History Museum and the British Phycological Society as a much more detailed replacement for Newton. The parts so far published are:

7.Dixon, P.S. and Irvine, L.M. 1978. *Seaweeds of the British Isles. Vol.1 Rhodophyta. part 1. Introduction, Nemaliales, Gigartinales.* (currently £30 from NHBS, Taunton)

8. Irvine, L.M. 1983. *Seaweeds of the British Isles. Vol 1. Rhodophyta. part 2a. Cryptonemiales (sensu stricto), Palmariales, Rhodymeniales.* (currently £25 from NHBS, Taunton)

9. Chamberlain, Y. 1993. *Seaweeds of the British Isles. Vol 1. Rhodophyta. Part 2b . Corallinales.* [especially useful for the colour plates of the encrusting Corallinales] (currently out of print)

10. Maggs, C.A. & Hommersand, M. 1993. *Seaweeds of the British Isles. Vol 1. Rhodophyta. Part 3a. Ceramiales.* (currently £48 from NHBS, Taunton)

11. Brodie, J.A. & Irvine, L.M. 2003. *Seaweeds of the British Isles. Vol. 1 Rhodophyta, Part 3B Bangiophycidae* (currently £40 from NHBS, Taunton)

12. Fletcher, R.L. 1987. *Seaweeds of the British Isles. Vol 3. Fucophyceae (Phaeophyceae). Part 1.* (currently out of print)

13. Burrows, E.M. 1991. *Seaweeds of the British Isles. Vol 2. Chlorophyta.* (currently £37.50 from NHBS, Taunton). Effectively now replaced by Brodie et al. no 15 below.

14. Christensen, T. 1987. *Seaweeds of the British Isles, Vol 4. Tribophyceae (Xanthophyceae).* [effectively this whole book is on one genus, *Vaucheria*, which is especially abundant in the upper reaches of estuaries] (currently £10 from NHBS, Taunton)

15. Brodie, J., Maggs, C.M. and John, D.M. (editors) 2007, Green Seaweeds of Britain and Ireland. British Phycological Society. Available from NHBS, Taunton, at £25. This is a multi-authored work (14 different authors) which gives excellent colour photographs courtesy of financial support from SEPA and EA.

A further part (Vol. 3, part 2) is in preparation to cover the remaining half of the brown algae. It might be expected in late 2007 or 2008.

There are unpublished trial keys to all three of the seaweed groups

- Keys, illustrations and descriptions of brown seaweeds by Ian Tittley
- Keys to green seaweeds by Ian Tittley
- Keys to red seaweeds by Ian Tittley
- Keys to genera of brown seaweeds by George Russell
- Keys to species within genera of browns by George Russell

The brown ones are the only complete up-to-date keys which cover the whole of the British browns until the Seaweeds of the British Isles series is completed with Vol. 3, part 2.. We cannot cite formal references to these keys as they are unpublished typescripts but we thank the authors for their use.

Overseas keys and floras that may be useful

There are other useful works published for areas outside Britain which may help you when the British ones do not seem to be getting you anywhere. But remember that because they relate to areas outside Britain you must beware of mistakenly identifying species which have not been found in Britain - refer to the check-lists or to the seaweed atlas (see section on check-lists later in this booklet). They include the following:

16. Pankow, H. 1971. ***Algenflora der Ostsee. I. Benthos. (Blau-, Grun-, Braun- un Rotalgen).*** **Stuttgart, Gustav Fischer Verlag.**
[A pity this book is in German! I have really found it to be one of the most useful books for brackish-water algae; partly because it is written specifically for a brackish sea (Baltic) and partly because Pankow seems to have a knack of simplifying the taxonomically-difficult microscopic species without losing scientific validity].

17. Cabioch, J., Floc'h, J.Y. & Toquin, A. 1992. ***Guide des algues des mers d'Europe.*** **Delachaux et Niestle.**
In French. This book has extensive colour photographic coverage which includes many species that occur in Britain. Make sure that you are in the Atlantic coast section of the book – not the Mediterranean section! There is an unconfirmed rumour that an English language edition is in preparation. Now out of print.

18, Gayral, P. 1966. ***Les Algues des Cotes Francaises (Manche et Atlantique).*** In French. Now reprinted by Koeltz Scientific Books and available from them or at £31.50 from NHBS Taunton. Original 1966 edition may be available for this or lesser price form www.abebooks.co.uk. Black and white photographs of most species listed, unusual for a flora 40 years ago, a useful book.

19. Gams, H. 1974. ***Keine Kryptogamenflora Band Ib. Makroskopische Meeresalgen.*** **Stuttgart, Gustav Fischer Verlag.**
[Another German language work. This is occasionally very useful as it is simple and specifically includes the Baltic brackish flora but beware on three counts: It also includes other European locations with subtropical species e.g. the Mediterranean, it excludes microscopic species, it is only a key - not a complete flora so results *must* be checked elsewhere. On the whole it is *occasionally* useful for a non-specialist but not recommended as a main source key.]. (currently £28.50 from NHBS, Taunton)

20. Kornman, P. & Sahling, P-H. 1977. ***Meeresalgen von Helgoland. Benthische Grun-, Braun- und Rotalgen.*** **Hamburg, Biologische Anstalt Helgoland.**
Originally published as a lengthy paper in *Helgolander Wissenschaftliche Meeresuntersuchungen* (vol 29, 1-289, 1977). This was reissued as a separate book and has since had a supplement issued:
21. Kornmann, P. and P-H, Sahling. 1983. Meeresalgen von Helgoland: Erganzung. ***Helgolander Wiss. Meeresunters.*****, 36, 1-65.**
[This does not contain keys, nor does it contain every species. Its great value is that all species named are represented by high quality photographs and/or photomicrographs rather than line drawings, so it's good for checking you've got something right when Newton's or Pankow's drawings are inadequate. Beware that

Kornmann has a nasty habit of using a different set of names for species than most other European phycologists so cross-refer to check-lists though you may not find all his names there.]

22. Taylor, W.R. 1957. *Marine Algae of the North Eastern coast of North America.* Ann Arbor, The University of Michigan Press, 2nd edition.
[This is the definitive work for it's area - their equivalent of Newton. Since our flora is similar to that of N.E. America it can be used for its illustrations, keys and descriptions many of which are superior to those of Newton. Again you must beware that it doesn't have all our species and it has some which are not present here - so cross-refer to check-lists.]

23. South, G.R. and Cardinal, A. 1973. Contributions to the flora of marine algae of Eastern Canada. 1. Introduction, historical review and key to the genera. *Naturaliste, can.,* 10, 605-630.
[As for Taylor, above, this key to genera covers some but not all of our species and contains some extra ones. It should only normally be used as a last resort when West European keys fail, and you must cross-refer to the check-lists.]

24. Stegenga, H and Mol,I. 1983. *Flora de Nederlandse Zeewieren.* Koninklijke Nederlandse Naturhistorische Vereniging, Amsterdam. (in Dutch but good diagrams).

Specialist works on particular groups or genera

1. Chlorophyta

Normally Newton, Jones, Hiscock, Pankow and the check-list should be enough for your needs. If you are doing algal work seriously the following specialist works on selected groups which include species found in brackish waters may be particularly valuable.

25. Bliding, C. 1963. A critical survey of European taxa in Ulvales. Part I. *Capsosiphon, Percursaria, Blidingia, Entermorpha. Opera Botanica, 8* (3), 1-160.

26. Bliding, C. 1968. A critical survey of European taxa in Ulvales. Part II. *Ulva, Ulvaria, Kornmannia, Monostroma. Botaniska Notiser, 121,* 553-629.

[These two classic Bliding papers do not contain keys but are lavishly illustrated with macro- and micro-photographs. They are the most wide-ranging monographs on variation in these difficult genera. Do not use these unless you are experienced or you may end even more confused]

27. Koeman, R.P.T. and C. van den Hoek, 1980. The taxonomy of *Ulva* (Chlorophyceae) in the Netherlands. *Br. phycol. J.,* 16, 9-53.

28-30. Koeman, R.P.T. and C. van den Hoek. The taxonomy of *Enteromorpha.* Link, 1920, (Chlorphyceae) in the Netherlands.
I. *Arch. Hydrobiol. Suppl.* 63, 279-330 (1982).
II. *Cryptogamie Algol.* 3, 37-70 (1982).
III. *Cryptogamie Algol.* 5, 21-61 (1984).

31. Lokhorst, G.M. and B.J. Trask. 1981. Taxonomic studies on *Urospora* (Acrosiphoniales, Chlorophyceae) in Western Europe. *Acta Bot. Neerl.,* 30, 353-431.

32. Kornmann, P. and P-H Sahling. 1974. Prasiolales (Chlorophyta) von Helgoland. *Helgolander Wiss. Meeresunters.,* 26, 99-133.

33. Van den Hoek, C. 1963. *Revision of the European Species of Cladophora.* Leiden. (Reprinted 1976 by Otto Koeltz Science Publishers, Koenigstein, FRG.)

34. Soderstrom, J. 1963. Studies in *Cladophora. Botanica Gothoburgensia,* 1, 1-147.

35. Lokhorst, G.M. 1978. Taxonomic studies on the marine and brackish water species of Ulothrix (Ulotricales, Chlorophyceae) in Western Europe. *Blumea,* 24, 191-299.

Excellent illustrations, but not keys, of some only of the species particularly important in estuaries are to be found in:

36. Carter, N. 1933. A comparative study of the algal flora of two salt-marshes II. *J. Ecol., 21,* 128-208.

An annotated check-list of marine and estuarine algae of the Clyde, while apparently of local interest, contains a tremendous amount of algal natural-history information of the behaviour and distribution of many species. It is possible that such a list could be very useful to the partly-trained worker in assessing whether or not a problematical identification is likely to be correct. One must however be careful as behaviour of the plants may be different a long way from the Clyde e.g. the South coast of England. The reference is:

37. Clokie, J.J.P. & Boney, A.D. 1979. Check-list of marine algae of the Firth of Clyde. *Scottish Field Studies.* 1979, 3-13.

2. Chrysophyta

The principal chrysophytes to be found in estuaries and sometimes on the open coast, particularly on mud or in salt-marsh are:

(a) mats of *Vaucheria* spp. (Xantophyceae) – an obvious feature of the upper reaches of many estuaries
(b) epilithic films of diatoms and benthic sediment dwelling diatoms (Bacillariophyceae)
(c) benthic filamentous phases in the life histories of otherwise planktonic forms in the Haptophyceae and Chrysophyceae, found in salt-marshes or on mud.

(a) ***Vaucheria*** spp. This coenocytic filamentous plant forms distinct ruffled or velvety cushions in a wide range of habitats and can often be identified to genus level with the naked eye in the field. Species identification is very difficult. It is based on the structure and position of sexual organs and consequently cannot be done on non-reproductive specimens or without microscopy. The normal practice is to excise a small area, say 1 or 2 sq. cm., of algal mat and to maintain it in the laboratory at about 15^{o}C under a long-day length in a closed petri-dish without added culture medium. This appears to induce the formation of sex organs. Specimens collected in the summer are quite likely to be reproductive at the time of collection.

In addition to Christensen's Tribophyceae volume in the "Seaweeds of the British Isles" (see above) another good identification work for *Vaucheria* is:

38. Knutzen, J. 1973. Marine species of *Vaucheria* (Xanthophyceae) in South Norway. *Norw. J. Bot., 20,* 163-181.

This key is specifically on North-West European material and includes useful habitat notes. Two more general works which include species from elsewhere (hence reference to check-lists needed to confirm likely identifications) are:

39. Blum, J.L. 1972. *Vaucheriaceae. North American Flora Series II, Part 8.* New York Botanical Garden.

40. Venkataraman, G.S. 1961. *Vaucheriaceae.* New Dehli, Indian Council of Agricultural Research.

A good key (but not very good illustrations) to West European species is included in Pankow (see reference earlier).

(b) ***Diatoms.*** Detailed identification of the massive range of diatoms found in benthic samples is probably beyond the capabilities of most workers - even macrophycologists! It sometimes requires detailed microscopic examination of the structure of the siliceous frustule after protoplasm has been cleared away by vigorous treatment with acids and oxidising agents. It is however possible to identify some of the commonest estuarine diatoms without such clearing.

For all diatoms three works are particularly useful:

41. Hendey, N.I. 1964. *An introductory account of smaller algae of British coastal waters. Part V. Bacillariophyceae (Diatoms).* Fishery Investigations Series. London, H.M.S.O.

42. Van Heurck, H. 1896. *A treatise on the Diatomaceae.* London, Wesley. Reprint, 1962 by Wheldon & Wesley and J. Cramer.

43. Hustedt, F. 1930. *Bacillariophyta.* In: *Die Susswasserflora Mitteleuropas.* Vol. 10. Ed. A. Pascher. Publ. Fisher Verlag, Jena. [Since issued as a reprint - a freshwater work but still useful]

In addition there is a very useful key to the diatoms commonly grouped under the form genus name "***Schizomena***". These diatoms are naviculoid forms which live in colonies in mucilaginous tubes and resemble filamentous brown algae to the naked eye. These are common on rocky shores subjected to high suspended solids and turbidity and are also found in estuaries. The key is:

44. Cox, E.J. 1977. The distribution of tube-dwelling diatom species in the Severn estuary. *J. mar. biol. Ass. U.K.*, 57, 19-27.

Diatoms are not included in any of the seaweed check-lists and nomenclature can be revised in accordance with their own check-list:

45. Hendey, N.I. 1974. A revised check-list of British marine diatoms. *J. mar. biol. Ass. U.K.*, 54, 277-300.

(c) ***Benthic forms of planktonic chrysophytes.***

The most likely ones to be found include members of the genera *Apistonema, Chrysomeris* and *Ruttnera.*

Descriptions are to be found in Pankow, Carter (references given earlier) and a further reference to Carter:

46. Carter, N. 1937. New or interesting algae from brackish-water. *Arch. Protistenk.*, 90, 1-68 Figs. 1-8.

3. *Blue-green algae*

These are a major component of the epilithic and epibenthic flora of the upper reaches of estuaries. Identification is difficult because of their incredible morphological plasticity and the high level of disagreement between authors. There are at least two very different taxonomic schemes in regular use. One is based solely on earlier morphological descriptions and a more recent one on laboratory culture work by Drouet & Dailly who claimed a substantial reduction in the number of taxa by interconverting even quite dissimilar forms into each other by manipulation of culture conditions. This has been popular with some workers because it makes it easy for them to give a name to members of a group that they do not enjoy having to include in their species lists. My personal preference is not to accept the over-simplification proposed by Drouet & Dailly. Even if the original recognised taxa have often been shown not to be genuine species in the "higher-plant" sense, it seems preferable to continue to use them for the time-being for two reasons; a particular morphological form or ecophene may indicate a particular set of environmental conditions; the high level of disagreement among phycologists about Drouet and Dailly's ideas makes it desirable to record data in the more complete older format.

A good key to brackish blue-greens is found in Pankow (reference given earlier).

Keys to genera of blue-greens together with keys to species within genera and, very usefully, tables showing equivalent names between Drouet and Dailly's taxonomy and the traditional taxonomy are given in:

47. Humm, H.J. and S.R. Wicks. 1980. *Introduction and guide to the marine blue-green algae.* Wiley.

This probably all that is needed. It is arguable whether or not more detailed treatment is desirable from non-expert phycologists. If more detailed works are needed the following are particularly recommended:

48. Desikachary, T.V. 1959. *Cyanophyta.* New Dehli, Indian Council of Agricultural Research.

49. Fremy, P. 1972. *Cyanophycees des Cotes d'Europe.* Asher and Co. BV., Amsterdam. Reprint of original series of articles published 1929-33 in *Mem. Soc. Nat. Math. Cherbourg.*

50. Geitler, L. 1932. *Cyanophyceae* in *Rabenhorsts Kryptogamen-Flora.* Leipzig. Akademische Verlagagesell-schafft m.b.H. Reprinted 1971, Johnson Reprint Corporation. New York and London.

You should note that Parke & Dixon's check-list is of limited value for blue-greens because it is based on Drouet and Dailly's revised taxonomy and blue-greens are not even included in later seaweed check-lists.

4. Euglenophyceae

Green patches of benthic euglenoids are common on intertidal muds of some estuaries, particularly in Summer, interspersed with diatoms. The commonest ones appear to be *Euglena obtusa* and *E. vermiformis.*

A good key is:

51. Butcher, R.W. 1961. *An introductory account of the smaller algae of the British coastal waters. Part VIII Euglenophyceae.* Fishery Investigations Series. London, H.M.S.O.

Many of these references are out of print but second-hand or reprint copies can usually be obtained from: Koeltz Scientific Books, P.O. Box 1360, D-6240 Koenigstein, Germany. Ask for their catalogue on Algae & Phytoplankton, issued every year or two, which contains many hundreds of algal books. They are expensive. Copies of most which are in print can be obtained in Britain from NHBS – Natural History Book Service, 2-3 Wills Road, Totnes, Devon TQ9 5XN, Tel: 01803 865913; Fax: 01803 865280; www.nhbs.co.uk

A good way of trying to find second hand copies of many books on all subjects including quite obscure scientific books is to log on to www.abebooks.co.uk which will search the stocklists of tens of thousands of second hand booksellers in Europe and North America and enable you to order from them using a credit card which simplifies ordering in foreign currencies. I have found many second hand copies of seaweed books this way.

Common Species of Seaweed on Scottish Seashores

These notes are meant to accompany your sensible and enquiring use of keys and identification books. They have been built up over many years of field courses to assist students with the commonest problems that they have in algal identification but they do not replace the proper literature.

Firstly you need to **decide on the colour of the weed - red, brown or green.** Remember that some of the large brown algae - particularly the fucoids - often look greenish; and that *Porphyra*, although it is a red seaweed, may appear brown. Also the red and brown seaweeds, particularly the more delicate filamentous forms, often turn green, white or yellowish in preservative, if they are decaying or if they have been bleached by sunlight.

1. GREEN SEAWEEDS

Most of the green seaweeds are either foliose (i.e. flat) or are filamentous. Foliose includes tubular ones. There are microscopic filamentous ones that bore into mollusc and barnacle shells, turning them green, and endophytic ones living inside the tissues of larger red and brown seaweeds. These microscopic ones are not covered here. Remember to stain the pyrenoids of green algae with iodine in potassium iodide. External structure of the plant, chloroplast shape, cell size and shape, and number of pyrenoids per cell are important features.

(a) Foliose green seaweeds

Prasiola stipitata - tiny foliose plant, 1 layer of cells thick, cells in regularly arranged square pattern. 1 stellate chloroplast per cell tghough often indistinct, forming a band in the upper intertidal, often the highest species on open rock surfaces, may need to be wetted to remove off rock and confirm identification under microscope.

Enteromorpha (tubular plants now included in the genus ***Ulva)*** - tubular, foliose plant, cells normally greater than 12µm wide with single parietal chloroplast. Found at all shore heights, open rocks and pools and in freshwater influence. Commonest species:

- ***E. intestinalis*** - cells irregularly arranged, 1 (-2) pyrenoids per cell, unbranched.
- ***E. compressa*** - as *E. intestinalis* but branched (N.B. these are major branches like the main axis rather than small hairy projections)
- ***E. prolifera*** - cells, especially near base, approximate to ordered rows and columns, 1 (-2) pyrenoids per cell, numerous forms both branched and unbranched, including hairy proliferous branching.
- ***E. linza*** - linear like *Enteromorpha* but flat like *Ulva* because tube is compressed – under the microscope you will be able to see the folding over of cells at the edge showing that it is tubular but compressed.

Other species of *Enteromorpha* occur with more pyrenoids per cell - refer to specialist keys. These species are less common. Pyrenoids can be made more visible under compound microscope, as dark circles in chloroplast, by staining with iodine in potassium iodide. Note that the inclusion of *Enteromorpha* within *Ulva* does not change the species that exist e.g. *E. intestinalis* simply becomes *U. intestinalis*.

Ulva lactuca - flat, foliose plant, **2** layers of cells thick - check this by focusing up and down under compound microscope. There are other species of *Ulva* so see books if your plant is unusual. It now seems that other species are commoner than has been appreciated and there might be many entities misidentified commonly as *U. lactuca.* see now green book

4 families of this

Monostroma grevillei - foliose plant like *Ulva* but only 1 layer of cells thick - hence paler green than *Ulva* - check under microscope. Occurs particularly in rock pools on upper shelf of shore in spring - rest of year as *Codiolum* phase (see life-history notes). When very young may be small, water-filled sac which later tears to give flat thallus. Not likely to be found in Autumn but see *Ulvaria.* elongated basal cells in Monostroma

Ulvaria oxysperma (now ***Gayralia oxysperma***) - this is also a monostromatic foliose plant (1 layer thick), also sometimes called *Monostroma oxyspermum*, but it occurs all year round and is usually confined to estuaries. It is attached by very elongated rhizoidal cells at the base (lacking in *M. grevillei* which is attached by a basal disc of cells), and has a characteristic angular cell shape.

Blidingia - a tube, like a small *Enteromorpha.* Cells usually less than 10µm so under the microscope they do not appear to have easily distinguishable contents. May form a top-shore band on open rocks but also attached at various shore-heights as a turf on limpets and *Fucus*. Need to verify under microscope. Don't attempt to separate 2 species, *B. minima and B. marginata* - this is suspect.

(b) Filamentous species

The main distinguishing features are the diameter of the cells, the type of chloroplast (reticulate or simple), whether branched or not.

The genus ***Chaetomorpha*** - unbranched filaments with reticulate (net-like) chloroplasts, cells about as long as broad or longer than broad, often slightly barrel-shaped cells. There are 3 common species none of which penetrate estuaries (check *Rhizoclonium* or *Cladophora glomerata* if you think you,ve got this in an estuary):

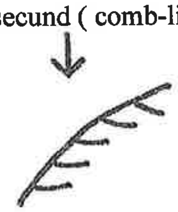
> ***C. mediterranea*** – (now ***C. ligustica***) woolly masses with cells < 100µm , very soft masses, often like green cotton wool tangled round othe weeds, individual filaments may appear spiral under microscope.
> ***C. linum*** - tough, wiry masses with cells 100-300 µm, on rocks or on mud flats.
> ***C. melagonium*** - solitary filaments in rock pools - cells up to 1 mm visible to naked eye, collapse very quickly on drying after taking out of pool.

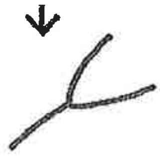
The genus ***Cladophora*** - branched filamentous tufts with all branches made up of similar type of cells, reticulate chloroplast but usually so dense a network that the cells appear uniformly green - many pyrenoids on staining with I/KI. The commonest species are: many epiphytes e.g. Audouinella

terminal cell may have circular reproductive bodies (at tips) → when released leave white tips

> ***C. rupestris*** - broad filaments (>80 µm) dark green and multidichotomous branching i.e.

> ***C. sericea*** - also broad filaments but lighter green with normal dichotomous branching and sometimes secund (comb-like) branching near tips of axes.





These are the commonest species and almost all will be one of these two. But *C. albida* is a very distinctive species because it has very fine axes (30-80 µm), much finer than any other and very pale green, may occur as epiphyte on bigger species of *Cladophora;* and *C. pellucida* has giant basal cells, several mm long, visible to naked eye. Other species need specialist keys.

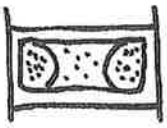
Spongomorpha/Acrosiphonia - branched filamentous tufts like *Cladophora* but bright green owing to more open chloroplasts - network of chloroplast fibrils clearly visible under compound microscope, with swollen ends of fibrils possibly giving false appearance of discoid chloroplasts. Young plants very bright green with one type of cell / branch. Older plants at first look like a different species - darker with 3 types of cell / branch: normal ones, pale thin downward-growing rhizoidal ones, and short hook-shaped ones pulling branches together into "ropes".

Acrosiphonia arcta **-** *Cladophora*-like plant in rock pools and open rocks.
Spongomorpha aeruginosa **-** Epiphytic turf-forming version on red and brown algae but also occurs free-living in pools and is like the dark form of *A.arcta.*

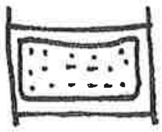
Ulothrix **-** unbranched filaments with small cells (10-30 μm) with a single band-shaped parietal chloroplast with an interruption in it. Ask for specialist key by Lokhorst if you are willing to have a go at identification to species level.

TS of cell

Viewed from A



Viewed from B



Urospora **-** unbranched uniseriate filaments like *Ulothrix* but with reticulate chloroplast (20 - 100 μm). Species distinction needs specialist key.

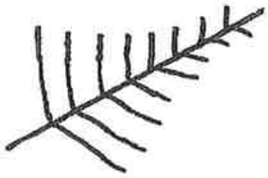
Ulothrix **and** ***Urospora*** **-** usually have cells shorter than broad or length and breadth the same. (*Chaetomorpha* cells are often longer than broad and barrel-shaped rather than straight sided). *Ulothrix* and *Urospora* may form turfs on rocks or may be epiphytic, particularly on *Fucus* - distinguish from epiphytic *Blidingia* using a microscope. Uniseriate filaments

Rhizoclonium **-** keys are confusing here - this is a very common alga but often doesn't look like the books say - they say it is branched. Most often it has unbranched filaments - cells usually longer than broad, straight sided, with open reticulate chloroplast. If branched, the branches are only 1-3 cells long forming rhizoidal branches

e.g.
cells up to 100μm long and 40μm broad but can be smaller, forms green mats in estuaries and on upper shore rocks on open coast or forming turf around fresh-water inflows and on top-shore particularly on grass just above shore. Most recently we have reverted to the former name of ***Rhizoclonium riparium*** for all entities, instead of ***R. tortuosum***. *R. riparium, R. implexum* and *R. tortuosum* are all the same marine species and probably the same as the fresh water *R. hieroglyphicum*.

* Chlorochytium w/in diatom colony
↳ unicellular microscopic green
* Dog whelks + Periwinkle bored by green Codiolum (tail) phase of Monostroma + other greens

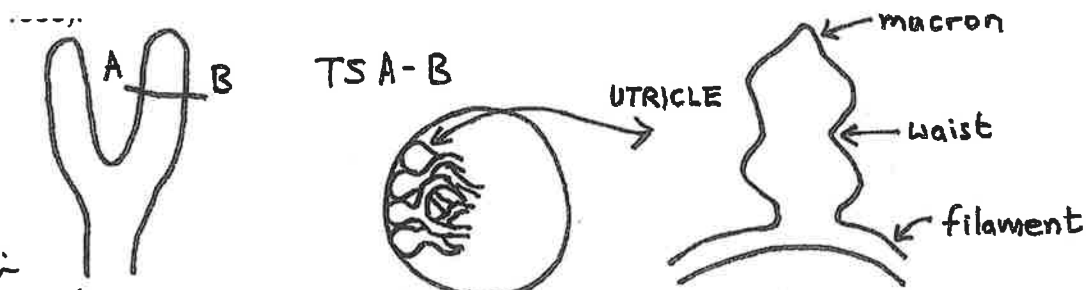
Bryopsis - coenocytic - not divided into cells - forming a beautiful regular, feather-like plant.



Although recently we have not always distinguished *B. plumosa* and *B. hypnoides* – it is now believed that they are genuinely separate species: ***B. plumosa*** – flat plant pinnately branched in one plane; ***B. hypnoides*** at least 2nd order of branches not all in one plane so plant appears more radially branched.

Codium - like *Bryopsis* made up of coenocytic (also pseudoparenchymatous) filaments, but hundreds of them wound tightly together to make a sponge-like green branched plant up to 1cm diameter in individual branches. Identification to species and sub-species level needs a small section of plant to be squashed and the individual filaments (and their swellings - the utricles) to be inspected under a compound microscope. Most if not all found will be *C. fragile* subsp. *atlanticum*. (see Silva in **J. mar. biol. Ass. U.K.** vol 34, pp 565-577, 1955).

outer wall cells, imp in speciation



2. BROWN SEAWEEDS

The dominant open rock fucoids are *Pelvetia canaliculata, Fucus spiralis, F. vesiculosus, F. serratus* and *Ascophyllum nodosum*. Remember that some change form with environmental conditions, e.g. *F. vesiculosus* may lack vesicles under strong wave action. *A. nodosum* is especially intolerant of wave action and under such conditions it may appear as a short mass of fleshy olive-green branches without bladders. *F. ceranoides* is distinctly restricted to strong freshwater influence. Dont confuse it with evesiculate *F. vesiculosus* on the open coast. *F. spiralis* really needs the sterile rim of tissue to be seen around the receptacle for firm identification. It is particularly prone to hybridise with *F. vesiculosus* to give *F. spiralis x vesiculosus* with characteristics of both species. There are reduced ecads of fucoids that occur on salt marshes often called *F. muscoides* although a form of other species, to which they appear to have no resemblance at first sight. There is a loose lying form of *Ascophyllum* in very sheltered sea-lochs, not attached to any rock, which looks at first sight more like a huge *Pelvetia*.
A fucoid which is common in mid and lower shore rock pools is the pod-weed, *Halidrys siliquosa*.
Under strong wave action the lower shore may have *Fucus* replaced by or mixed with another fucoid, *Himanthalia elongata*. This may appear as small and button shaped:

Chondrus crispus } v. variable morphology esp.
Ascophyllum nodosum } dependent on exposure.

Ascophyllum mackaii - cf free living Pelvetia

but when reproductive bears long thong-like receptacles:

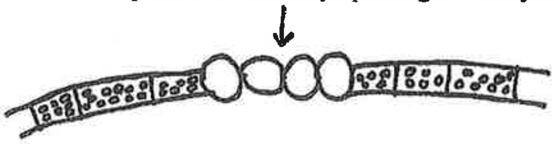
Kelps are the laminarians. These are subtidal or restricted to the sublittoral fringe on open rocks. However two species may occur a little higher intertidally in rock pools. *Laminaria saccharina* has a single blade without a midrib and is a classic rock pool plant on the lower shore. (Beware of confusing small plants with *Petalonia fascia* (see keys). Also beware of confusing *Petalonia* with sporelings of any *Laminaria* species). The other intertidal *Laminaria* is *L. digitata* which has a digitate frond and forms a band around low-water mark and can occur around intertidal pools. It has a smoothly surfaced stipe which tends to lack epiphytes, which aids its distinction from the other digitate *Laminaria, L. hyperborea*. This is the one that forms the sublittoral kelp forests. It has a rough stipe, usually clothed with epiphytes, the stipe probably more circular in TS than that of *L. digitata.* It is not likely to be found in intertidal pools and only on intertidal rocks on the very lowest spring tides. Its very tough stipe gives it an upstanding appearance.
On wave exposed shores, *L digitata* may be mixed with or replaced by *Alaria esculenta.* Like *L. saccharina* this has a single linear blade but also has a midrib. The blade is often torn at right angles to the midrib and there may be wing-like sporophylls on the short stipe below the blade.
Other common brown seaweeds in the intertidal include:

Asperococcus - like a tough brown *Enteromorpha* to the naked eye but not tubular. Take care to distinguish from *Enteromorpha* which has turned brown due to a surface coating of epiphytic diatoms.

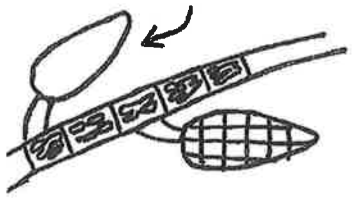
Scytosiphon - again superficially like *Enteromorpha* - paler than *Asperococcus*, tubular and constricted at intervals - probably only in rock pools.

Cladostephus - dense whorls of branches round a tough wiry axis make it look like a dirty brown moss plant - common on open rocks.

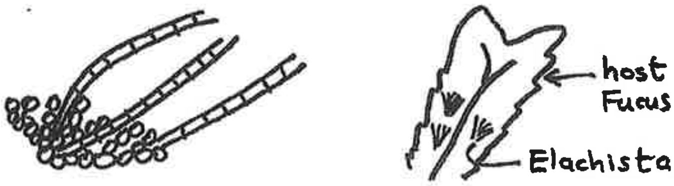
Filamentous Browns - There are numerous possibilities but the common ones are:
(i) Uniseriate
(a) On open rocks
-discoid chloroplasts, intercalary sporangia - ***Pilayella*** (mainly on open rocks).



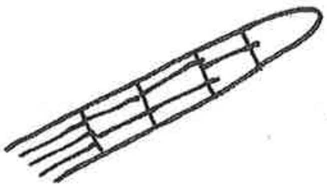
-linear chloroplasts, sporangia on special side branches - ***Ectocarpus*** (on rocks, in pools and epiphytic)



(b) As an epiphyte on fucoids
- macroscopically like a small shaving brush in tufts - a base of rounded branched cells bearing unbranched filaments of square cells - ***Elachista***



(ii) Multiseriate
- ***Sphacelaria*** - various species possible and you would need to refer to specialist keys to identify them. They are oviously multiseriate filaments which taper to a single apical cell at the tips of the filaments as shown in the diagram below.



Brown Crusts - on rocks - many species have brown basal portions or discoid encrusting phases in their life histories. If they are extensive crusts they may be a species in their own right, of the genus *Ralfisa.* The commonest is *R. verrcicosa* which is tough and leathery, appears to peel off the rock, and may also occur on limpet shells.

3. RED SEAWEEDS

The possibilities are too numerous to detail most of them. The following is a list of the commonest genera: this is followed by some hints on a few tricky ones.

Porphyra - foliose - brownish in colour - umbilicate attachment - *P. ubilicalis* - or linear - *P. purpurea.*

Polysiphonia, Ceramium - branched, tufted, filamentous; pools, open rocks and epiphytic - see later notes on separating these genera and what to look for in the species. lanosa on Ascophyllum

Mastocarpus, Chondrus - cartilaginous (see illustrations in keys) and easily confused. *Mastocarpus stellatus* is slightly channelled in TS, sometimes bears many small "blobbles" or cystocarps - which are the carposporophyte generation - and is an exceptionally abundant zone-former on open rocks on the west coast, particularly the Firth of Clyde - rarely occurs in pools, also known as *Gigartina stellata. Chondrus crispus* is flat in TS, largely restricted to pools, does not have obvious cystocarps, and sometimes has an opalescent blue coating.

Callithamnion

Corallina - branched filamentous, coated with calcium carbonate giving pink colour - like a string of pink beads - largely in pools.

Dumontia - externally like a red *Enteromorpha.*

Palmaria - *P. palmata* (also known as *Rhodymenia palmata*) is a reddish flat cartilaginous plant with usually oval blades, which may or may not bear oval proliferations at the edge which if present make it look unlike pictures in some books.

Plumaria - *P. elegans* is very abundant in shaded situations such as under overhangs and in crevices and couloirs. It is a branched filamentous plant with branches in one plane making it look flat. Branches are very closely packed but in units of four which may only be detected under the microscope.

Lomentaria - *L. articulata* like *Corallina* appears a branched string of beads or sausages but is bright red - but not coated with calcium carbonate .

Membranoptera - *M. alata* is usually but not always very small - up to a few cm long - it is flat with a distinct midrib surrounded by 2 wings.

Catanella - *C. repens* or *C. caespitosa* (the same species) often appears blackish when dry - forms small turfs on open rocks in the upper intertidal. Under a microscope it can be seen to be flat, but twisted and of an irregular outline being constricted at intervals. Beware of keys confusing you with *Bostrychia* which is restricted mainly to salt marshes and which you are unlikely to find.
Rhodomela - a tough filamentous plant - see following notes on *Polysiphonia.*

Turf Formers
- red turfs, particularly in the upper intertidal on open rocks may be of several genera:

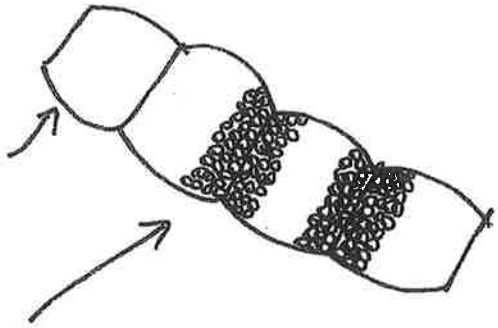
> ***Catanella*** - already described
> ***Ceramium shuttleworthianum*** - (= *C. acanthonotum*) - see notes
> ***Aglaothamnion hookeri*** *(= Callithamnion hookeri)* - see books
> ***Rhodothamniella floridula*** *(=Audouinella floridula)* - may be in whole tidal range, monosiphonous filaments with branching at tips. Forms turfs binding with sediment. some collected.
> ***Audouinella purpurea*** - commoner in estuaries, dark crevices and on upper shore, monosiphonous filaments with branching at tips but does not bimd much with sediment.

Red Crusts on Rocks and In Pools
- either calcified with calcium carbonate and thus appearing pink - or not calcified
- if calcified there are many species whose separation is a highly skilled task - best just to record them as either " encrusting corallines" or "Litholhamnia". Do not use the particular genus name *Litholhamnion* as this is only one of several possible genera.
- not calcified - may just be basal stages of many different species - especially in *Gigartina* where this plant sometimes dies back to a basal crust. Again separation of those that are true species is a highly specialist task - ask for keys - but there is one easy one - ***Hildenbrandia*** - small dots - bright red - cells closely packed and only about 4µm.

Notes on *Ceramium* and *Polysiphonia*
These both look superficially similar but have a different structure under the microscope.

Ceramium -

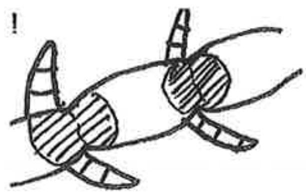
large central axial cells



masses of small corticating cells giving striped appearance : covering varies

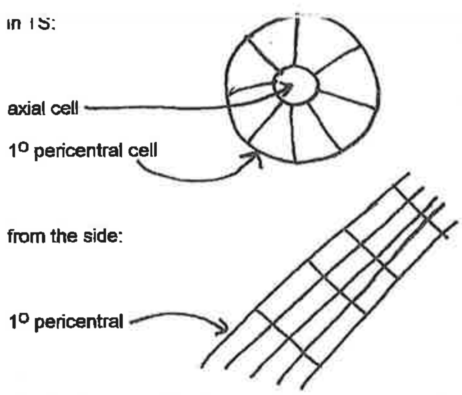
Cortical cells may unite from one band to the next by downgrowth in some species, especially in older plants - then the plant is not striped and has a uniform covering of small cells.
If the stripes are very apparent and the plant bears **no** spines then it is pointless to attempt detailed species delimitation. It is a aggregate species known under two names: *C. strictum or C. diaphanum.* If completely corticated throughout or nearly so in much of the plant and again there are **no** spines - it is the aggregate *C. rubrum agg*. This is the commonest one.
If there are spines in at least the younger ones - spines are short pointed side branches just a few cells long on most of the red stripes - then the keys can be used for species - but is most likely the turf-former *C. shuttleworthianum*. Spines look as follows – don't confuse epiphytic diatoms with them!

easy feature

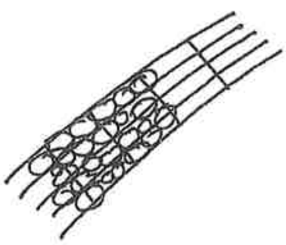


Polysiphonia - The central single axial filament is obscured by regular longitudinal filaments external to it : in TS:

need to know # of cell rows round axis to speciate (double # causes)



1° pericentrals may be obscured in some species,. especially in older plants by 2° cortication.



Use of keys to identify to species level in *Polysiphonia* requires whether or not there is 2° cortication and the number of 1° pericentrals in TS. Don't bother cutting a TS, just count cells from the side under a microscope and double them - works in most cases. *P. lanosa*, epiphyte on *Ascophyllum* (given as *P. fastigiata* in Newton) is the only species where the central axis can be seen through the 1° pericentrals. *Rhodomela* is related to *Polysiphonia* but is **completely** clothed by 2° cortication.

As with the green and brown algae there are many microscopic forms that exist as epiphytes or endophytes that can omly be seen under the microscope. make a habit of combing through plants such as *Cladophora* for such epiphytes. The commonest are the frequently branched uniseriate ***Audouinella*** and the unbranched ***Erythrotrichia***. But there are many more and even within *Audouinella* there are many different epiphytic species.

↳ look at basal cell

Endozoic Audouinella (3 sp) w/in hydroid skeletons

Ectocarpus - ribbon shaped chloroplasts.

Seaweed identification – the use of check-lists

What is a check-list?

A list of all seaweed species believed to occur in a particular area together with the currently accepted names for the seaweeds with the nomenclatural authorities for the names used. These nomenclatural authorities, after the genus and species name, tell the reader which particular concept of the species that is being used. See the separate handout "*Nomenclatural Authorities and the Correct Citation of Algal Names*" for an explanation of how nomenclatural authorities should be written.

Why do we need a check-list?

- To show which species it is reasonable to find in an area in which we are collecting.
- To determine if we have found a species new to an area.
- To have a uniform style of species list using a standard nomenclature that is used by all workers in an area, so making it possible to compare species lists between workers and/or sites.
- To check the currently accepted taxonomic concept of a plant which we have identified:
  - Because separate species in an earlier flora or identification book may have been united under a single name if it has since been found by research that they are just variants of the one species – the nomenclatural authorities indicate the concept of the species that is used.
  - Because a species may have changed its name because research has shown that an earlier name has legal precedence – the nomenclatural authorities indicate the concept of the species that is used
  - Because research has shown that what was previously regarded as a single species may have now been subdivided into two or more species – the nomenclatural authorities indicate the concept of the species that is used

When citing species names in a scientific paper or report we should always quote the appropriate nomenclatural authorities on the first mention in the paper of a particular species – alternatively in a paper or report with species lists we can make a blanket statement in the Methods section, or at the top of a table of all the species recorded, of the following form "All the species names are cited in accordance with the taxonomic nomenclature of the check-list of South & Tittley (!986)".

What check-lists are available for the seaweed flora of the British Isles?

Normally you should quote your names in accordance with one of the most recent check-lists and throughout any single paper or report you should keep to the one check-list. The recommended recent ones are:

- Guiry, M.D. 1997. Benthic red, brown and green algae. pp 341-367 In: Howson, C.M. & Picton, B.E. *The Species Directory of the Marine Fauna and Flora of the British Isles and Surrounding Seas.* Ulster Museum, Belfast and Marine Conservation Society, Ross on Wye.

Or

- Hardy, G and Guiry, M.D. 2003. *A Check-list and Atlas of the Seaweeds of Britain and Ireland.* British Phycological Society.

The second one was initially produced in a limited edition of 200 copies which is now sold out but has been reprinted with minor modifications which do not affect the check-list part and is available from Otto Koeltz antiquarian booksellers in Germany, with discount for British Phycological Society members. However the entire first printing of the book, including distribution maps and notes for every species in Britain, can be downloaded free of charge as a PDF file from the British Phycological Society website: www.brphycsoc.org It is about 24MB in size so if you have a small memory you may not have space for it and if you do not have broadband it may take some time to download.

Both the above check-lists suffer from not having an index so you have to sort through the names in family order until you find the one you want, unless you already know what family to look in. They also lack comprehensive notes on the history of names that have changed from previous lists so that you can find what species were called in the past, which you might need if you are trying to interpret an old species list.

The first one has largely been superseded by the second one but the first one has all species coded in a numbering system which includes marine invertebrates and so is favoured by consultants and conservation agencies because they can use it to set up numerical databases. It was also the current check-list when WFD species lists and databases were set up and so continues in use for that purpose for the present.

Earlier check-lists of British seaweeds

To track previous names and changes in them over the last century it is necessary to know the history of earlier check-lists.

The first modern style systematic listing of the British seaweeds was:

- Batters, E.A.L. 1902. A catalogue of the British marine algae. *J. Bot. Lond.,* **40 Suppl.,** 1-107.

The taxonomic system of this list formed the basis on which Newton's handbook was based. This was the last book which gave a professional treatment of seaweed identification which contained all the British seaweeds in a single book:

- Newton, L. 1931. *A Handbook of the British Seaweeds.* British Museum (Natural History), London.

Second hand copies of Newton can still commonly be found for about £10-20. To search thousands of second hand booksellers throughout Europe and North America for this (or for any other 2nd hand book) log on to www.abebooks.co.uk (If you mistakenly log on to abebooks.com you will get prices in US Dollars rather than £ Sterling).

A succession of check-lists was published from the 50's to the 80's which updated the taxonomic treatment in Newton:

- Parke, M. 1953. A preliminary check list of British marine algae. *J. mar. biol. Ass. U.K.,* **32,** 497-520.
- Parke, M. & Dixon, P.S. 1964. A revised check list of British marine algae. *J. mar. biol. Ass. U.K.,* **44,** 499-542.
- Parke, M. & Dixon, P.S. 1968. Check list of British marine algae.- second revision *J. mar. biol. Ass. U.K.,* **48,** 783-832.
- Parke, M. & Dixon, P.S. 1976. Check list of British marine algae.- third revision *J. mar. biol. Ass. U.K.,* **56,** 527-594.

These are all available in Heriot-Watt library in the journals at the references given above.

These lists are the best that have been published for British marine algae. They have an index to genus and species names both current and past.- back to the time of Newton –not only to names in the check-list but also to superseded names in the notes pages. They have footnotes on many names, either at the name itself in the list or in the notes at the end of each class, enabling the history of changes to be followed back to the time of Newton and there is a comprehensive listing of bibliographic references for all changes that are recorded. They also include phytoplankton and cyanobacteria (blue-green algae) as well as seaweeds.

These were susperseded in 1986 by a new style of list:

- South, G.R. & I. Tittley 1986. *A checklist and distributional index of the benthic marine algae of the North Atlantic Ocean.* Huntsman Marine Laboratory and British Museum (Natural History), St. Andrews, New Brunswick, and London.

This list gives the currently accepted names at 1986 incorporating revisions since the previous list in 1976 but crucially does not have any reference back to the previous names in earlier check-lists or in Newton, so that these revisions cannot be traced back to the previous names. What is new is that it covers the whole North Atlantic and for each species it lists its occurrence in each of the 32 areas into which it divides the American and European North Atlantic coasts. Instead of a bibliography tracking taxonomic changes it has a bibliography listing sources for the occurrence of species in each of the 32 areas.

When this was replaced by the two lists by Guiry, which are the current ones, the practice of not giving the history of changes back to Newton was continued. The Guiry lists do not cover the whole North Atlantic, just the British and adjacent coasts e.g. Atlantic French coast, but unlike South & Tittley they do not give references to country of occurrence so that you should beware of assuming that everything in the Guiry lists is found in Britain.

Making a seaweed herbarium

A herbarium is a reference collection of dried, pressed plants, one per sheet, labelled to indicate the full Latin name of the species together with the nomenclatural authorities for the name used. The label also includes habitat information, information on the state of the plant, date and place of collection, and the identity of both the identifier and collector. Professional herbaria are used to maintain reference collections of the flora of different places at different times, and particularly to keep safely the original material on which the description of a genus or species was based – this is called the type material. They therefore contain specimens which may be centuries old and to have been adequately prepared so that they remain in good condition for 100's of years. Now that we are looking at changes in flora that may have come about due to climate change, disturbance to shores, or recovery from pollution, it is becoming apparent that we need reference specimens (known professionally as voucher specimens) to show us what workers in past times called by particular names. So pressing plants is not just a handicraft for tweedy individuals but a scientific necessity.

In order to understand nomenclature you should read the sections on:

- **"Algal Taxonomy and the Correct Nomenclatural Citation of Plant Names"** (separately issued)
- **"Seaweed Identification – The Use of Check-Lists"** (in this booklet)

Sheets of standard labels, similar to those used in professional herbaria, and illustrated in this booklet, should be used. They should be fixed to the bottom right hand corner of the herbarium sheet, on the same side as the specimen, using paste or gum. Sellotape should never be used for fixing purposes of any kind in a herbarium because it does not have long-term keeping properties – turning brown and peeling off after a few years.

Professional herbarium specimens are usually mounted on thin card sheets about A3 in size. This is expensive and not easily handled for routine use. You can therefore mount your specimens on good quality unlined A4 paper (subject to specimens not being too large).

Mounting is carried out as follows. The algal specimen is floated in shallow (c. 1cm or less) seawater in a sorting tray large enough to hold the width of an A4 sheet and the branches are laid out so as to represent its natural morphology. If it is necessary to trim the plant do not destroy its natural appearance. The paper on which the specimen is to be mounted is gently inserted in the tray underneath the plant and is then withdrawn with the plant laid out in the desired manner. Excess moisture is removed by gently placing on newspaper.

A piece of muslin is placed over the specimen and the whole sheet is then placed on several thicknesses of newspaper or drying paper. Several more thicknesses are placed over the muslin. Other specimens so treated may be stacked up and the whole pile is then placed in a plant press which is screwed down tightly and left in a warm place for the plants to dry. The drying paper should be changed daily for a few days and then at less frequent intervals until the sheets are thoroughly dry. It is essential that they are dry or the specimens may be spoilt by fungal infections.

Muslin is expensive and you may find that accessible and cheap alternatives are J-cloths and some paper nappy liners, though you may have to search a little these days for chemists that still stock these..

You will have difficulty pressing large bulky specimens such as fucoids. They will not adhere to the paper with their own mucilage and would have to be fixed to the sheet with very thin strips of white gummed paper.

In the absence of a plant press you can simply press your specimens between two wooden boards. These can be pressed together under the weight of a pile of books or using the straps that are sold (in places such as B&Q or Homebase) for going around luggage.
The names of species (to species or subspecies level - not just to genus level) together with appropriate nomenclatural authorities must be in accord with current taxonomic concepts as embodied in the following a following recent algal checklist (see the pages in this handout on checklists).

Completing Herbarium labels

Heriot-Watt University - Seaweed Herbarium
species: Name in full, both genus and species, nomenclatural authorities must be shown for the concept of the species that you have used, taken only from one of the two suggested check-lists, punctuation and style (capital/lower case letters and abbreviations must be exactly as in check-list. Do not enter the author of the identification work used instead of the nomenclatural authority.
place of collection: Give as precise a location as possible, both local and within the country, using names available on the standard national maps (for UK use Ordnance Survey), grid ref and/or latitude and longitude could be given if desired.
date of collection: write in full using name for month and year given in full – shortened versions could be ambiguous between day and month, and century.
habitat: give as much information as possible e.g. sub-habitat, position on shore, exposure grade, and any other modifying factor that could define the habitat type.
special features: any feature of the plant worthy of note e.g. generation in life-cycle, presence and type of reproductive organs, any unusual morphological features, on your actual specimen – not general notes from a flora or textbook
name of collector: the actual collector, you or whoever else collected the particular specimen.
name of identifier: whoever identified your actual specimen even if it is not - make sure you trust them to be right!
specimen number: starting from 1 in collection of: your name

A completed example:

Heriot-Watt University - Seaweed Herbarium
species: Enteromorpha intestinalis (L.) Link
place of collection: Dunbar, East Lothian
date of collection: 16 March 2004
habitat: mid-littoral rock pool on sheltered shore
special features: fertile, distal cells producing spores
name of collector: Martin Wilkinson
name of identifier: Paul Wood
specimen number 6 in collection of Martin Wilkinson

Neatness and clarity is essential. You do not need to type the labels but, if completed by hand, you must ensure they are legible, and printed not joined up handwriting, and completed in black waterproof ink.

Glossary of Algal Terms

Most identification works make extensive use of technical botanical jargon which can be confusing. Some such as the "Seaweeds of the British Isles" series have a glossary to the terms used but not all have this and some of them are incomplete. Therefore a list of some terms is given below. For completeness this glossary contains general algal terms as well as those that are found in seaweed identification books.

ACRONEMATIC - refers to a type of flagellum which has a smooth outer casing lacking hairs, scales or other external appendages (also known as smooth or whiplash flagella).

ALGA (plural algae) - a plant which has not reached the level of differentiation of archegoniate plants i.e. does not have a specifically differentiated sterile cellular wall around the sex organs. Hence the group algae contains several distantly related plant lines whose only close affinity is in this lack of development. The green line is the only one to have advanced to the archegoniate level and is believed to have given rise to all the other plant groups.

ANGIOSPERM - a flowering plant, a seed-producing, vascular plant which is well adapted to the terrestrial environment and where the dominant plant is the sporophyte generation with the gametophyte reduced to a few cells contained within the pollen grain and the ovule on the sporophyte.

ANISOGAMY - sexual reproduction in which the gametes are different in size but similar in shape and behaviour.

APICAL GROWTH - growth by division of a cell or group of meristematic cells at the distal tip of algal fronds, filaments or branches.

APICAL MERISTEM - a group of actively mitotically dividing cells localised at the distal tip of algal fronds, filaments or branches.

ARCHEGONIUM - the flask shaped female reproductive organ of the bryophytes, pteridophytes and gymnosperms in which sterile (i.e. non-gamete) cells, specifically differentiated as part of the organ, form a venter surrounding the ovum or fertile egg cell, and further specifically differentiated sterile cells form a neck canal connecting the ovum to the outside environment to allow entry of sperm for fertilisation.

AUXOSPORE - the naked cell formed when a diatom loses its frustules after shrinking through successive cell divisions - may function as a gamete and is involved in swelling back to original size before screting new frustules.

AXIAL FILAMENTS - filaments which form the central skeleton up the middle of an algal frond and whose continued growth gives rise to growth in length of the frond (also known as filaments of unlimited growth).

AXILE - refers to a chloroplast which is in the centre of a cell or spreads out from the centre, as opposed to a parietal one which is spread around just inside the cell membrane.

BILOPROTEINS - water soluble photosynthetic pigments in red algae, blue-greens and cryptophytes - two types - phycocyanin (blue) and phycoerythrin (red) - proteins similar in structure to the plant photomorphogenetic pigment phytochrome and to the bile pigments of mammals - can act as accessory light absorbers for photosynthesis in the mid region of the visible spectrum which is not well-utilised by chlorophylls (also known as phycobiliproteins and phycobilins).

BONNEMAISONIA TYPE LIFE HISTORY - a life history of a floridiophycean red alga involving gametophyte, carposporophyte and tetrasporphyte phases in which the gametophyte and tetrasporophyte phases are morphologically different from each other.

BROAD CLASSIFICATION OF THE ALGAE - the classification of the algae into major groups, divisions or classes, based on five fundamental features: photosynthetic pigment combination; chemical nature of the photosynthetic reserve product; cell wall constituents; presence, number and type of flagella; other major cellular features. Since these are more fundamental cellular or biochemical features they are independent of external morphology and allow a full range of grades of construction to be found in different algal divisions.

BRYOPHYTE - a moss or liverwort - primitive land plants which lack vascular tissue and extensive tissue differentiation and in which the sporophyte grows epiphytically on the gametophyte, requires external water for fertilisation but has aerially dispersed spores released by drying from a capsule.

CAROTENES - hydrocarbon photosynthetic pigments, brown in colour, of which one type, from □,□ or□ is present in each taxonomic group of algae, can act as accessory light absorbers for photosynthesis in the mid region of the visible spectrum and may also protect the photosynthetic system from high light damage by absorbing excess energy and converting it to heat.

CAROTENOIDS - brownish hydrocarbon photosynthetic pigments, soluble in organic solvents rather than water, which can be subdivided into carotenes and xanthophylls, can act as accessory light absorbers for photosynthesis in the mid region of the visible spectrum.

CARPOGONIUM - the female cell or gamete attached to the gametophyte which after fusion will develop into the carposporophyte generation of a floridiophycean red alga.

CARPOSPORE - an asexual non-motile diploid spore produced on the carposporophyte generation of floridiophycean red algae.

CARPOSPOROPHYTE - the generation in a life history of floridiophycean red algae which is produced by sexual fusion on the gametophyte and develops attached to the gametophyte.

CELL WALL - the outer covering of a plant cell, not present in animal cells, external to the cell membrane, composed of insoluble fibrils of macromolecular carbohydrates cross linked by smaller soluble carbohydrate molecules (the secondary cell wall constituents), to give a semi-rigid, slightly elastic and extensible outer coat to the cell. Extension of the cell wall under pressure from turgid cell contents enables plant cells to grow by cell enlargement.

CHLOROPHYLLS - the major group of photosynthetic pigments - all plants including algae have chlorophyll-a and most, according to taxonomic group, have a second accessory chlorophyll chosen from chlorophylls b to e.

CHLOROPLAST - an organelle in eucaryotic plant cells, surrounded by its own membrane, which contains the photosynthetic pigments localised on membranes in the chloroplast known as thylakoid lamellae.

CHROMATOPHORE - an alternative term sometimes used for chloroplast in algae.

CLASS - the taxonomic rank between order and division usually ending in -phyceae.

COCCOID - refers to non-motile cells lacking flagella - existing as unicells and colonies which either never have flagella or only have them as reproductive cells (spores and gametes).

CODIOLUM PHASE - a large single-celled sporophyte phase in the life-histories of various green algae, often with the cell wall extended at one end of the cell to produce a cellulosic rhizoid, similar to members of the genus *Codiolum.* Upsets the classification into orders proposed by Fritsch based on grade of construction because this phase appears in life histories of members of several orders including Ulvales, Ulotrichales, Chaetophorales and Cladophorales.

COENOBIUM - a colony of a fixed size and shape which is predetermined at reproduction e.g. *Volvox* or *Gonium.*

COENOCYTIC - refers to non-cellular plants in which nuclear division and division of organelles is not accompanied by cross wall formation so that filaments are filled with numerous nuclei and numerous discoid chloroplasts.

COLONIAL - refers to multicellular organisms composed of aggregations of unicells.

COMPLEX FILAMENT - a filamentous alga where the filaments are not merely branched but form two distinct types of branching system as in heterotrichy.

CONCHOCELIS PHASE - a filamentous shell-boring phase in the life-history of the red alga *Porphyra.*

CORTEX - the outer layers of cells, outer to the axial cells, in a multiseriate filament or in a frond with internal tissue differentiation.

CORTICATING FILAMENTS - filaments which grow on the outside of a filamentous plant investing its outer surface and increasing the thickness of the filament.

CUTICLE - the outer wall on the epidermal layer of cells which is thickened or strengthened thus reducing wave damage or dessication.

CYSTOCARP - the carposporophyte generation, including its carposporangium and carpospores, visible as a swelling attached to the gametophyte of members of the Floridiophyceae.

DICHOTOMOUS - refers to branching where two equally dominant axes diverge in a Y - shape - often occurs by equal division of a single apical cell.

DIFFUSE GROWTH - growth which may occur anywhere in the thallus, more or less at random, and is not localised to meristematic areas.

DIPLOHAPLONT - refers to a life-history which contains both haploid and diploid phases, irrespective of how many of them there are and whether or not they are morphologically similar.

DIPLONT - refers to a life history with only diploid phases irrespective of how many of them there are and whether or not they are morphologically similar.

DIVISION - the highest taxonomic ranking within the plant kingdom - broadly equivalent to the animal phylum, name ends in -phyta.

ELABORATION OF THE HETEROTRICHOUS SYSTEM - can occur by suppression of either the prostrate or erect system of filaments to be a small part of the plant, and development of the other, non-suppressed system by formation of true parenchyma or pseudoparenchyma. Suppressed erect systems can give rise to encrusting froms and suppressed prostrate systems can become the attachment organs for erect plants.

ENDOPHYTE - a plant which lives inside the tissues of another plant.

EPIDERMIS - the outer layer of cells on a plant - only one layer in thickness - may be overlain by a cuticle.

EPIPELIC - see microphytobenthos.

EPIPHYTE - a plant which lives attached to another plant.

EPIPSAMMIC - see microphytobenthos.

ERECT SYSTEM - the system of filaments in a heterotrichous plant which grows upwards from the substratum (or into the host if an endophyte) - see heterotrichy.

EUCARYOTIC - the type of cellular organisation characteristic of animals and true plants in which organelles are present which are bounded by their own limiting membranes, and the DNA in the nucleus is clearly organised into distinct chromosomes bound together with histones.

FAMILY - the taxonomic rank below order, name usually ending in -aceae.

FILAMENT - a row of cells in a wire like or string of bead like arrangement - but can be more than one cell thick (= trichome + sheath in blue-greens).

FILAMENTS OF LIMITED GROWTH - filaments which grow out for a limited distance as side branches of an axial filament, giving rise to increase in thickness of a plant, may give rise to the cortex and/or medulla of a plant.

FILAMENTS OF UNLIMITED GROWTH - the axial filaments of a plant which continue to grow so giving rise to increase in length of a plant.

FLAGELLUM (plural flagella) - a whiplike appendage projecting from a cell; has an internal structure of 9 outer microfibrils surrounding 2 inner ones, used in locomotion, may have a smooth (whiplash, acronematic) or ornamented (pantonematic, flimmer, tinsel) outer covering.

FLIMMER FLAGELLUM - a flagellum ornamented on the outside by one or more rows of hairs (flimmergeisel) or scales (also known as pantonematic or tinsel flagella).

FRUSTULE - the silica encasement of a diatom cell - two overlapping frustules or valves encase a cell - with a very detailed sculpturing characteristic of genus and species - concentric or radially symmetrical in centric diatoms - bilaterally symmetrical about the raphe in pennate diatoms.

GAMETOPHYTE - the sexually reproducing generation in a life history.

GIRDLE BAND - the point on the side of a diatom cell where the two valves overlap.

GIRDLE VIEW - the view of a diatom cell from the side looking at the ovelap of the two valves or frustules.

GYMNOSPERM - highly evolved land plants which include the conifers and cycads, with vascular tissue, seed formation and tissue differentiation reminiscent of flowering plants, but still with archegonia as the female reproductive organs in female cones, but not requiring external water for fertilisation, the archegonium exudes its own water.

GRADE OF CONSTRUCTION - the series of types of plant morphology found within many of the algal divisions - they can be thought of as increasingly complicated grades of construction e.g. motile unicells, motile colonies, non-motile unicells, non-motile colonies, palmelloid forms, simple filaments, complex heterotrichous filaments, pseudoparenchymatous forms, truly parenchymatous forms, multinucleate segmented forms, coenocytic (siphonaceous) forms.

HAPLONT - refers to a life history with only haploid phases irrespective of the numnber of them and whether or not they are morphologically similar.

HAPTONEMA (plural haptonemata) - a flagellum like appendage found only in the division Haptophyta (or class Haptophyceae of the division Chrysophyta). It is retractile with an adhesive tip and has an internal structure of 6+0 or 7+0 fibrils instead of the 9+2 arrangement found in flagella. Ordinary flagella are also present along with the haptonema.

HETEROCYST - the cell in a blue-green which is responsible for nitrogen fixation. It is larger than surrounding cells, has less densely coloured contents, and an internal reducing environment to aid nitrogen fixation.

HETEROKONT - an old term referring to cells where the flagella are unequal in length.

HETEROMORPHIC LIFE HISTORY - a life history which involves phases which are different in form from each other.

HETEROTRICHY - the existence in the one plant of two separate systems of filaments which may differ in cellular morphology and branching pattern: a prostrate system which
creeps along the substratum (or thr surface of a host plant) and an erect system which rises up inyo yhe water column (or burrows into the tissue of the host plant). See also "elaboration of the heterotrichous system".

HORMOGONE (= hormogonium; plural hormogonia) - a section of a blue green filament a few cells long which separates off and glides out of the sheath to become a vegetative reproductive propagule.

INTERCALARY GROWTH - growth which occurs somewhere in the middle of the plant i.e. not at the base or apex, but which is localised into a particular area (compare with diffuse growth).

INTERCALARY MERISTEM - the localised area of actively mitotically dividing cells somewhere in the middle of a plant that brings about intercalary growth.

ISOGAMY - the simplest form of sexual reproduction where the fusing gametes are identical in size shape and behaviour.

ISOKONT - an old term referring to cells where the flagella are equal in length.

ISOMORPHIC LIFE HISTORY - a life history where all the phases look alike i.e. they are morphologically similar.

LATERAL MERISTEM - an area of actively mitotically dividing cells on the side of the plant (common in brown algae) - see also "meristoderm".

LIFE HISTORY - the sequence of nuclear and somatic phases in the life of a plant.

MEDULLA - the large central loose tissue between the cortex or epidermis and the central axis seen in a transverse or longitudinal section of a complex alga with internal tissue differentiation.

MEDULLARY HYPHAE - the loose filaments forming the secondary phase of gtowth packing the centre of the midrib of fucoids.

MERISTEM - an area of cells giving rise to growth by repeated mitosis.

MERISTODERM - an outer epidermal layer which has become meristematic and thus is a lateral meristem (common in brown algae).

MICROPHYTOBENTHOS - the microscopic algae, usually single-celled, that live in or on sediments and when abundant may colour sediments green or brown. Epipelic algae live in mud and consist mainly of diatoms and euglenoids, though blue-greens may sometimes be present. Epipsammic algae live on sand grains and consist mainly of diatoms though dinoflagellates may sometimes be present. Epipelic algae have vertical migration rhythms so that they are on the mud surface and can photosynthesise when the tide is out during daylight.

MONOSIPHONOUS - refers to a filament one cell in thickness i.e. it has one siphon or row of cells.

MORPHOGENESIS - the development of the form of the plant.

MORPHOLOGY - the form of the plant - usually taken to mean external form - internal structure is referred to as anatomy.

MULTIAXIAL - refers to the situation where the axis in the centre of a pseudoparenchymatous thallus is composed of several filaments rather than of one filament only.

MULTINUCLEATE SEGMENTED FORMS - plants where the division of cells does not occur as frequently as division of nuclei, so that apparently cellular filaments are made up of multinucleate segments, which also contain complex chloroplasts, e.g. *Cladophora.*

MULTISERIATE - refers to a filament which is more than one cell thick.

NITROGEN FIXATION - the ability to utilise atmospheric nitrogen, N2, as a nitrogen source for growth. Normally eucaryotic plants must take in their nitrogenous nutrients in combined inorganic form such as the nitrate or ammonium ions. Some bacteria and blue-greens can fix nitrogen but no other algae can do so.

NUCLEAR PHASES - refers to the chromosome numbers, e.g. haploid or diploid, of different phases in a life-history, irrespective of their morphological similarities or differences.

OOGAMY - a type of sexual reproduction in which the fusing gametes are different in size shape and behaviour. Usually found in the most advanced algae.

ORDER - the taxonomic rank below class but above family, usually ending in -ales. In the Chlorophyta a separate order was used for each grade of construction in Fritsch's simple classification system.

PALMELLA - a temporary phase where many motile volvocalean unicells become embedded in a common mucilage.

PALMELLOID FORMS - plants where the normal vegetative state rather than a temporary phase is a palmella e.g. *Tetraspora.*

PANTONEMATIC FLAGELLUM - see flimmer flagellum.

PARENCHYMA - in algae this has a different meaning to higher plants. In the latter it refers to a tissue composed of unspecialised thin-walled storage or packing cells. In algae it refers to the formation of a multiseriate or large plant body by division of cells in all directions, so that adjacent cells may be from the same mother cell. This is in contrast to pseudoparenchyma where such a plant body is formed by filaments becoming clustered together and fused, so that adjacent cells may not have been immediately formed from the same mother cell.

PARIETAL - refers to a chloroplast which is distributed around the outer part of the cytoplasm just inside the cell membrane.

PHOTOPERIODIC - refers to a phenomenon that is controlled by length of day such as the change between phases in some life-histories e.g. *Porphyra*, under short day or long day conditions.

PHOTOSYNTHETIC PIGMENTS - the coloured cellular components that absorb light for photosynthesis. All algae have chlorophyll - a, most have an accessory chlorophyll; all have one carotene, and several xanthophylls. Only blue-greens, red algae and cryptophytes have biloproteins. The diversity of pigments is characteristic of the algal divisions and contrasts with the higher plants where there is much more uniformity with similar pigment combination to the green algae. The range of pigments allows more effective absorption of light energy over the full spectrum of visible light and assists algae which live in a low light environment underwater. The dominant pigment type determines the colour of the plant. It is therefore possible for a red alga, which has characteristic biloproteins, to look brown if the red biloprotein colour is masked by a lot of carotenes or xanthophylls.

PHYCOBILINS - see biloproteins.

PHYCOBILIPROTEINS - see biloproteins.

PHYCOCYANIN - the blue form of the biloprotein photosynthetic pigments of blue greens and red algae.

PHYCOERYTHRIN - the red form of the biloprotein photosynthetic pigments of blue-greens and red algae.

PHYTOCHROME - the photomorphogenetic pigment of higher plants which exists in two forms, far-red light (730nm near infra red) absorbing form PF, and the red light (660nm) absorbing form PR. A globular protein similar in structure to the biloprotein photosynthetic pigments. Phenomena similar to those mediated by phytochrome exist in algae though its presence is not firmly established in them.

PIGMENTS - coloured molecules in plants which absorb light of particular wavelengths for biochemical or physiological processes. Higher plants have pigments such as anthocyanins which colour the plant for purposes other than photosynthesis e.g. to attract pollinating insects, but algae usually only have the photosynthetic pigments in addition to possible photomorphogenetic pigments (see phytochrome).

PLANT - a eucaryotic organism which photosynthesises using water as the hydrogen donor and chlorophyll-a as the primary light trapping pigment.

PLASTID - a membrane bound inclusion in a plant cell. Higher plants have various types in addition to chloroplasts, e.g. leucoplasts, but algae mainly have only the chloroplasts.

POLYSIPHONIA TYPE LIFE HISTORY - a type of floridiophycean red algal life-history with gametophyte, carposporophyte and teterasporophyte generations, where the gametophyte and tetrasporophyte are morphologically similar.

POLYSIPHONOUS - refers to a filament which is made up of several rows of uniseriate filaments bundled together.

PROPAGULE - a means by which algae propogate and disseminate through the water. It can thus mean spores and gametes but also has a particular meaning for specifically differentiated multicellular bodies which drop off some algae, float away, and function as a form of vegetative reproduction.

PROCARYOTIC - refers to the primitive type of cell arrangement which lacks membrane bound organelles and lack an organised nucleus with DNA clearly organised into chromosomes. The only alga-like procaryotic organisms are the blue-greens, now known as Cyanobacteria, which have some bacterial and some plant affinities. Blue-greens have typical plant photosynthesis but with the pigments on thylakoid lamellae dispersed throuhg the cytoplasm rather than in chloroplasts.

PROSTRATE SYSTEM - the system of filaments in a heterotrichous plant which creeps along the substratum (or the surface of the host plant) - see heterotrichy.

PSEUDOPARENCHYMA - a tissue formed by the aggregation of filaments (see parenchyma).

PTERIDOPHYTE - ferns and clubmosses - members of the plant kingdom which are successful on land with a large dominant sporophyte generation with vascular tissue and stomata and aerially dispersed spores, but with an archegoniate gemetophyte which still needs external water for fertilisation.

PYRENOID - a ring shaped body in a chloroplast where the photosynthetic reserve product accumulates.

RAPHE - the groove down the middle of a pennate diatom frustule about which it is bilaterally symmetrical.

RESERVE PRODUCT - the insoluble form in which excess carbohydrate from photosynthesis can be stored. May be starch, other large carbohydrates, fats or proteins, and its chemical nature is characteristic of the division of algae.

RETICULATE - refers to the form of a chloroplast which is made up of a network of fibrils.

SECONDARY CELL WALL COMPONENTS - see cell wall - these components are characteristic of the division of algae and some, e.g. alginates, may also be of economic value.

SHEATH - the mucilage coat around the cells, filaments or thalli of blue-greens.

SIMPLE FILAMENT - a filament, branched or unbranched, which is not heterotrichous.

SIPHONACEOUS FORMS - plants made up of coenocytic filaments.

SMOOTH FLAGELLUM - see acronematic flagellum.

SOMATIC PHASES - refers to the different types of morphological phases in an algal life-history, irrespective of their nuclear state (i.e. irespective of whether they are haploid or diploid).

SPERMATIUM - the male gamete in the Floridiophyceae, free-floating lacking flagella, which fuses with the carpogonium attached to the gametophyte plant to give rise to the carposporophyte generation.

SPOROPHYTE - the asexually reproducing, spore producing generation in a life-history.

STELLATE - star shaped - usually referring to the shape of one type of axile chloroplasts.

STEPHANOKONT - refers to surrounding of a cell by a fringe of many flagella as in the zoospores of the Oedogoniales.

STORAGE PRODUCT - see reserve product.

TETRASPORE - an asexual spore produced in groups of four by meiosis in a tetrasporangium in the floridiophycean red algae.

TETRASPOROPHYTE - the diploid generation in a floridiphycean red algal life history which produces just four asexual spores by meiosis in a tetrasporangium.

THALLUS (plural thalli) - an old fashioned term used to refer to the plant body in lower plants (which used to be called the Thallophyta in the days when Fungi were regarded as plants).

TINSEL FLAGELLUM - see pantonematic flagellum.

TRICHOME - the chain of cells in a filamentous blue green which exists inside a mucilage sheath together with which it constitutes the filament.

TRUE PARENCHYMA - same as parenchyma - to which you should refer.

UNIAXIAL - refers to the situation where the central axis of a pseudoparenchymatous thallus is a uniseriate filament.

UNISERIATE - refers to a filament which is one cell thick i.e. a single row of cells like a string of beads.

VALVE - see frustule.

VALVE VIEW - the view of a diatom cell looking onto the face of a single valve or frustule.

WHIPLASH FLAGELLUM - see smooth flagellum.

XANTHOPHYLLS - brown hydrocarbon photosynthetic pigments, soluble in organic solvents, which are oxygenated derivatives of carotenes. Many xanthophylls can be present in a single species and while some are characteristic of the class or division, many are used to separate families and orders.

Worksheet to help you identify the full range of structural types

List examples of what you have found in your collections in each category below. Give several examples where possible. This is not a list for marking but a check-list for your own benefit to help you learn to find a wide range of algal types. You can list the same species under more than one heading.

Identification

- Colonial forms
- Filaments
    - Branched
    - Unbranched
    - Uniseriate filaments (one cell thick)
    - Multiseriate filaments (> 1 cell thick)
    - Macroscopic filaments
    - Microscopic filaments
- Pseudoparenchymatous forms (growing by aggregation of filaments)

- Parenchymatous (growing by cell division in 2 or more planes):
    - Tubular
    - Foliose

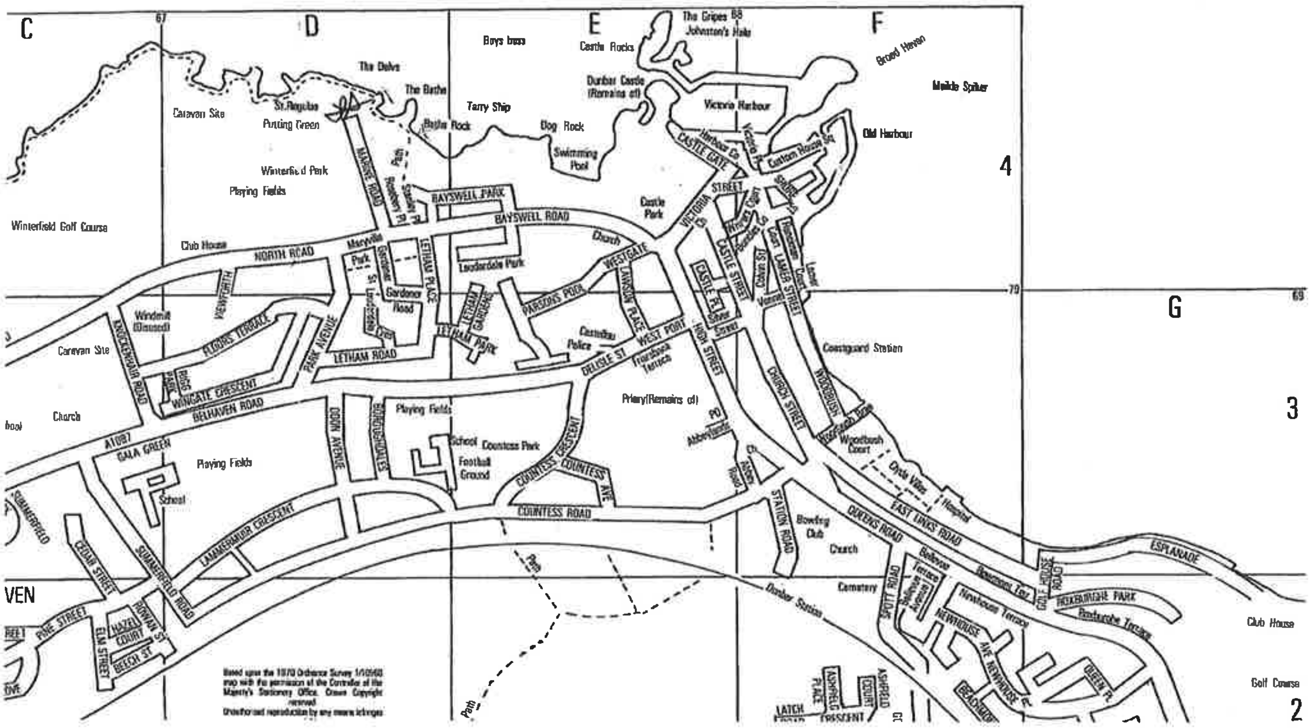
- Epilithic encrusting species on rock surfaces
- Encrusting corallines (calcareous)
- Other non-calcareous encrusters
- Brown
- red

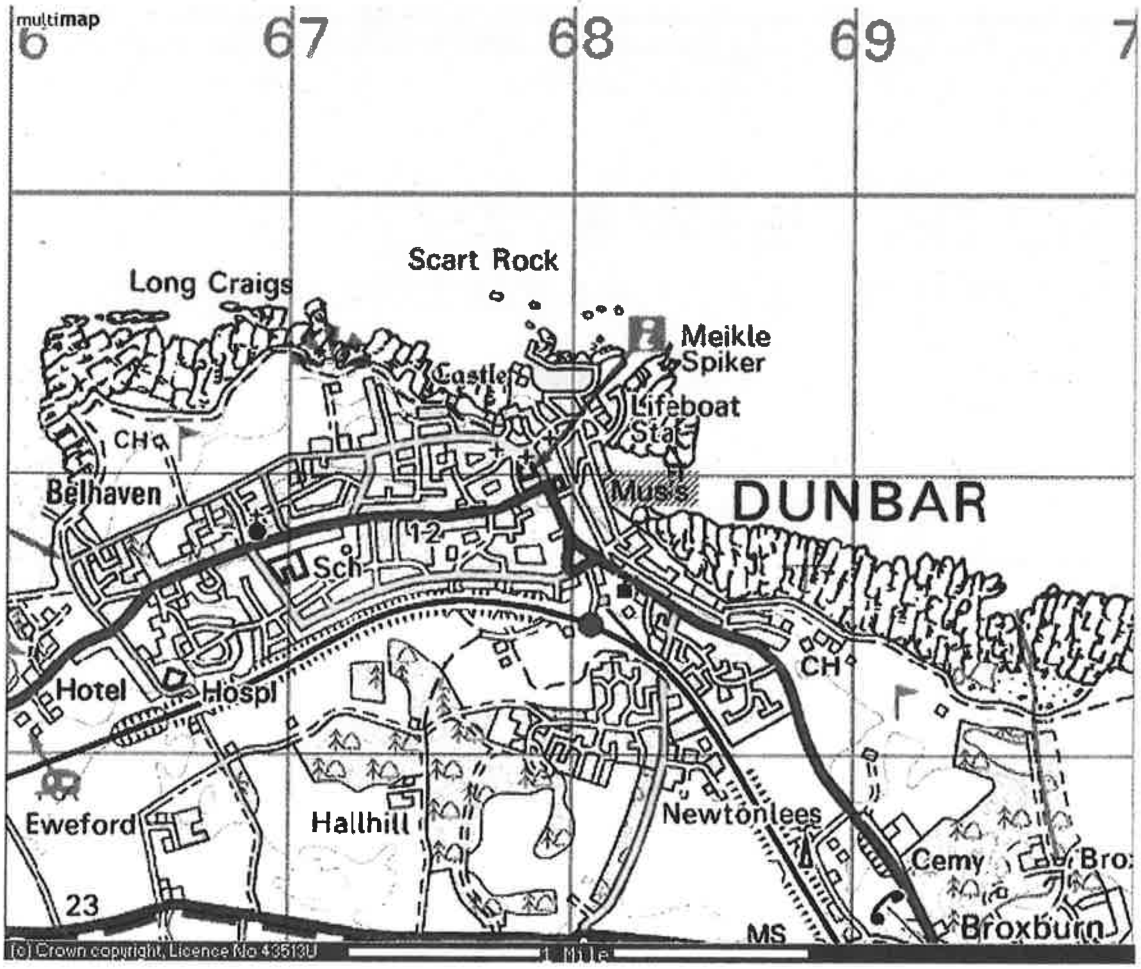
- Coenocytic forms (made up of acellular filaments like fungal hyphae)
- Multinucleate-segmented forms (made up of mutinucleate segments which resemble large cells)
- Large cartilaginous forms

- Examples of chloroplast morphology in cells (compound microscopic examination) may be
  - Parietal – forming a cylinder around the cell inside the cell wall
  - Axile – passing through the middle of the cell cavity
  - Simple – a non-perforated plate or cylinder
  - Band shaped – a girdle almost completely encircling the cell
  - Discoid – often may discs per cell
  - Reticulate – a network – sometimes made up of lots of filaments of chloroplast material or sometimes formed by lots of perforations and lobes on a parietal cylinder
  - Ribbon-like
  - Any other type of chloroplast?
- Pyrenoids
  - How many per cell when stained with iodine?
  - Any other species with pyrenoids that doesn't stain with iodine?

- Examples of branching pattern:
    - irregular
    - alternate
    - opposite
    - secund (all on one side like a comb)
    - dichotomous

- Epiphytes on particular algal species
- Endophytes in particular algal species
- Epizoans on particular animal species
- Endozoans in particular animal species


C
D
E
F
G
4
3
2
VEN
Castle Rocks
Victoria Harbour
Old Harbour
Meikle Spiker
Winterfield Golf Course
Caravan Site
Putting Green
Winterfield Park
Playing Fields
Club House
NORTH ROAD
BAYSWELL PARK
BAYSWELL ROAD
Lauderdale Park
LETHAM PLACE
LETHAM ROAD
Gardener Road
PARSONS POOL
WESTGATE
WEST PORT
DELISLE ST
HIGH STREET
CASTLE STREET
CHURCH STREET
VICTORIA STREET
Coastguard Station
Priory(Remains of)
Playing Fields
School
Countess Park
Football Ground
COUNTESS ROAD
COUNTESS CRESCENT
LAMMERMUIR CRESCENT
SUMMERFIELD ROAD
BELHAVEN ROAD
WINGATE CRESCENT
FLORES TERRACE
KNOCKENHAIR ROAD
PARK AVENUE
BOROUGHDALES
HOOD AVENUE
STATION ROAD
QUEENS ROAD
EAST LINKS ROAD
ESPLANADE
ROXBURGHE PARK
SPOTT ROAD
Bowling Club
Church
Cemetery
Club House
Golf Course
ELM STREET
PINE STREET
CEDAR STREET
BEECH ST
GALA GREEN


multimap
6
67
68
69
7
Long Craigs
Scart Rock
Meikle Spiker
Castle
Lifeboat Sta
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Belhaven
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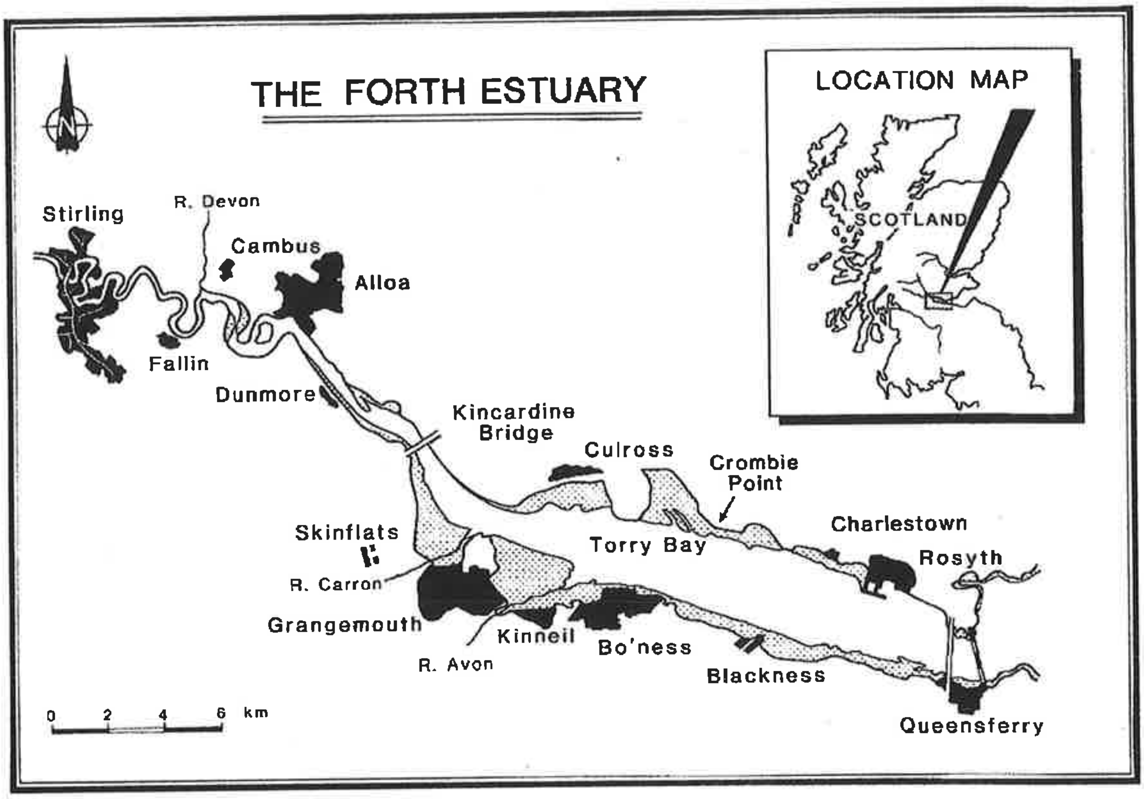
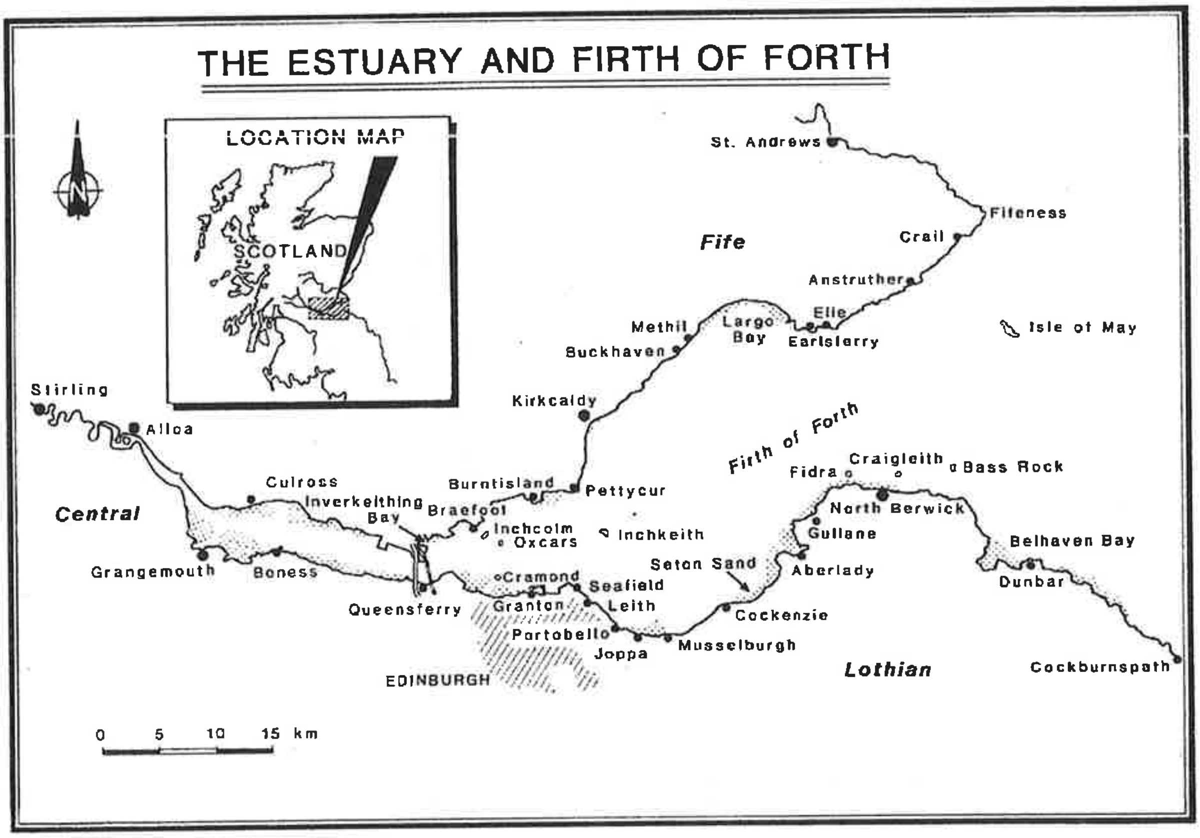

THE FORTH ESTUARY
LOCATION MAP
SCOTLAND
Stirling
R. Devon
Cambus
Alloa
Fallin
Dunmore
Kincardine
Bridge
Culross
Crombie
Point
Skinflats
Torry Bay
Charlestown
Rosyth
R. Carron
Grangemouth
Kinneil
Bo'ness
R. Avon
Blackness
Queensferry
0 2 4 6 km

Figure 1


THE ESTUARY AND FIRTH OF FORTH
LOCATION MAP
SCOTLAND
St. Andrews
Fifeness
Fife
Crail
Anstruther
Elie
Methil
Largo
Bay
Earlsferry
Isle of May
Buckhaven
Kirkcaldy
Stirling
Alloa
Firth of Forth
Craigleith
Fidra
Bass Rock
Culross
Burntisland
Pettycur
Central
Inverkeithing
Bay
Braefoot
North Berwick
Inchcolm
Oxcars
Inchkeith
Gullane
Belhaven Bay
Seton Sand
Grangemouth
Boness
Cramond
Seafield
Aberlady
Dunbar
Queensferry
Granton
Leith
Cockenzie
Portobello
Musselburgh
Joppa
Lothian
Cockburnspath
EDINBURGH
0 5 10 15 km

Seaweeds of the Lothians

What is a seaweed?

"Seaweed" is a non-technical term meaning algae attached to the rocky seashore, both intertidal and below low-water mark (sublittoral). Algae are the simplest plants. Some recent classifications place at least some algae in other kingdoms, but here they are regarded as plants, united in the mechanism of photosynthesis. They differ from other plants in the simplicity of the reproductive organs, which lack cellular walls, and in their biochemical diversity. One aspect of this diversity is the existence of many colour groups of algae, with different pigment combinations, compared with the uniformly green land plants. Just three of the colour groups contain seaweeds, green brown and red seaweeds, in the taxonomic divisons Chlorophyta, Phaeophyta and Rhodophyta respectively.

They range from microscopic single cells to large cartilaginous kelp plants (up to 3 m in Britain but up to 70 m elsewhere!). All share the absence of resistant stages such as seeds, development of the next generation being immediate. They face different stresses to land plants. Immersed in water that supplies all nutrients direct to their cells, they do not need transport systems such as xylem and phloem, nor do they need systems to regulate water loss and gas exchange, such as stomata. Buoyed up by water they have no need of support tissues. Internally they are, therefore, much simpler than land plants. The largest seaweeds have a very superficial similarity to leaves stems and roots with flat, photosynthetic fronds, supported by a stem-like stipe, attached to the rocks by a holdfast which, unlike roots, does not penetrate and is non-absorptive. Instead they need physical toughness of cell walls, combined with flexibility of the plant, to avoid damage by wave action or water movement.

Types of seaweed

About 619 species of seaweed are listed for the British Isles by South & Tittley (1986). Over 100 can be found on a single shore (Wilkinson & Rendall 1985). This number, which surprises many, is partly achieved through the wide habitat range. In addition to epilithic seaweeds, attached to rocks, there are endophytic, endozoic and epiphytic ones. Endophytes are microscopic, filamentous forms creeping between cells of larger seaweeds. Endozoic forms are microscopic unicells and filaments living in the chitinous tests of hydroids and bryozoans, and boring through the calcareous shells of molluscs, barnacles and tube-worms. Epiphytism is especially common in seaweeds. This is growth of plants attached to other plants. There can be several degrees of smaller plants growing on larger host plants. Many larger filamentous seaweed species may have several species of smaller forms attached to them, which cannot be seen without microscopic examination.

Epilithic seaweeds have a wide range of encrusting and erect forms. Encrusting ones, only mm thick, appearing as stains on the rock surface, can be mistaken for the rock itself. The crustose corallines are red encrusters that secrete calcium carbonate, appearing whitish or pink, and even more like part of the rock. Some encrusters are not species in their own right but stages in the life-cycle of erect plants (e.g. *Petrocelis* is now known to be an encrusting stage in the life-cycle of *Mastocarpus*. Some other encrusters may be extended basal portions of normally erect plants, e.g the calcareous filamentous plant *Corallina*, which looks like a branched string of beads, sometimes takes a flat encrusting form hard to distinguish from genuine crustose coralline species.

Erect forms can be filamentous, foliose or cartilaginous. Filamentous forms may be unbranched, irregularly branched, or branched in a very regular pattern e.g. *Plumaria*. Similarly, foliose plants may be irregular in outline e.g. *Ulva*, or tubular e.g. *Enteromorpha*, or have a regular shape, perhaps with midribs such as *Phycodrys* which resembles oak leaves.

The really large leathery cartilaginous forms are mainly brown. There are two major types. The rockweeds, also known as wracks or fucoids, dominate the intertidal zone of shores sheltered from wave-action, while the kelps, or laminarians, form dense underwater forests. These kelp forests are the most widespread habitat type in temperate and subpolar waters. Just as terrestrial forests have tree, shrub and herb layers, so kelp forests have strata of smaller plants adapted to living in the shade cast by the kelp canopy.

Seaweeds have more diverse life-cycles than land plants. Many have an asexual, spore-producing generation, or sporophyte, and a sexual generation or gametophyte. Unlike higher plants there is not a strict pattern. In some green seaweeds (e.g. *Cladophora, Enteromorpha* and *Ulva*) both generations look identical. Others may be very distinct. In kelps the large, leathery plant is the sporophyte and there is a microscopic filamentous gametophyte. Some green and red seaweeds have a shell-boring stage as one generation. In *Porphyra*, the foliose red plant eaten as laver bread in south Wales, the shell-boring sporophyte was a separate species, *Conchocelis rosea*, until the life-cycle was elucidated by laboratory culture in 1948. We cannot know life-cycles without culture experiments. Since many seaweeds have not been cultured, it is likely that the species number may be reduced in future when existing separate species are discovered to be in the same life-cycles.

Seaweeds on the intertidal seashore

Seaweeds are not usually found on sedimentary shores unless attached to rocks. These shores have other algae, the microphytobenthos, microscopic single-celled diatoms, euglenoids and dinoflagellates, and cyanobacteria, living between sand and mud particles. Although not individually visible to the naked eye they can be abundant, forming coloured patches, and accounting for much primary production.

Shores composed of pebbles and small boulders have few algae due to movement of the rocks in the waves. Larger boulders and bedrock shores show well-marked vertical and horizontal distribution patterns of seaweeds. A brief summary of these patterns is given here. Further information is available in Wilkinson (1992).

Horizontal patterns are lateral variations along the shore, mainly in response to variations in wave action. Vertical distribution refers to zonation in relation to tidal height. This is clearest on very sheltered shores where the abundant, dominant fucoids occur in the following order going down from the high shore:

Pelvetia canaliculata - the channelled wrack
Fucus spiralis - the spiral wrack
Fucus vesiculosus - the bladder wrack
Ascophyllum nodosum – the knotted wrock or egg wrack
Fucus serratus - the toothed wrack

Subordinate species may also be zoned but these zones do not coincide with the fucoid zones, and a few tolerant species may occur throughout the whole shore e.g. *Enteromorpha*. Zonation is also apparent on wave-exposed shores but is dominated by sturdy, sessile animals e.g. mussels and barnacles. On shores of intermediate exposure it can be more difficult to see zonation clearly. At each level on such shores, there may be several possible communities in adjacent, small patches giving a mosaic appearance.

It used to be thought that zonation was due solely to physical tolerance to desiccation. This is supported by the decrease in species number with height on the shore, since longer emersion times will be more stressful for marine species. Since about 1960 many field experiments have shown that biotic interactions, such as competition and grazing, play a role. Limpets and periwinkles are aggressive grazers on seaweeds while barnacles and mussels compete with them for space. Generally, on the lower shore where there are many species and conditions are strongly marine, species boundaries are set by competition and grazing. On the upper shore, where there are fewer species to interact, and conditions are harsher with longer tidal emersion, species boundaries are set by physical tolerance.

Increased wave action affects seaweed distribution patterns in several ways. Zones become wider and occur higher on the shore as a consequence of spray wetting greater heights on the shore. Species characteristic of shelter are replaced by those tolerant to exposure e.g. in the kelp zone on the fringe between sublittoral and intertidal the kelp *Laminaria digitata* is replaced by *Alaria esculenta*, and on the lower shore *Himanthalia elongata* replaces *Fucus serratus*. The mosaic pattern seen on shores of intermediate exposure is enhanced by several other modifying factors that vary along the shore such as rock type, aspect and slope.

Rock pools are a specialised habitat. They provide continuous submersion, like the sublittoral, but their small volume means they undergo fluctuations in temperature and salinity, unlike the sublittoral. Consequently those lower on the shore are more like the sublittoral but with increasing intertidal height they become more distinct. The lowest pools may contain sublittoral species, including kelps, while the highest pools are restricted to a few tolerant green seaweeds. Mid-shore pools may have a wide range of species including some from outside pools, some from open rocks lower on the shore, but also some largely restricted to pools e.g. *Halidrys*, the podweed.

Zonation patterns are not constant in time. There are seral and cyclic successions. Separate but adjacent small patches of rock may be at different stages in successions, adding to the mosaic pattern of intermediately exposed shores. An example of a cyclic succession is the regular alternation, taking several years, between fucoids and barnacles. An example of a seral succession is the recolonisation of bare shore. Sometimes when a space is cleared by removal of dead plants, replacement may be by whatever is fruiting adjacently, but sometimes a successional sequence commences with smaller, short-lived, filamentous, green forms, which are replaced progressively with foliose red and brown species, culminating in fucoids after a few years.

There is also long-term change. Geographical ranges of species spread and diminish naturally e.g. *Codium fragile* ssp *atlanticum* has spread northwards up the west coast of Britain during the 20th Century. Since a major factor in determining the geographical distribution of seaweeds is water temperature, it will be interesting to see during the 21st Century if species composition in particular areas such as the Forth changes due to sea temperature rise as a consequence of global warming.

Distribution of Seaweeds in the Lothians

The Firth of Forth is an arm of the North Sea. Most of it is fully marine. The Forth estuary proper starts about the Forth Bridges, where the salinity can be measurably diluted below that of seawater. The inner Firth can occasionally suffer some dilution of water when high freshwater flows down rivers in the winter. The inner Firth may also have slightly more turbid water than the outer Firth due to estuarine influence. As a consequence three area of seaweed flora can be subjectively observed which correspond roughly to the three Lothian counties:

- Outer Firth of Forth – clear water – marine – East Lothian
- Inner Firth of Forth – water slightly turbid – mainly marine – Mid-Lothian including City of Edinburgh
- Outer Forth estuary – water turbid – salinity reduced – West Lothian

The Edinburgh shoreline is additionally impacted by former severe crude sewage pollution (see later) and alteration of shores due to land reclamation. More detail of seaweeds in the Forth is given by Wilkinson et al (1987).

The conventional distribution of seaweeds into an estuary (Wilkinson 1980; Wilkinson et al 1995) is as follows:

1. Species numbers are reduced going upstream, due to selective attenuation firstly of red seaweeds then of brown seaweeds
2. A few brackish-water species, e.g. *Fucus ceranoides*, may occur in the mid- and upper reaches
3. The outer estuary is characterised by fucoid-dominated shores, which are species poor in comparison with such shores on the surrounding sheltered open coast
4. The inner estuary is characterised by turfs of microscopic filamentous algae (mainly green species) and cyanobacteria with only a few species on each shore.

Some features of this can be seen if the transition from East to Mid to West Lothian is seen as a gradient as shown by species totals in Table 1. (Totals for each individual shore can be found in Wilkinson et al (1987)).

The inner zone of the estuary is upstream of the county boundary at the River Avon so the west Lothian shores are species-poor, fucoid shores, typical of the outer estuary. In this county the lower species number can be related to the relative uniformity of the shores, predominantly shingle or muddy with boulders or rock outcrops. The full estuarine algal distribution including the turf-forming upper estuarine flora (Wilkinson et al 1987; Wilkinson & Slater 1997) can be seen in the Lothians in the small sub-estuaries of the Forth, principally the Peffer Burn, Esk, Almond and Avon.

The greatest variation in flora is in the outer Firth, where species totals are greatest. This is seen where there is the greatest habitat variation as, for example, at Dunbar. In as little as 100m there can be a change from exposed to sheltered shores; from shores with little seaweed cover in the midshore and exposure indicators, *Alaria* and *Himanthalia* dominating the lower shore, to densely fucoid-covered shores with *Ascophyllum* and *Pelvetia* characteristic of shelter.

Temporal Changes in Lothian Seaweeds

Edinburgh was a centre of marine research in the 19th Century and several famous phycologists collected in the Forth. Particularly important among these was George William Traill who lived at Joppa. He published authoritative lists for Joppa and Dunbar (Traill 1886, 1890). In the 1970's Dunbar showed broadly similar species richness to 1890 (Wilkinson et al 1987). By contrast, Joppa, described as a luxuriant shore by Traill in the 1880's, which all phycologists should visit, had lost half its species by the 1970's. This was ascribed to discharge of crude sewage from Edinburgh. Since the inauguration of Edinburgh's sewage scheme about 1980, water quality has improved. Species richness has only slightly increased at Joppa. It seems that the change from seaweed domination to a mussel/barnacle dominated shore, induced by the sewage, has given rise to a resistant animal-dominated climax community which is hard to dislodge. This did not occur at Granton where the sewage-induced climax was a fragile silt covering on the rocks, inhabited by small polychaete worms. Without the continual input of silt from sewage this was lost and replaced by a fucoid-dominated more seaweed-rich community.

Continued monitoring at Granton and Joppa since the publication of the above conclusions (Wilkinson et al 1987) has shown that natural successions may also be involved. Individual rocks have been observed at Granton starting with photographic records from the 1960's (kindly provided by Prof J C Smyth). Rocks, which had been seen to change from polychaete cover to fucoid cover, have now changed to greater abundance of mussels and barnacles in place of seaweeds. Similarly, the concrete wall erected around the new sewage works at Seafield in the 1970's was initially colonised by fucoid-dominated seaweeds but by the late 1980's this had been replaced by barnacles and mussels, even though this was after introduction of the sewage scheme.

In comparing species totals on shores, it is important to consider how the data are collected. Wilkinson & Tittley (1979) suggested seaweed species richness remains broadly constant in the absence of environmental change, although the detailed list on successive occasions may be different. About one-third of the species may be ephemeral. This has recently been substantiated in monthly surveys at Granton and Joppa by a Heriot-Watt Ph.D. student, Emma Wells. If successive surveys are aggregated together, the cumulative species totals increase. The total of 84 species at Joppa (Wilkinson et al 1987) makes it seem a rich site. Yet it remains a mussel/barnacle-dominated shore to this day with only about 30-40 species likely to be found on a single visit, including many in trace amounts. The reason it appears to have a high total is because it has been sampled more often than other shores because of its interest, so giving a high cumulative total.

Change may be less likely in estuaries where the harsh conditions induced by wide salinity fluctuations and high turbidity mean that the few species present are hardy. Nonetheless a change observed elsewhere by the author in recent years is the migration upstream of the lower estuarine fucoid-dominated, species-poor community, linked to improvements in water quality. There has been an approximate 15km upstream migration of the fucoid limit in both the Tyne and Tees estuaries. No such change has been seen in the Lothian sub-estuaries of the Forth but one sub-estuary just outside the geographical remit of this chapter, the Carron at Grangemouth, has undergone dramatic change. Virtually devoid of seaweeds in 1975, when it received large amounts of effluent from ICI, following removal of the effluents it was initially colonised by a few species of turf-forming green seaweeds. Following further general water quality improvements, it attained dense fucoid cover in the 1990's. The only candidate sub-estuary for such change in Lothian is the Avon, also at Grangemouth. A substantial effluent from BP Chemicals was removed from this estuary about 20 years ago but the flora has not changed. Nonetheless experiments with fucoids transplanted to the estuary, and salinity measurements within it, suggest that fucoids should be able to invade it. It may be just a matter of time for this immigration to occur.

With the rich shores of East Lothian, the outer estuarine shores of West Lothian, the shores recovering from pollution around Edinburgh, and the upper estuarine environment in the sub-estuaries of the Forth, Lothian presents a wide range of seaweed communities.

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Systematic list of intertidal seaweeds species recorded in the Lothian counties

From unpublished surveys of the Martin Wilkinson (HWU), Clare Scanlan (SEPA) and Ian Tittley (Natural History Museum) between 1977 and 1987. Taxonomic nomenclature accords with the check-list of South & Tittley (1986). X indicates presence

	West Lothian	Midlothian	East Lothian
CHLOROPHYTA			
Acrochaete repens			X
Acrochaete wittrockii			X
Blidingia marginata	X	X	X
Blidingia minima	X	X	X
Bolbocoleon piliferum			X
Bryopsis hypnoides		X	X
Bryopsis plumose	X	X	X
Capsosiphon fulvescens		X	
Chaetomorpha capillaries		X	X
Chaetomorpha linum		X	X
Chaetomorpha melagonium		X	X
Cladophora albida		X	X
Cladophora glomerata		X	
Cladophora laetevirens		X	X
Cladophora rupestris	X	X	X
Cladophora sericea	X	X	X
Codium fragile atlanticum			X
Enteromorpha clathrata			X
Enteromorpha compressa		X	X
Enteromorpha flexuosa			X
Enteromorpha intestinalis	X	X	X
Enteromorpha linza	X	X	X
Enteromorpha prolifera	X	X	X
Enteromorpha torta		X	X
Endoderma leptochaete			
Entocladia perforans	X	X	X
Entocladia viridis		X	X
Epicladia flustrae	X	X	X
Eugomontia sacculata	X	X	X
Monostroma grevillei	X	X	X
Monostroma oxyspermum	X	X	X
Ostreobium queketti			X
Percursaria percursa		X	X
Prasiola stipitata	X	X	X
Pringsheimiella scutata		X	X
Rhizoclonium riparium	X	X	X
Rosenvingiella polyrhiza	X	X	X
Spongomorpha aeruginosa			X
Spongomorpha arcta	X	X	X
Tellamia contorta	X	X	X
Ulothrix flacca	X	X	X

Ulothrix implexa	X	X	X
Ulothrix palusalsa	X	X	X
Ulothrix speciosa	X	X	X
Ulothrix subflaccida	X	X	X
Ulva lactuca	X	X	X
Ulva rigida			X
Urospora bangioides	X	X	X
Urospora penicilliformis	X	X	X
PHAEOPHYTA			
Acinetospora crinita		X	X
Alaria esculenta			X
Ascophyllum nodosum	X	X	X
Asperococcus fistulosus		X	X
Chorda filum			X
Chorda tomentosa			X
Chordaria flagelliformis			X
Cladostephus spongiosus	X	X	X
Cutleria multifida			X
Desmarestia aculeate			X
Desmarestia viridis			X
Dictyosiphon chordaria			X
Dictyosiphon foeniculaceus			X
Dictyota dichotoma			X
Ectocarpus fasciculatus		X	X
Ectocarpus siliculosus		X	X
Elachista fucicola		X	X
Eudesme virescens			X
Fucus ceranoides			X
Fucus serratus	X	X	X
Fucus spiralis	X	X	X
Fucus vesiculosus	X	X	X
Giffordia granulosa	X	X	X
Giffordia hincksiae		X	X
Giffordia sandriana		X	
Halidrys siliquosa			X
Hecatonema maculans			X
Herponema velutinum			X
Himanthalia elongata			X
Isthmoploea sphaerophora	X	X	
Laminaria digitata	X	X	X
Laminaria hyperborean	X	X	X
Laminaria saccharina	X	X	X
Leathesia difformis			X
Litosiphon laminariae			X
Microspongium globosum			X
Mikrosyphar polysiphoniae		X	X
Mikrosyphar porphyrae			X
Myrionema magnusii			X
Myrionema strangulans			X

Myriotrichia clavaeformis			X
Pelvetia canaliculata	X	X	X
Petalonia fascia	X	X	X
Pilayella littoralis	X	X	X
Protectocarpus speciosus			X
Pseudolithorderma extensum			X
Punctaria latifolia			X
Punctaria tenuissima			X
Ralfsia verrucosa	X	X	X
Scytosiphon lomentaria	X	X	X
Sphacelaria cirrosa			X
Sphacelaria fusca			X
Sphacelaria plumigera		X	
Sphacelaria plumose		X	X
Sphacelaria radicans		X	X
Spongonema tomentosum		X	
Stictyosiphon tortilis			X
Waerniella lucifuga			X
RHODOPHYTA			
Ahnfeltia plicata			X
Antithamnion cruciatum			X
Antithamnionella floccose		X	X
Antithamnionella spirographidis			X
Audouinella concrescens		X	
Audouinella daviesii		X	X
Audouinella endozoica			X
Audouinella floridula	X	X	X
Audouinella membranacea			X
Audouinella parvula			X
Audouinella purpurea	X	X	X
Audouinella secundata	X	X	X
Audouinella virgatula		X	X
Bangia atro-purpurea	X	X	X
Bostrychia scorpioides			X
Brogniartella byssoides			X
Callithamnion corymbosum			X
Callithamnion hookeri	X	X	X
Callithamnion sepositum		X	X
Callithamnion tetragonum		X	
Callophyllis laciniata			X
Catenella caespitose	X	X	X
Ceramium diaphanum	X	X	X
Ceramium flabelligerum			X
Ceramium rubrum	X	X	X
Ceramium shuttleworthianum	X	X	X
Chondrus crispus	X	X	X
Choreocolax polsiphoniae			X
Corallina elongata			X
Corallina officinalis		X	X

Cruoria pellita			X
Cryptopleura ramose			X
Cystoclonium purpureum	X	X	X
Delesseria sanguinea	X		X
Dilsea carnosa		X	X
Dumontia contorta	X	X	X
Erythrotrichia carnea		X	X
Erythrotrichiopeltis boryana			X
Furcellaria lumbricalis			X
Gelidium pusillum	X	X	X
Gracillaria verrucosa			X
Griffithsia flosculosa		X	X
Halarachnion ligulatum			X
Hildenbrandia rubra	X	X	X
Hypoglossum woodwardii		X	X
Jania rubens			
Kallymenia reniformis			
Laurencia hybrida		X	X
Laurencia pinnatifida		X	X
Lithophyllum incrustans			X
Lithothamnion glaciale	X	X	X
Lomentaria articulata		X	X
Lomentaria clavellosa	X	X	X
Lomentaria orcadensis			X
Mastocarpus stellatus	X	X	X
Melobesia membranacea			X
Membranoptera alata	X	X	X
Nemalion helminthoides			X
Odonthalia dentate	X		X
Palmaria palmate	X	X	X
Peysonnelia dubyi			X
Peysonnelia harveyana			X
Phycodrys rubens	X	X	X
Phyllophora crispa			X
Phyllophora pseudoceranoides	X	X	X
Phyllophora traillii		X	X
Phymatolithon lenormandii	X	X	X
Phymatolithon polymorphum			X
Plocamium cartilagineum		X	X
Plumaria elegans	X	X	X
Polyides rotundus			X
Polysiphonia brodiaei	X	X	X
Polysiphonia elongata			X
Polysiphonia fibrata			X
Polysiphonia lanosa	X	X	X
Polysiphonia macrocarpa	X	X	X
Polysiphonia nigra		X	X
Polysiphonia nigrescens	X	X	X
Polysiphonia urceolata	X	X	X
Porphyra leucosticta		X	X

Porphyra linearis			X
Porphyra purpurea	X	X	X
Porphyra umbilicalis	X	X	X
Pterosiphonia parasitica			X
Ptilota plumosa			X
Ptilothamnion plumula			X
Rhodomela confervoides	X	X	X
Rhodomela lycopodiodes			X
Titanoderma pustulatum			X

Water Framework Directive Reduced Species List for Rocky Shore Classification for Scotland and Northern England (using nomenclature of Guiry 1997).

Greens

Blidingia sp.
Chaetomorpha linum
Chaetomorpha melagonium
Cladophora rupestris
Cladophora sericea
Enteromorpha sp.
Sykidion moorei
Ulva lactuca

Browns

Alaria esculenta
Ascophyllum nodosum
Asperococcus fistulosus
Chorda filum
Chordaria flagelliformis
Cladostephus spongious
Desmarestia aculeata
Dictyosiphon foeniculaceus
Dictyota dichotoma
Ectocarpus sp.
Elachista fucicola
Fucus serratus
Fucus spiralis
Fucus vesiculosus
Halidrys siliquosa
Himanthalia elongata
Laminaria digitata
Laminaria hyperborea
Laminaria saccharina
Leathesia difformis
Litosiphon laminariae
Pelvetia canaliculata
Pilayella littoralis
Ralfsia sp.
Scytosiphon lomentaria
Spongonema tomentosum

Reds

Aglaothamnion/Callithamnion
Ahnfeltia plicata
Calcareous encrusters
Callophyllis laciniata
Ceramium nodulosum
Ceramium shuttleworthanium
Chondrus crispus
Corallina officinalis
Cryptopleura ramosa
Cystoclonium purpureum
Delesseria sanguinea
Dilsea carnosa
Dumontia contorta
Erythrotrichia carnea
Furcellaria lumbricalis
Lomentaria articulata
Lomentaria clavellosa
Mastocarpus stellatus
Melobesia membranacea
Membranoptera alata
Odonthalia dentata
Osmundea hybrida
Osmundea pinnatifida
Palmaria palmata
Phycodrys rubens
Phyllophora sp.
Plocamium cartilagineum
Plumaria plumosa
Polyides rotundus
Polysiphonia fucoides
Polysiphonia lanosa
Polysiphonia sp.
Porphyra leucosticta
Porphyra umbilicalis
Ptilota gunneri
Rhodomela confervoides
Rhodothamniella floridula

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