SEAWEED DIVERSITY IN THE NORTH ATLANTIC OCEAN

IAN TITTLEY

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Seaweed species-richness in the arctic and temperate North Atlantic Ocean (north of 39º N) is reviewed. Comparisons with other oceanic areas show, for example, the Indian Ocean to be richer in species but the northern North Atlantic Ocean to have a greater diversity of brown algal genera. Comparisons between North Atlantic regional floras show the north-east Atlantic to be richer in species than the north-west, and a gradient of species richness to occur from south to north along both coasts. The area comprising Ireland, southern England, Atlantic France and Spain may be considered a "hot-spot" of species richness. The mid-Atlantic Azores archipelago has been recently shown to be richer in species than sites on the American coast and in northern Europe. The conservation of seaweed biodiversity is briefly considered.

Ian Tittley (e-mail: it@nhm.ac.uk), Department of Botany, The Natural History Museum, Cromwell Road, London SW7 5BD, UK.

INTRODUCTION

Marine algae (seaweeds) comprise relatively small groups of marine organisms mostly occupying only a narrow inshore strip of our oceans but which make important contributions to local biodiversity, ecosystem functioning, and also to man's well-being through their economic uses. Notwithstanding some preliminary assessments (EDDY et al. 1992; JOHN 1994), seaweed biodiversity still remains a neglected topic (NORTON et al. 1996).

A checklist and distributional index to the benthic marine algae (seaweeds) of the North Atlantic Ocean (SOUTH & TITTLEY 1986) presented a comprehensive collation of taxonomic and distributional information following earlier collations of BØRGESEN & JÓNSSON (1905) and SCHMIDT (1931). The systematic part of the checklist indicated *inter alia* amphi-atlantic taxa requiring reappraisal. The geographical data provided a basis for an overview of algal biogeography (SOUTH 1987) and for area by area comparison of species richness and a re-evaluation of phyco-geographical provinces in the North Atlantic (TITTLEY et al. 1990). Contemporaneously, algal data were being collated for parts of the Atlantic Ocean to the south; these facilitate floristic comparison between the warm and cold north Atlantic regions. A revised inventory for tropical atlantic America (WYNNE 1986, 1998) presented taxonomic information for the region from Virginia to Uruguay. A checklist for tropical and subtropical Atlantic Africa and adjacent islands (since completed as a series: LAWSON & PRICE 1969; PRICE et al. 1978, 1986, 1988, 1992; JOHN et al. 1979, 1994; LAWSON et al. 1995; WOELKERLING et al. 1998) provided a critical assessment of the flora from Western Sahara and the Canary and Salvage Islands to Namibia. Other recent algal checklists for Atlantic locations include HAROUN et al. (2002) for the Canary Islands and NETO et al. (2001) for Madeira. A detailed inventory for the Indian Ocean (SILVA et al. 1996) has provided a basis for comparison of floras between oceans. Such endeavours have been considerably supported by taxonomic and floristic studies (e.g. AFONSO-CARILLO & SANSÓN 1999; BIRD & MCLACHLAN 1992; COPPEJANS 1995, 1998; LAWSON & JOHN 1987; MAGGS & HOMMERSAND 1993; SCHNEIDER & SEARLES 1991; SEARS 1998). Aspects of the evolutionary history of the North Atlantic Ocean and its seaweed flora are considered in GARBARY & SOUTH (1990).

Patterns and anomalies in marine diversity have been addressed in several studies. BOLTON (1994), using selected examples of floras including some from the Atlantic Ocean, confirmed earlier assertions for the absence of a peak of species numbers in tropical latitudes. CLARKE & CRAME (1997) concluded that study of shallow water soft bottom infauna communities has yet to provide evidence of a latitudinal cline in alpha diversity. SOUTH (1987) identified nine distribution patterns of algal species in the North Atlantic. TITTLEY & NETO (1995) reassessed diversity and biogeographical affinities of the mid-Atlantic Azores marine flora; the latter contrasted with other northern and southern Atlantic island floras (e.g. Faroes, Ascension) where species diversity was lower. Changes in the seaweed flora and its diversity in another part of the North Atlantic, the North Sea, is considered in SCOTT & TITTLEY (1998).

This paper reviews seaweed biodiversity in the North Atlantic Ocean (defined as coastal areas to the north of latitude 39º N, the northern boundary of Carolina and the Straits of Gibraltar, to the Arctic). Species richness in the North Atlantic is compared with four other oceanic areas and between regional floras of the North Atlantic. The paper concludes with observations on the conservation of marine floristic diversity.

THE CURRENT STATUS OF THE FLORA

A checklist and distributional index for the North Atlantic (SOUTH & TITTLEY 1986) listed 1116 species from 33 regional floras (Table 1). A revision of the checklist (NIELSEN & TITTLEY *unpub.*) contains 1200 species reflecting *inter alia* improved floristic knowledge for poorly known areas. An example is the mid-Atlantic Azores archipelago for which 186 species were listed in SOUTH & TITTLEY (1986); a decade of study has increased the total to 360 species (NETO 1994; TITTLEY et al. 1998; PARENTE & NETO 2000; TITTLEY et al. 2001). Even at better-known locations nomenclatural and taxonomic information continues to change and new algal records continue to be accumulated (e.g. BARTSCH & KUHLENKAMP (2000) for Helgoland, GUIRY (1997) for the British Isles, and STEGENGA et al. (1997) for the Netherlands). TITTLEY & FARNHAM (2001) have increased the Shetlands flora to 281 species, NIELSEN & GUNNARSSON (2001) have increased the Faroes flora to 264 species, and GUNNARSON & JÓNSSON (2002) have added 21 new species records to the Iceland flora (now 234). Data for the less-worked arctic areas remain incomplete; also generally less studied are subtidal areas.

The North Atlantic species total represents approximately 10% of currently recognised marine algal (seaweed) species in the world (cf. NORTON et al. 1996). Similar proportions (9-10%, Table 1) are known for the green and red algae, but a larger proportion of the world's brown algal species occurs in the North Atlantic (21-22%).

Table 1
The arctic and temperate North Atlantic Marine Flora (SOUTH & TITTLEY 1986).

	Genera	**Species**	**World Total**	**% of World Total***
Chlorophyceae**	*67*	*253*	*2700*	*9.4*
Phaeophyceae**	*127*	*324*	*1500*	*21.6*
Rhodophyeae**	*193*	*539*	*6000*	*9.0*

* See NORTON et al. (1996) which may include some freshwater species.
** Class-level nomenclature follows SILVA et al. (1996).

COMPARISON WITH OTHER OCEANIC FLORAS

Table 2 compares the species total for the North Atlantic with those of four other oceanic regions. The tropical east Atlantic is the least species-rich area and the Indian Ocean the most species rich with over twice as many as the North Atlantic (such comparisons have to be viewed with caution since the areas differ in extent, latitudinal range, and other factors). Table 3 compares totals of genera and species for these areas. In the green algae greatest generic and species diversity occurs in the Indian Ocean with almost twice the number of species recorded compared with the North Atlantic. Although the Indian Ocean brown algal flora contains many more species than other areas, generic diversity is not as great as in the North Atlantic; the 127 genera reported from the North Atlantic form the largest proportion of

genera in the compared floras. Brown algal species in the Indian Ocean comprise 18% of the overall flora compared with 31% in the North Atlantic. In the red algae lowest generic diversity occurs in the North Atlantic while maximum diversity is in the Indian Ocean where the 390 genera comprise 71% of the genera in the overall seaweed flora. The Indian Ocean red algal flora contains over three times as many species as that of the North Atlantic.

Table 2
Species totals for selected oceanic/regional floras.

	Species
Arctic-temperate North Atlantic Ocean (NIELSEN & TITTLEY *unpub.*)	*1200*
Tropical-subtropical American Atlantic Ocean (WYNNE 1998)	*1232*
Tropical-subtropical African Atlantic Ocean (JOHN & LAWSON 1997)	*911*
Indian Ocean (SILVA et al. 1996)	*2587*
Japanese Pacific Ocean (YOSHIDA et al. 2000)	*1389*

Unique and shared elements at all taxonomic levels are present in the five floras; Table 4 compares totals of genera and species shared between the North Atlantic and tropical-subtropical West Atlantic and Indian Ocean floras. The North Atlantic shares slightly more green algal genera with the Indian Ocean than with the tropical-subtropical America, and a similar number of brown algal genera with both areas; a larger number of red algal genera are shared with the Indian Ocean. Slightly more brown algal species are shared with tropical America than with the Indian Ocean while the converse applies to the red algae.

COMPARISON OF SEAWEED FLORAS WITHIN THE NORTH ATLANTIC OCEAN

Of the 1200 species recorded from the arctic and temperate North Atlantic Ocean, the majority are restricted to the east Atlantic (720 species, 60% of the flora). A smaller proportion (420 species, 35%) is common to both European and American coasts, and 60 species (5%) occur only on the American coast. A small but significant proportion of the north Atlantic algal flora (currently 360 species, 30%) occurs in the isolated mid-Atlantic Azores archipelago (latitude 39º N).

Table 3
Comparison of genus and species totals.

	Genera	Species
Chlorophyceae		
Arctic-temperate North Atlantic Ocean (SOUTH & TITTLEY 1986)	67 (17%)	253 (22%)
Tropical-subtropical American Atlantic Ocean (WYNNE 1998)	75 (19%)	301 (24%)
Tropical-subtropical African Atlantic Ocean (JOHN & LAWSON 1997)	40 (14%)	153 (17%)
Indian Ocean (SILVA et al 1996)	77 (13%)	474 (18%)
Japanese Pacific Ocean (YOSHIDA et al. 2000)	67 (15%)	230 (17%)
Phaeophyceae		
Arctic-temperate North Atlantic Ocean	127 (32%)	324 (31%)
Tropical-subtropical American Atlantic Ocean	72 (19%)	169 (14%)
Tropical-subtropical African Atlantic ocean	45 (16%)	138 (15%)
Indian Ocean	96 (16%)	447 (18%)
Japanese Pacific Ocean	107 (24%)	306 (22%)
Rhodophyceae		
Arctic-temperate North Atlantic Ocean	193 (51%)	539 (47%)
Tropical-subtropical American Atlantic Ocean	226 (62%)	764 (62%)
Tropical-subtropical African Atlantic Ocean	201 (70%)	620 (69%)
Indian Ocean	390 (71%)	1667 (64%)
Japanese Pacific Ocean	271 (61%)	853 (61%)

Figures in parentheses indicate proportion of overall local seaweed flora.

The species richer north east Atlantic contrasts with tropical areas where the east Atlantic is less rich in species than the west (JOHN & LAWSON

1997). However, it should be noted that the Canary Islands (latitude 28º-29º N) have a species-rich (currently 628) algal flora (AFONSO-CARILLO & SANSÓN 1999; HAROUN et al. 2002). Other islands just to the south of 39º N currently have species totals close to that of the Azores. Bermuda (latitude 32º N but tropical with coral reef, 3000km SW of the Azores) has 377 species (TAYLOR & BERNATOWICZ 1969, an under-estimate) but shares only 56 species (15% of the total flora of the Azores). The Madeiran Archipelago (latitude 30º-33º N, 1000km SE of the Azores) has 359 species (NETO et al. 2001) and shares 161 with the Azores (45% of the Azores flora).

Table 4
Genera and species shared.

	Genera shared	Species shared
Arctic-temperate North Atlantic and Tropical-subtropical west Atlantic floras***		
Chlorophyceae	39	78
Phaeophyceae	55	75
Rhodophyceae	115	146
Arctic-temperate North Atlantic and Indian Ocean Floras****		
Chlorophyceae	43	84
Phaeophyceae	57	60
Rhodophyceae	167	156

* Modified SOUTH & TITTLEY (1986) and additional records; ** comparison based on taxonomy and nomenclature of WYNNE (1998); *** comparison based on taxonomy and nomenclature of SILVA et al. (1996).

Changes in species richness occur from south to north along both east and west coasts in the North Atlantic (also shown by NORTON et al. (1996, Fig. 2) for the British Isles). Fig. 1 shows a south to north (Azores to the British Isles) increase in seaweed species (all groups) richness in the east Atlantic. This is followed by a decrease to the western Baltic Sea (an area of reduced salinity) and also the Shetlands and Faroes. France is the most species rich area in the North Atlantic, followed by England, northern Spain, and Ireland. Together these create an area ("hot-spot") of species richness in the North Atlantic. The Maritime Provinces region of Canada is the most species rich area in the north western Atlantic with more than in the Shetlands and Faroes, but fewer than in the mid-Atlantic Azores and the Low Countries of Europe (381 species) where suitable hard substrata for macroalgal colonisation are sparse. The Iceland and North Norway floras are similar in content as well as total; other sites in the arctic region (e.g. Jan Mayen, Bear Island, and Spitzbergen) have species-poor floras. The short, non-rocky, coastlines of Delaware and Maryland have depauperate seaweed floras and, as with the low seaweed species diversity recorded in Virginia and North Carolina to the south, this may relate to the fact that these coasts consist of estuaries and lagoons (RAY et al. 1997).

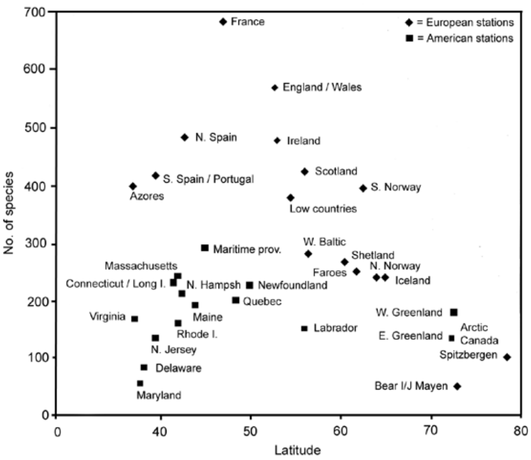

Fig. 1. Seaweed species richness with latitude (mean latitude of stations in SOUTH & TITTLEY 1986).

Comparison of species richness of green algae (Fig. 2) shows the north-east Atlantic flora (with the exception of France) to be only a little richer in species than the north-west Atlantic; a south to north increase in species richness is followed by a decrease. Arctic floras in the west are a little richer in species than those to the east. TITTLEY & NETO (1995) compared the green algal floras of the North Atlantic using an ordination method and showed that the Azores flora was different due to species not present elsewhere. Figures 3 and 4 plot species richness against latitude for brown and red algae respectively; both show the species richer east Atlantic and similar trends to those described previously. The flora of the Azores is poorer in brown algal species compared

with most temperate areas in Europe to the north but richer in red algae (see below). Unlike the green algae, ordination of the brown and red algal floras of the Azores (TITTLEY & NETO 1995) positioned them in a south to north series along the coast of the eastern North Atlantic Ocean.

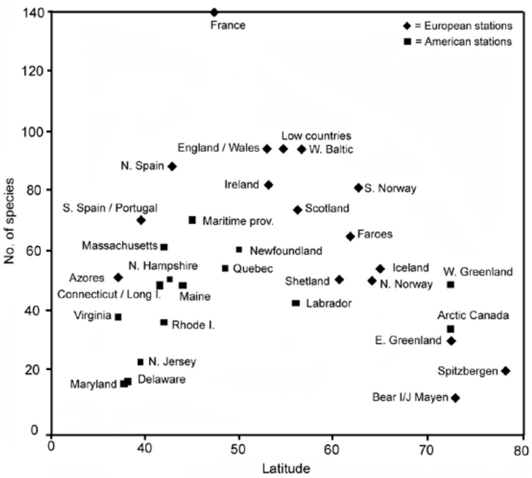

Fig. 2. Green algae species richness with latitude (mean latitude of stations in SOUTH & TITTLEY 1986).

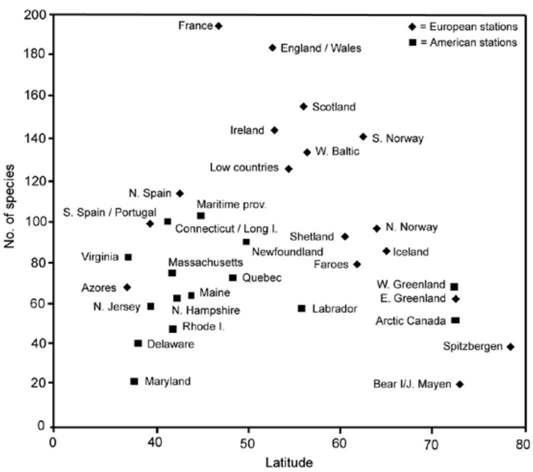

Fig. 3. Brown algae species richness with latitude (mean latitude of stations in SOUTH & TITTLEY 1986).

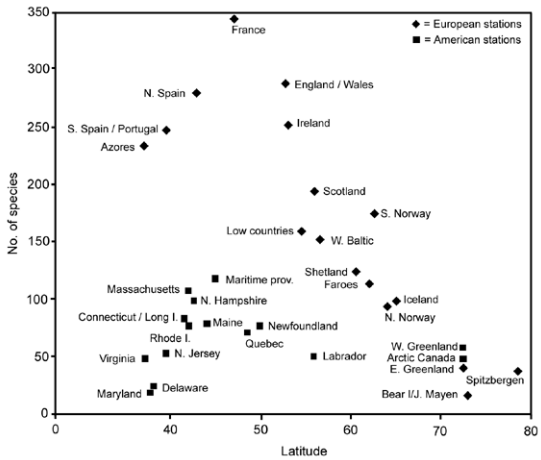

Fig. 4. Red algae species richness with latitude (mean latitude of stations in SOUTH & TITTLEY 1986).

The proportion of red to brown algae in the local floras of the North Atlantic when plotted against latitude differs on the two sides of the ocean (Fig. 5). In the north-east Atlantic the greatest proportion of red algal species occurs in the Azores with 3.4 red algal species recorded for every brown algal species; this complements the high ratios in the Salvage Island (6.5 to 1) and Canary Island (4.5 to 1) floras noted by JOHN & LAWSON (1997). Ratios decrease from the south to north with a steep drop from the Azores to the Low Countries and Scotland where the ratio is 1.25 red to brown algae; the curve in the graph flattens from the Low Countries to the Arctic where ratios are closer to 1 to 1. In the north-west Atlantic low ratios of 0.6 - 0.9 to 1 occur in the south with more brown algae than red algae in the floras from Virginia to Connecticut; higher ratios occur in the floras of Rhode Island, Massachusetts and New Hampshire. The ratio then decreases from New Hampshire to Newfoundland where at 0.8 to 1 there are more brown algal species in the flora; a similar trend in relative importance of brown algae is to be found also on the eastern side throughout the Arctic region. SOUTH (1987) also noted proportional differences in the distribution of benthic marine algae.

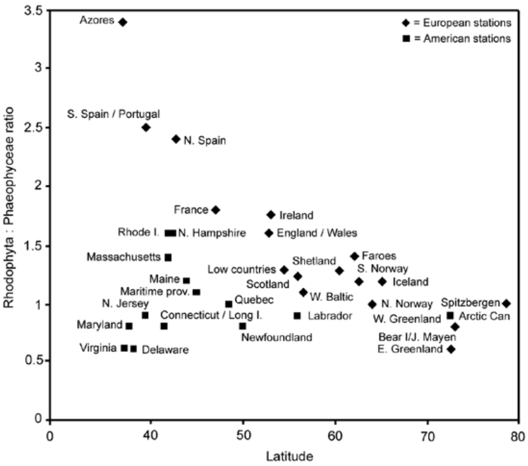

Fig. 5. Ratio of red algae to brown algae with latitude (mean latitude of stations in SOUTH & TITTLEY 1986).

SHARED ELEMENTS IN THE NORTH ATLANTIC SEAWEED FLORA

Each of the 33 regional floras of SOUTH & TITTLEY (1986) shares species in common but few species are common to all areas. An example, totals of the brown algal species shared in England and Wales with 31 other regional floras (excluding the eastern Baltic as it is a low salinity environment; for details of the algae of this area see NIELSEN et al. 1995) is shown in Table 5. The brown algal flora of England and Wales comprises 183 (57%) of the 321 species listed for the North Atlantic Ocean and shares most species in common with neighbouring France, Scotland, Ireland, South Norway and the Low Countries. Forty-two percent is shared with the Maritime Provinces of Canada, more than with the Faroes. Only two species (*Mesogloia neglecta* Batters and *Buffhamia speciosa* Batters) appear endemic to England. The ordinations of the brown and red algal floras of the North Atlantic Ocean (TITTLEY & NETO 1995) form a series that suggests an overlap in floras with more shared species between neighbouring floras than between those geographically further apart. Ordination of green algal floras as a tight cluster (with the exception of the Azores) indicated a large proportion species in common.

RARITY

As stated, very few species of seaweed tolerate the full, wide, range of environmental conditions in the North Atlantic Ocean. A frequency distribution of red, brown and green species in the North Atlantic using the 33 stations of SOUTH & TITTLEY (1986) as possible sites of occupation shows that almost 22% of species have been recorded from a single site, and a further 11% are known from two sites only. Thus one-third of all algal species could be deemed rarities. However, the comparison is skewed by many factors including differences in sizes of areas compared. Many of the rarities are under-recorded species, often microscopic forms identified by specialists and missed by generalists, or taxonomically difficult groups also requiring specialist attention. Examples of rarities include *Gelidiocolax christinae* J.Feldmann et G.Feldmann (a parasitic species known only from North Spain), *Platysiphon verticillata* Wilce (known only from East Greenland) and *Buffhamia speciosa* a small epiphyte on *Dictyosiphon foeniculaceus* (Hudson) Greville (known only from southern England) not recorded since the late nineteenth century. Further study may reveal such species to be more widespread.

Rarities also include a few elements of the North Atlantic flora that are restricted to southern, warmer, waters but which are widespread in tropical -subtropical areas of the Atlantic Ocean; examples are listed in Table 6A, many of which are from the Azores. Fewer rarities are restricted in occurrence to the Arctic North Atlantic; examples are *Phaeosiphoniella cryophila* Hooper, Henry & Kuhlenkamp and *Platysiphon verticillata*.

Other more widespread species are globally restricted (endemic) to the North Atlantic. Examples of brown algae (Fucales and Laminariales) and their distribution are given in Table 6B. *Himanthalia elongata* forms a monospecific familiy (Himanthaliaceae) restricted to the northeast Atlantic. All are functionally important species and key characterising elements of sea-shore or subtidal communities or biotopes. *Delesseria sanguinea*

Table 5
Shared components of Phaeophyceae floras; England & Wales (stn. 10) and regional floras in the North Atlantic Ocean (from SOUTH & TITTLEY 1986).

Stn	Total spp.	% of North Atlantic flora	% local flora shared with England & Wales	No. of shared species	% of England & Wales flora shared
0 Azores	72	23	69	50	27
1 S. Spain & Portugal	99	31	80	80	44
2 N.Spain	114	36	86	98	53
3 France	194	60	75	149	81
4 Low Countries	126	39	90	114	62
5 W.Baltic	134	42	82	109	60
6 E.Baltic *	-	-	-	-	-
7 S.Norway	141	44	85	120	65
8 N.Norway & Russia	97	30	75	74	40
9 Ireland	144	45	84	120	65
10 England & Wales	183	57	-	-	-
11 Scotland	135	42	94	128	70
12 Shetland	93	29	97	90	49
13 Faroes	83	26	87	75	41
14 Jan Mayen & Bear I.	20	6	50	10	5
15 Spitzbergen	39	12	72	28	15
16 Iceland	86	27	71	61	33
17 E.Greenland	63	20	57	36	20
18 W.Greenland	68	21	48	33	19
19 Arctic E. Canada	52	16	63	33	19
20 Labrador	58	18	64	37	20
21 Newfoundland	90	28	71	64	35
22 Quebec	73	23	74	54	30
23 Maritime Provinces	103	32	75	77	42
24 Maine	64	20	81	52	28
25 New Hampshire	63	20	79	50	27
26 Massachusetts	75	23	63	52	28
27 Rhode I.	47	15	79	37	20
28 New York & Long I.	100	31	38	38	21
29 New Jersey	59	18	34	20	11
30 Delaware	40	12	35	14	8
31 Maryland	21	6	19	4	2
32 Virginia	83	26	33	27	15

* Stn 6. E. Baltic omitted - brackish environment

(Hudson) Lamouroux is an example of a red alga restricted in distribution to the northeast Atlantic Ocean (France to Iceland and Norway). The order Tilopteridales (*Haplospora globosa* Kjellman, *Phaeosiphoniella cryophila* and *Tilopteris mertensii* (Turner in Kützing) was considered to be endemic to the North Atlantic (LÜNING 1990), but there is new evidence to suggest the order occurs in the North Pacific Ocean (Kuhlenkamp pers. comm.). Nonetheless, *P. cryophila* is currently known only from Newfoundland. Some other species restricted to the North Atlantic but with wider distributions on European and American coasts are listed in Table 6C.

Species considered to be endemic to the geographically isolated Azores archipelago have proven to be more widespread (e.g. *Codium elisabethae* O.C. Schmidt, recorded recently in the Madeiran archipelago). Otherwise they are members of taxonomically unresolved groups

(e.g. *Cladophora michaelensis* O.C. Schmidt*, C. theotonii* O.C. Schmidt, *C. weizenbauri* O.C. Schmidt, *Lithophyllum azorum* Lemoine in O.C. Schmidt*, L. bipartitum* Lemoine, *Polysiphonia azorica* O.C. Schmidt*, P. hochstetteriana* O.C. Schmidt). AFONSO-CARILLO & SANSÓN (1999) noted that the total of species endemic to the Canary Islands is small and stands at 17 (2.6% of the local flora).

Table 6
Examples of rare species in the North Atlantic.

A. Southern (warm water) species	
Cladophoropsis membranacea (C. Agardh) Børgesen	*Azores*
Codium elisabethae O.C. Schmidt	*Azores, Madeira*
Cottoniella filamentosa (Howe) Børgesen	*Azores, S.Spain/Portugal*
Dictyota bartayresii Lamouroux	*Azores*
Halymenia floresii (Clemente) C.Agardh	*S.Spain/Portugal*
Hydroclathrus clathratus (Bory) Howe	*Azores, S. Spain/Portugal*
Liagora divaricata Tseng	*Azores*
Taenioma nanum (Kützing) Papenfuss	*Azores, S.Spain/Portugal*

B. Species globally restricted to the northeast Atlantic	
Bifurcaria bifurcata Ross	*Morocco to S. England and Ireland*
Fucus ceranoides Linnaeus	*Portugal to N. Norway, Russia and Iceland*
Halidrys siliquosa (Linnaeus) Lyngbye	*S. Spain to N. Norway, Russia and Iceland*
Himanthalia elongata (Linnaeus) S.F. Gray	*S. Spain to N. Norway and Iceland*
Laminaria hyperborea (Gunnerus) Foslie	*S. Spain to N. Norway and Iceland*
Laminaria ochroleuca Bachelot de la Pylaie	*Azores, Morocco to S. England*
Pelvetia canaliculata (Linnaeus) Decaisne & Thuret	*S. Spain to N. Norway and Russia*
Saccorhiza polyschides (Lightfoot) Batters	*Morocco and the Mediterranean Sea to Norway*

C. Species globally restricted to the east and west coasts of the North Atlantic	
Ascophyllum nodosum (Linnaeus) Le Jolis	*N. Spain to Russia, Iceland, W. Greenland, Labrador to Delaware*
Chondrus crispus Stackhouse	*Portugal to N. Norway, Iceland, Newfoundland to Delaware*
Fucus serratus Linnaeus	*N. Spain to Russia, Iceland, Gulf of St Lawrence*
Fucus vesiculosus Linnaeus	*Morocco to Russia, Iceland, E. and W. Greenland,, Arctic Canada to Virginia*
Laminaria digitata (Hudson) Lamouroux	*N. Spain to Russia, Spitzbergen, Iceland, E. and W. Greenland, Arctic Canada to Connecticut*
Laminaria solidungula J. Agardh	*Arctic, Newfoundland*
Membranoptera alata (Hudson) Stackhouse	*France to N. Norway, Iceland, W. Greenland, Labrador to Connecticut*
Phyllophora pseudoceranoides (S.G. Gmelin) Newroth & A.R.A. Taylor	*(Black Sea), France to central Norway, Iceland, Newfoundland to Delaware*
Saccorhiza dermatodea (Bachelot de la Pylaie) J. Agardh	*N. Norway to Russia, Spitzbergen, Iceland, E. and W. Greenland, Newfoundland to Massachusetts*

NON NATIVE SPECIES

Two percent of the British seaweed flora comprises recent immigrants (FARNHAM 1994, 1998); introductions to the North Atlantic generally are of the same order of magnitude (32 species). Some, such as *Sargassum muticum* (Yendo) Fensholt, *Codium fragile* (Suhr) Hariot,

have been aggressive invaders; *S. muticum*, originally from Japan, has spread to Norway in the north and Portugal in the south. The kelp, *Undaria pinnatifida* (Harvey) Suringar, also from Japan, is now established on European Atlantic shores from France to the Netherlands. Even isolated locations have introduced algal species; ARDRÉ et al. (1974) and TITTLEY et al. (1998) reported the widespread occurrence in the Azores of the small, creeping, red alga *Symphyocladia marchantioides* (Harvey) Falkenberg (originally from New Zealand). ATHANASIADIS & TITTLEY (1994) suggested that *Antithamnion diminuatum* Wollaston, *A. pectinatum* (Montagne) Brauner and *Scageliopsis patens* Wollaston recently discovered in the Azores may also be introduced species. Within the North Atlantic, *Fucus serratus* Linnaeus has probably been introduced to North American from European waters, and *Mastocarpus stellatus* (Stackhouse) Guiry to Helgoland (BARTSCH & KUHLENKAMP 2000). Although the impact of non-native species in the marine environment is not as great as on the land, there is increasing concern about the effects of introduced species to European waters on local ecosystems, and a call for legislation to limit this (BOUDOURESQUE et al. 1994). By contrast, *Laminaria ochroleuca* De la Pylaie is a recent migrant to England through natural range extension.

CONSERVATION OF MARINE FLORISTIC BIODIVERSITY

Maintenance of marine floristic biodiversity is the aim of most conservation management programmes irrespective of species richness; some areas (e.g. the arctic North Atlantic) are intrinsically low in species diversity but nonetheless of conservation value. Strategies for achieving conservation of biodiversity in the sea have been proposed by NORSE & GERBER (1993) for global issues, HISCOCK (1997) for the North-east Atlantic, and JOHN (1994) for algae.

As mentioned, northern Spain, France, Ireland and England represent areas of high species diversity for seaweeds and these needs to be taken into account when developing policies and programmes for the conservation and sustainable management of marine resources. Although anthropogenic disturbance is significant in these areas, the marine inshore environment (and associated plant diversity) still remains much less altered than the terrestrial environment. Examples of changes in the marine flora of one area of the North Atlantic, the North Sea, are presented in SCOTT & TITTLEY (1998); both a loss of local marine floristic diversity and long-term persistence of species and communities are described. A feature of the marine environment in the North Sea and other areas is the ability of algal communities to survive short and long-term environmental perturbation, and the ephemerality of many algal populations.

Conservation success in the marine environment is achieved through the protection of habitats, and thereby species and communities or biotopes (cf. BRODIE 1998). For species in the UK (ANON. 1995) attention has been focused on those whose numbers or range have declined significantly in recent years, endemic species, and those under a high degree of international threat, and/or are covered by conventions, directives or legislation. Since only 156 species of British seaweeds have been mapped (NORTON 1985) in a single time-frame, it is difficult to assess comprehensively change in distribution range with time and thus threat and decline cannot be addressed in any detail. From the distribution data in SOUTH & TITTLEY (1986) and LÜNING (1990), the international importance (cf. ANON. 1995) of some key seaweed species has been estimated for the UK (Table 7).

Table 7
Importance of selected UK algal species

Estimate of world population in UK	
Himanthalia elongata	25%
Pelvetia canaliculata	20%
Halidrys siliquosa	20%
Laminaria hyperborea	20%
Membranoptera alata	20%
Phyllophora pseudoceranoides	20%
Chondrus crispus	17%
Delesseria sanguinea	17%
Saccorhiza polyschides	17%
Fucus ceranoides	17%
Bifurcaria bifurcata	14%
Fucus serratus	13%

For habitat conservation in the UK, priority lies with those for which it has international obligations, or is at risk owing to a high rate of decline, or is rare, functionally critical, or important for key species. Although it is recognised (ANON. 1995) that the quality of the marine environment around the UK is affected by human activities, there are no seaweeds listed as threatened or declining and thus requiring immediate action. There is no evidence of extinction from the UK marine flora although several species recorded in the nineteenth century have not been recorded since then.

The EC Habitats Directive promotes the conservation of habitats and species within the European Union (ANON. 1992). The designation of "Special Areas of Conservation" is one of the main measures by which the directive will be implemented; these will form a network of European protected sites called "NATURA 2000" which will be regularly monitored. This measure will contribute to the protection of algal diversity in the north eastern Atlantic Ocean.

CONCLUSIONS

This review of seaweed diversity in the North Atlantic using species richness is inevitably superficial, and almost immediately outdated by new floristic and taxonomic information. It represents only part of the story, for implicit in biological diversity is the degree of taxonomic diversity (improved taxonomic knowledge is therefore a continuing requirement). Organisms which differ widely from each other may be considered to contribute more to overall diversity than those which are similar (GROOMBRIDGE 1992; NORTON et al. 1996) and unique taxa, especially at higher levels, may merit greater attention for conservation purposes. Thus in the North Atlantic for example, the brown alga *Himanthalia elongata* (a monospecific family of limited global distribution), a species not statutorily protected in the UK, could be rated higher for conservation purposes than the red alga *Anotrichium barbatum* (C.Agardh) Nägeli, a listed species for which an action plan has been prepared in the UK. *A. barbatum* is a member of a genus common in the warmer waters of the Atlantic and a family (Ceramiaceae) globally widespread. The restricted occurrences of for example *Codium elisabethae* (Azores and Madeira) and *Phaeosiphoniella cryophila* (Newfoundland) suggest other species that would merit action plans for conservation.

Although the North Atlantic Ocean is well studied in comparison to other oceans, much remains to be done. Large areas remain poorly surveyed, especially those in the Arctic. Floristic study is often uneven and may be strongly influenced by personal taxonomic interest. There are many critical groups at all taxonomic levels (e.g. Corallinales, Cystoseiraceae, *Ceramium*, *Cladophora*) that require further taxonomic study. Nonetheless, from the pool of information on the diversity of the seaweeds of the North Atlantic Ocean, it can be concluded that: (i) The North Atlantic is less rich in genera and species than the tropical west Atlantic, the Indian Ocean and the Japanese Pacific area. (ii) Brown algae form a larger proportion of the flora at genus and species level than the other compared floras, particularly at northern (arctic) latitudes. (iii) Species richness is greater in the east Atlantic than the west. (iv) Species richness is greater in southern parts of the east Atlantic. (v) A latitudinal cline (decrease) in diversity occurs from south to north and is more noticeable in the east Atlantic. (vi) The mid Atlantic Azores archipelago is not species-poor. Latitudinal changes in sea-temperature, cold- and warm-water currents, day-length, suitable substrate, biological interactions, as well as evolutionary history, are significant in determining the present patterns of algal diversity in the North Atlantic Ocean.

TITTLEY et al. (1990) noted that the difficulties in undertaking ecological-biogeographical analyses, which apply also to analysis of species diversity, relate to problems of sampling and that of achieving comparable sampling effort. LAWSON'S (1988) suggestion of analysing the flora of unit lengths of coastline represents a solution but data are currently not available in this format. When the UK seaweed atlas is completed, comparison of mapping grid squares will enable recognition of key areas for conservation of maximum biodiversity. Unfortunately such schemes are largely incomplete for the North Atlantic despite

intensive field-work, extensive data in museum collections and much published literature, thus holding back objective assessment of diversity.

The "Convention on Biological diversity" signed in 1992 drew attention to the need for sustainable development and conservation. Species inventories provide an important tool to enable policy-makers and others to frame programmes for the conservation of biodiversity based upon the best taxonomic and biogeographical information (cf. ANON. 1995; EDDY et al. 1992). Continued improvement to such alpha data resources in the North Atlantic Ocean is of high priority for the better understanding and sustainable management of seaweed biodiversity.

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