Cryptogamie, Algol., 2003, 24 (3): 245-267

Composition and distribution of subaerial algal assemblages in Galway City, western Ireland

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(Received 5 October 2002, accepted 26 March 2003)

Abstract – The subaerial algal assemblages of Galway City, western Ireland, were studied by examination of field collections and culture observations; four main types of assemblages were identified. The blue-green assemblage was the most common on stone and cement walls; it was particularly well-developed at sites characterised by poor water drainage. *Gloeocapsa alpina* and other species of *Gloeocapsa* with coloured envelopes were the most common forms; *Tolypothrix byssoidea* and *Nostoc microscopicum* were also found frequently. The *Trentepohlia* assemblage occurred also on walls; it was usually produced by large growths of *Trentepohlia iolithus*, mainly on concrete. *Trentepohlia* cf. *umbrina* and *Printzina lagenifera* were less common and occurred on different substrata. The prasiolalean assemblage was the community usually found at humid sites at the basis of many walls and corners. *Rosenvingiella polyrhiza*, *Prasiola calophylla* and *Phormidium autumnale* were the most common entities; *Klebsormidium flaccidum* and *Prasiola crispa* were locally abundant at some sites. The *Desmococcus* assemblage was represented by green growths at the basis of many trees and electric-light poles and less frequently occurred at the bases of walls. *Desmococcus olivaceus* was the dominant form, sometimes with *Chlorella ellipsoidea*. *Trebouxia* cf. *arboricola*, *Apatococcus lobatus* and *Trentepohlia abietina* were the most common corticolous algae. Fifty-one subaerial algae were recorded; most did not exhibit any obvious substratum preference, the Trentepohliaceae being the only remarkable exception. A comparison with the scanty literature available suggests a general similarity of the composition of the algal assemblages of Galway city with those of other European cities. Distribution patterns and ecological peculiarities of the algal assemblages of Galway are discussed.

artificial surfaces / Cyanobacteria / Ireland / subaerial algae / urban ecology

Résumé – Composition et distribution d'associations algales subaériennes dans la ville de Galway, Irlande occidentale. Les associations algales subaériennes dans la ville de Galway, ouest de l'Irlande, ont été étudiées par l'examen de récoltes sur le terrain et par des observations en culture ; quatre types principaux de peuplements ont été identifiés. Une association d'algues bleues est la plus commune sur des murs de pierre et de ciment ; elle est particulièrement bien développée sur des sites mal drainés. *Gloeocapsa alpina* et d'autres espèces de *Gloeocapsa* à gaine colorée sont les formes les plus communes ; *Tolypothrix byssoidea* et *Nostoc microscopicum* ont aussi été fréquemment observées. L'association à *Trentepohlia* se développe aussi sur des murs ; elle est généralement représentée par des peuplements importants de *Trentepohlia iolithus*, surtout sur le béton. *Trentepohlia* cf. *umbrina* et *Printzina lagenifera* ont été plus rarement observées, sur des substrats différents. L'association à Prasiolales est le plus souvent trouvée dans des sites humides, à la base de

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nombreux murs et dans les coins. *Rosenvingiella polyrhiza*, *Prasiola calophylla* et *Phormidium autumnale* en sont les représentants les plus fréquents ; dans quelques sites, *Klebsormidium flaccidum* et *Prasiola crispa* ont été aussi abondants. L'association à *Desmococcus* est représentée par des peuplements verts à la base de nombreux arbres et poteaux électriques, plus rarement à la base des murs. *Desmococcus olivaceus* est la forme dominante, parfois avec *Chlorella ellipsoidea*. *Trebouxia* cf. *arboricola*, *Apatococcus lobatus* et *Trentepohlia abietina* sont les algues corticoles les plus communes. Cinquante et une algues subaériennes ont été observées ; la plupart n'ont pas montré de préférence nette pour un type de substrat, les Trentepohliacées étant la seule exception digne d'être notée. Une comparaison avec la rare littérature disponible suggère que les associations algales subaériennes de la ville de Galway ont une composition généralement semblable à celle d'autres villes européennes. Les types de distribution et les aspects particuliers de l'écologie des associations algales de Galway sont discutés.

algues subaériennes / Cyanobacteria / écologie urbaine / Irlande / surfaces artificielles

INTRODUCTION

Species of algae occur virtually in any sort of terrestrial habitat and on any type of subaerial surface. Stable hard substrata that are widespread in terrestrial habitats, including rock, cement and other artificial surfaces, woodwork, tree bark, shells and animal skins, are known to host more or less diversified microalgal assemblages (Hoffmann, 1989).

Despite having attracted the long-term attention of scientists, the information available on several aspects of the biology of terrestrial algal assemblages is still fragmentary; this applies in particular to some types of terrestrial environments, among which urban areas are a remarkable example. Urban habitats are effectively artificial environments, of which little is known. In these locations, artificial surfaces, such as concrete and limestone walls, are the main substrata available for algal colonisation and growth. Very few studies have been carried out in these environments and, to date, no detailed accounts of the subaerial algal flora of an urban area have been published. Most contributions on algae in urban environments have focused on practical problems created by these organisms. In warm and humid tropical areas, species of subaerial algae produce extensive coloured growths that cause aesthetically unacceptable discoloration of buildings (Wee & Lee, 1980; Lee & Wee, 1982; Tripathi *et al.*, 1990) ; this problem has been reported only occasionally for temperate regions (Gaylarde & Gaylarde, 2000; Rindi & Guiry, 2002a). For some species an involvement in the deterioration of stone surfaces has been documented (Krumbein, 1972; John, 1988; Ortega-Calvo *et al.*, 1991; Wakefield *et al.*, 1996; Noguerol-Seoane & Rifón-Lastra, 1997; Kováčik, 2000) ; it is thus not surprising that most studies on algae of temperate urban areas have concerned monuments or other buildings of high aesthetic value (Palleni & Curri, 1968; Favali *et al.*, 1978; Anagnostidis *et al.*, 1983; Danin & Caneva, 1990; Ortega-Calvo *et al.*, 1993; Lamenti *et al.*, 2000; Tomaselli *et al.*, 2000; Rifón-Lastra & Noguerol-Seoane, 2001).

Observations made by one of us (MDG) in the last 25 years indicate that many urban habitats of western Ireland host a rich and diversified subaerial algal flora. The atypical climate of this region, with high rainfall and very mild winter conditions in comparison to most of northern Europe, probably plays an important role in this regard (Rindi & Guiry, 2002b). Due to the previous almost complete lack of information, in the last few years we have concentrated our attention on some groups of subaerial algae widespread in the west of Ireland. We have examined in detail the morphology and life history of two groups, the Prasiolaceae (Rindi *et al.*, 1999) and the Trentepohliaceae (Rindi & Guiry, 2002a). In the last 18 months, however, we have extended our observations to virtually every type of terrestrial habitat found in Galway City that hosts macroscopically observable subaerial algal assemblages. We studied the most common assemblages by extensive field and culture work and we examined in detail their composition, trying to gain an understanding of which are the most important factors influencing their distribution. Although determination at species-level is not yet possible for several entities (mainly taxonomically difficult chlorococcalean green algae), we have identified the most common species and collected a range of general observations on the patterns of spatial distribution of the algal assemblages. Here we summarise our findings, discussing some interesting ecological characteristics of the subaerial vegetation of western Ireland; this is the first study in which such a comprehensive account of the subaerial algal assemblages of an urban area is presented.

MATERIALS AND METHODS

During the period February 2001-February 2002, samples of subaerial algae were collected at 160 freely accessible sites in the city center of Galway and in nearby suburbs (for a map of the area, see Rindi & Guiry, 2002a). Only places hosting an algal assemblage detectable by visual inspection (in the form of black, grey, green, red or orange growths) were sampled. The algae were removed from a few cm^2 of substratum with a scalpel or a sharp knife; the material was examined by light microscopy on the same or on the following day and the algae observed were determined at the best possible level of taxonomic resolution. For each site, a number of environmental factors was noted (orientation of the colonized surface, width of the intervening space, substratum type, kind of habitat, height from the ground and distance from sea). Most sites were sampled once, but for some of them collections were repeated at different times (in different seasons). The sites were chosen as a random sample representative of all types of habitats occupied by subaerial algae in Galway City. The types of habitat considered were the following: cement and stone walls, mainly sampled at 1-1.5 m from the ground (sites 1-81) ; bases of walls and corners, 0-0.2 m from the ground (sites 82-118) ; bases of trees and public light or telephone poles, either wood or cement, 0-0.3 m from the ground (sites 119-134) ; bark of trees, 0.3-1.5 m from the ground (sites 135-154) ; bare ground (sites 155-157) and unconsolidated gravel mixed with mosses (sites 158-160). All samples have been conserved as dry material and, for the larger species, voucher specimens have been deposited in the Phycological Herbarium, National University of Ireland, Galway (GALW).

Many terrestrial microalgae, especially chlorococcalean representatives, can be determined with confidence only through isolation in culture (John, 1988; Broady, 1996). For this reason, culture observations were used to support field observations in the identification of the algae. At 30 sites, material was aseptically scraped into sterile test-tubes; approximately 1 g of material was spread over the surface of Petri dishes containing 40 ml of agarized Jaworski's Medium (Tompkins *et al.*, 1995). The dishes were incubated in a constant temperature room at 15 °C, 16:8 h light:dark, 40-50 µmol photons $m^{-2}s^{-1}$ and examined after 15 days of incubation. Several common species were subsequently isolated in unialgal cultures (maintained partly in agarized and partly in liquid Jaworski's Medium).

Literature used for identification included general taxonomic treatments and specific works for European blue-green algae (Geitler, 1932; Bourrelly, 1985; Hoffman, 1986; Komárek & Anagnostidis, 1998; Whitton, 2002) and terrestrial green algae (Printz, 1939, 1964; Bourrelly, 1990; Lokhorst, 1996; Rifón-Lastra & Noguerol-Seoane, 2001; John, 2002). Microphotographs of subaerial algae were taken with a Nikon DXM1200 digital camera and mounted in plates using Adobe Photoshop 4.0®.

RESULTS

Overall, 51 subaerial algae were identified: 27 Chlorophyta, 19 Cyanophyta, 1 Xanthophyceae and 4 Bacillariophyceae (Tab. 1). For many chlorococcalean algae and for the Bacillariophyceae we are not able to propose a determination, even at genus-level; in general, however, these represented a quantitatively negligible part of the assemblages.

Although some species appeared to be widespread and to occupy a large range of habitats, most occurred in a single type of habitat. In each habitat some algae were typically much more abundant than others; several algal assemblages, associated with different habitats, were recognisable and appeared to be relatively persistent throughout the whole period of the study. For practical purposes we recognised four main algal assemblages, using the names of the most abundant forms: the blue-green assemblage, the *Trentepohlia* assemblage, the prasiolalean assemblage and the *Desmococcus* assemblage. We describe below the composition and distribution of each assemblage, providing details on the morphology of the most common species; we also add notes about some species that, although not generally widespread, appeared locally abundant (*Nostoc commune* and the corticolous *Trebouxia* cf. *arboricola*, *Apatococcus lobatus* and *Trentepohlia abietina*).

The blue-green assemblage

Composition and distribution

We use this name to indicate grey or black growths typically occurring on stone and cement walls and other artificial surfaces in the urban area of Galway. This assemblage was dominated by cyanobacteria. *Gloeocapsa alpina*, cf. *Gloeocapsa magma* and cf. *Gloeocapsa chroococcoides* were the most common forms; *Tolypothrix byssoidea*, *Nostoc microscopicum*, *Gloeocapsa* cf. *sanguinea* and other forms of *Gloeocapsa* were also frequently observed but, except for a few sites, they were not as abundant as the previous entities. Green algae were generally present in this assemblage, but they were never quantitatively comparable to blue-greens. The most common were *Klebsormidium flaccidum*, *Printzina lagenifera* and several species of sarcinoid (*Apatococcus lobatus*, *Desmococcus olivaceus*, cf. *Chlorosarcinopsis* sp.) and coccoid algae (*Trebouxia* sp., *Chlorella* spp., cf. *Muriella terrestris*, cf. *Tetracystis* sp.).

The aggregation of colonies of *Gloeocapsa alpina* and cells of cf. *Gloeocapsa magma* and cf. *Gloeocapsa chroococcoides* formed thin, extensive

Table 1. Species of subaerial algae determined in collections from the city center and suburban areas of Galway City.

CHLOROPHYTA
Apatococcus lobatus (Chodat) Boye Petersen
Chlorella ellipsoidea Gerneck
Chlorella luteoviridis Chodat
Chlorella vulgaris Beijerinck
Cf. *Chlorosarcinopsis* sp.
Desmococcus olivaceus (Persoon *ex* Acharius) Laundon
Cf. *Dictyochloropsis splendida* Geitler
Cf. *Elliptochloris subsphaerica* (Reisigl) Ettl *et* Gärtner
Cf. *Fernandinella alpina* var. *semiglobosa* Fritsch *et* John
Haematococcus pluvialis Flotow
Klebsormidium flaccidum (Kützing) P.C. Silva, Mattox *et* Blackwell
Cf. *Muriella terrestris* Boye Petersen
Cf. *Prasiococcus calcarius* (Boye Petersen) Vischer
Prasiola calophylla (Carmichael *ex* Greville) Kützing
Prasiola crispa (Lightfoot) Kützing
Printzina lagenifera (Hildebrandt) Thompson *et* Wujek
Rosenvingiella polyrhiza (Rosenvinge) P.C. Silva
Cf. *Spongiochloris* sp.
Stichococcus bacillaris Nägeli
Cf. *Tetracystis* sp.
Trebouxia cf. *arboricola* De Puymaly
Trebouxia sp.
Trentepohlia abietina (Flotow) Hansgirg
Trentepohlia aurea (Linnaeus) Martius
Trentepohlia iolithus (Linnaeus) Wallroth
Trentepohlia cf. *umbrina* (Kützing) Bornet
Ulothrix implexa (Kützing) Kützing

CYANOPHYTA
Aphanothece sp.
Calothrix parietina Nägeli *ex* Bornet *et* Flahault
Chroococcus sp.
Chroococcus varius A. Braun
Cyanosarcina chroococcoides (Geitler) Kováčik
Gloeocapsa alpina (Nägeli) Brand
Cf. *Gloeocapsa chroococcoides* Nováček
Gloeocapsa cf. *fusco-lutea* (Nägeli) Kützing
Cf. *Gloeocapsa magma* (Brébisson) Kützing
Gloeocapsa cf. *sanguinea* (C. Agardh) Kützing
Gloeocapsa cf. *shuttleworthiana* Kützing
Cf. *Myxosarcina concinna* Printz
Nostoc commune (Linnaeus) Vaucher *ex* Bornet *et* Flahault
Nostoc microscopicum Carmichael *in* Harvey *ex* Bornet *et* Flahault
Nostoc cf. *sphaericum* Vaucher *ex* Bornet *et* Flahault
Phormidium autumnale C. Agardh *ex* Gomont
Phormidium cf. *tenue* Meneghini *ex* Gomont
Synechocystis pevalekii Ercegović
Tolypothrix byssoidea (Berkeley *ex* Bornet *et* Flahault) Kirchner

HETEROKONTOPHYTA

XANTHOPHYCEAE
Tribonema sp.

BACILLARIOPHYCEAE
Bacillariophyceae spp. (4 undetermined species)

mats producing a crustose layer on many surfaces. In particular, the blackish purple mucilage of *Gloeocapsa alpina* and the grey sheath of cf. *Gloeocapsa chroococcoides* were responsible of the dark grey or black colour of these communities. In general, growths attributable to the blue-green assemblage were observed on every weathered wall of Galway City; among the assemblages considered, this was undoubtedly the most widespread. Blue-green growths were common both on stone and cement walls, either with limited and very wide intervening space, from a few centimetres to many metres from the ground and on surfaces facing in all compass directions; the main species seemed to be generalist in this type of habitats, and no correlation with particular factors was apparent for any of them. However, the most conspicuous growths appeared to occur in spots characterised by bad drainage of water or other conditions providing high moisture. At sites where rain gutters and down-pipes were broken, this assemblage flourished and produced thick, black crusts, which occurred in the form of patches or irregular vertical stripes (the type of communities appropriately named by German authors "Tintenstriche", ink stripes).

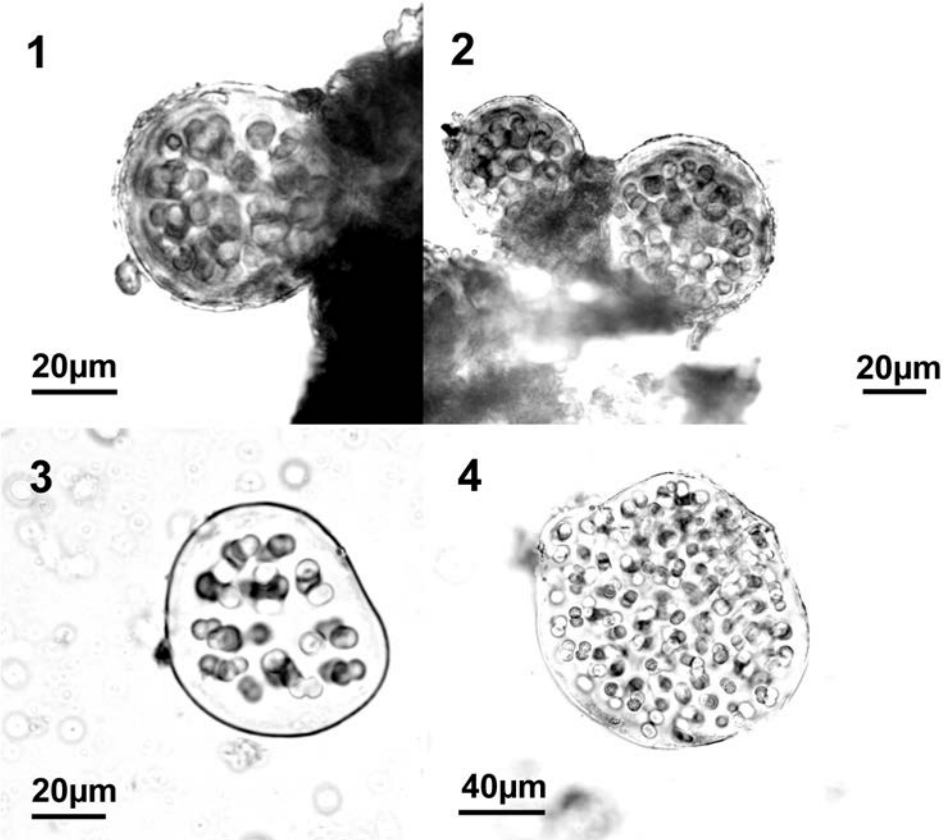
Morphology of the most common species

Gloeocapsa alpina. Colonies were globular or ovoid, 20-50 µm wide (occasionally up to 180 µm), with a more or less wide colonial sheath (Figs 1, 2). Individual cells were spherical (or elliptical before division), light blue-green, 4-6 µm in diameter; they were included in individual sheaths of variable thickness. The sheaths of the colonies were purple, with variable intensity. Some colonies showed a marked polarisation of the colour, with the surface directly exposed to the light intensely purple and the other parts colourless; *Aphanocapsa*-stages, with completely colourless sheaths, were also observed (Figs 3, 4).

Cf. *Gloeocapsa magma* occurred as isolated cells or small colonies, usually formed by 2-8 cells; less commonly, the colonies appeared to be formed by several subcolonies of 2-16 cells. Individual cells were globular, ovoid or broadly elliptical (Fig. 5), 3-10 µm in diameter (mainly 4-7 µm; 3-8 µm wide and 5-10 µm long if elliptical), enclosed in a golden-brown, firm sheath. Each cell divided transversally, producing two hemispherical daughter cells (Fig. 6). Subsequent divisions took place before the daughter cells assumed the size of the original cell and small colonies formed by 4-8 cells, enclosed in the wall of the original mother cell, were frequently observed (Fig. 7). Reproduction took place by release of the cells by breaking of the wall. This most frequently happened when the colonies were formed by 6-8 cells, but larger colonies, with cells irregularly arranged, were occasionally observed (Figs 8, 9).

Cf. *Gloeocapsa chroococcoides*. Individual cells were globular or broadly elliptical, 3-14 µm in diameter (mainly 5-8 µm; 5-8 µm wide and 6-12 µm long if elliptical), with a thin and firm deep grey sheath (Figs 10, 11). The cells were often found in large numbers, producing conspicuous masses (Fig. 12). They divided transversally producing two hemispherical daughter cells and the subsequent development probably proceeded by irregular divisions. Reproduction took place by release of cells, 3-4 µm wide and 4-5 µm long, by breaking of the wall of the original mother cell; 8-16 cells were usually released from a single mother cell (Fig. 13).

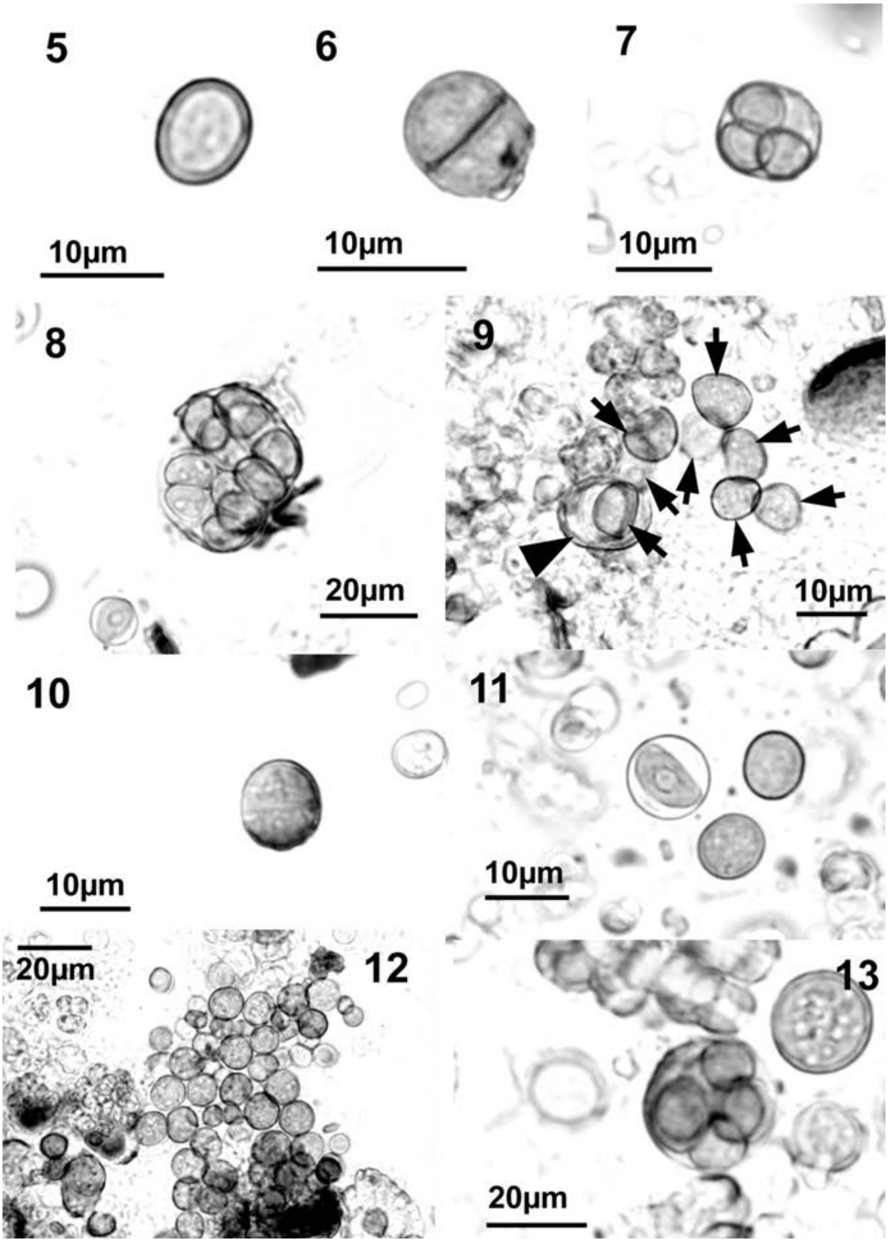
Gloeocapsa cf. *sanguinea*. Colonies were globular or irregular, 20-70 µm wide (Fig. 2) ; the cells were spherical or slightly elliptical, pale blue-green, 4-6.5 µm in diameter, provided with individual sheaths of variable thickness. The sheaths were red-orange, but colourless *Aphanocapsa*-stages were also observed for this species.



Figs 1-4. *Gloeocapsa* spp. Fig. 1. *G. alpina*: habit of a colony. Fig. 2. *G*. cf. *sanguinea* (left, red sheath) and *G. alpina* (right, purple sheath) : two colonies. Fig. 3. *G. alpina*: habit of a young colony, *Aphanocapsa*-like, with colourless mucilage. Fig. 4. *G. alpina*: habit of a large, *Aphanocapsa*-like colony.

Tolypothrix byssoidea. Filaments were 8-18 µm wide and consisted of trichomes enclosed in a more or less thick, brown sheath (Fig. 14) ; they were irregularly branched, with false branching (Fig. 15). Individual cells were blue-green, 6-12 µm wide and 0.2-1 times as long as wide; heterocysts, produced at the basis of branches, were 8-12 µm wide and 6-8 µm long.

Nostoc microscopicum. The thallus was spherical, subspherical or ovoid, up to 500 µm in diameter, with a firm external envelope (Fig. 16) ; the filaments were irregularly entangled, the external ones enclosed in a lamellated, transparent or brownish individual sheath. The cells were moniliform or barrel-shaped, blue-green to olive green, 5-8 µm wide and 5-9 µm long; heterocysts were 7-8 µm wide and 6-8 µm long.



Figs 5-13. Cf. *Gloeocapsa magma* and cf. *Gloeocapsa chroococcoides*.
Figs 5-9. Cf. *Gloeocapsa magma*. Fig. 5. Habit of an individual cell. Fig. 6. A cell dividing transversally. Fig. 7. A colony consisting of four cells. Fig. 8. A larger colony, formed by several subcolonies. Fig. 9. Reproduction, taking place by release of eight individual cells (arrows) from the mother cell (the wall of which is indicated by arrowhead).
Figs 10-12. Cf. *Gloecapsa chroococcoides*. Fig. 10. An individual cell. Fig. 11. Two cells (in a mixed culture, with *Chlorella luteoviridis*). Fig. 12. A large group of cells. Fig. 13. Reproduction, taking place by division of a mother cell in many individual cells.

The *Trentepohlia* assemblage

Composition and distribution

We refer to this assemblage dark red growths, observable on many concrete walls (less frequently stone walls), at variable heights from the ground. Such growths consisted mainly of green algae of the family Trentepohliaceae, mainly *Trentepohlia iolithus*, less frequently *Trentepohlia* cf. *umbrina* and *Printzina lagenifera*.

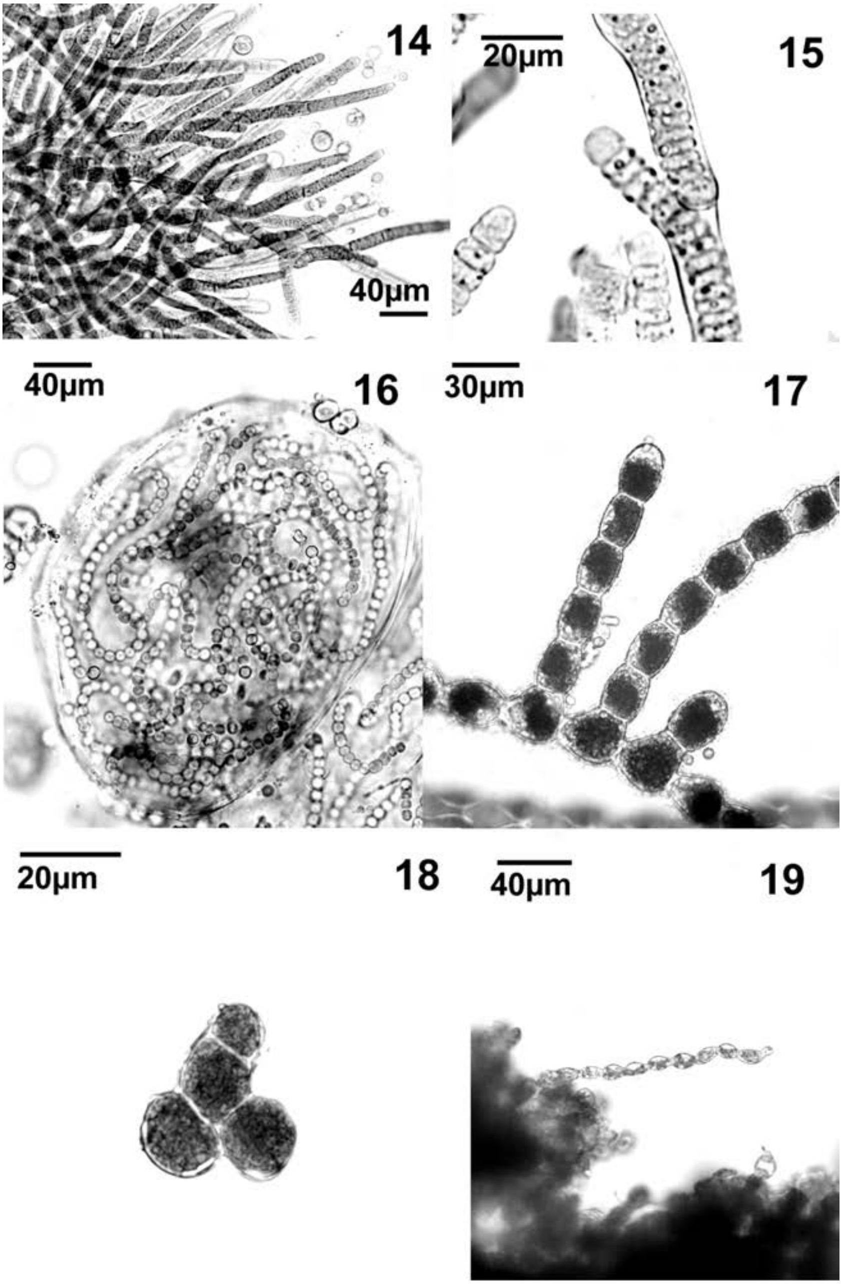
Trentepohlia iolithus formed well-developed populations on weathered concrete walls, either painted or not; apart from this, however, it occurred in a wide range of different conditions. The most developed populations occurred on walls with a very wide intervening space (many tens of m.), but no correlations were evident for other factors: *Trentepohlia iolithus* was found growing both a few centimetres from the ground or many meters from the ground, on walls directly facing the sea and at sites several km far from the sea, and on walls facing in all compass directions. When the alga was abundant, it formed almost monospecific assemblages and a few green coccalean algae were usually the only other entities observable. However, *Trentepohlia iolithus* and the blue-green assemblage did not exclude each other and transitional situations were frequent. In such cases, *Trentepohlia iolithus* was generally mixed with the blue-greens previously mentioned, and other green algae such as *Klebsormidium flaccidum*, *Apatococcus lobatus* and several undetermined green coccoids.

Trentepohlia cf. *umbrina* and *Printzina lagenifera* were noticeably less common than *Trentepohlia iolithus*. *Trentepohlia* cf. *umbrina* showed a marked substratum specificity, occurring only on limestone. It was recorded at several sites, but formed abundant populations only on two old limestone walls facing North, where it produced brownish red growths at 1-2 m height from the ground. *Printzina lagenifera* was not infrequent and microscopic examination revealed the occurrence of this species in many samples where the macroscopic appearance did not indicate its presence. It was usually mixed with other blue-green and green algae, such as *Gloeocapsa* spp., *Tolypothrix byssoidea*, *Klebsormidium flaccidum*, *Desmococcus olivaceus*, *Apatococcus lobatus* and several green coccoids. Only on a few occasions did this species produce visible growths and only at a single site did it occur as a dense, monospecific assemblage. This was a building of asbestos sheeting in the area of NUI, Galway, with a very wide intervening space. In general, however, this species was very generalist, occurring on a variety of substrata (stone, cement and concrete, bark of trees) and in many different conditions (from shaded places to more exposed habitat, at different heights from the ground).

Morphology of the most common species

Trentepohlia iolithus. Individual specimens consisted of prostrate axes which were densely and irregularly branched; the growth of many entangled individual algae produced a crustose, pseudoparenchymatous growth form. Individual cells were cylindrical to globular, 10-30 µm wide and 15-40 µm long (Fig. 17). No specialised reproductive structures were observed, either in field specimens or in culture.

Trentepohlia cf. *umbrina.* Individual algae formed compact masses of entangled filaments, easily breakable into short fragments (Fig. 18) ; the cells were globular or swollen, 8-20 µm wide and 1-2 times as long as wide. Presumptive gametangia were globular or flask-shaped, 15-20 µm in diameter, produced by enlargement and differentiation of normal vegetative cells, that at maturity released oval biflagellate swarmers, 4-6 µm × 8-10 µm.



Figs 14-19. Algae of the blue-green assemblage and of the *Trentepohlia* assemblage.
Figs 14-15. *Tolypothrix byssoidea*. Fig. 14. Habit of a specimen grown in mixed culture. Fig. 15. Detail of false branching. Fig. 16. *Nostoc microscopicum*: habit of a colony. Fig. 17. *Trentepohlia iolithus*: detail of branching of a cultured specimen. Fig. 18. *Trentepohlia* cf. *umbrina*: a short fragment consisting of four cells. Fig. 19. *Printzina lagenifera*: detail of a short individual filament; note presumptive gametangium in the background (rigth down).

Printzina lagenifera. Field specimens consisted of small cushion-like masses, produced by irregularly branched, entangled filaments (Fig. 19). The cells were 6-12 µm wide and 1-3 times as long as wide; in field specimens they were globular to barrel-shaped, becoming regularly cylindrical in culture. Presumptive gametangia were globular or flask-shaped, 10-25 µm in diameter, with a more or less pronounced neck, and released oval biflagellate swarmers, 4-6 µm × 8-10 µm.

The prasiolalean assemblage

Composition and distribution

This was the algal assemblage observable at the bases of many walls and corners in humid places in the urban area of Galway City, where it produced light to dark-green growths; communities attributable to this assemblage occurred also at the bases of trees and light poles. The assemblage mainly consisted of green algae of the family Prasiolaceae, such as *Rosenvingiella polyrhiza*, *Prasiola calophylla* and *P. crispa*. Other Chlorophyta associated with this assemblage were *Klebsormidium flaccidum* and *Desmococcus olivaceus*. *Phormidium autumnale* was the only common blue-green alga represented in the prasiolalean assemblage; other cyanophytes (mainly *Gloeocapsa* spp.) were observed very rarely.

This assemblage was generally widespread in the city centre of Galway, but its abundance and small-scale distribution appeared to be variable. The best developed populations were found at the bases of old walls, especially on northerly facing concrete with a relatively small intervening space (which provided some degree of shelter from direct sunlight) ; in these conditions *Rosenvingiella polyrhiza* flourished, producing a green belt 5-10 cm high and extended horizontally for several meters. However, growths attributable to the prasiolalean assemblage occurred in a wide range of habitats and conditions, the only common feature being the height from the ground: these growths constantly occurred at ground level or on vertical surfaces no higher than 10-15 cm from the ground.

Most samples attributable to the prasiolalean assemblage were found to consist largely of *Rosenvingiella polyrhiza*. *Prasiola calophylla* was almost always present, but generally less abundant than *Rosenvingiella polyrhiza*; at a few sites, however, notably at the bases of poles or public seating, *Prasiola calophylla* produced virtually monospecific populations. *Phormidium autumnale* was also frequently associated with *Rosenvingiella* and *Prasiola*, occurring as short individual fragments mixed in the mats produced by these species, but it was never observed to form monospecific growths. *Klebsormidium flaccidum* was not uncommon, but it generally seemed to be outcompeted by *Rosenvingiella polyrhiza*; at a few sites, however, it was the most abundant species. *Prasiola crispa* was not as frequent as *P. calophylla* and mostly occurred as small, microscopic blades mixed with *Rosenvingiella polyrhiza*. At two sites, however, at the bases of north-facing old walls, respectively on cement and bare ground, it formed large populations, in which the blades were several centimeters wide and assumed the typical crisped habit of this species.

Morphology of the most common species

Rosenvingiella polyrhiza. Plants consisted of unbranched, uniseriate filaments 7-15 µm wide, with cells 0.3-1 times as long as wide, provided with an axial stellate chloroplast with a central pyrenoid (Fig. 20). The filaments were attached to the substratum by unicellular rhizoids, produced singly or in pairs by adjacent cells. In samples collected in the spring of 2001 some filaments were observed to produce pluriseriate cylindrical parts (*Gayella*-stages, presumptive gametangia).

Prasiola calophylla. Thalli were ribbon-like monostromatic blades, 0.5-1 mm wide and 2-5 mm long, attached to the substratum by an uniseriate stipe 20 µm wide (Fig. 21). Cells were 4-6 µm wide and 5-12 µm long, arranged in longitudinal and transversal rows, with a stellate chloroplast bearing a central pyrenoid. Reproduction by release of aplanosporangia produced in the apical part of the blades was observed in some specimens collected in the spring of 2001.

Phormidium autumnale. Thalli consisted of short filaments, light to dark grey, straight or with flexuous apex, 4-7 µm broad, either enclosed or not in a diffluent sheath (Fig. 22). Individual cells were usually isodiametric, 0.5-1 times as long as wide; apical cell was rounded or more or less markedly capitate. Reproduction took place by vegetative fragmentation.

Klebsormidium flaccidum. Specimens occurred either as short fragments or long filaments, 6-9 µm wide, slightly or not constricted at the cross-walls (Fig. 23), showing a tendency to fragment in culture. Individual cells were 0.5-2 times as long as wide, with a parietal chloroplast covering approximately a half of the cell wall and containing a pyrenoid. Reproduction took place by vegetative fragmentation and by release of presumptive aplanospores and zoospores.

Prasiola crispa. Young specimens were rounded or irregular monostromatic blades which consisted of quadrate or rectangular cells, 2-5 × 6-9 µm, clustered in regular groups (Fig. 24). Well-developed blades were irregularly folded, several centimetres long and wide, and were often mixed with uniseriate filamentous stages; all intermediate forms between the two were observed. Reproduction took place by vegetative fragmentation and release of akinetes from the decaying edges of blades.

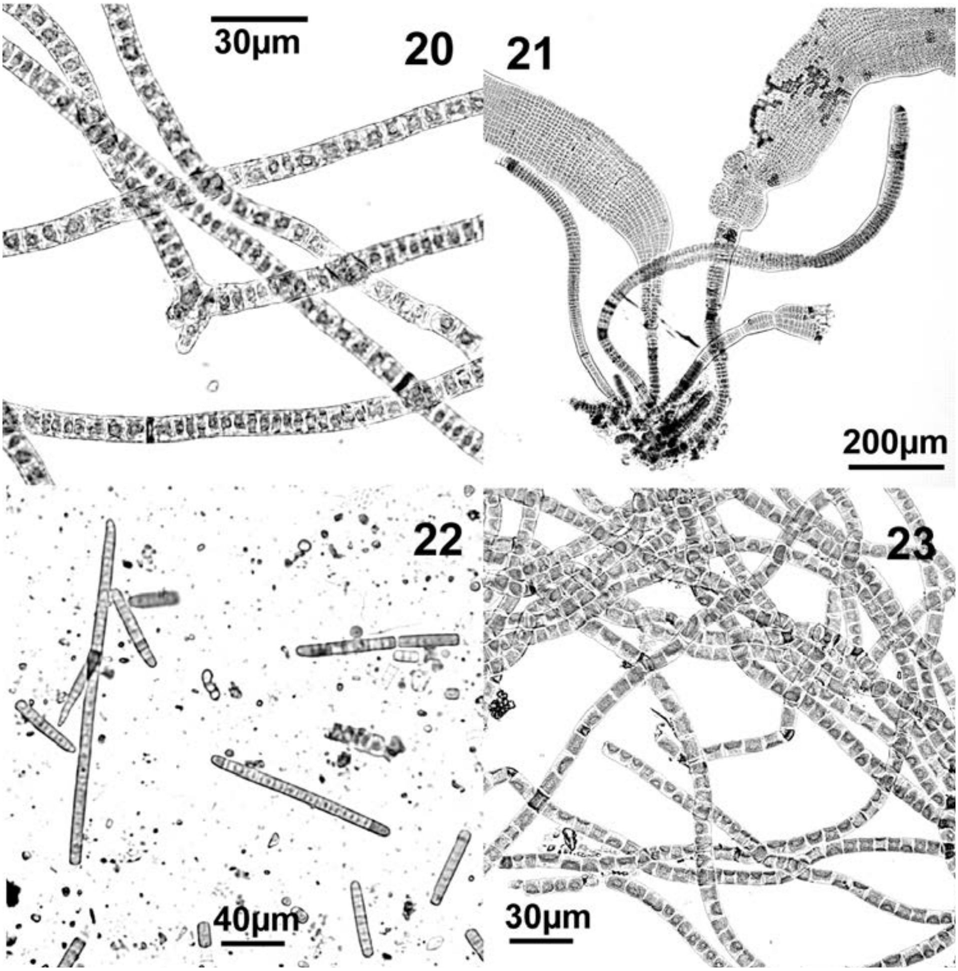
The *Desmococcus* assemblage

Composition and distribution

This assemblage consisted of light-green growths occurring on the basal part (20-30 cm) of many wooden poles and trees, less frequently on vertical stone surfaces or bark of trees at greater height from the ground. In many cases such growths appeared more developed on the parts of poles and trees facing North, but exceptions were not infrequent. These growths were usually dominated by dense populations of the green alga *Desmococcus olivaceus*; other common members of the assemblage were also chlorophytes, such as *Chlorella ellipsoidea* and *Apatococcus lobatus*. *Trebouxia* sp. and several undetermined coccalean green algae were also observed, but they were never as abundant as the previous species. The separation between the *Desmococcus* assemblage and the prasiolalean assemblage was not always clear and transitional situations in which *Desmococcus* and *Rosenvingiella* were mixed in similar amounts were observed.

Morphology of the most common species

Desmococcus olivaceus. The alga occurred as unicells or colonies of 2 or 4 cells united in cubical packets. The unicellular form was globular, 6-7 µm in diameter; in colonies collected in the field individual cells were subquadrate, 3-6 µm long and wide. In culture, however, the alga assumed a filamentous growth form and the cells were 2-4 µm wide, 2-5 times as long as wide. Each cell included



Figs 20-23. Algae of the prasiolalean assemblage.
Fig. 20. *Rosenvingiella polyrhiza*: habit of some filaments. Fig. 21. *Prasiola calophylla*: basal part of some blades. Fig. 22. *Phormidium autumnale*: some short filaments. Fig. 23. *Klebsormidium flaccidum*: habit of some filaments.

a parietal chloroplast; in some cells a small, generally indistinct pyrenoid was occasionally observed. Reproduction took place by globular aplanosporangia, 8-25 µm in diameter, with a wall ornamented by many small spiny outgrowths (Fig. 25).

Chlorella ellipsoidea. Cells were solitary, elliptical or ovoid, 5-6 µm long and 3-4 µm wide when young, 10-13 µm long and 7-9 µm wide when mature and close to reproduction (Fig. 26). Each cell bore a band-shaped or saucer-shaped chloroplast occupying a third to a half of the cell wall, with a more or less distinct pyrenoid. The alga reproduced by division of the cell contents in 4 or 8 daughter cells of unequal size.

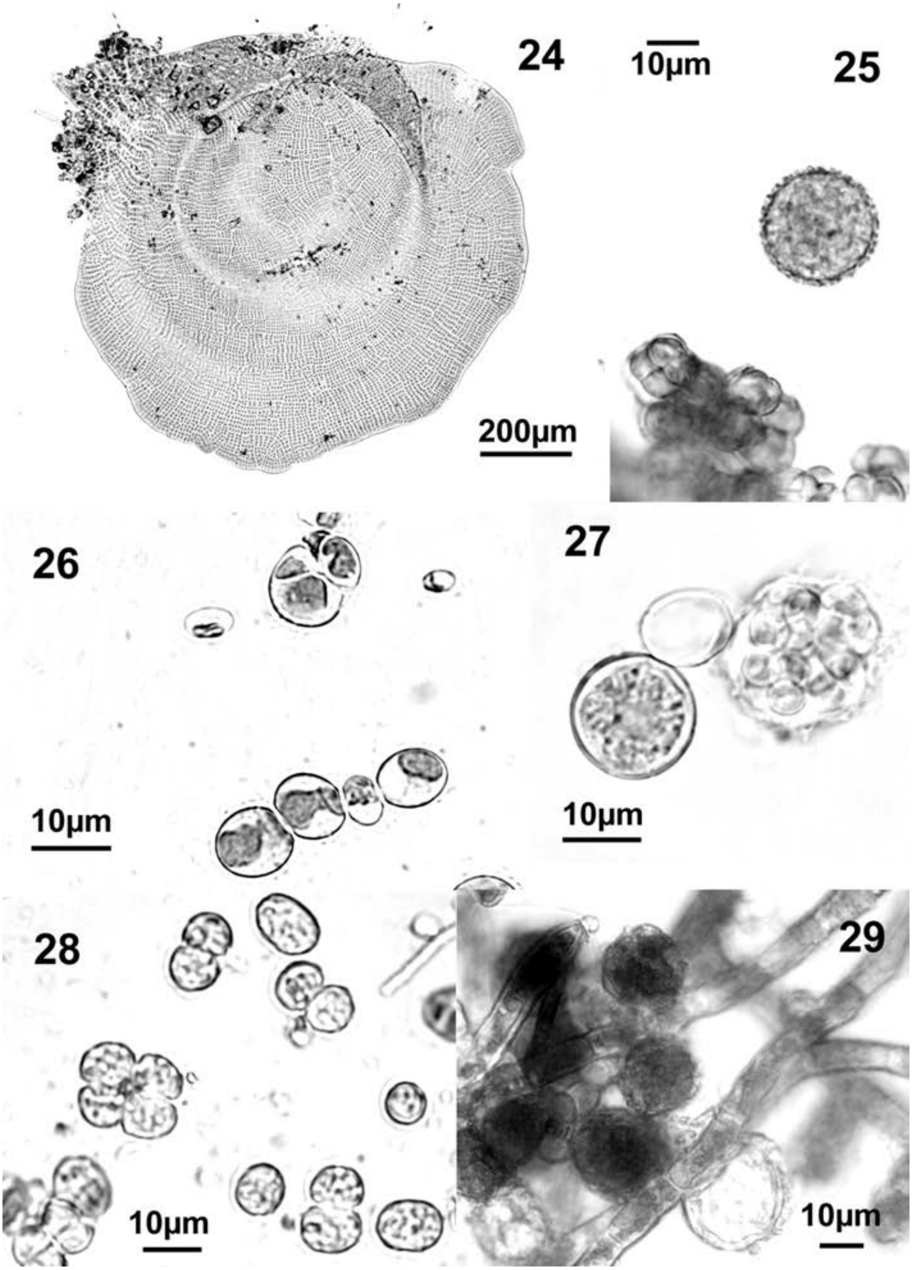
Other locally abundant species

Nostoc commune. This species was generally rare, producing large populations only at three sites, consisting of horizontal stone or asphalt partially covered by loose, unconsolidated gravel (few mm to few cm in diameter), usually mixed with mosses and grass. There *Nostoc commune* produced leathery, expanded thalli up to 20 cm wide, which accumulated in brownish green, irregular masses.

Trebouxia cf. *arboricola*, *Apatococcus lobatus* and *Trentepohlia abietina* were the three most common corticolous algae in the urban area of Galway. In Galway City, trees are generally uncommon; they are essentially concentrated in two separate areas, Eyre Square in the city centre and the campus of the National University of Ireland, Galway (NUI, Galway). They are more numerous and species-diverse at the latter location, where the corticolous vegetation appeared more abundant and developed.

Trebouxia cf. *arboricola* occurred on the bark of many trees, primarily limes (*Tilia* spp.), beeches (*Fagus sylvatica* Linnaeus), horse chestnuts (*Aesculus hippocastanum* Linnaeus) and planes (*Platanus* sp.). Best growth conditions for this entity appeared to be on large trees, providing shaded habitats; however, it was also commonly observed in more exposed situations, without apparent correlation with height from the ground or orientation. The best-developed populations occurred on the NUI, Galway campus, where the alga produced (either in pure populations or mixed with *Apatoccus lobatus*), a pale-green, powdery and hydrorepellent layer on the surface of the bark. Other green algae (*Desmococcus olivaceus*, *Stichococcus bacillaris* and *Chlorella* spp.) were occasionally mixed with *Trebouxia* cf. *arboricola*. The latter was clearly widespread, occurring also in samples of bark from Eyre Square and other sites, but without producing as dense and abundant populations as at NUI, Galway. Vegetative cells of *Trebouxia* cf. *arboricola* were spherical, 6-14 µm in diameter (up to 20 µm in culture), with a massive axial chloroplast bearing a more or less evident central pyrenoid (Fig. 27). Reproduction took place by division of vegetative cells producing tetrads or packages of autosporangia; at maturity, these released 16 or more autospores, which grew into normal vegetative cells. No release of zoospores was observed.

Apatococcus lobatus occurred frequently mixed with *Trebouxia* cf. *arboricola* and at some sites it produced an almost monospecific assemblage. However, although forming the largest populations on bark of trees and woodwork, this was one of the most widespread subaerial algae in Galway City; colonies were found virtually on any type of substratum and habitat examined, and in any of the assemblages described. This species occurred as isolated cells, pairs or colonies of 3-4 cells (rarely more), forming packets similar to *Desmococcus* but less regularly divided and orientated. Unicells were globular (elliptical before division), 8-10 µm in diameter; in colonies, individual cells were 6-9 µm long and wide (Fig. 28). In field-collected specimens, the morphology of the chloroplast was usually not clear, due to accumulation of droplets and granules in the cytoplasm; but in cultured material the cell contents showed the appearance typical of this species, with a lobed chloroplast and a conspicuous, well observable nucleus. However, *Apatococcus lobatus* was apparently not able to tolerate permanent submersion in liquid medium; after a few divisions most cells lost pigmentation and died, and it was not possible to maintain this species in liquid culture on the long term. Reproduction seemed to take place both in the field and in culture mainly by vegetative fragmentation of the colonies and no specialised structures or swarmers were observed.



Figs 24-29. Algae of the prasiolalean assemblage, algae of the *Desmococcus* assemblage and corticolous algae.
Fig. 24. *Prasiola crispa*: habit of a young blade. Fig. 25. *Desmococcus olivaceus*: an aggregation of several packets of cells and an aplanosporangium. Fig. 26. *Chlorella ellipsoidea*: material grown in culture; note cell dividing unequally (top). Fig. 27. *Trebouxia* cf. *arboricola*: a vegetative cell (left) and an autosporangium (right). Fig. 28. *Apatococcus lobatus*: some individual cells and packets of cells. Fig. 29. *Trentepohlia abietina*: detail of some presumptive gametangia.

Trentepohlia abietina was most abundant and developed in the area of the campus of the NUI, Galway, where it formed thin orange mats on several deciduous trees. When well-developed, *Trentepohlia abietina* was the dominant corticolous species; however, several blue-green (*Gloeocapsa alpina*, *Gloeocapsa* cf. *sanguinea*) and green algae (*Trebouxia* cf. *arboricola*, *Stichococcus bacillaris*, *Chlorella* spp. and other coccaleans) were generally mixed with this species. In Eyre Square, microscopic examination revealed the presence of *Trentepohlia abietina* on bark of horse chestnuts on which the alga was not detectable by naked eye and was largely overgrown by *Apatococcus lobatus* and *Trebouxia* cf. *arboricola*. Individual specimens were formed by erect axes, 400-750 µm tall, arising from a limited prostrate system; individual cells were 5-9 µm wide, 1.5-2 times as long as wide. The erect axes were poorly branched, with a few branches unilaterally or irregularly arranged, bearing several globular or ovoid presumptive gametangia, 10-20 µm in diameter, formed laterally or apically at the tip of branches (Fig. 29). Release of elliptical biflagellate spores, 4-5 µm × 6-8 µm, was observed in several samples.

DISCUSSION

Floristic and taxonomic considerations

Most of the 51 subaerial algae noted in this study are widespread species, reported for several regions of Europe (Ercegovic, 1925; Boye Petersen, 1928; Jaag, 1945; Golubic, 1967; Hoffmann, 1986; Noguerol-Seoane & Rifón-Lastra, 1997). Since no comprehensive studies have been published for any other city, it is impossible to compare the number of species with results for other urban areas. In any case, we could not determine several entities at the species or genus level. We consider that the actual number of subaerial algae occurring in Galway City is greater than 51 and that further investigations are necessary to obtain a more detailed characterisation of the subaerial flora of the area.

Interestingly, only 8 species are common to our results and to the only previous general study of the subaerial algae of Ireland (Schlichting, 1975), in which 50 taxa were reported from castles and old houses outside cities. This is probably due both to the fact that our study concerned only Galway City and that Schlichting (1975) sampled a limited range of habitats, as it is evident from the fact that he did not record species that are clearly very common in Ireland (such as *Trentepohlia iolithus*, *Printzina lagenifera*, *Rosenvingiella polyrhiza*, *Prasiola calophylla*, *Prasiola crispa*, *Phormidium autumnale*). However, both in our and Schlichting's (1975) lists several entities are determined only at the genus level (and in our case the few diatoms encountered are not determined at all) and the actual number of species common to the two studies is probably greater than eight.

For most of the common species, the features of our material are in agreement with descriptions and illustrations available in the literature. However, some comments are necessary about a few entities, especially cyanobacteria, for which identification presents some problems.

Species of *Gloeocapsa* with coloured sheaths are clearly widespread members of the subaerial flora of Galway. In agreement with Geitler (1932) and Whitton (2002), we identify the most common species of *Gloeocapsa*, with purple sheath and cells 4-6 µm in diameter, as *G. alpina*. This entity seems to have a wide geographical distribution and our material is in good agreement with collections in other parts of Europe, usually reported as stages of *Gloeocapsa sanguinea* (Jaag, 1945; Turian, 1979; Hoffmann, 1986). In particular, Jaag (1945) merged several species of *Gloeocapsa* with red and purple sheaths (*G. alpina*, *G. magma*, *G. ralfsiana*) in *Gloeocapsa sanguinea*, describing them as morphological variants of this species. Our material corresponds very well to variants described by Jaag (1945) as "status familiaris, lamellosus, coloratus, alpinus, typicus" and "status perdurans, coloratus, alpinus".

For the other forms of *Gloeocapsa*, we do not feel willing to name the species at this stage. For two forms in particular, cf. *Gloeocapsa magma* and cf. *Gloeocapsa chroococcoides*, identification is problematic. At present, the section of *Gloeocapsa* for which Komárek & Anagnostidis (1998) erected the genus *Gloeocapsopsis* seems to us the most appropriate group for generic attribution; however, following Whitton (2002), we do not separate this group at generic level and we use the provisional working names of cf. *Gloeocapsa magma* and cf. *Gloeocapsa chroococcoides* for these two entities. These algae, however, show similarities with other chroococcalean genera, such as *Chroococcidiopsis* and *Pseudocapsa*, and further observations are necessary to clarify their position; unfortunately, due to overgrowth by chlorococcalean greens, we have been thus far unsuccessful in isolating them in culture.

Composition and distribution of the subaerial algal assemblages

The four algal assemblages that we recognise here were usually well characterised and associated with different types of habitats. However, algal communities that showed intermediate characteristics were also observed; in particular, communities that were intermediate between the blue-green assemblage and the *Trentepohlia* assemblage were not unusual and a complete range of situations between the two was observed. We stress that the recognition of different assemblages is a distinction that we use here only to report our results in a clear and understandable way; the distribution patterns of many subaerial algae are far more complex and variable than this crude separation would suggest, with great variation in abundance on even very small spatial scales (cm and tens of cm). Detailed experimental studies with appropriate sampling designs, which we are planning to carry out in the near future, will be necessary to elucidate the distribution patterns of the main species and provide estimates of their variability in space and time. It should be noted, however, that the assessment of spatio-temporal variability in the distribution of subaerial algae is an aspect that has been virtually completely neglected thus far. Most works on spatial distribution of subaerial algae are descriptive studies, focusing on the characterisation of different algal communities or associations (Frémy, 1925; Jaag, 1945; Barkman, 1958; Golubic, 1967) or differences in micro-distribution, usually referred to chemical or physical heterogeneity of the substratum (e.g., Schlichting, 1975; John, 1988; Ortega-Calvo *et al.*, 1993).

From an ecological point of view, the prasiolalean assemblage and the *Trentepohlia* assemblage are the most interesting communities of the subaerial vegetation of Galway City. Species of Prasiolaceae and Trentepohliaceae are common members of subaerial algal assemblages in Europe and other temperate zones (Hariot, 1889; Knebel, 1936; Barkman, 1958; Printz, 1964), but the exceptional development and the widespread distribution that these algae assume in western Ireland are not mentioned elsewhere (although this may be in part due to oversight or ignorance of their habit in the field, see Rindi *et al.*, 2003). We have reported in detail on the ecology of these groups in previous studies (Rindi *et al.*, 1999; Rindi & Guiry, 2002a). Here we will comment on two interesting characteristics of the distribution of the Trentepohliaceae in Galway City. The general abundance of *Trentepohlia iolithus* and *Printzina lagenifera* and the rarity of *Trentepohlia aurea* are remarkable, in consideration of many studies indicating *Trentepohlia aurea* as the most common species in Europe (Frémy, 1925; Boye Petersen, 1928; Howland, 1929; Rishbeth, 1948; Printz 1964; Fjerdingstad, 1965). Furthermore, a marked substratum specificity is a noteworthy feature differentiating several trentepohliacean algae from the other subaerial forms. *Trentepohlia iolithus* and *Trentepohlia* cf. *umbrina*, in particular, occur respectively only on cement and limestone (and *Trentepohlia abietina* only on bark of trees). *Printzina lagenifera*, by contrast, occurs on a much wider range of substrata. In many studies substratum has been regarded as an important factor influencing the distribution of subaerial algae (Frémy, 1925; Schlichting, 1975; John, 1988; Ortega-Calvo *et al.*, 1993; Rifón-Lastra & Noguerol-Seoane 2001) and different substrata have been reported to be colonised by different algae. Several characteristics of the substratum (such as pH, hardiness, texture, porosity) may be important; however, chemical composition of the surface is generally considered to play a major rôle. Several species of subaerial algae, especially blue-greens, are reported to occur on alkaline rocks and to be absent on acidic ones (Frémy, 1925; Schlichting, 1975; John, 1988; Komárek & Anagnostidis, 1998). This is a possible explanation for the general uniformity of composition of the subaerial assemblages growing on walls in Galway City, in particular the blue-green assemblage. Because of ready availability, limestone (that is calcareous, alkaline stone) is the type of stone that is mostly used for building in western Ireland. Acidic rock, such as granite and gneiss, are not used almost at all, except in parts of Connemara. Concrete is also an alkaline substratum, with pH that in newly prepared surfaces can reach 11 or 12 (John, 1988). If this factor is actually important, similar algae can be expected to colonise these substrata, which seems to be the case for most forms in Galway City. This is clearly not true for *Trentepohlia iolithus*, which occurs only on cement and concrete; for this species, evidently other characteristics of the substratum must be more important.

In contrast to the prasiolalean assemblage and the *Trentepohlia* assemblage, the blue-green assemblage and the *Desmococcus* assemblage are a much more widespread type of community. Subaerial assemblages more or less directly referable to these have been reported in many other studies.

Our blue-green assemblage corresponds to cyanobacterial crusts recorded by several authors. These communities are nearly cosmopolitan, occurring in tropical (Fritsch, 1907; Büdel, 1999), temperate (Diels, 1914; Jaag, 1945; Fjerdingstad, 1965; Wessels & Büdel, 1995) and, less frequently, polar regions (Broady, 1981, 1996). When particularly conspicuous, they occur as irregular vertical stripes called "Tintenstriche" (= ink stripes). Jaag (1945) and Golubic (1967) described these assemblages from mountainous areas of central Europe. Epilithic cyanobacteria have a great capacity to withstand severe stress by irradiance, heat and desiccation (Lüttge, 1997; Büdel, 1999), which makes them excellent pioneer organisms. Urban buildings are a very harsh habitat, on which only few organisms are able to settle and grow; blue-green algae are probably the only forms able to colonise newly erected walls. Remarkably, the few studies reporting details of the blue-green communities occurring in this type of habitat in Europe suggest a composition quite similar to that observed in Galway. Species of *Gloeocapsa* with coloured sheaths are dominant forms even in Geneva, Switzerland (Turian, 1979, 1981, 1985), where they occur together with *Nostoc microscopicum* and nostocalean filaments (*Calothrix parietina* and *Scytonema myochrous* Dillwyn *ex* Bornet *et* Flahault). These forms are most likely typical members of these assemblages in European cities, with variations due to both large-scale (i.e. climatic) and local, microclimatic factors. For the blue-green assemblages of the Dinaric Alps, Golubic (1967) distinguished eight different associations, correlated with different conditions of light intensity and humidity. He reported the *Scytonemo-Gloeocapsetum* assemblage as the most widespread association, occurring on rock surfaces exposed to sunlight and wetted sporadically. At high light intensity and increasing humidity, this association is replaced by the *Tolypothricetum byssoideae* (in which *Tolypothrix byssoidea*, rather than *Scytonema myochrous*, is the dominant nostocalean filament). The blue-green assemblage of Galway is intermediate in composition between these associations; the abundant occurrence of *Gloeocapsa* with coloured sheaths is common to the *Scytonemo-Gloeocapsetum*, but *Tolypothrix byssoidea* is the most common nostocalean filament. In Galway, the composition of the blue-green assemblage appears relatively constant; quantitative differences of the abundance of the algae seem to be more important than qualitative variations. The sites at which this assemblage is best developed are clearly sites where local conditions of high moisture occur (usually due to bad drainage of water). This is in agreement with several studies indicating water seepages on rocky surfaces as the typical sites at which "Tintenstrich" assemblages develop and persist (Jaag, 1945; Hoffmann, 1989; Broady, 1996).

The *Desmococcus* assemblage is also very common. *Desmococcus olivaceus* has been called "the commonest green alga in the world" (Laundon 1985) and records of this species (under different names) are available for virtually all regions where subaerial algae have been studied (Fritsch, 1907; Frémy, 1925; Nakano, 1971; Handa & Nakano, 1988; Broady & Weinstein, 1998; Rifón-Lastra & Noguerol-Seoane, 2001; John, 2002). The assemblage dominated by this species has been variously termed (*Pleurococcetum vulgaris*, Barkman, 1958; proto-pleurococcoid assemblage, John, 1988; *Pleurococcetum*, Hoffmann (1989) and Barkman (1958) provided a detailed account of its ecology. This seems to be the most tolerant subaerial algal assemblage, characterised by a very wide ecological amplitude. It can develop in conditions such as polluted air, very high nitrogen concentrations, deep, permanent shade and situations that would be too dry for other algal assemblages (Barkman, 1958). In Galway, the assemblage occurs primarily at the bases of poles and trees and is less frequent in other habitats. Furthermore, it shows remarkable variability in small-scale distribution, forming large green coatings at the basis of some poles and appearing absent or less developed on identical poles at a distance of metres and tens of metres. Several factors are probably important in determining abundance and composition of the *Desmococcus* assemblage and we are also planning to carry out detailed experimental work on this subject. However, the possibility that the ecological amplitude reported by Barkman (1958) is at least in part due to incorrect identifications (several, morphologically close entities occurring in different habitats) should not be dismissed.

For *Nostoc commune*, morphology and type of habitat occupied in Galway are in complete agreement with previous reports (Mollenhauer *et al.*, 1999). In suitable habitats, this species is probably common in Ireland. However, as noted by Mollenhauer *et al.* (1999), human impact can be a serious threat to species of *Nostoc* in many different forms. This problem may be particularly important in urban areas, where building activities and rearrangements may determinate loss of habitats for these algae (in the case of *Nostoc commune*, hard, stable substratum replacing the unconsolidated gravel on which this species occurs). In fact, the population of *Nostoc commune* sampled at one of the three Galway sites recently disappeared for this reason.

For the most common corticolous algae, ecological comparisons with other studies are difficult because of taxonomic problems. We suspect that the entity that we identify as *Trentepohlia abietina* has been treated by other authors as a reduced form of *Trentepohlia aurea*, but examination of voucher specimens would be necessary to assess this. For *Trebouxia* cf. *arboricola*, at the moment we are not able to propose a confidant determination at species level and a detailed discussion will be possible only after further work.

In conclusion, it seems appropriate to reinforce how little is known of the algae of urban environments; in fact, a more detailed discussion of our observations will be possible only when similar studies for other urban areas of Europe become available. Despite being the places in which most of us live, cities are by far the most neglected and least known environments from the point of view of the phycologist; there is no doubt that the algae of urban habitats are worthy of much more attention and offer the potential for exciting and creative research.

Acknowledgements. The study was funded by the Higher Education Authority, Ireland, PRTLI Programme for the Environmental Change Institute, National University of Ireland, Galway. We are grateful to Professor Brian Whitton and Dr Alan Donaldson for helpful discussion and remarks about some species of cyanobacteria and to Hans Baumann for collections and useful information about populations of *Nostoc commune*. Dr Pierre Compére kindly provided the French translation of the abstract.

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