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Mass Development of Marine Benthic Sarcinochrysidales (Chrysophyceae *s.l.*) in Corsica

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A mass development of benthic Sarcinochrysidales (Chrysophyceae *s.l.*), especially of *Chrysoreinhardia giraudii* comb. nov. (basionym: *Tetraspora giraudii*) and *Nematochrysopsis marina* comb. nov. (basionym: *Tribonema marinum*), is reported from the Corsican coast. Morphology, habitat and seasonal development of these taxa as well as of the less regularly observed *Chrysonephos lewisii* and of some Chrysophyceae *s.l.* associated with *Chrysoreinhardia giraudii* sheaths are presented.

Introduction

Large-scale mucilage accumulation events due to different types of planktonic or benthic algae have plagued different seas in recent years (Vollenweider and Rinaldi 1995). Pelagic mucilage formation is well known in the North Sea where mucilage from *Phaeocystis* (Haptophyta) colonies can produce great quantities of foam accumulating along the coasts (Lancelot 1995). In the Adriatic Sea several diatom species [especially *Cylindrotheca closterium* (Ehrenberg) Lewin *et* Reimann, *Chaetoceros affinis* Lauder and *Skeletonema costatum* (Greville) Cleve] are responsible for large-scale pelagic mucilage production (Degobbis *et al.* 1995, Mingazzini and Thake 1995), as has also been observed along other European coasts (e. g. Boalch and Harbour 1977 off the coast of south-west England). Benthic mucilaginous aggregates have mainly been described from the Tyrrhenian Sea (Rinaldi *et al.* 1995, Diviacco 1992, Giaccone 1992, Cinelli 1992, Rinaldi 1992, Innamorati 1992, Sartoni and Sonni 1992, Innamorati 1995). The most frequently reported taxa from these benthic communities are *Tribonema marinum* J. Feldmann (formerly considered to be a member of the Tribonematales, Xanthophyceae), *Acinetospora crinita* (Carmichael *ex* Harv.) Sauvageau (Ectocarpales, Phaeophyceae), *Microcoleus lyngbyaceus* (Kützing) Crouan (Oscillatoriales, Cyanophyceae; this name usually covers a variety of filamentous blue-green algae) and *Lophocladia lallemandii* (Montagne) Schmitz (Ceramiales, Rhodophyceae) (Giaccone 1992). The causes of these mucilaginous aggregates are still subject to discussion. The development of the *Phaeocystis* blooms in the North Sea (Lancelot 1995) is apparently due to the increase of N relative to P and especially silica. Mucilage development in the Adriatic Sea also seems to depend largely on the N/P ratio, the physical environment and climatic conditions (Rinaldi *et al.* 1995).

The benthic algal vegetation of the Bay of Calvi (north-western coast of Corsica) has been monitored since the late sixties. Since 1987, great changes have occurred in the structure of this vegetation. Indeed, the *Cystoseira* communities which dominated all the rocky substrates until 1987 have been subject to a dramatic regression of their cover and biomass (Hoffmann *et al.* 1988, Janssens *et al.* 1993 and unpublished observations by Demoulin and coworkers). At the same time several benthic macroalgae (Janssens *et al.* 1993), especially nitrophilous species such as *Cladophora prolifera* (Roth) Kützing and *Colpomenia sinuosa* (Mertens *et* Roth) Derbès *et* Solier, as well as epiphytic microalgae (e. g. Bangiophyceae) (Hoffmann *et al.* 1994) show a clear progression. In addition, massive development of mucilaginous benthic microalgae was observed, the most conspicuous components of these mucilages are palmelloid and filamentous Sarcinochrysidales (Chrysophyceae *s.l.*).

The order Sarcinochrysidales was erected by Gayral and Billard (1977) and included marine Chrysophyceae characterised by having motile cells similar to those of brown algae. On ultrastructural and phytochemical grounds the homogeneity of this group has been questioned (Billard 1984, see also Billard *et al.* 1990), followed by O'Kelly (1989) and Sartoni *et al.* (1994). Small subunit ribosomal RNA sequences confirmed the difference between the Sarcinochrysidales *s. str.* and the order Chrysomeridales that still lacks formal description (Saunders *et al.* 1997). A tendency exists to multiply classes among the heterokont algae and the Sarcinochrysidophyceae has been provisionally introduced by van den Hoek *et al.* (1995), while Saunders *et al.* (1997) favour an inclusion in the Pelagophyceae which may not convince those who want a strong morphological basis for taxa. Several taxa have still not been studied for some critical ultrastructural, chemical or molecular characters and a final decision seems premature to

us. However, it should be clear that we are referring here to organisms belonging to the order Sarcinochrysidales *s. str.* within the Chrysophyceae *s. l.*

The purpose of this paper is to give an account of the benthic chrysophycean flora of the Corsican coast, especially of the Calvi area, together with an outline of the seasonal pattern and habitat of the most frequently encountered species.

Materials and Methods

Field observations and collections of specimens were made by SCUBA diving at several locations on the Corsican coast. Most observations were performed in Revellata Bay near the town of Calvi (north-west coast of Corsica) where the benthic algal vegetation has been regularly monitored since the late sixties, and especially since 1988, with repeated samplings at fixed points. The points usually monitored numbered 19, regularly distributed along the 12 km shoreline between the harbour of Calvi and the tip of the Punta Revellata (Janssens *et al.* 1993). Routine observations were carried out until the rocky substrates ceased or down to 15 m depth, deeper on more occasional dives.

Light microscopical observations were carried out using a Leitz Dialux microscope; photographs, measurements with a screw micrometer and camera lucida drawings were made from living material. Material brought back to Caen was maintained in the enriched seawater medium ES-Tris (Cosson 1973), at room temperature under natural daylight illumination. Living cells were examined and photographed with a Leitz Orthoplan microscope equipped with interference optics. For biomass estimations, the mucilaginous algae were collected from a 100 cm^2 surface. Dry weight was obtained after lyophilisation of the collected material. The organic matter weight (ash-free dry weight) was determined by subtracting from the original dry weight the weight of the ash remaining after combustion for 6 h in a muffle furnace at 500 °C. Chlorophyll *a* concentration was determined after extraction in 90% acetone according to Jeffrey and Humphrey (1975). Herbarium specimens are held at the Herbarium of the University of Liège (LG).

Results and Discussion

Abundant mucilaginous aggregates have been observed from May to July in different sites on the Corsican coast since 1989. Some of the algae involved were present previously since *Nematochrysopsis marina* comb. nov. was already occasionally observed in the seventies (Demoulin unpublished observations) and its occurrence recorded together with that of *Chrysoreinhardia giraudii* comb. nov. by Coppejans and Boudouresque (1983) as *Tribonema marinum* and *Pulvinaria giraudii* (Derbès *et* Solier) Bourrelly, respectively. In 1989, however, the attention of one of the authors (V. D.) was drawn to their abundance and possible link to the *Cystoseira* regression. Besides *Acinetospora crinita*, different diatoms and blue-green algae (especially from the genera *Hydrocoleum* and *Pseudanabaena*), form mucilaginous aggregates which, however, are dominated by different species of the order Sarcinochrysidales, the most frequently observed being *Chrysoreinhardia giraudii* and *Nematochrysopsis marina* and more locally *Chrysonephos lewisii* (Taylor) Taylor. Other Chrysophyceae *s.l.* are also regularly observed but do not form large aggregates.

Chrysoreinhardia Billard, nom. nov.

Replaced synonym: Pulvinaria Reinhard, *Notes de la Société de Chercheurs en Sciences Naturelles de Novorosisk, IX, 2*: 248, 1885, non *Pulvinaria* Bonorden, *Handb. Mykol.*: 272, 1851.

The genus name *Pulvinaria* used by Reinhard (1885) is illegitimate because of the earlier homonyms *Pulvinaria* Bonorden as well as *Pulvinaria* Fournier (Farr *et al.* 1979, p. 1464). The new name *Chrysoreinhardia* is therefore proposed. This name has already been suggested several years ago and has provisionally been used by some authors but had never been validly published.

Type species: Chrysoreinhardia algicola (Reinhard) Billard comb. nov.

Basionym: Pulvinaria algicola Reinhard, *Notes de la Société de Chercheurs en Sciences Naturelles de Novorosisk, IX, 2*: 248, 1885.

In the Calvi area, the genus is represented by the species:

Chrysoreinhardia giraudii (Derbès *et* Solier) Billard comb. nov. (Figs 3–6)

Basionym: *Tetraspora giraudii* Derbès *et* Solier, *Suppl. C. R. Acad. Sci., I*: 8, pl. I, figs. 1–6, 1856.

Synonyms: Phaeocystis giraudii (Derbès *et* Solier) Lagerheim, *Pulvinaria giraudii* (Derbès *et* Solier) Bourrelly (invalid combination: incomplete reference).

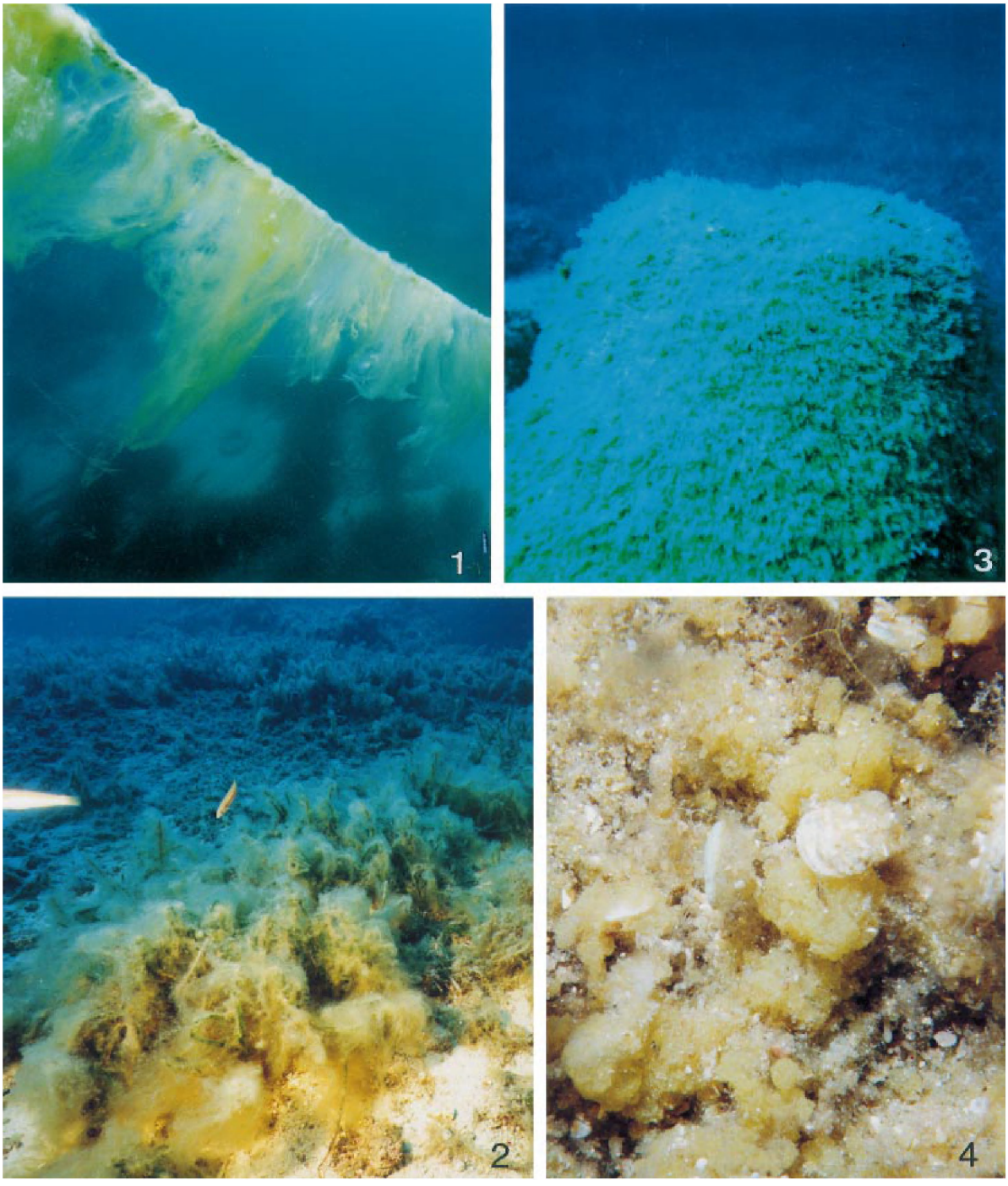
Description: The mucilaginous light brownish colonies are up to 15 mm in diameter (Fig. 6). Cells are hemispherical to spherical, 7–10 µm in diameter and are embedded in a homogeneous non-stratified muci-

Table I. Observations of macroscopic colonies of *Chrysoreinhardia* in the Calvi area.

	J	F	M	A	M	J	J	A	S	O	N	D
1995					*	*	*	*	*			
1996				*	*	*	*	*	*			
1997			*	*	*	*	*	*	*	*	*	
1998			*	*	*	*	*	*	*	*	*	

lage (palmelloid stage) or in a stratified mucilage (gloeocystoid stage) (Fig. 5). Numerous granules are present at the periphery of the cell. Cells contain two yellow-brown chloroplasts with pyrenoids and one or several lipidic granules. Reproduction is by vegetative cell division and by zoospore formation.

Habitat and ecology: Chrysoreinhardia giraudii was first collected at Alga (not Algajola as erroneously reported) in Revellata Bay in June 1979 from the rhizomes of *Posidonia oceanica* (L.) Delile, at a depth of 3 m by one of the authors (VD)(Coppejans and Boudouresque 1983), but was inconspicuous until 1989. The development of *C. giraudii* is maximal at the end of spring and in summer (Table I). It generally appears in macroscopically visible aggregates in May and disappears in September. In 1997 and 1998, the colonies remained in large numbers until November. From our collection data, *C. giraudii* extends to a depth of at least 38 meters, but is often more sparse below 20 m. The maximum development



Figs 1–4. *In situ* underwater pictures.
1) *Nematochrysopsis marina* filaments on a rope; 2) *Nematochrysopsis marina* filaments developing on the leaves of *Posidonia*; 3) *Chrysoreinhardia giraudii* colonies covering a large concrete block; 4) *Chrysoreinhardia giraudii* colonies.

is usually at shallow depths in relatively calm and well lit situations in agreement with Verlaque's (1987) classification in the 'groupe photophile infralittoral thermophile'. There it can form a layer several mm thick (Figs 3, 4) that replaces the macroalgae. In more exposed situations it may, however, start deeper and have its maximum at depths of 15–20 m. Competition with *Nematochrysopsis marina,* which is even more wave limited, seems to be a major factor in usually limiting this latter species to the first 10 meters. Dry weight: up to 400 µg cm^{-2}; organic matter: up to 110 µg cm^{-2}, chlorophyll *a*: up to 0.25 µg cm^{-2}.

Geographic distribution: Corsica [Bay of Revellata (Coppejans and Boudouresque 1983, this study), Pte Caldano, Punta Bianca, Bravone, Gulf of Porto, Porto-Vecchio (this study), Galeria (Verlaque 1987)]; Mediterranean coast of France (Castagne 1851, Derbès and Solier 1856, Hamel 1930); Adriatic Sea (Feldmann in Magne 1959); Red Sea (Nasr 1941).

Comments: This benthic species, first described in the genus *Tetraspora*, and later transferred to the genus *Phaeocystis* Lagerheim (Haptophyceae), belongs in fact to the genus *Pulvinaria* Reinhard (= *Chrysoreinhardia* Billard) as suggested by Bourrelly (1957). Bourrelly's combination (1957: 373) was, however, invalid according to article 33 of the International Code of Botanical Nomenclature (Greuter *et al.* 1994), as no complete reference to the basionym was given.

The type species of *Chrysoreinhardia*, *C. algicola*, also forms mucilaginous colonies (1–2 mm in diameter) epiphytic on macroalgae such as species of *Ceramium* and *Striaria* and is closely related to *C. giraudii*, if not conspecific. *Chrysoreinhardia algicola* is known so far from a single collection from the shores of the Black Sea (Reinhard 1885). If *C. giraudii* and *C. algicola* proved to be identical, the specific epithet '*giraudii*' would nevertheless have priority over '*algicola*'.

The third species of the genus is *C. feldmannii* (Bourrelly *et* Magne) Billard *et* Fresnel comb. nov. (basionym: *Chrysobotrys feldmannii* Bourrelly *et* Magne, *Rev. gén. Bot. 60*: 684, 1953). Synonym: *Pulvinaria feldmannii* (Bourrelly *et* Magne) Billard *et* Fresnel (*Cryptogamie: Algologie 1*: 281, 1980). It forms almost monospecific stands on the mud at the base of halophytes or on porous limestone rocks in the supralittoral zone of the French Atlantic coast (Billard and Fresnel 1980, Billard 1988).

Nematochrysopsis marina (Feldmann) Billard comb. nov. (Figs 1, 2, 9)

Basionym: Tribonema marinum Feldmann, *Bull. Soc. Hist. Nat. Afrique du Nord 32*: 56, 1941.

Synonyms: Nematochrysopsis roscoffensis Chadefaud, *Nematochrysopsis roscoffensis* f. *giganteus* Billard.

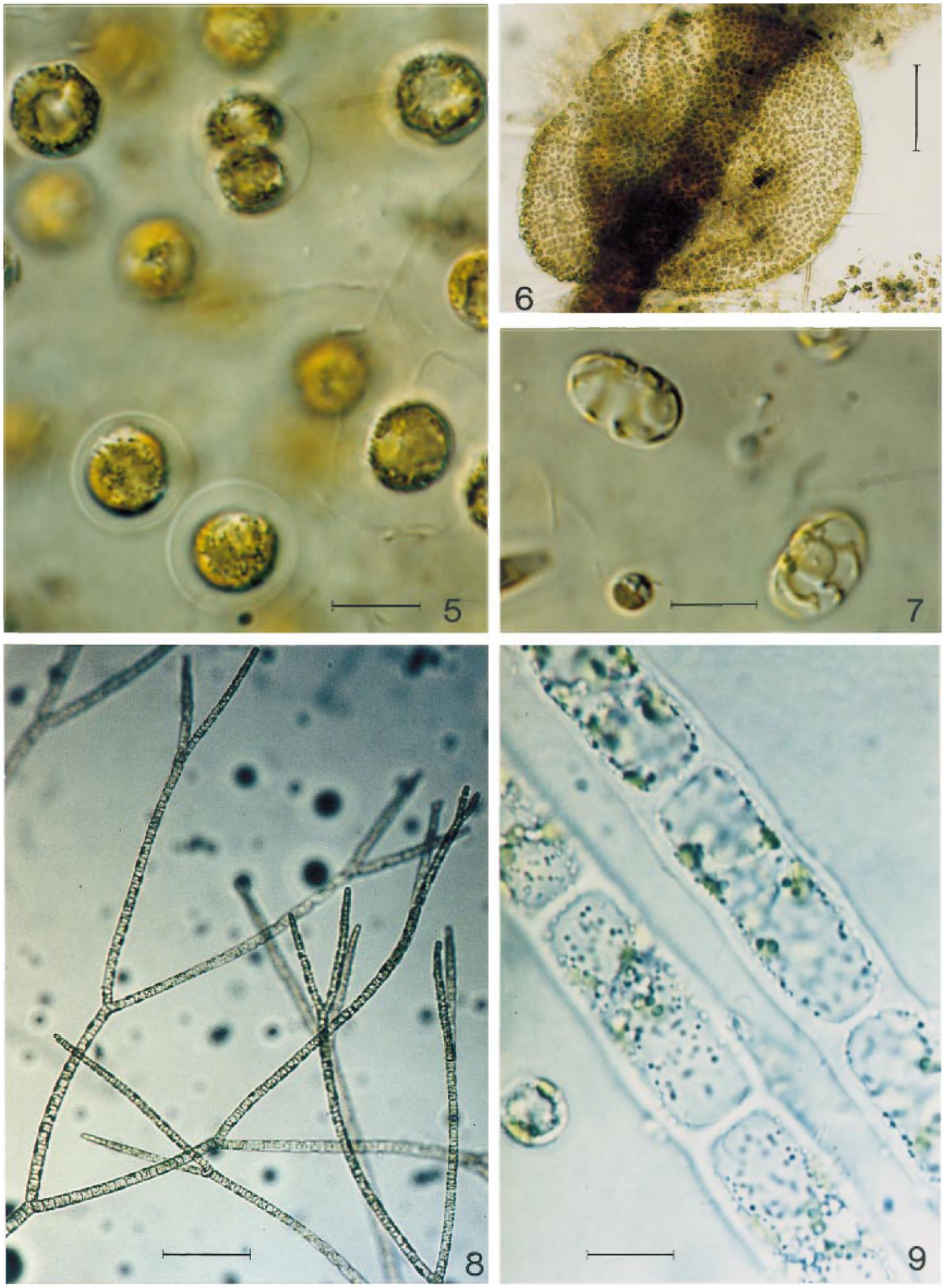
Description: The filaments are attached by a basal cell with a mucilaginous sole. Uniseriate filaments are unbranched, 13–15(17) µm wide. The cell wall is formed by H-pieces. Cells are 10–13 µm wide, 15–30 µm long and contain 4 light yellow chloroplasts with stalked pyrenoids, numerous mucous bodies and lipid droplets (Fig. 9).

Table II. Observations of macroscopic *Nematochrysopsis* in the Calvi area.

	J	F	M	A	M	J	J	A	S	O	N	D
1995				*	*	*	*	*	*			
1996			*	*	*	*	*	*	*			
1997				*	*	*	*	*	*	*	*	
1998				*	*	*	*	*	*			

Habitat and ecology: The alga was first observed by one of the authors (V. D.) on several occasions in the seventies in the Bay of Calvi and studied with Coppejans and Boudouresque in 1979 (Coppejans and Boudouresque 1983). Since 1989 it has been regularly observed. Continuous monitoring since 1995 indicates that the filaments of *Nematochrysopsis* generally appear before *Chrysoreinhardia* in spring (April–May) and that it is most abundant from mid-May to July (Table II). Towards the end of September, macroscopically visible aggregates generally disappear, except in 1997, when it was still abundant in November. It grows on various macroalgae, in particular on *Cystoseira balearica* Sauvageau and species of *Dictyota*, on the leaves of the seagrass *Posidonia oceanica* (L.) Delile (Fig. 2), animals (especially gorgonians), but also on any hard substrates including artificial ones (metal cages, ropes, etc.) (Fig. 1). This alga, which is easily disintegrated by waves, only grows near the surface in very calm places. In most areas it only grows below 6 meters and even deeper in very exposed situations. The optimum is usually between 7 and 20 meters and it has been recorded down to 42 meters. According to Sartoni *et al.* (1994), this species does not tolerate summer sunshine, but this is contrary to our observations which links its rarer occurrence near the surface with wave sensitivity. Indeed, in our network of stations this species does not show a gradual decrease up to the surface as would be expected if light intensity was involved, but starts abruptly. The first occurrence is several meters deeper in exposed stations as characterised by indicator species and minimal depth installation of *Cystoseira balearica* as studied by Clarisse (1984). Furthermore, the development largely depends on the weather conditions; strong agitation of the sea can 'clean' the whole bay of the species in summer with no later resettlement. Dry weight: up to 1,800 µg cm^{-2}. Organic matter up to 800 µg cm^{-2}; chlorophyll *a*: up to 5 µg cm^{-2}.

Geographic distribution: Corsica [Bay of Revellata (Coppejans and Boudouresque 1983, this study), îles Lavezzi (Frick *et al.* 1996), Punta Bianca, Gulf of Porto, Gulf of Lava, Porto-Vecchio (this study)]; Me-



Figs 5–9. Light microscopy.
5) *Chrysoreinhardia giraudii* cells (bar = 10 µm); 6) *Chrysoreinhardia giraudii* colony on *Halopteris* (bar = 100 µm); 7) Unidentified Chrysophyceae (bar = 10 µm); 8) *Chrysonephos lewisii* filaments showing pseudodichotomous branchings (bar = 100 µm); 9) *Nematochrysopsis marina* cells (bar = 10 µm).

diterranean coast of France (Feldmann 1941, Billard 1988); Italy: Sicily (Giaccone 1992, Calvo *et al.* 1995), Tuscan Archipelago (Sartoni and Sonni 1992, Sartoni *et al.* 1993), Adriatic Sea (Sartoni *et al.* 1994); Spain (Ballesteros *et al.* 1986); Atlantic coast of France (Chadefaud 1947, Gayral and Lepailleur 1971, Billard 1988).

Comments: *Tribonema marinum* was described as belonging to the Xanthophyceae because of the presence of H-pieces in the cell wall by Feldmann (1941), on the basis of material collected at a depth of 20–25 m near Cape Béar (Pyrénées Orientales) where it formed mucilaginous tufts on different macroalgae, especially *Cystoseira spinosa* Sauvageau. A similar species was described five years later by Chadefaud (1947) as belonging to a new chrysophycean genus *Nematochrysopsis* (*N. roscoffensis*) on the basis of material collected from aquariums at Roscoff, on the north-western coast of France. Comparison of *Tribonema marinum* recently obtained from the type locality (Billard unpublished), with a cultured strain of *N. roscoffensis* isolated from Normandy (strain CHR8 of ALGOBANK, Caen Culture Collection) confirms that the two names apply to the same species, *T. marinum* being identical to *N. roscoffensis* f. *giganteus* considered a large, Mediterranean form (Billard 1988). The distinction between the two forms of *Nematochrysopsis* based on size differences only seems unnecessary at the moment and can be attributed to different ecological conditions. As noted by Billard (1988), large filaments of *Nematochrysopsis* collected from the Mediterranean can give rise in culture to smaller individuals. Furthermore, ultrastructural and biochemical observations on this taxon by Sartoni *et al.* (1994) clearly indicate that this alga does not belong to the Xanthophyceae but to the Sarcinochrysidales. *Tribonema marinum* is thus transferred to the genus *Nematochrysopsis* established by Chadefaud, the specific epithet '*marinum*' having priority over the later epithet '*roscoffensis*', the name of the species becoming *Nematochrysopsis marina*.

Chrysonephos lewisii (Taylor) Taylor (Fig. 8)

Description: The plants form delicate, whitish to pale yellow tufts, up to 4 cm long. The mostly uniseriate filaments are attached to the substrate by an inconspicuous holdfast, with pseudodichotomous branchings especially above (Fig. 8). Filaments are 20–38 µm wide; cells 8–18 µm long, 8–11 µm wide surrounded by an up to 14 µm wide hyaline, non stratified sheath. Cells have two, four-lobed, band-shaped, parietal yellowish chloroplasts with stalked pyrenoids.

Habitat and ecology: Bay of Revellata, August 1995: on *Posidonia* leaves at a depth of 30 m (Pointe), on *Posidonia* leaves at a depth of 20 m (Bibliothèque), epiphytic on *Cystoseira* at a depth of 25 m (Pointe), epiphytic on *Halopteris* sp. at a depth of 20 m (Oscellucia), epiphytic on *Cystoseira* at a depth of 9 m, July 1997 (Bibliothèque).

Geographic distribution: Corsica (Bay of Revellata, this study); Italy: Tuscan Archipelago (Sartoni *et al.* 1995); Florida, Bermuda Islands (Taylor 1951); Pacific Ocean and in the Caribbean (cited in Boddi *et al.* 1999).

Comments: The monotypic genus was established by Taylor (1951, 1952) on the basis of material collected in Florida and the Bermuda Islands and has been very rarely reported since. This is the second report for the Mediterranean Sea. According to Sartoni *et al.* (1995), *C. lewisii* disappears from the photophilic algal communities during the warmest months and is then present at a depth range of 15–40 m.

Chrysonephos is a close relative of the genus *Nematochrysopsis* with respect to its general habit and cytological characters such as presence of chloroplasts with stalked pyrenoids in agreement with the diagnostic features of the order Sarcinochrysidales to which these two algae definitely belong, as already pointed out by Sartoni *et al.* 1995 and Boddi *et al.* (1999), rather than to the Chrysomeridales as proposed in O'Kelly's (1989) and Preisig's (1995) classifications.

Other members of the Chrysophyceae associated with *Chrysoreinhardia giraudii*: *Polypodochrysis teissieri* Magne

Description: Isolated cells are 10 µm wide and 15–18 µm high, with up to 5 open tube-like and up to 100 µm long expansions. They have a single yellow chloroplast and lack a pyrenoid.

Habitat and ecology: The species is regularly observed in the mucilage of *Chrysoreinhardia* colonies.

Geographic distribution: Corsica (Bay of Revellata, this study), Atlantic coast of France (Magne 1975, Billard pers. obs.).

Comments: This rarely reported monotypic genus was described by Magne (1975) on the basis of material collected from aquariums in Roscoff, but its presence in the Mediterranean was suspected (Magne 1975). *Polypodochrysis teissieri* is a distinctive marine organism currently placed in the Chrysophyceae *s. l.*

Unidentified species (Fig. 7)

Description: The ellipsoidal cells are isolated or in small groups, embedded in a homogeneous non-stratified mucilage (palmelloid stage) (Fig. 7) or in a stratified mucilage (gloeocystoid stage). Cells are 8–10 µm long, 5–7 µm wide with generally a single, very deeply lobed yellow chloroplast containing a stalked pyrenoid. Cells are smooth without peripheral granules, but with one or several lipidic inclusions.

Habitat and ecology: The taxon is regularly observed as small groups of cells in the mucilage of *Chrysoreinhardia* colonies.

Comments: This organism represents a new genus probably belonging to the Sarcinochrysidales and will be described in detail later.

The mucilaginous aggregates found along the Corsican coast are of the same benthic type as the mucous developments in the Adriatic and Tyrrhenian Seas, where *Acinetospora crinita* and *Nematochrysopsis marina* (= *Tribonema marinum*) are the most important components of these mucilages. The Corsican flora is remarkably rich in Sarcinochrysidales and especially in *Chrysoreinhardia giraudii* which so far has not been reported from the recent studies of benthic mucilages on the Italian coast, whereas it is frequently encountered and in important biomasses on the Corsican coast. According to Sartoni (pers. comm.), it may, however, be present. The difference may be due to the fact that *Chrysoreinhardia giraudii* remains benthic and does not form floating aggregates which are considered nuisances by fishermen. Its ecological importance in suffocating benthic communities may, however, be superior to that of the other algae described here.

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