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A first study of the algal flora of the Tiber River basin (Italy)

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Abstract – The floristic composition and spatial distribution of algal communities in 97 stations in the Tiber River and its tributaries were studied. A total of 128 taxa were found, belonging mainly to the Chlorophyta, Bacillariophyta and Cyanophyta. Filamentous algae (*Cladophora glomerata*, *Vaucheria geminata*, *Oedogonium* sp. and *Spirogyra* spp.) were the most common and abundant species. *Melosira varians*, *Cocconeis pediculus*, *Gomphonema olivaceum*, *Cyclotella meneghiniana*, *Fragilaria crotonensis*, *Leptolyngbya valderiana* and several species of *Oscillatoria* were also widely distributed but they were not important in terms of biomass. Spatial variations of species richness were found, with the middle and upstream sections showing a wider range of taxa than the downstream sections. *Chamaesiphon incrustans* and *Lemanea fluviatilis* were found only in the upstream sections of some watercourses of the basin in fast-flowing, cool, well-oxygenated waters, while *Stigeoclonium tenue* and *Ulva flexuosa* was recorded exclusively in downstream sections with slow-flowing, warm and eutrophic waters.

algae / floristic composition / spatial distribution / Tiber River basin / Italy / watercourses

Résumé – **Première étude de la flore algale du bassin du Tibre (Italie).** La composition floristique et la distribution spatiale des communautés algales ont été étudiées dans 97 stations dans le Tibre et ses affluents. Au total, 128 taxons ont été trouvés, appartenant principalement aux Chlorophyta, Bacillariophyta et Cyanophyta. Les algues filamenteuses (*Cladophora glomerata*, *Vaucheria geminata*, *Oedogonium* sp. et *Spirogyra* spp.) sont les plus fréquentes et les plus abondantes. *Melosira varians*, *Cocconeis pediculus*, *Gomphonema olivaceum*, *Cyclotella meneghiniana*, *Fragilaria crotonensis*, *Leptolyngbya valderiana* et différentes espèces d'*Oscillatoria* sont largement distribués mais peu importants du point de vue de la biomasse. Des variations spatiales de la richesse en espèces sont observées. Les secteurs du centre et en amont montrent une plus grande variété de taxons par rapports aux secteurs en aval. *Chamaesiphon incrustans* et *Lemanea fluviatilis* sont présents seulement dans les sections en amont de certains cours d'eau du bassin aux eaux rapides, fraîches, bien oxygénées, tandis que *Stigeoclonium tenue* et *Ulva flexuosa* sont présents uniquement dans les sections en aval aux eaux lentes, chaudes et eutrophes.

algues / bassin du Tibre / Italie / composition floristique / distribution spatiale / rivières

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INTRODUCTION

Much of the freshwater phycological research in Italy has been centred on plankton algae in lentic systems, and very few studies have been carried out in lotic environments. Except for three investigations on macroalgae (Pedrotti, 1969; Cattaneo *et al*., 1975; Dell'Uomo, 1991), the latter have dealt mainly with diatoms (Dell'Uomo, 1999; Torrisi & Dell'Uomo, 2001), which have been used as water quality bioindicators also in the watercourses of the Tiber River basin (Dell'Uomo, 1981; Cappelletti *et al.*, 2005; Ciutti *et al.*, 2007).

The aim of this paper is to provide a first study on the identity and occurrence of algae in watercourses of the Tiber River basin, which has been formally identified as a pilot basin for ecological studies (Bagnini *et al*., 2005). Our knowledge of the algal flora of this basin is very scant (Grönblad, 1960) and confined to some of the first (Tardella *et al.*, 2009) and second order tributaries of the Tiber (Dell'Uomo & Ciccotti, 1977; Dell'Uomo, 1982). The work is part of a more comprehensive river survey programme analysing the relationships between plant communities and water quality in the Tiber basin.

MATERIALS AND METHODS

Study area

With a surface area of ca. 17500 km^2, the Tiber River basin (Fig. 1) is the largest catchment area in the Italian peninsula. It occupies a large part of the Tyrrhenian side of the central Italy, mostly in the regions of Umbria and Latium (IRSA, 1978). From a hydromorphological point of view it is composed of three main sectors: 1) an upper sector in the mountainous zone, which generally has steep slopes, torrential character and rocky substrate; 2) a middle sector in the region of Umbria, characterized by pebble-gravelstone substrates and variable slopes giving rise to an alternation of shallow sections with fast flow and turbulent motion, and deep sections with middle laminar flow, and 3) a lower sector almost entirely within the region of Latium, lentic in character and with typical fluvial regime and calcareous sandy-muddy substrates. The prevailing lithotype is calcareous. The bioclimate is temperate in the upper and middle sectors (Biondi & Baldoni, 1994) and transitional Mediterranean in the lower one (Blasi, 1994). The plant landscape of the basin is in a good state of conservation in the mountainous and sub-mountainous zones. By contrast, most of the valley floors and plains have lost most of their original fluvial characteristics, especially as a result of agricultural activities and urbanization. This land use, especially in the middle and lower sections of most of the basin's rivers, is the main cause of water mineralization and eutrophication in this basin (Casini & Giussani, 2006).

Sampling

A total of 97 stations (Fig. 1) were investigated during the summers of 2006, 2007 and 2008. Floating masses of filamentous algae were collected by means of a 25 μm-mesh plankton net. Epilithic and epiphytic algae were collected by manually scraping stones, macrophytes and pebbles with a scalpel. Because no

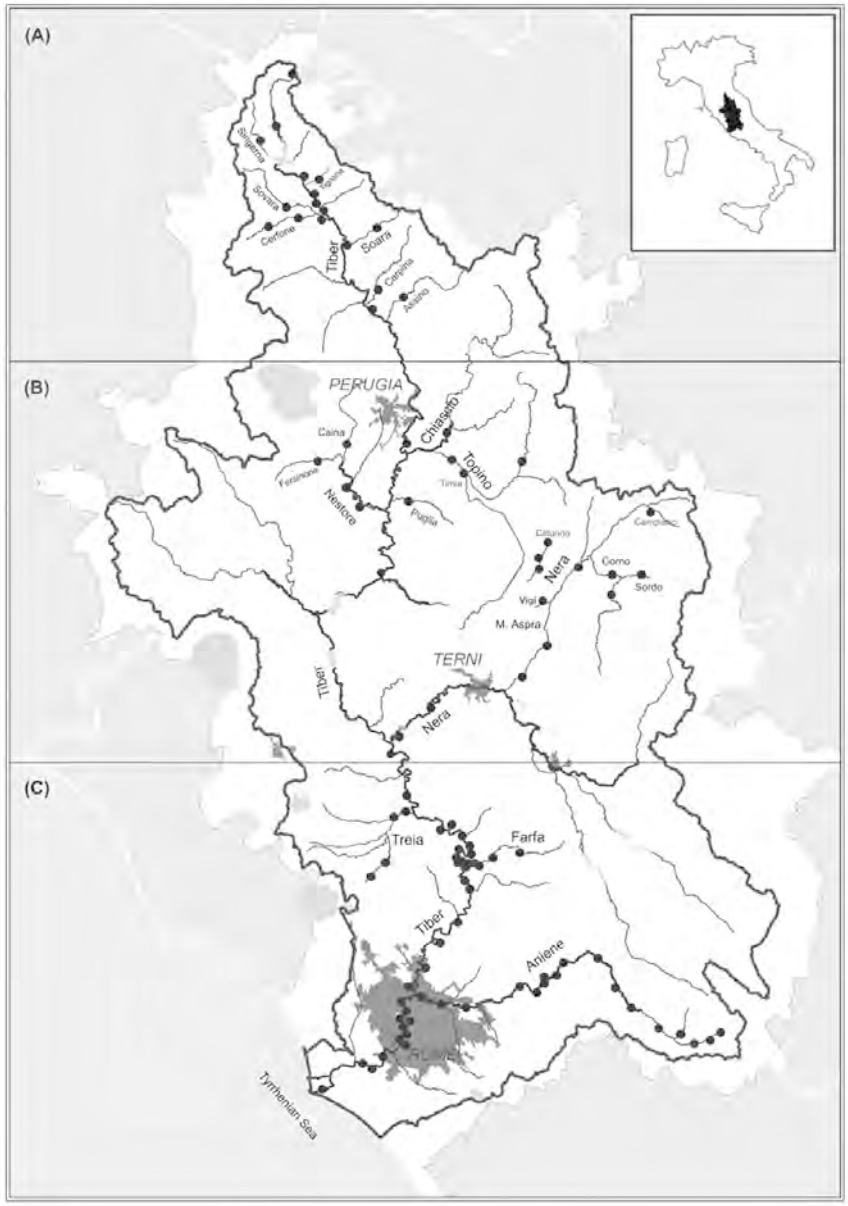

Fig. 1. Map of the Tiber River basin showing the location of the sampling stations. The stations are numbered sequentially starting with the more upstream ones: (A) Tiber River (T_1-T_8); Singerna Stream (S_1); Tignana Stream (Ti_1); Sovara Stream (Sov_1); Cerfone Stream ($Cerf_1$-$Cerf_3$); Soara Stream (Soa_1); Carpina Stream (Car_1); Assino Stream (Ass_1). (B): Tiber River (T_9-T_{11}); Chiascio River (Chs_1); Topino River (Top_1-Top_2); Timia River (Tim_1); Puglia Stream (Pug_1); Caina Stream (Cai_1); Fersinone Stream (Frs_1); Nestore River (Nes_1-Nes_2); Campiano Stream (Cmp_1); Corno Stream (Crn_1-Crn_2); Sordo Stream (Srd_1); Clitunno River ($Clit_1$-$Clit_3$); Vigi River (Vig_1); Nera River (N_1-N_5). (C) Tiber River (T_{12}-T_{39}); Treia River (Tr_1-Tr_4); Farfa River (Fa_1-Fa_6); Aniene River (An_1-An_{17}).

special method was used for sampling diatoms, the true occurrence of diatoms in the basin was underestimated during our survey. All samples were fixed in formaldehyde (4% final concentration).

Taxonomic identification and species coverage

An inventory of the algal taxa present at each station was carried out. Algae were identified morphologically using a Leica DM RB light microscope in connection with a Leica IM1000 computerized image analysis system. Identification was based on Komárek & Anagnostidis (1998, 2005) for the cyanoprokaryotes, Krammer & Lange-Bertalot (1896-1991) for the diatoms, Komarek & Fott (1983) for the Chlorococcales, Prescott *et al.* (1977-1982) for the desmids, and John *et al.* (2002) for the other algal divisions. Works by Bourrelly (1981, 1985, 1990), Ettl & Gärtner (1995), Hegewald (2000) for the genera *Scenedesmus* and *Desmodesmus,* and Hayden *et al.* (2003) for the genera *Enteromorpha* and *Ulva* were also consulted. A number of taxa were identified only down to the genus level owing to the absence of reproductive structures in the observed specimens. The extent and coverage percentage of the macroscopic species were estimated on a section of watercourse about 5 m^2 in surface area using the scale of Braun-Blanquet (1964): + = species occurring sporadically; 1 = covering 1-5% of the area; 2 = covering 5-25% of the area; 3 = covering 25-50% of the area; 4 = covering 50-75% of the area; 5 =: covering 75-100% of the area). Taxa which were ranked higher than 25% were considered dominant.

RESULTS

A total of 128 algal taxa belonging to the Cyanophyta, Chlorophyta, Rhodophyta, Xanthophyta, Euglenophyta and Bacillariophyta were found (Table 1). The most represented divisions were Chlorophyta (52 taxa), Bacillariophyta (43 taxa) and Cyanophyta (26 taxa) (Fig. 2). *Cladophora*

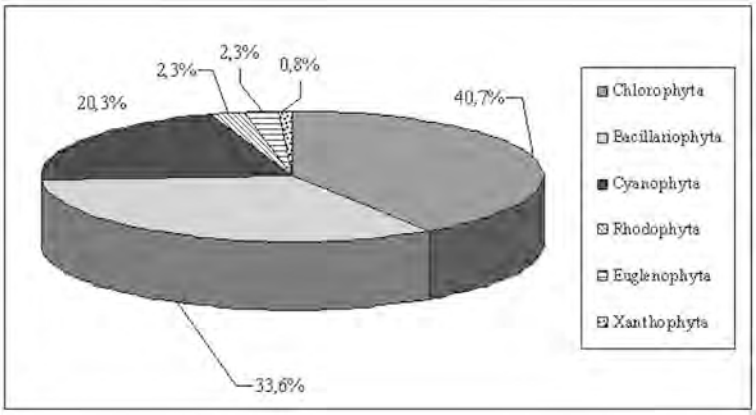

Fig. 2. Species composition of the algal flora of the Tiber River basin by algal division (relative percentages of species in each algal division to the total number of species found).

Table. 1. List and distribution of the species found in the watercourses of the Tiber River basin

Taxon	*Stations*
Division ***Cyanophyta***	
Order ***Chroococcales***	
Chamaesiphon confervicola A. Braun	Vig_1
Chamaesiphon incrustans Grunow	N_1; N_2; An_1; An_3; An_4
Chroococcus turgidus (Kützing) Nägeli	N_5
Merismopedia elegans A. Braun *ex* Kützing	T_2; T_3; T_9; T_{10}; T_{37}; N_3; N_5; Nes_1; $Clit_1$; Sov_1
Microcystis flos-aquae (Wittrock) Kirchner	T_3
Order ***Oscillatoriales***	
Pseudanabaena limnetica (Lemmermann) Komárek	T_{12}; T_{15}; T_{17}; T_{18}; T_{28}; T_{29}; T_{30}; T_{35}; T_{38}
Geitlerinema amphibium (Agardh *ex* Gomont) Anagnostidis	An_{17}
Leptolyngbya valderiana (Gomont) Anagnostidis *et* Komárek	T_3; T_7; T_9, T_{10}; T_{12}; T_{15}, T_{21}; T_{26}; T_{30}, T_{33}; T_{35}; T_{37}; T_{38}; N_3; N_5; Fa_2; An_{17}; $Clit_2$
Heteroleibleinia kuetzingii (Schmidle) Compère	T_{15}; T_{19}; T_{26}; T_{35}; T_{39}; An_4
Phormidium amoenum (Gomont) Anagnostidis *et* Komárek	T_3; T_{10}; T_{12}; T_{15}; T_{17}; T_{23}; T_{30}; An_6; Tr_1; Tr_3; Fa_1; Nes_1; Crn_1
Phormidium breve (Kützing *ex* Gomont) Anagnostidis *et* Komárek	$T_{15,}$ T_{29}
Phormidium formosum (Bory *ex* Gomont) Anagnostidis *et* Komárek	Frs_1
Phormidium retzii (Agardh *ex* Gomont) Gomont	Sov_1; $Clit_1$
Phormidium sp.	An_{13}
Porphyrosiphon luteus (Gomont) Anagnostidis *et* Komàrek	T_{15}
Oscillatoria limosa Agardh *ex* Gomont	T_3; T_7; T_{12}; T_{14}; T_{24}; T_{37}; An_8; An_{10}; An_{13}; Top_1; Frs_1; $Clit_1$
Oscillatoria subbrevis Schmidle	T_7; T_{18}; T_{19}; T_{23}; T_{29}; T_{30}; T_{35}; T_{36}; T_{39}; Fa_4; $Clit_1$; Sov_1; Vig_1; Crn_1; Cam_1; Cai_1; Car_1
Oscillatoria tenuis Agardh *ex* Gomont	T_3; T_{15}; T_{10}; N_1; Tr_1; Fa_4; Top_1; $Clit_1$; Cmp_1; Ass_1
Oscillatoria sp.	T_3; T_{33}; An_5; An_6; An_8; An_{11}; An_{16}; N_5; Pug_1
Lyngbya aestuarii Liebman *ex* Gomont	An_6; An_{10}
Lyngbya martensiana Meneghini *ex* Gomont	T_{26}
Lyngbya sp.	An_{11}
Order ***Nostocales***	
Anabaena sp.	T_{15}; T_{21}; T_{23}, T_{29}; T_{30}; Sov_1; An_6; An_8; An_{10}
Aphanizomenon sp.	T_{36}
Nostoc punctiforme (Kützing) Hariot	T_2; T_{21}; S_1; Ti_1; N_5; An_5
Order ***Stigonematales***	
Hapalosiphon fontinalis (C. Agardh) Bornet	Fa_2
Division ***Rhodophyta***	
Subclass Bangiophycidae	
Order ***Bangiales***	
Bangia atropurpurea (Roth) C. Agardh	Ti_1; N_3; An_4; An_6; An_{10}
Subclass Florideophyceae	
Order ***Acrochaetiales***	
Audouinella hermannii (Roth) Duby *in* De Candolle	T_2; $Clit_3$; An_6
Order ***Batrachospermales***	
Lemanea fluviatilis (L.) C. Agardh	Ti_1; $Cerf_1$
Division ***Euglenophyta***	
Order ***Euglenales***	

Table. 1. List and distribution of the species found in the watercourses of the Tiber River basin *(cont.)*

Taxon	*Stations*
Phacus sp.	Tr_1
Trachelomonas hispida (Perty) F. Stein *ex* Deflandre	Cmp_1
Trachelomonas sp.	T_6; T_7; Car_1
Division ***Xanthophyta***	
Order ***Vaucheriales***	
Vaucheria geminata (Vaucher) De Candolle	T_3; T_5; T_6; T_7; T_{12}; T_{17}; T_{23}; T_{26}; T_{29}; T_{30}; T_{32}; T_{33}; T_{34}; T_{35}; T_{37}; Sov_1; $Cerf_1$; Car_1; Ass_1; Soa_1; Top_1; $Clit_2$; $Clit_3$; Pug_1; N_1; N_4; Cmp_1; Crn_1; Crn_2; Vig_1; Tr_3; Tr_4; Fa_2; Fa_4; An_2; An_3; An_4; An_5; An_6; An_8; An_9; An_{10}; An_{11}; An_{12}; An_{13}; An_{14}; An_{16}
Division ***Bacillariophyta***	
Order ***Centrales***	
Cyclotella meneghiniana Kützing	T_2; T_7; T_8; T_{10}; T_{12}; T_{17}; T_{28}; T_{36}; An_3; An_6; An_{10}; An_{12}; Tr_1; Nes_1; $Clit_1$; Crn_1; Cmp_1; Car_1
Melosira varians Agardh	T_3; T_5; T_6; T_7; T_8; T_9; T_{15}; T_{19}; T_{21}; T_{23}; T_{27}; T_{28}; T_{29}; T_{30}; T_{35}; T_{36}; T_{38}; Car_1; Soa_1; Top_2; Tim_1; $Clit_1$, $Clit_2$; $Clit_3$; Nes_1; N_1; N_3; Cmp_{14}; Crn_1; Tr_1; Tr_2; Tr_3; Tr_4; Fa_2; Fa_3; Fa_4; Fa_5; An_3; An_4; An_6; An_7; An_8; An_9; An_{10}; An_{11}; An_{12}; An_{13}; An_{15}
Order ***Pennales***	
Diatoma mesodon (Ehrenberg) Kützing	Tr_1
Diatoma vulgaris Bory De Saint-Vincent	T_7; An_3; Tr_1; Top_1; Cmp_1; Ass_1
Diatoma sp.	T_2; T_7
Fragilaria capucina Desm.	T_7
Fragilaria crotonensis Kitton	T_3; T_5; T_7; T_{19}; T_{26}; T_{27}; T_{30}; An_4; An_{10}; Tr_3; Fa_2; Fa_3; N_1; Soa_1; Cmp_1; Ass_1; Car_1
Fragilaria sp.	T_2; An_6; Tr_1; N_3; Top_1
Fragilaria ulna (Nitzsch) Lange-Bertalot	Tr_1; Tr_3
Tabellaria flocculosa (Roth) Kützing	T_2; T_7; T_{26}; T_{27}; Sov_1; Ass_1; N_3; Cmp_1; Vig_1; Fa_2; An_3; An_4; An_{10}
Eunotia sp.	Top_1; An_6; An_{10}; Vig_1
Achnanthes lanceolata (Bréb.) Grunow	Cmp_1; Car_1; Tr_1
Achnanthes minutissima Kützing	T_5; T_6; An_6; Cmp_1; Car_1
Cocconeis pediculus Ehrenberg	T_2; T_3; T_5; T_6; T_7; T_9; T_{15}; T_{24}; T_{26}; T_{27}; T_{28}; T_{30}; T_{32}; T_{36}; T_{37}; S_1; Ti_1; Sov_1; $Cerf_1$; Car_1; Ass_1; Top_1; $Clit_1$; N_1; N_3; Tr_1; Fa_1; Fa_2; An_1; An_2; An_3; An_4; An_6; An_{10}; An_{11}; An_{14}; Soa_1; Vig_1; Cmp_1
Cocconeis placentula Ehrenberg	T_9
Amphora ovalis (Kützing) Kützing	T_6; T_7; T_9; Tr_1; Ass_1; Car_1
Amphora pediculus (Kützing) Grunow	T_3; T_7; T_{28}; An_{10}; Tr_1
Caloneis sp.	T_7; T_9; Tr_1; N_4
Cymatopleura solea (Brébisson) W. Smith	Car_1
Cymatopleura sp.	T_7; T_9; Car_1; Tr_1
Cymbella minuta Hilse	Cmp_1; Car_1
Cymbella affinis Kützing	T_7; Cmp_1; Ass_1; Car_1
Cymbella helvetica Kützing	T_2; T_6; T_7; T_9; T_{18}; An_4; N_1; N_3; $Clit_1$; Vig_1; Cmp_1; Ass_1; Car_1
Cymbella sp.	T_2; T_7; T_9; Car_1; An_2; An_3; An_6; Tr_1; Top_1
Diploneis elliptica (Kützing) Cleve	T_9; Tr_1
Gomphonema acuminatum Ehrenberg	T_7
Gomphonema olivaceum (Hornemann) Brébisson	T_2; T_3; T_6; T_7; T_9; T_{12}; T_{26}; T_{28}; An_6; An_{10}; An_{12}; Fa_2; N_1; N_3; Top_1; $Clit_1$; S_1; Vig_1; Cmp_1; Ass_1; Car_1
Gomphonema parvulum Kützing	T_7; Car_1; Ass_1; Cmp_1
Gomphonema sp.	T_2; T_7; An_3; An_6; Car_1; Tr_1
Gyrosigma attenuatum (Kützing) Rabenhorst	T_5; T_6; T_7; T_9; T_{10}; T_{12}; T_{15}; An_3; An_4; Tr_1; N_3; Sov_1; Ass_1; Car_1
Hantzschia amphioxys (Ehrenberg) Grunow	Tr_1
Navicula cryptocephala Kützing	T_6; Car_1; Cmp_1; S_1; $Clit_1$

Table. 1. List and distribution of the species found in the watercourses of the Tiber River basin *(cont.)*

Taxon	*Stations*
Navicula cryptotenella Lange-Bertalot	T_5; T_6; T_7; T_{15}; Tr_1; Top_1; Soa_1; $Clit_1$; S_1; Vig_1; Cmp_1; Ass_1; Car_1
Navicula gregaria Donkin	T_7; T_9
Navicula lanceolata (Agardh) Ehrenberg	T_6; Cmp_1; Car_1
Navicula sp.	T_2; T_7; T_9; Cmp_1; Top_1; An_2; An_3; An_6; N_3; Tr_1
Nitzschia acicularis (Kützing) W. Smith	T_2; T_7; An_6
Nitzschia palea (Kützing) W. Smith	T_7; T_9
Nitzschia dissipata (Kützing) Grunow	T_6; T_9; $Clit_1$; Cmp_1; Car_1
Nitzschia sp.	T_2; Car_1; Tr_1; An_2; An_6
Pinnularia sp.	T_{12}; T_{28}; $Clit_1$; Cmp_1; Tr_1; An_2; An_3
Surirella brebissonii Krammer & Lange-Bertalot	T_7; Car_1; Cmp_1
Surirella sp.	T_2; T_7; T_9; Tr_1; Car_1
Division ***Chlorophyta***	
Order ***Volvocales***	
Pandorina morum (O. Müller) Bory de Saint-Vincent	T_7
Order ***Chlorococcales***	
Ankistrodesmus falcatus (Corda) Ralfs	T_9; T_{29}
Characium sp.	T_{28}; T_{32}; T_{36}; T_{37}; T_{38}; S_1
Closteriopsis acicularis (G. M. Smith) J. H. Belcher *et* Swale	An_8
Coelastrum microporum Nägeli *in* A. Braun	T_5; T_{19}
Coenochloris fottii (Hindak) Tsarenko	T_7; T_{21}; Fa_2
Desmodesmus communis (Hegewald) Hegewald	T_6; T_7; T_9; Sov_1; Car_1; Ass_1; Nes_1; N_3; N_5; Crn_1; An_{10}
Desmodesmus serratus (Corda) An, Friedl *et* Hegewald	An_{10}
Monoraphidium arcuatum (Korshikov) Hindak	Nes_1
Monoraphidium contortum (Thuret) Komarkova-Legnerova	T_9
Oocystis borgei Snow	T_6; T_7; T_{21}; T_{28}; N_5; An_{10}; An_{13}
Pediastrum boryanum (Turpin) Meneghini	T_6; T_7; Nes_1; Crn_1
Pediastrum boryanum var. *cornutum* (Raciborski) Sulek	Nes_1
Pediastrum duplex Meyen	T_7; T_{19}; N_1; N_3; Crn_1; An_{10}
Pediastrum integrum Nägeli	T_7; Nes_1; An_{10}
Pediastrum simplex Meyen	T_{23}
Pediastrum tetras (Ehrenberg) Ralfs	T_{21}; T_{23}
Scenedesmus arcuatus (Lemmermann) Lemmermann	T_7; T_{19}; T_{21}; T_{23}; T_{30}; N_5; An_6; An_{10}; An_{13}
Scenedesmus ellipticus Corda	T_7; Nes_1
Scenedesmus falcatus Chodat	T_7; T_{15}; An_{10}
Scenedesmus granulatus W. West *et* G.S. West	T_2; T_7; N_3
Scenedesmus obtusus Meyen	An_{10}
Order ***Oedogoniales***	
Oedogonium sp.	T_2; T_3; T_5; T_6; T_7; T_9; T_{15}; T_{19}; T_{21}; T_{23}; T_{27}; T_{31}; T_{35}; T_{37}; T_{38}; Sov_1; Ass_1; Soa_1; Nes_1; Nes_2; Cai_1; N_5; Cmp_1; Crn_1; Tr_1; Fa_2; Fa_4; Fa_6; An_2; An_8; An_{10}; An_{11}; An_{12}; An_{13}; An_{14}
Order ***Chaetophorales***	
Chaetophora elegans (Roth) C. Agardh	T_{17}
Stigeoclonium tenue (Agardh) Kützing	T_{39}; An_{17}
Uronema elongatum Hodgetts	T_{15}; T_{17}; T_{26}; T_{37}; T_{38}; Soa_1; Cai_1; An_{11}

Table. 1. List and distribution of the species found in the watercourses of the Tiber River basin *(cont.)*

Taxon	*Stations*
Order ***Klebsormidiales***	
Klebsormidium flaccidum (Kützing) Silva, Mattox *et* Blackwell	T_{19}
Order ***Microsporales***	
Microspora amoena (Kützing) Rabenhorst	T_2; T_3; T_{19}; T_{33}; T_{37}; N_5; Tr_3; Tr_4; F_2; An_6; An_8; An_{10}
Order ***Ulotrichales***	
Ulothrix tenuissima Kützing	T_2; T_{17}; T_{30}; T_{38}; Nes_1; An_{10}
Ulothrix zonata (Weber *et* Mohr) Kützing	Crn_1; An_1; An_5; An_{10}; An_{14}
Order ***Chladophorales***	
Cladophora glomerata (L.) Kützing	T_2; T_3; T_4; T_5; T_6; T_7; T_9; T_{12}; T_{13}; T_{15}; T_{16}; T_{17}; T_{19}; T_{21}; T_{22}; T_{23}; T_{24}; T_{25}; T_{26}; T_{27}; T_{28}; T_{29}; T_{30}; T_{31}; T_{32}; T_{35}; T_{36}; T_{37}; T_{38}; T_{39}; S_1; Ti_1; Sov_1; Car_1; Ass_1; Soa_1; Top_2; Tim_1; $Clit_3$; Nes_1; Nes_2; Cai_1; Frs_1; N_1; N_2; N_3; N_5; Crn_1; Vig_1; Tr_1; Tr_2; Tr_3; Fa_1; Fa_2; Fa_3; An_1; An_2; An_3; An_4; An_6; An_7; An_8; An_9; An_{10}; An_{11}; An_{12}; An_{13}; An_{14}; An_{16}; An_{17}
Order ***Ulvales***	
Ulva flexuosa Wulfen	T_{39}; An_{17}
Order ***Zygnematales***	
Suborder Zygnematiinae	
Mougeotia sp.	T_{17}; An_6
Spirogyra communis (Hassall) Kützing	T_{18}; An_{10}; An_{12}
Spirogyra fluviatilis Hilse	T_{12}; T_{15}; T_{18}; T_{23}; Soa_1; Top_1; Nes_1
Spirogyra sp.1	T_2; T_3; T_4; T_6; T_7; T_8; T_9; T_{10}; T_{18}; T_{21}; T_{22}; T_{23}; T_{35}; T_{38}; Ti_1; Ass_1; Soa_1; $Clit_1$; Frs_1; N_1; N_3; N_5; Tr_4; Fa_2; Fa_4; Fa_5; An_1; An_2; An_6
Spirogyra sp.2	T_3; T_{23}; Soa_1
Zygnema sp.	Sov_1; Ass_1; Soa_1; Nes_1; Frs_1; Crn_1; Fa_2; An_{10}
Suborder Closteriineae	
Closterium closterioides (Ralfs) A. Louis *et* Peeters	T_7; Top_1
Closterium ehrenbergii Meneghini *ex* Ralfs	T_2; T_3; T_6; T_7; T_9; T_{19}; Sov_1; Car_1; Ass_1; $Clit_3$; N_1; Crn_1; Fa_2; An_{12}
Closterium kuetzingii Brébisson	T_{18}
Closterium praelongum var. *brevius* (Nordstedt) Willi Krieger	T_7
Suborder Desmidiineae	
Cosmarium bioculatum Brébisson *ex* Ralfs	T_{18}
Cosmarium botrytis Meneghinini *ex* Ralfs	T_2; T_7; N_5; Crn_1; An_{10}
Cosmarium granatum Brébisson *in* Ralfs	Nes_1
Cosmarium humile (F. Gay) Nordstedt *in* De Toni	An_{10}
Cosmarium impressulum Elfving	T_2; An_{10}; N_3
Cosmarium laeve Rabenhorst	T_3; T_{19}; T_{21}
Cosmarium meneghinii Brébisson *in* Ralfs	T_{21}; T_{23}
Cosmarium punctulatum Brébisson	T_{19}
Staurastrum dilatatum Ehr.	An_{10}
Order ***Charales***	
Chara sp.	T_7; T_{27}; Ass_1; Soa_1; Fa_4; An_{10}

Legend: T = Tiber River (upper section: T_1-T_5, middle section: T_6-T_{10}, lower section: T_{11}-T_{35}, mouth: T_{36}-T_{39}); An = Aniene River (upper section: An_1-An_7, middle section: An_8-An_{12}, lower section: An_{13}-An_{17}); N = Nera River; S = Singerna Stream; Ti = Tignana Stream; Sov = Sovara Stream; Cerf = Cerfone Stream; Car = Carpina Stream; Ass = Assino Stream; Soa = Soara Stream; Top = Topino River; Tim = Timia River; Clit = Clitunno River; Nes = Nestore River; Cai = Caina Stream; Frs = Fersinone Stream; Pug = Puglia Stream; Cmp = Campiano Stream; Crn = Corno Stream; Vig = Vigi River; Tr = Treia River; Fa = Farfa River.

glomerata occurred in 70 out of 97 investigated stations (80%) and was therefore the most widely distributed species in the Tiber basin. Other taxa (*Vaucheria geminata*, *Oedogonium* sp. and *Spirogyra* spp.,) were also widely distributed (Fig. 3). *Melosira varians*, *Cocconeis pediculus*, *Gomphonema olivaceum*, *Cyclotella meneghiniana*, *Fragilaria crotonensis*, *Leptolyngbya valderiana*, *Closterium ehrenbergii* and species of the genera *Oscillatoria* were also found frequently although they were not important in terms of biomass (Fig. 3).

Other taxa were found only in one watercourse of the basin. A total of 25 taxa, including 13 green algae and 6 cyanoprokaryotes, were found exclusively in the Tiber River. *Lyngbya aestuarii*, *Geitlerinema amphibia*, *Closteriopsis acicularis*, *Cosmarium humile*, *Scenedesmus obtusus*, *Desmodesmus serratus* and *Staurastrum dilatatum* were found only in the Aniene River. *Monoraphidium arcuatum*, *Cosmarium granatum* and *Pediastrum boryanum* var. *cornutum* were recorded only in the Nestore River, *Hantzschia amphioxys*, *Phacus* sp., *Diatoma mesodon* and *Synedra ulna* only in the Treia River, *Chamaesiphon confervicola* in the Vigi River, *Chroococcus turgidus* in the Nera River, *Phormidium formosum* in the Fersinone Stream, *Hapalosiphon fontinalis* in the Farfa River, *Trachelomonas hispida* in the Campiano Stream, and *Cymatopleura solea* in the Carpina Stream.

Variations in species richness were recorded along the longitudinal axis of the watercourses. In general diversity was highest in the middle sections and it decreased considerably in the terminal ones, especially in the case of the Tiber and Aniene Rivers (Table 2). In the Tiber River, 41 taxa were recorded in the upper section, among which *Audouinella hermannii* and *Cosmarium impressulum* were unique to that section. The middle section had the highest number of taxa (61), of which 26 (including 8 Chlorophyta and 17 Bacillariophyta) were found exclusively in that section. In the lower section, which flows in part through the city of Rome, fewer taxa were found, of which 16 (mostly represented by Chlorophyta) were exclusive to that section; floating masses composed mainly of *Spirogyra*, *Mougeotia*, *Microspora elegans*, *Chaetophora elegans, Oedogonium* and

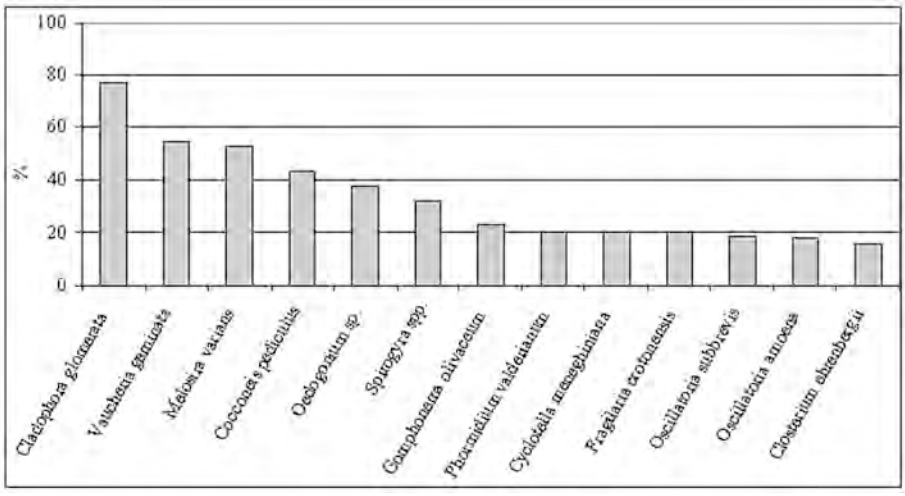

Fig. 3. Frequencies of the most common species in the Tiber River basin sampling stations (expressed as relative percentage of the number of stations where each species occurs).

Table 2. Species richness in the different sectors of the Tiber and Aniene Rivers

Tiber River	*Number of stations*	*Number of taxa*	***Aniene River***	*Number of stations*	*Number of taxa*
Upper sector	5	41	Upper sector	7	35
Middle sector	5	61	Middle sector	5	39
Lower sector	25	55	Lower sector	5	15
Mouth sector	4	17			

Lyngbya species were also observed frequently in that section. Towards the mouth of the river an ever-decreasing number of taxa was found; *Ulva flexuosa*, *Stigeoclonium tenue* and *Aphanizomenon* sp. only occurred in that section. In the Aniene River, we found 17 taxa (mainly Bacillariophyta) exclusively in the upper section, 19 taxa (primarily green algae, of which *Closteriopsis acicularis*, *Desmodesmus serratus*, *Scenedesmus obtusus*, *Cosmarium humile* and *Staurastrum dilatatum*, were unique floristic records for the entire basin), and 5 taxa exclusively in the terminal sector, the only section where *Ulva flexuosa* was recorded, analogous to the case of the Tiber River. Likewise, *Stigeoclonium tenue* was also recorded only in slow-flowing, warm and turbid waters of lower watercourse sections, whereas *Chamaesiphon incrustans* and *Lemanea fluviatilis* were found only in the upper sections of some watercourses with turbulent, fresh and clear waters.

DISCUSSION

Overall we found a relatively high species richness which varied along the river sections, with a higher diversity in the middle sections of the watercourses of the basin and a lower diversity in the upper sections. In the latter, lower diversity may be related to the presence of rapidly-flowing waters, rocky substrates and shaded riverbeds, which may represent unfavourable ecological conditions for the development of algal species. In river stretches subjected to human disturbance, a reduction in diversity and changes in the floristic composition were recorded, especially in many of the terminal sections of the river basin (where human impact is strongest), which showed the lowest recorded diversity and a greater spread of cosmopolitan, euriecious and synanthropic taxa. However, in the case of the Tiber River it is worth noting that in the section nearest the mouth there was an increase in diversity. We postulate that this may be linked to the proximity to the sea, which could permit the growth of halophile species.

Several taxa with a wide tolerance to environmental factors were recorded, including *Cladophora glomerata*, *Closterium ehrenbergii*, *Vaucheria geminata*, *Cyclotella meneghiniana*, *Melosira varians*, *Fragilaria crotonensis*, *Tabellaria flocculosa*, *Cocconeis pediculus*, *Gomphonema olivaceum* and *Oscillatoria limosa*, *O. subbrevis*, *Phormidium amoenum* and *Leptolyngbya*

valderiana. Cladophora glomerata is also able to tolerate high levels of eutrophication (Dodds & Gudder, 1992; AFNOR, 2003; Gutowski *et al*., 2004; Sand-Jensen *et al*., 2008), and its presence in high numbers indicates nutrient-rich waters.

Other species were present only under specific environmental conditions, being more sensitive to environmental variability along the different watercourses of the basin. In particular, *Chamaesiphon incrustans*, *Bangia atropurpurea*, *Lemanea fluviatilis*, *Ulothrix zonata* and *Closteriopsis acicularis* were found in fast-flowing, cool, well-oxygenated waters with scarce nutrients, even though there exists some disagreement on the trophic preferences of some of these species. For instance, *Bangia atropurpurea* has been considered to be typical of oligotrophic waters (Dell'Uomo, 1991; Gutowski *et al.*, 2004; Tardella *et al.*, 2009), although it has also been found in nutrient-rich waters (Sabater *et al.*, 1989). *Lemanea fluviatilis* has been reported as an oligotrophic water species (Rott *et al*., 1999) which is sensitive to eutrophication (Newman *et al*., 1997; AFNOR, 2003; Gutowski *et al.*, 2004), although it has also been found in waters subject to moderate pollution levels (Dell'Uomo, 1991). By contrast, *Phormidium breve*, *Pseudanabaena limnetica*, *Stigeoclonium tenue*, *Ulva flexuosa* and *Aphanizomenon* sp., were found mainly in slow-flowing, muddier, mineralized and nutrient-rich waters with lower oxygen levels in the lower and terminal stretches of the investigated rivers with highest levels of eutrophication, in accordance with available literature suggesting that these species are able to tolerate high eutrophication levels (Rosemond & Brawley, 1996; John *et al*., 2002; AFNOR, 2003; Gutowski *et al.*, 2004; Jurisic, 2004; Lougheed & Stevenson, 2004; Sand-Jensen *et al*., 2008).

In conclusion, our study provides a first contribution to the knowledge of the occurrence, diversity and distribution of algae in the Tiber River basin, revealing a diverse flora in the various watercourses and their sections. Species with well-defined ecological preferences, as mentioned above, appear to be of potential value as bioindicators. Further studies on the ecological preferences of these species will clarify if this is indeed the case.

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