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Diatoms from thermal-sulphur waters of "Fiume Caldo" (North-western Sicily)

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Abstract – The present study describes the taxonomic composition, richness and seasonal dynamics of the diatom community from thermal-sulphur waters of "Fiume Caldo" (North-western Sicily). The diatom flora of these waters consists of 64 taxa, showing similarities with thermal diatom communities from different geographical areas. Among the recorded taxa, *Diadesmis confervacea* Kütz. is a new record for Sicily. Seasonal changes in assemblage composition and richness have been recorded; the highest diversity values were observed during winter and spring, while during summer the diatom community consisted of a limited number of organisms whereas blue-green algae were quantitatively dominant. Inside the studied community several species showed a preference for certain substrata. Most diatom taxa were classified as alkaliphilous, β-mesosaprobic and eutraphentic according to their affinity for pH, saprobity and trophic state. Some taxa were considered very representative of this habitat and therefore been identified as the characteristic group of species for these waters.

Sicily / thermal-sulphur waters / diatoms / taxonomic composition / seasonal dynamics

Résumé — Diatomées des eaux thermales sulphurées du " Fiume Caldo " (Nord Ouest de la Sicile). La présente étude a permis de déterminer la composition taxonomique, la richesse spécifique et la variabilité saisonnière du peuplement diatomique des eaux thermales sulphurées du "Fiume Caldo" (Nord-ouest de la Sicile). La flore diatomique de ces eaux, comprenant 64 taxons, présente des similitudes avec les communautés diatomiques thermales d'autres zones géographiques. Parmi les taxons identifiés, *Diadesmis confervacea* Kütz. est signalé pour la première fois en Sicile. Des changements saisonniers dans la structure taxonomique et la richesse floristique sont observés ; les prélèvements d'hiver et du printemps présentent une plus grande richesse, alors que pendant l'été on observe une faible diversité taxonomique lorsque les cyanobactéries sont dominantes. Dans la communauté étudiée, diverses espèces montrent des préférences pour certain substrats. La majorité des taxons est classée comme alcaliphiles, β-mésosaprobiens et eutrophiques. Un petit groupe de taxons, significatif de cet environnement, est considéré comme le groupe spécifique caractéristique de ces eaux.

Sicile / eaux thermales sulphurées / diatomées / composition taxonomique / dynamiques saisonnières

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INTRODUCTION

Diatom assemblages of Sicilian rivers have been poorly studied, with the available data dealing mostly with phytoplankton communities in lakes or artificial basins (e.g. Calvo *et al.*, 1993; Naselli Flores & Barone, 1998; Naselli Flores & Barone, 2002). Recently, an investigation into the algal communities of some rivers of North-western Sicily was undertaken to extend and update knowledge, especially with reference to benthic diatoms, which are strongly influenced by ecological features of the habitat and therefore may be considered good ecological indicators (Mannino, 2001, 2002).

In particular, a study on the algal community from the thermal-sulphur waters of "Fiume Caldo" (in the area of Trapani, North-western Sicily) (Fig. 1) was undertaken. Thermal springs, aquatic ecosystems characterized by extreme pH, temperature and salinity values, are widespread in Sicily, where Romans, and after them Arabs, left numerous and impressive reminders of their love for thermal waters. In Sicily approximately 16 thermal springs (Carapezza *et al.,* 1987), some of which are now completely exhausted (e.g. the thermal spring inside the Natural Reserve of "Bagni di Cefalà Diana e Chiarastella" – in the area of Palermo, North-western Sicily), are present (Fig. 2).

These thermal waters, whose extreme environmental conditions lead to specific algal assemblages, have been studied almost exclusively from a geochemical and hydrogeological point of view and data on the algal communities are poor (Tomaselli Feroci & Balloni, 1976; Pinto & Taddei, 1978; Bambina, 1994; Mannino, 2002).

Therefore, the aim of this study is to characterize, taxonomically and ecologically, the diatom community colonizing this much stressed and selective environment, and to examine its seasonal dynamics. In addition, the relationship between environmental factors and taxonomic composition was analysed. Furthermore, a comparison with floristic lists concerning thermal systems of different geographical areas has been made in order to establish the degree to which they are similar.

Fig. 1. A view of the study site.

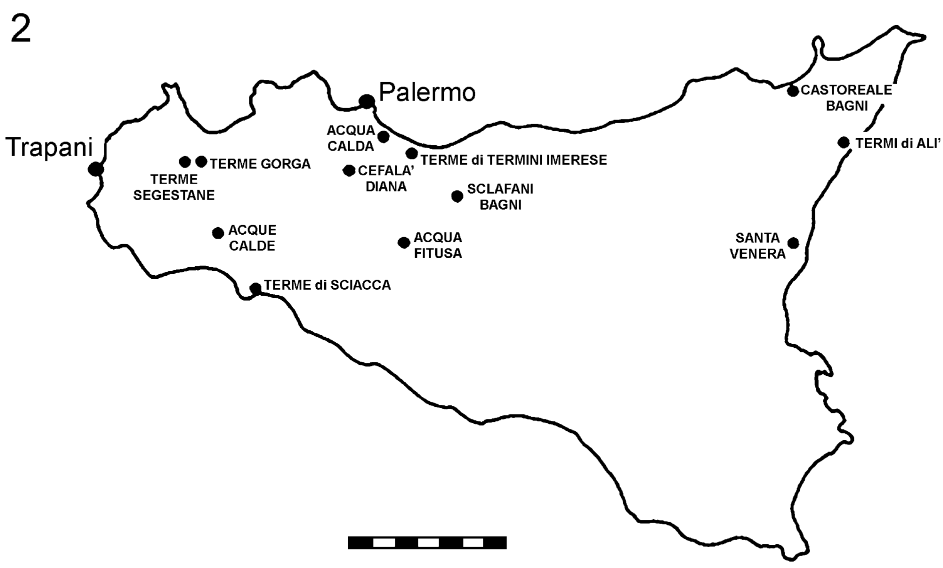


Fig. 2. Map showing the location of the principal Sicilian springs. Scale = 50 km.

MATERIALS AND METHODS

Study site

The "Fiume Caldo", located in the North-west of Sicily, represents the lower section of the Kàggera river (the ancient Krimisos) originating south of Calatafimi (in the area of Trapani). The hydrographic basin of the "Fiume Kàggera" crosses the territory of Segesta-Calatafimi and before flowing into the San Bartolomeo River (in the area of Alcamo) is called "Fiume Caldo" (i.e. *Hot River*) due to the presence of thermal-sulphur springs.

Five springs are present, located on both the left and right banks of the "Fiume Caldo", close to a small thermal establishment called "Terme di Segesta". The therapeutic purposes of thermal waters have been well documented since the 5^{th} century BC; the Arab geographer al-Idrisi (12^{th} century AD), who settled in Sicily at the court of Roger II, described the waters of these springs as "restoring". The bottom of this river is covered with stones and mud. On some stones there is a greenish-brown coating of diatoms, on other stones there are extensive, thick, dark blue felts of blue-green algae. Tufts of green algae (*Cladophora glomerata* (L.) Kütz. and *Oedogonium* sp.) were also found attached to the stones. Furthermore, the characteristic smell of Hydrogen sulphide (H_2S) was also present.

Sampling

Sampling was carried out seasonally for 2001 in order to record the occurrence of differences in community composition. Diatoms were sampled (see Kelly *et al*., 1998; Dell'Uomo, 2004) from stones by brushing the surface with a toothbrush, with at least five replicates taken; pebble-to-cobble (5-15 cm) sized stones were randomly chosen for sampling.

Epiphytic samples were taken by squeezing macroalgae. All samples were preserved in 4% formalin solution, and digested in 30% H_2O_2 overnight to remove organic matter by oxidation. Cleaned valves were either mounted in Naphrax® or onto aluminium stubs for SEM observations. Three replicate slides or stubs of each sample were prepared. Species were identified using Krammer & Lange-Bertalot (1986-1991) and Round *et al.* (1990).

A floristic list was produced and arranged in such a way that different groups are easily recognizable (Table 1). That is, groups present throughout the year, groups present during some seasons or a particular season, and so on. For each taxon, abundance was estimated. Furthermore, some

Table 1. List of taxa recorded in the present work and some ecological indicator values (**H** = Salinity; **S** = Saprobity; **T** = Trophic state; **M** = Moisture). **Sp** = Spring; **Su** = Summer; **Au** = Autumn; **Wi** = Winter; **R** = Rare; **S** = Scarce; **C** = Common; **VC** = Very Common; **A** = Abundant; • = missing value; * = in common with other thermal systems.

Diatoms	*Sp*	*Su*	*Au*	*Wi*	*H*	*pH*	*S*	*T*	*M*
Amphora pediculus (Kützing) Grunow	VC	VC	VC	VC	2	4	2	5	3
Caloneis bacillum (Grunow) Cleve *	S	S	S	S	2	4	2	4	2
Cocconeis placentula Ehrenberg *	VC	VC	VC	VC	2	4	2	5	2
Cocconeis placentula var. *euglypta* Ehrenberg	C	S	S	S	2	4	2	5	2
Gomphonema gracile Ehrenberg *	C	S	C	C	2	3	1	3	3
Gomphonema minutum (Agardh) Agardh	VC	VC	VC	VC	2	3	2	5	•
Gomphonema parvulum Kützing *	S	S	C	C	2	3	4	5	3
Navicula cryptotenella Lange-Bertalot	VC	VC	VC	VC	2	4	2	7	2
Navicula gregaria Donkin *	R	R	R	S	3	4	3	5	3
Navicula subhamulata Grunow	R	R	R	R	2	3	1	4	3
Navicula tripunctata (O.F. Müller) Bory	VC	VC	VC	VC	2	4	2	5	3
Nitzschia amphibia Grunow *	VC	VC	VC	VC	2	4	3	5	3
Nitzschia clausii Hantzsch	S	S	S	S	4	4	3	5	3
Nitzschia commutata Grunow	C	S	C	C	4	•	•	•	•
Nitzschia fonticola Grunow *	C	S	C	C	2	4	2	4	1
Nitzschia inconspicua Grunow	S	S	S	C	3	4	3	5	3
Rhoicosphenia abbreviate (C. Agardh) Lange-Bertalot*	VC	VC	VC	VC	2	4	2	5	2
Achnanthes exigua Grunow	S	S	S	–	2	4	2	7	3
Diploneis oblongella (Naegeli) Cleve-Euler	C	C	C	–	2	4	1	•	4
Fragilaria sp. 1	S	S	S	–					
Nitzschia frustulum (Kützing) Grunow *	C	S	C	–	3	4	2	5	3
Cocconeis neodiminuta Krammer	R	R	–	R	2	•	•	•	•
Gomphonema olivaceum (Hornemann) Brébisson*	S	S	–	S	2	5	2	5	1
Nitzschia dissipata (Kützing) Grunow	C	S	–	C	2	4	2	4	3
Planothidium lanceolatum (Brébisson *ex* Kützing) Round *et* Bukhtiyarova *	S	R	–	S	2	4	3	5	3
Surirella ovalis Brébisson *	R	R	–	R	4	4	3	5	3
Achnanthes minutissima Kützing *	C	–	C	C	2	3	2	7	3

Table 1. *(continued)* List of taxa recorded in the present work and some ecological indicator values (**H** = Salinity; **S** = Saprobity; **T** = Trophic state; **M** = Moisture). **Sp** = Spring; **Su** = Summer; **Au** = Autumn; **Wi** = Winter; **R** = Rare; **S** = Scarce; **C** = Common; **VC** = Very Common; **A** = Abundant; • = missing value; * = in common with other thermal systems.

Diatoms	*Sp*	*Su*	*Au*	*Wi*	*H*	*pH*	*S*	*T*	*M*
Amphora veneta Kützing	S	–	S	S	3	5	4	5	3
Diploneis ovalis (Hilse) Cleve *	S	–	C	C	2	4	1	•	4
Fragilaria construens (Ehrenberg) Grunow var. *binodis* (Ehrenberg) Grunow	S	–	S	S	2	4	1	4	2
Gomphonema angustum Agardh	S	–	S	S	2	4	1	1	•
Gyrosigma attenuatum (Kützing) Rabenhorst	R	–	R	R	2	5	2	5	1
Nitzschia hungarica Grunow *	R	–	R	R	3	4	3	5	1
Nitzschia sigma (Kützing) W. Smith *	S	–	S	S	4	4	3	5	2
Nitzschia constricta (Kützing) Ralfs	–	R	R	R	4	4	3	5	2
Nitzschia levidensis (W. Smith) Grunow	S	S	–	–	3	4	3	5	1
Nitzschia palea (Kützing) W. Smith *	–	R	R	–	2	3	5	6	3
Achnanthes brevipes Agardh var. *intermedia* (Kützing) Cleve *	S	–	S	–	•	•	•	•	•
Amphora libyca Ehrenberg	S	–	–	S	2	4	2	5	1
Cymatopleura elliptica (Brébisson) W. Smith	R	–	–	R	3	4	2	5	1
Cymbella leptoceros (Ehrenberg) Kützing	S	–	–	S	1	4	1	1	3
Cymbella minuta Hilse	S	–	–	S	2	3	•	•	•
Cymbella silesiaca Bleisch	S	–	–	S	2	3	3	7	1
Cymbella tumida (Brébisson) Van Heurck	S	–	–	S	2	4	1	4	1
Cymbella tumidula Grunow	S	–	–	S	2	4	1	•	3
Diploneis marginestriata Hustedt	S	–	–	S	1	•	1	•	•
Fragilaria capucina var. *capitellata* Grunow Lange-Bertalot sensu lato	S	–	–	S	2	3	3	5	5
Fragilaria pulchella (Ralfs) Lange-Bertalot	S	–	–	S	•	•	3	5	3
Fragilaria ulna (Nitzsch) Lange-Bertalot *	S	–	–	S	2	4	4	7	2
Gomphonema parvulum var. *exilissimum* Grunow	S	–	–	S	1	3	1	1	•
Navicula capitata Ehrenberg var. *hungarica* (Grunow) Ross	S	–	–	S	2	4	2	4	3
Navicula cincta (Ehrenberg) Ralfs	S	–	–	S	2	4	3	5	4
Navicula pygmaea Kützing	R	–	–	R	3	5	3	5	2
Nitzschia graciliformis Lange-Bertalot *et* Simonsen	S	–	–	S	2	4	2	5	•
Stauroneis smithii Grunow	S	–	–	S	2	4	2	7	3
Surirella angusta Kützing	S	–	–	S	2	4	2	5	3
Surirella brebissonii Krammer *et* Lange-Bertalot	S	–	–	S	3	4	•	•	•
Cyclotella meneghiana Kützing	R	–	–	–	3	4	4	5	2
Eucocconeis flexella (Kützing) Cleve	R	–	–	–	1	3	1	1	3
Fragilaria sp. 2	S	–	–	–					
Gomphonema sp. 1	R	–	–	–					
Melosira varians Agardh *	R	–	–	–	2	4	3	5	2
Diadesmis confervacea Kützing	–	A	–	–	3	3	3	5	3
Rhopalodia gibberula (Ehrenberg) O.F. Müller	–	–	R	–	3	4	•	•	3

Table 2. Ecological indicator values (from Van Dam *et al.*, 1994 modified).

	pH		*Saprobity*
1	acidobiontic	1	oligosaprobous
2	acidophilous	2	β-mesosaprobous
3	circumneutral	3	α-mesosaprobous
4	alkaliphilous	4	α -meso-/polysaprobous
5	alkalibiontic	5	polysaprobous
6	indifferent		
	Trophic state		*Salinity*
1	oligotraphentic	1	fresh < 0.2 ‰
2	oligo-mesotraphentic	2	fresh brackish < 0.9 ‰
3	mesotraphentic	3	brackish fresh 0.9-1.8 ‰
4	meso-eutraphentic	4	brackish 1.8-9.0 ‰
5	eutraphentic		
6	hypereutraphentic		
7	oligo- to eutraphentic		
	Moisture		
1	never, or only very rarely, occurring outside water bodies		
2	mainly occurring in water bodies, sometimes on wet places		
3	mainly occurring in water bodies, also rather regularly on wet and moist places		
4	mainly occurring on wet and moist or temporarily dry places		
5	nearly exclusively occurring outside water bodies		

Table 3. Main characteristics of thermal-sulphur waters (data from ARPA, Sicily).

Characteristics	*27/07/01*	*17/08/01*	*29/10/01*	*18/12/01*	*26/03/02*
Conductivity (µS/cm^{-1})	2610	2520	2260	2064	2040
Carbonate hardness (mg/l^{-1})	1212	1003	1026	932,6	989
Dissolved oxygen (mg/l^{-1})	8,17	7,36	6,1	8,79	7,85
Cl^- (mg/l^{-1})	556	495,7	442	222,2	266,1
SO_4^{--} (mg/l^{-1})	601	610,5	637,4	595,6	639,7

ecological indicator values, such as pH, salinity, saprobity, trophic state and moisture were recorded for each taxon (for the coded keys see Table 2), assigned according to the scheme in Van Dam *et al.* (1994). Water temperature (from 30°C to 38°C) and pH (7.5) were measured *in situ*. Other parameters were provided by ARPA, Sicily: Conductivity, Carbonate hardness, Dissolved O_2, Cl^- and SO_4^{--} (Table 3).

RESULTS AND DISCUSSION

In all, 64 taxa were recognised, representing 21 genera in 17 families and 10 orders (Table 1). *Diadesmis confervacea* Kütz. (Figs 3-4) is a new record for Sicily, the second for the Italian Peninsula (Granetti, 1984). Approximately 50% of the taxa have been noted from Sicilian running waters (Mannino, 2001). Comparison with thermal diatom communities from different geographic areas (Andreoli & Rascio, 1975; Economou-Amilli, 1976; Reháková, 1976; Dell'Uomo, 1986; Villeneuve & Pienitz, 1998) indicated a 31% level of similarity (taxa shared with other thermal systems are marked with an asterisk in Table 1).

The highest number of species per genus was found in *Cymbella* C. Agardh, *Fragilaria* Lyngb., *Gomphonema* Ehrenb., *Navicula* Bory and *Nitzschia* Hass. The most abundant species, in decreasing order, were *Amphora pediculus* (Kütz.) Grun., *Cocconeis placentula* Ehrenb., *Gomphonema minutum* (C. Agardh) C. Agardh, *Navicula cryptotenella* Lange-Bertalot, *Navicula tripunctata* (O.F. Müll.) Bory, *Nitzschia amphibia* Grun., *Rhoicosphenia abbreviate* (C. Agardh) Lange-Bertalot, *Gomphonema gracile* Ehrenb. and *Nitzschia commutata* Grun. (Figs 5-8).

Diadesmis confervacea, recorded exclusively during summer, was particularly abundant, forming very long and persistent chains (Fig. 3).

Diadesmis confervacea, characteristic of thermal waters of tropical and subtropical areas as well as waters rich in organic matter, may be considered a good indicator of hot water in temperate regions (Coste & Ricard, 1990; Coste & Ector, 2000).

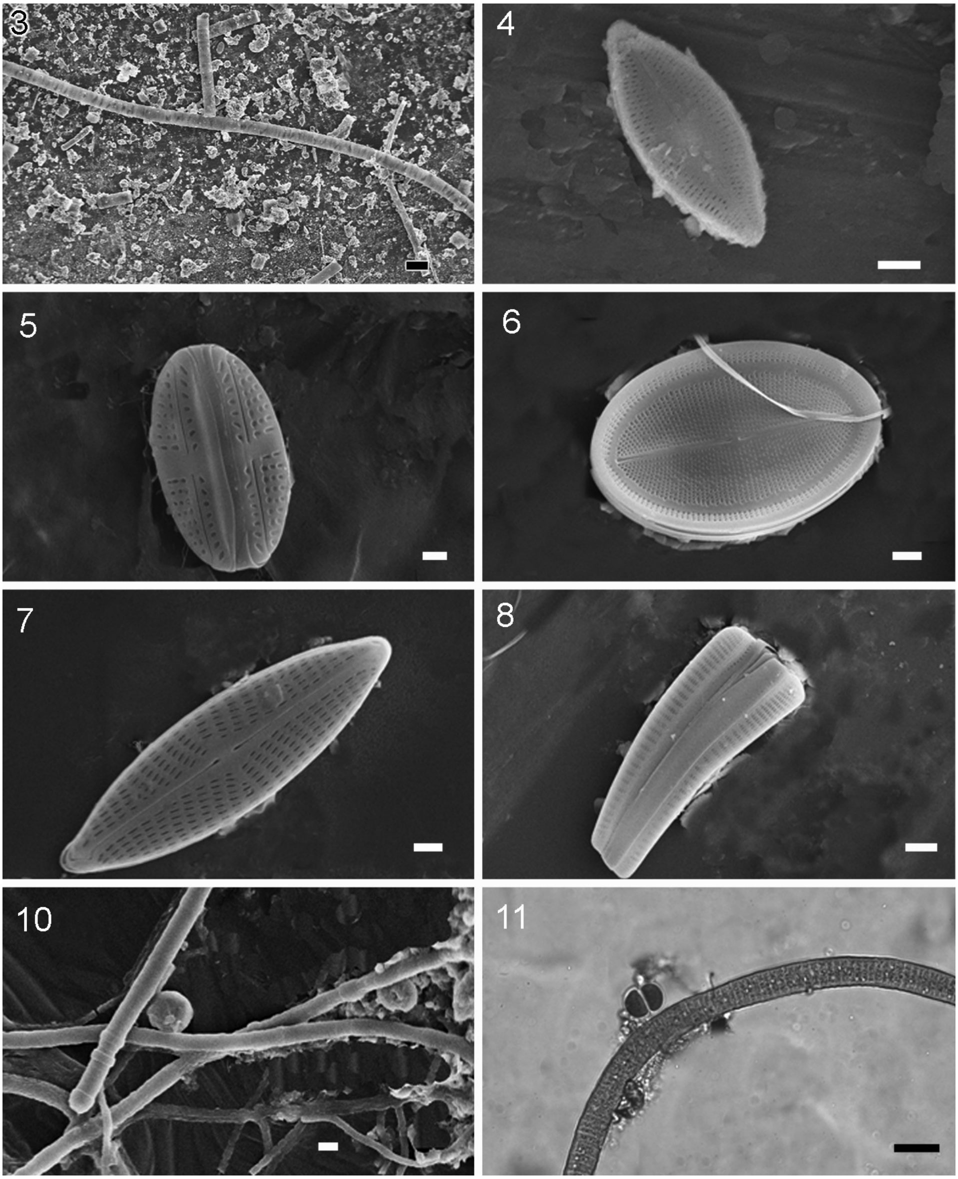
Only two species belonging to the Centrales were noted, *Melosira varians* C. Agardh and *Cyclotella meneghiana* Kütz., both recorded exclusively during the spring.

Several species showed a preference for particular substrata. *Gomphonema parvulum* Kütz., *Achnanthes minutissima* Kütz. and *Planothidium lanceolatum* (Bréb. *ex* Kütz.) Round *et* Bukhtiyarova were confined to stone surfaces, the latter two species being found epiphytically on macroalgal surfaces.

Species belonging to the genera *Gomphonema* and *Rhoicosphenia* Grun. (forming jelly stalk-like structures for attachment), *Achnanthes* Bory and *Cocconeis* Ehrenb. (with whole frustules attached by the secretion of jelly) had the highest specificity for macroalgal surfaces, particularly *Cocconeis placentula* and *Rhoicosphenia abbreviate*, both found on *Cladophora* thalli. Most of the identified taxa (72.5%) are directly linked to the aquatic environment, and wet and moist places.

The results indicate a seasonal variation for taxon abundance, rapidly increasing from the summer (30) to spring, when a maximum of 60 taxa were recorded (Fig. 9). In summer when the lowest number of taxa was recorded, the qualitative and quantitative dominance of blue-green algae was observed (Figs 10-11).

The frequency of taxa occurring exclusively in one season is very low: 8% in spring, 1.5% in summer and in autumn, with none occurring exclusively in the winter season. *Diadesmis confervacea* is a typical summer species. All these occurrences are significantly lower than those occurring throughout the year (26.5%); indeed, 17 taxa occurred regularly in all seasons. Therefore a significant number of species can withstand a wide range of temperature and can be considered "eurytherms". Among them, the highest occurrence (52%) was recorded for species in the genera *Nitzschia* and *Navicula.* The high frequency of



Figs 3-8; 10-11. **3-4**. *Diadesmis confervacea* Kütz. **3.** SEM of girdle view of colony. Scale = 30 µm. **4.** SEM of external view of valve face. Scale = 3 µm. **5**. *Amphora pediculus* (Kütz.) Grun.: SEM of girdle view of valve. Scale = 1 µm. **6**. *Cocconeis placentula* Ehrenb.: SEM of external view valve face. Scale = 3 µm. **7**. *Navicula cryptotenella* Lange-Bertalot: SEM of external view of valve face. Scale = 1 µm. **8**. *Rhoicosphenia abbreviate* (C. Agardh) Lange-Bertalot: SEM of girdle view of the entire valve. Scale = 3 µm. **10-11**. Coccoid and filamentous blue-green algae. **10.** SEM. Scale = 3 µm. **11.** Light micrograph. Scale = 20 µm.

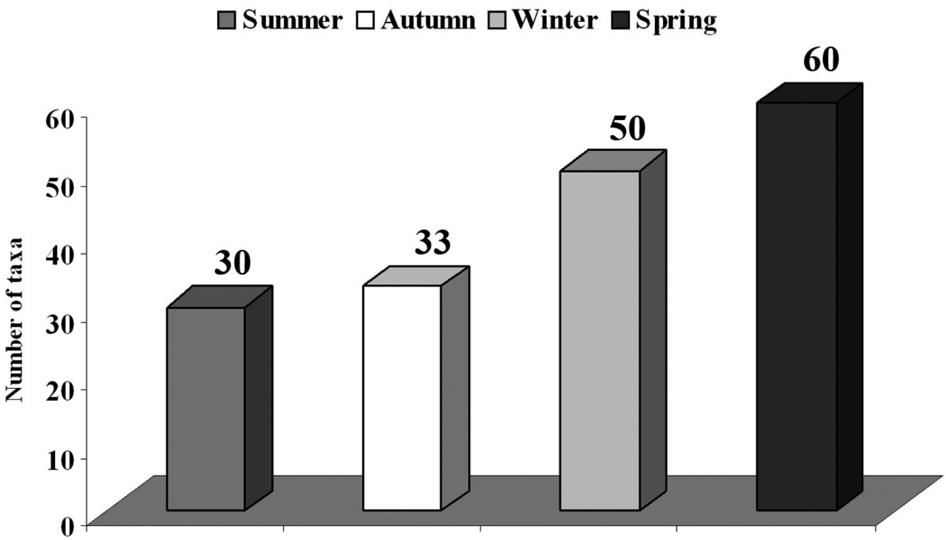


Fig. 9. Graph of seasonal variation throughout the study period, relative to the number of taxa.

eurythermic taxa is not peculiar for this area but common to other Mediterranean thermal habitats (Dell'Uomo, 1986).

According to Van Dam *et al.* (1994), the pH-spectrum of the taxa recognised in this study indicates that alkaliphilous predominate (62.5%), with just a few circumneutral (19%). These data agree with pH values found in these waters (7.5). In relation to pH, significant similarities with thermal habitats from different geographic areas (Economou-Amilli, 1976; Reháková, 1976; Dell'Uomo, 1986) can be noted, where a high frequency of alkaliphilous taxa together with low frequency of species typical of acid waters was recorded.

Using Van Dam *et al.* (1994), 33% of the taxa are β-mesosaprobous, followed by 25% α-mesosaprobous. The predominance of β-mesosaprobous taxa agrees with other studies (Economou-Amilli, 1976; Dell'Uomo, 1986). Furthermore, a good percentage of taxa are considered either good or excellent indicators of pollution (Dell'Uomo, 2004), most belonging to the genera *Navicula* and *Nitzschia* (e.g. *Navicula gregaria* Donk., *Nitzschia palea* (Kütz.) W. Smith and *Nitzschia amphibia*). This indicates a moderate nutrient input of human origin (recreational activities and pastures). The classification of trophic state (following Van Dam *et al.*, 1994) is as follows: the majority of the taxa are eutraphentic (50%), followed by 11% meso-eutraphentic. The saprobic level and the trophic state are well correlated. Several eutraphentic taxa, particularly those in the genera *Amphora* Ehrenb. *ex* Kütz., *Gomphonema*, *Navicula* and *Nitzschia*, were frequent and often abundant in the samples.

For salinity preferences (Van Dam *et al.*, 1994), just over half (59%) are fresh brackish (< 0.9‰), followed by 19% brackish fresh (0.9-1.8‰). Thus the identified taxa can be classified as oligohalobic indifferent or halophilic (Kolbe, 1927, 1932). Salinity, together with conductivity and pH, are recognised as important variables in determining taxon distribution.

Species such as *Amphora pediculus*, *Nitzschia amphibia*, *Nitzschia hungarica* Grun. and *Surirella ovalis* Bréb. seem to prefer alkaline waters with high conductivity (Almeida & Gil, 2001).

CONCLUSIONS

Diatoms were found to be the most important component of the microflora for the site that was studied. They are quantitatively less represented than blue-green algae (particularly in summer season), nevertheless provide more information and allow the characterization of the habitat due to their qualitative richness and sensitivity to the variations in the chemical and physical properties of the environment (e.g. pH, salinity, temperature, etc.).

Altogether 64 taxa were recognised, among which a high frequency of pennate diatoms (the majority belonging to Naviculoid and Nitzschoid groups) were observed. The dominance of Pennales together with the low occurrence of Centrales may be due to shallow waters, not favourable to planktonic forms. The movement of water could have influenced assemblage composition, favouring forms that can attach themselves by a gelatinous mass or stalks. The absence or low presence of centric diatoms was already noted for thermal waters (Villeneuve & Pienitz, 1998).

Seasonal trends in taxonomic composition and richness were observed, particularly that the number of taxa rapidly increases from summer (30) to spring when a maximum of 60 taxa was recorded. Temperature seems to significantly affect the assemblage composition, indeed a half of the taxa recorded in spring are completely absent in summer, when the highest values of temperature were reached. Seasonal variations could be affected also by two different habitats (substrata); epiphytic community is probably more responsible for changes in species composition than the epilithic one (more stable) because of the firmness of stony substrata (Soininen & Eloranta, 2004). Moreover, the shift from very rapid colonizers (e.g. many *Achnanthes* species) or very persistent species but poor competitors, to species competing well under stressing condition, could be also responsible for seasonal changes in assemblage composition (McCormick & Stevenson, 1991).

Diadesmis confervacea, a new record for Sicily, is characteristic of thermal waters; it has been recorded exclusively during summer when it was abundant. The long and persistent chains, joined by mucilage excreted through the raphe, are maintained by overlapping of marginal linking spines (Rosowski, 1980). The high frequency of alkaliphilous (62.5%) indicates a clearly basic habitat. The β-mesosaprobic (33%) show the highest frequency, indicating a moderate nutrient input in this river; the occurrence of species common of polluted rivers, such as *Nitzschia palea*, *Nitzschia amphibia* and *Fragilaria ulna* (Nitz.) Lange-Bertalot, was also noted.

Some taxa (*Amphora pediculus*, *Cocconeis placentula*, *Gomphonema minutum*, *Navicula cryptotenella*, *Navicula tripunctata, Nitzschia amphibia* and *Rhoicosphenia abbreviate*) are abundant and dominant in the material, their ecological preferences correspond to the characteristics of this habitat, and thus this group can be considered representative of the study site.

This survey has characterized both taxonomically and ecologically the diatom community colonizing these waters, showing some significant similarities with thermal diatom communities from different geographic areas. This may indicate that there exists a group of species possessing the ability to adapt well to environmental condition of thermal waters. These results provide new data on this stressed and selective environment. In addition, they indicate a relationship between environmental factors and taxonomic composition of the diatom community, highlighting the effectiveness of using diatoms to characterize habitats ecologically.

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