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RESEARCH ARTICLE

Multi-scale biodiverity patterns in phytoplankton from coastal lagoons: the Eastern Mediterranean

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Abstract

1 - The phytoplankton from Eastern Mediterranean coastal lagoons is analysed using a multi-scale approach, with the aim of testing if phytoplankton variations follow a hierarchical scheme based on eco-geographical location. The scale similarity is examined by using a taxonomic metric based on the Kullback-Leibler divergence and a related similarity index.

2 - A hierarchical sampling design was used to investigate variations in taxonomic composition and richness of phytoplankton assemblages. Data analyzed collected during summer season in 3 coastal lagoons in the Mediterranean Eco-region: two are located in Turkey (Akgöl and Paradeniz) and one is located in Greece (Korission). According to the Mediterranean typology, all lagoons are large, non-tidal and have mean salinity regimes of oligohaline (Akgöl), polyhaline (Paradeniz) and euhaline (Korission) designations.

3 - The taxonomic composition of phytoplankton assemblages varied markedly among lagoons, with the most representative phytoplankton in terms of taxa richness belonged to Chlorophyceae (33.33%) in Akgöl, to Dinophyceae (50.00%) in Paradeniz and to Dinophyceae (30.77%) in Korission.

4 - Within-habitat similarity was very high in all habitats and lagoons. At an ecosystem scale, phytoplankton was highly homogeneous in Akgöl and Paradeniz, suggesting that the distinctive physiognomic traits of the habitats exert a limited effect. In contrast, the phytoplankton is significantly heterogeneous in Korission, mostly because of the effect of the heterogeneous habitats, in fact the three sampled habitats showed well-differentiated characteristics.

5 - At an eco-regional scale, the pattern of similarity among lagoons suggests that local conditions (particularly salinity) and geographical location play roles of a comparable importance in determining the dissimilarity among phytoplankton guilds.

6 - The similarity index between adjacent lagoons having different salinity (Akgöl and Paradeniz) was comparable to the one between lagoons with similar salinity but different geographical location. This suggests that local conditions and geographical factors act in a complex way.

Keywords: phytoplankton, taxonomy, multi-scale approach, biodiversity, coastal lagoons, Mediterranean Eco-region.

Introduction

Biologists have studied large-scale biodiversity gradients in macro-organisms (Rosenzweig, 1995; Gaston, 2000; Willig *et al.*, 2003), resulting in many insights on the biogeographical variation of species richness. Microorganisms with their smaller size, high abundance, fasts population growth and long-range dispersal show only weak geographical variation in diversity compared to macro organisms (Stomp *et al.*, 2011; Fenchel and Finlay, 2004; Hillebrand, 2004). Recent studies indicate that spatial diversity patterns do exist for microorganisms (Martiny *et al.*, 2006). Relatively few studies have quantified spatial diversity gradients of entire phytoplankton communities (Irigoien *et al.*, 2004; Vadrucci *et al.*, 2008; Roselli *et al.*, 2009; Vadrucci *et al.*, 2009; Ptacnik *et al.*, 2010), although diversity patterns of specific taxonomic groups, such as diatoms, as well as of size spectra or size class have been studied in more detail (see Vyverman *et al.*, 2007; Passy, 2008, 2010; Cermeño and Falkowski, 2009; Soininen *et al.*, 2009; Wang *et al.*, 2011; Sabetta *et al.*, 2005, 2008a, 2008b, for diatom and size spectra patterns, respectively). Geographical variation in environmental factors affecting phytoplankton species coexistence at local scale, was implicated as a major determinant of large scale patterns in phytoplankton diversity (Stomp *et al.*, 2011). Recently, numerous studies on large-scale biodiversity patterns have provided many new insights, but a comprehensive understanding of the relative importance of different environmental drivers of phytoplankton diversity across large spatial scales is still lacking (Stomp *et al.*, 2011). To further the understanding of the fundamental mechanisms underlying the formation of diversity patterns in phytoplankton, the use of multi-scale approaches seems to be crucial (Borcard *et al.*, 2004; Irigoien *et al.*, 2004; Stomp *et al.*, 2011). Variability patterns of the environmental niche in transitional water ecosystems determine the biodiversity architecture at ecosystem and eco-regional scales, was recently addressed (Basset *et al.*, 2013). A first exploratory step could be done by examining the variation in the similarity between species assemblages as a function of spatial and ecological scales, in order to test whether phytoplankton variability follow a hierarchical scheme based on ecological or geographical location. The analysis of similarity at a habitat scale could be also useful to identify a “baseline” of variability within any Whittaker’s nomenclature - Whittaker, 1972). The analysis of similarity at ecosystem scale (or among different habitats) is useful to characterise the variability along environmental gradients (or the “beta diversity”), and, possibly, to identify the main local drivers and their impact on phytoplankton. The analysis of similarity among different ecosystems allows to characterize the variability at a regional scale. The examination of the whole pattern of scale similarity, also in comparison with other regional data, should help to evaluate the relative importance of local and large scale.

By following the above conceptual scheme, the present study examines a part of the data set collected in a large scale survey designed for investigating the patterns of eco-regions (the POR Strategic Project). The present study focuses on the Mediterranean Eco-Region, where two lagoons located in Turkey (Akgöl and Paradeniz) and one lagoon located in Greece (Korission) were selected and investigated by following a hierarchical approach. According to Mediterranean lagoon typology (Basset *et al.*, 2006) all lagoons pertain to non-tidal and large types, being Akgöl oligohaline while Paradeniz polyhaline and Korission euhaline, considering the mean salinity values. Here, we have used taxonomic similarity metrics between pairs of phytoplankton guilds as a proxy for the analysis of biodiversity crossscale components in phytoplankton guilds of the Mediterranean Eco-region.

The scale similarity was examined by using a taxonomic metric based on information theory (the Kullback-Leibler divergence; Kullback, 1959) and a related index of similarity (Ludovisi and Taticchi, 2006). Since the Kullback-Leibler measures are closely connected with thermodynamics (Ludovisi, 2009; Ludovisi and Jørgensen, 2009; Jørgensen *et al.*, 2010; Ludovisi *et al.*, 2012), the use of these measures is advantageous, because they allow us to frame the analysis of biodiversity patterns within a broader ecological context.

Material and methods

Study area

The lagoons are located in the Eastern Mediterranean area (Fig. 1).

Akgöl and Paradeniz are adjacent lagoons belonging to the Göksu Delta (Turkey) and cover an area of 13 km^2. Akgöl (8.2 km^2) has slightly salty and briny water characteristic (Ayas and Kolankaya, 1996). Akgöl is 0.5–1.0 meter deep and it is connected by a channel to Paradeniz lagoon. With a maximum depth of 1.5 meters, Paradeniz Lagoon (5 km^2) is constantly linked to the sea via a canal. Paradeniz Lagoon is situated in Silifke town by Mersin Bay. It is a oligohaline lagoon connected with the sea and located west of the Göksu River. Akgöl is located further west point of the same river. Surrounding the Akgöl lagoon are agriculture fields with hazelnut, maize, wheat, sugar beet, tobacco and fruit trees (Keçer *et al.*, 2007; Mutlu *et al.*, 2011). The salinity level decreases to the north where freshwater flows into the system. The salinity of Akgöl is as low as that of freshwater and is covered with dense reed beds. Both of these lagoon systems were formed as a result of bed displacements of the Göksu River and sea movements. In recent decades, the hydrology of the delta was transformed by agricultural development (Demirel *et al.*, 2011). Akgöl was used as a semi-permanent basin with no connection to the sea. Drainage water from fields to the north of the lagoon runs into Akgöl, which is

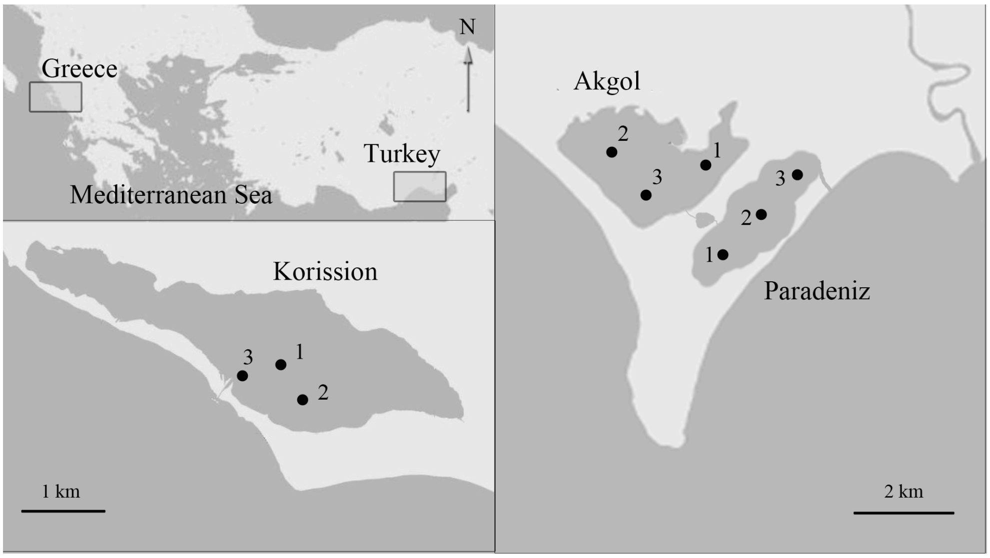

Figure 1. Map showing the investigated Mediterranean Eco-region with the sampled coastal lagoons: Korission in Greece, Akgöl and Paradeniz in Turkey. Numbers represent the three habitat typology sampled for each ecosystem.

connected with Paradeniz lagoon, the latter being connected to the sea. As a result, Akgöl now has a permanently densely vegetated shoreline with surrounding this fresh to brackish eutrophic lake were water levels peak in summer. Paradeniz, on the other hand, is an open, saline lagoon with very little vegetation. The Korission lagoon, located in the south-western Corfu Island (Greece), is a shallow coastal lagoon with a maximum depth of about 2 m. The area is included in the Natura 2000 network of protected areas and the wetland occupies 20 km^2 (Diamantopouloua *et al.*, 2008) while the lagoon surface reaches approximately 5 km^2 lying parallel to the coastline with NW-SE direction. The lagoon is connected to the sea by an artificial channel and its depth varies between 0.5 and 1.2 m. During summer salinity can exceeds 50 and surface temperature can reach 23.6–26.1°C, while DO values range between 75–100% of saturation. On the other hand, in winter salinity falls to about 19, surface temperature is 13.5–16.2°C and DO varies between 91 and 115% of saturation. Salt water intrusion occurs only to wells adjacent to the lagoon (Diamantopouloua *et al.*, 2008). The lagoon bottom is covered by sea grass, an ideal food source for fish and contains large amounts of shell fish and crabs. North-western Greece is one of the rainiest areas of the country in autumn and winter, but in summer it is dry in summer.

Sampling design

The hierarchical sampling design follows the criteria adopted in a large scale survey, which is currently in progress in various worldwide eco-regions (POR Strategic Project) (see, Durante *et al.*, 2013; Souza *et al.*, 2013; Stanca *et al.*, 2013a; Stanca *et al.*, 2013b, for other world eco-regions). In each of the five eco-regions three lagoons were selected. In each of them, a maximum of three categories of habitat were selected and, in each of them, three stations were sampled with three replicates (for further information website: http://phytobioimaging.unisalento.it/en-us/studysites/samplingdesign.aspx).

The selection of the habitat types was performed on the basis of sediment granulometry and type of bottom vegetation, according to Roff and Taylor (2000). In each lagoon, phytoplankton samples were collected in a single sampling survey carried out in May 2011 (Korission) and September 2011 (Akgöl and Paradeniz). Water samples for phytoplankton analyses were taken at a depth of 50 cm and fixed immediately with Lugol's solution (15 mlL^{-1}). Additional water samples were taken and conserved in refrigerated dark bottles for laboratory analyses of total carbon and total nitrogen. During the sampling, some water quality variables (temperature, salinity, dissolved oxygen and pH) were measured using a YSI 556 MPS multiprobe. Nutrient determinations in water samples were performed by a CHN Analyser (Dionex) according to EPA methods (www.epa.org). Taxonomic identification was performed on a sub-sample of 400 cells at 400× magnification under an inverted microscope (Nikon Eclipse T*i*-S) connected to a video interactive image analysis system (L.U.C.I.A, Version 4.8, Laboratory Imaging Ltd., Prague) with a lower detection limit of 5 µm, following Utermöhl's method (Utermöhl, 1958). For more detailed identification was used an inverted microscope Nikon Eclipse T*i*-E coupled with an image analysis system (NIS–Elements AR Nikon Instruments software version 3.06). The texts and journal articles used most frequently to aid in taxonomic identification were: Ralfs, 1848; Gomont, 1892-1893; West et al., 1912; Prescott, 1961; Gomont, 1962; Prescott and Vinyard, 1965; Dodge, 1982; Sournia, 1986; Cupp, 1943; Chrétiennot-Dinet, 1990; Streble and Krauter, 1997; Tomas, 1997; Kim et al., 1998; Pérez et al., 2002; Wehr and Sheath, 2003; Fernández and Parodi, 2005; Da Rodda and Parodi, 2005; Delgado and

Sánchez, 2007; Khondker et al., 2008; Şahin, 2009; Komárek and Hauer, 2013.

The "cf." qualifier was used to indicate specimens that were similar to (or many actually be) the nominate species. Taxa which contain the "undet." (undetermined) identifier were likely to be algal entities, but could not be identified as any knows genus. In some cases, species were broken out into separate taxa based on size (e.g., Dinophyceae undet.>20 µm). The term "Other" is referred to the group consisting of small phytoflagellates and other undetermined phytoplankton. During phytoplankton identification, sometimes is not possible to identify the organism to the species level, though recognizing common characteristics within a group of cells belonging to the same genus. In this case, to identify that organism in the phytoplankton list is reported the name of the genus followed by numbered "sp." (e.g. *Scenedesmus* sp. 1, *Scenedesmus* sp. 3, *Scenedesmus* sp. 5, etc). The complete list, including all numbered species, is available on the website www.phytobioimaging.unisalento.it.

Analysis of biodiversity

The variability of phytoplankton was characterized at different spatial and environmental scales by using the following measures of diversity based on the Kullback-Leibler divergence (Ludovisi and Taticchi, 2006):

Divergence

$$\hat{J}(P:Q) = \sum_{i=1}^{\hat{S}} \left(p'_{iP} - p'_{iQ}\right) ln \frac{p'_{iP}}{p'_{iQ}}$$

$\hat{J}$ (P:Q)≥ 0 [1]

Similarity index

$$s_J = 1 - \frac{\hat{J}(P:Q)}{\hat{J}(P:Q)_{max}}$$

$(0 \leq s_J \leq 1)$ [2]

Where p'_{iP} and p'_{iQ} are the proportions of the i-th species in the guilds under comparison (P and Q), $\hat{S}$ is the total number of species found in the two guilds, and $\hat{J}$ (P:Q)maxis the maximum value allowed to $\hat{J}$ (P:Q). The proportion of each species is adjusted for sample coverage, by using the estimator proposed by Turing (see Good, 1953), which is based on the proportion of singletons (f1/N) in a sample:

$C = 1\text{-}f1/N$ $(0 \leq C \leq 1)$ [3]

The above measures were calculated by comparing samples collected in the three replicates (within-habitat divergence and similarity), in the three stations or habitats (between-habitat divergence and similarity), in the three lagoons (between lagoons divergence and similarity). Between-habitats and between-lagoons diversity measures were calculated using count data integrated over replicates and stations respectively. The use of the above measures of similarity is advantageous, because they allow us, through the examination of the terms of the summation $\hat{J}$ (P:Q), to identify the taxa which mostly contributes to the dissimilarity between samples.

Results

The identified habitat types and the investigated water quality data are summarized in Table 1. The examination of water quality data shows that the three lagoons differed mainly in terms of salinity and oxygen saturation. Akgöl was oligohaline, whereas Paradeniz and Korission were, respectively, polyhaline and euhaline, with the latter showing a certain internal variability. The waters of Akgöl and Paradeniz were in almost all cases found to be over-saturated for oxygen, whereas in Korission the waters were mostly under-saturated. Also, in comparison with the other lagoons, Akgöl showed a higher

Table 1 - Mean value of the water quality variables observed in the three habitat types selected in the investigated lagoons.

Lagoon	Habitat typology	Temperature °C	Salinity	pH	Oxygen saturation (%)	Total Carbon (%)	Total Nitrogen (%)
Akgöl							
	1. Vegetation	30.12	2.41	8.79	135.47	0.08	0.02
	2. Mud	30.09	3.64	8.69	114.90	0.13	0.06
	3. Mud and sand	29.58	4.03	8.72	97.63	0.10	0.03
Paradeniz							
	1. Sand and mud 1*	29.47	29.08	8.08	113.40	0.06	0.01
	2. Sand and mud 2*	29.81	28.38	8.18	116.00	0.07	0.02
	3. Sand and mud 3*	30.29	29.00	8.21	110.00	0.07	0.01
Korission							
	1. Sand	18.24	26.70	7.98	68.10	0.07	0.01
	2. Mud	17.88	26.96	7.86	79.53	0.05	0.01
	3. Vegetation	18.37	37.73	7.85	106.13	0.06	0.01

* These habitat types differ for the different relative percentage of sand and mud in each typology

amount of total carbon and total nitrogen, and a higher heterogeneity for salinity and dissolved oxygen saturation. Overall, 51 in Akgöl, 56 in Paradeniz and 65 taxa in Korission, were found during the study (see Appendix 1). The taxa richness of phytoplankton classes is reported in Figure 2. In Akgöl the higher taxa richness of phytoplankton assemblages were Chlorophyceae and Trebouxiophyceae classes accounting for 33.33% and 17.65%, respectively; Cyanophyceae and Dinophyceae accounting for 9.80% and 7.84% of identified taxa. In Paradeniz, Dinophyceae accounted for 50.00% and Coscinodiscophyceae, Bacillariophyceae and Chlorophyceae accounted for 8.93%, 7.14% and 7.14%, respectively covered mostly of taxa richness. In the Korission lagoon taxa belonging to Dinophyceae were dominant in terms of species richness, accounting for 30.77% but Bacillariophyceae, Fragilariophyceae and Coscinodiscophyceae are present with 18.46%, 16.92% and 7.69% of the taxa richness, respectively.

The numerical abundance in terms of number of individuals counted for each class is reported in Table 2. In Akgöl the most representative phytoplankton were Chlorophyta with Chlorophyceae and Trebouxiophyceae classes accounting for 24.25% and 20.59% of sampled cells, respectively; other phytoplankton accounting for 41.66% of counted cells. In Paradeniz, Coscinodiscophyceae and Fragilariophyceae accounted for 45.16 and 17.37% respectively, and Chlorophyceae and Chrysophyceae accounted for 14.61% and the 10.90% of numerical abundance. In the Korission lagoon taxa belonging to Other phytoplankton and Dinophyceae were dominant in terms of number of individuals, accounting for 39.49% and 23.66%, respectively. Also, Bacillariophyceae and Cryptophyceae are present with 16.76% and 14.53% of the numerical abundance, respectively. Eight taxa belonging to Bacillariophyceae, Dinophyceae, Cryptophyceae classes and Other phytoplankton were found in all the lagoons. Scaling down species level, the most dominant taxa (in terms of percentage numerical abundance) in Akgöl were phytoplankton undetermined (41.56%) and *Monoraphidium contortum* (21.30%) and

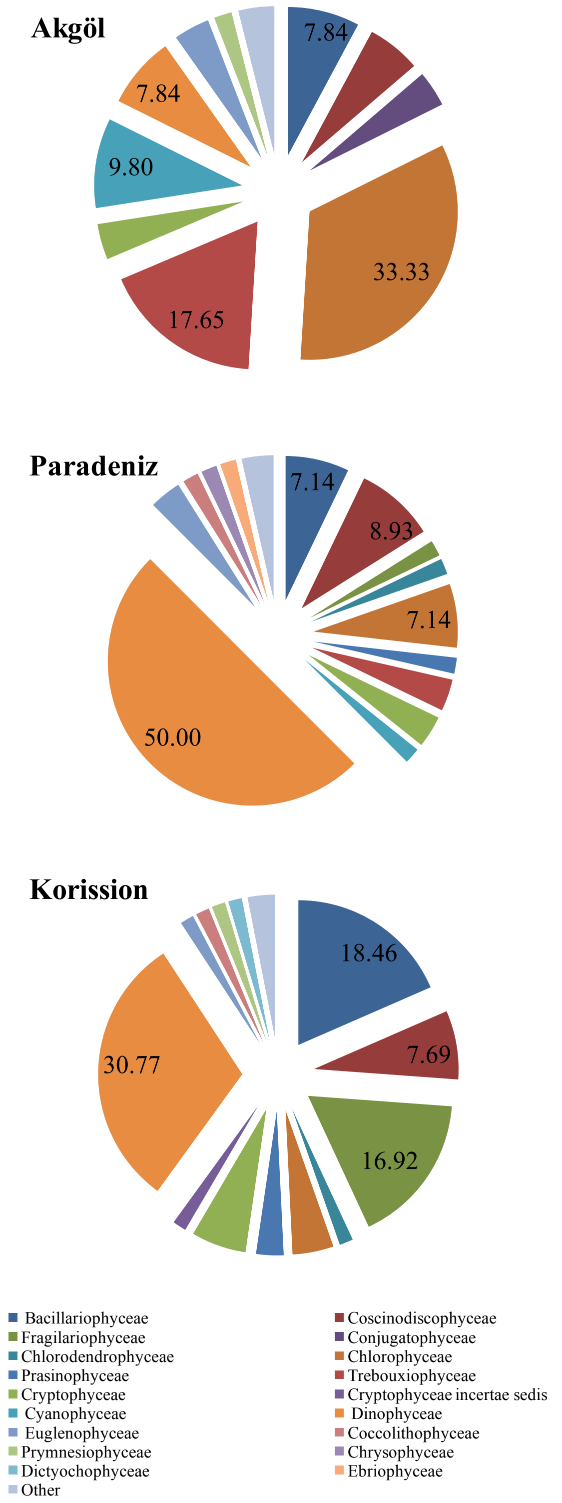

Figure 2. Taxonomic composition of phytoplankton assemblages in terms of percentage of taxa richness in the lagoons.

Chlorella sp. (19.32%); in Paradeniz were *Chaetoceros* spp. (27.04%) *Ceratoneis closterium* (17.37%) and Chlorophyceae undetermined (14.53%); in Korission phytoplankton undetermined (35.44%), *Plagioselmis prolonga* (16.16%).

Overall, the sample coverage (Eq. 3) was high in all stations, ranging from 0.987 to 0.999. Within-habitat similarities were also very high ($s_J > 0.95$) in all habitats and lagoons (Table 3), indicating that the replicates can be considered homogeneous one another. The between-habitats similarity (β diversity measure) was also high ($s_J > 0.90$) in Akgöl and Paradeniz (Table 3), but quite variable in Korission, mostly because of the effect of habitat 3. At this last lagoon, the analysis of the contribution of separate species to $\hat{J}(P:Q)$, (Eq. 1), showed that the almost complete absence in the habitat 3 of two phytoplankton species (*Plagioselmis prolonga* and *Prorocentrum scutellum*), which were dominant in habitats 1 and 2, caused the drop of phytoplankton homogeneity in Korission. The similarity declines drastically when comparing the phytoplankton of different lagoons (Table 3). The examination of the terms of the summation of $\hat{J}(P:Q)$ (Eq. 1) shows that the most important contributions are from *Monoraphidium contortum*, *Chlorella* sp. (dominant in Akgöl and absent in Paradeniz) and *Ceratoneis closterium* (dominant in Paradeniz and absent in Akgöl). The dissimilarity between Akgöl and Korission is also mostly due *Monoraphidium contortum* and *Chlorella* sp, which, being typical freshwater species, are absent in Korission; between Paradeniz and Korission, the dissimilarity is mostly due to *Plagioselmis prolonga* and *Ollicola* sp. 1 (which appear among the dominant species in Korission and Paradeniz respectively), together with some undetermined species (Phytoplankton undet.12, Chlorophyceae undet.1).

Table 1 - Taxonomic composition of phytoplankton assemblages in terms of percentage (%) of numerical abundance of taxa in the lagoons.

	TURKEY		**GREECE**
	Akgöl	**Paradeniz**	**Korission**
Bacillariophyta	**2.46**	**64.93**	**18.53**
Bacillariophyceae	0.80	2.40	14.51
Coscinodiscophyceae	1.66	45.16	0.11
Fragilariophyceae	-	17.37	3.86
Charophyta	**0.24**	-	-
Conjugatophyceae	0.24	-	-
Chlorophyta	**44.84**	**14.80**	**0.45**
Chlorodendrophyceae	-	0.09	0.18
Chlorophyceae	24.25	14.61	0.12
Prasinophyceae	-	0.01	0.15
Trebouxiophyceae	20.59	0.07	-
Cryptophyta	**0.05**	**0.81**	**17.80**
Cryptophyceae	0.05	0.81	16.76
Cryptophyceae incertae sedis	-	-	1.04
Cyanobacteria	**0.42**	**0.07**	-
Cyanophyceae	0.42	0.07	-
Dinophyta	**7.77**	**8.07**	**23.66**
Dinophyceae	7.77	8.07	23.66
Euglenophyta	**2.54**	**0.09**	**0.01**
Euglenophyceae	2.54	0.09	0.01
Haptophyta	**0.02**	**0.03**	**0.05**
Coccolithophyceae	-	0.03	0.04
Prymnesiophyceae	0.02	-	0.01
Ochrophyta	-	**10.90**	**0.01**
Chrysophyceae	-	10.90	-
Dictyochophyceae	-	-	0.01
Protozoa incertae sedis	-	**0.24**	-
Ebriophyceae	-	0.24	-
Other	**41.66**	**0.06**	**39.49**

Discussion

The eco-regional approach to analyze phytoplankton assemblages structure in transitional waters is supported by a series of studies carried out in freshwater lakes, in which large-scale geographical patterns of phytoplankton taxonomic characteristics were explained both by physiographical factors and by geographical variables such us altitude, latitude and longitude (Reynolds, 1997; Tolotti *et al.*, 2006, Stomp *et al.*, 2011). Vadrucci *et al.* (2008) showed that the two key components describing phytoplankton structure in transitional waters follow different eco-regional patterns, related to a variety of large-scale abiotic factors such as geometric complexity, physiographical features of water body, as well as geographic position.

Geometric complexity and physiographical features affect environmental heterogeneity, which may be an important determinant of

Table 3 - Kullback-Leibler divergence [Ĵ (P:Q)] and similarity index [sJ] for phytoplankton in Akgöl, Paradeniz and Korission lagoons at different spatial and environmental scales.

		Akgöl			**Paradeniz**			**Korission**		
		1	**2**	**3**	**1**	**2**	**3**	**1**	**2**	**3**
Within habitat	$\hat{J}(P:Q)$[a]	0.28	0.15	0.19	0.76	0.45	0.40	0.41	0.26	0.63
	s_J[a]	0.986	0.993	0.991	0.959	0.977	0.980	0.979	0.988	0.966

		1-2	**1-3**	**2-3**	**1-2**	**1-3**	**2-3**	**1-2**	**1-3**	**2-3**
Between habitats	$\hat{J}(P:Q)$	0.79	1.46	0.16	0.23	0.67	0.33	0.32	3.43	3.15
	s_J	0.964	0.933	0.993	0.989	0.968	0.985	0.984	0.835	0.855

		Akgöl-Paradeniz	**Akgöl-Korission**	**Paradeniz-Korission**
Between lagoons	$\hat{J}(P:Q)$	15.06	8.60	10.95
	s_J	0.308	0.605	0.486

[a] For brevity, within habitat divergence and similarity are shown as the average of the three comparisons made on replicates.

biodiversity (Tokeshi, 1999; Basset *et al.*, 2006) since it causes spatial variability in the availability of resources, favoring the coexistence of numerous phytoplankton species. Also, anthropogenic activities can affect species diversity of phytoplankton guilds, e.g. when affecting nutrient enrichment (Vadrucci *et al.*, 2003) and levels of toxicants (Masaya *et al.*, 2002). Nevertheless, nutrient concentration does not seem to play an important role in variation patterns of phytoplankton guilds at the large ecological scale (Vadrucci *et al.*, 2008).

The present study approaches the topic of eco-regional diversity in phytoplankton by following a multi-scale approach and focusing on a particular facet of the diversity, i.e., the scale similarity. In terms of sampling design, the results show that the sampling protocol used can be considered highly satisfactory, since sample coverage and within-habitat similarities are very high in all habitats and lagoons. At an ecosystem scale, phytoplankton was highly homogeneous in Akgöl and Paradeniz, suggesting that the distinctive physiognomic traits of the habitats (bottom granulometry and coverage) exert a limited effect on phytoplankton in these lagoons. In contrast, the phytoplankton from Korission is significantly heterogeneous, mostly because of the effect of a specific habitat, closer to the sea-exchange channel.

Climbing up on the spatial scale, the similarity breaks down at a regional level, i.e., when comparing the coastal lagoons one another. This result appears to support the hypothesis that phytoplankton variations follow a hierarchical scheme based on eco-geographical location. However, the fact that the similarity between adjacent lagoons having different salinity (Akgöl and Paradeniz) is comparable to the one between lagoons having similar salinity but different geographical location (Korission and Paradeniz), and both are lower than the similarity between lagoons differing in location and salinity (Akgöl and Korission), suggests that local conditions and geographical factors act in a complex way. Alternatively, they suggest that local conditions and geographical factors affect phytoplankton composition to a comparable extent. This conclusion is partially in contrast with some previous results (Vadrucci *et al.*, 2008), which have shown that transitional waters with similar morphometric and hydrodynamic properties have similar taxonomic compositions, and that the geographical distance is the principal factor explaining the diversity in phytoplankton assemblages.

The low similarity between lagoons having different salinity suggests that salinity plays a major role in determining the phytoplankton composition, irrespective to geographic separation. Phytoplankton taxonomic structure in the transitional ecosystems studied was characterized by the presence of Chlorophyta, Bacillariophyta and small other phytoplankton, as in other estuarine or transitional water ecosystems of temperate regions (Vadrucci *et al.*, 2008). Phytoplankton of ecosystems with low salinity are often characterized by species with higher freshwater affinity. Various authors (e.g. Margalef, 1978; Reynolds, 1997) indicate that these taxa may become dominant in environments characterized by high instability of the water column and in resource availability, which is typical of transitional water ecosystems. In such situations, phytoplankton community organization is typically dominated by opportunistic species of small dimensions with high replication rates and high surface/volume ratios, able to respond rapidly to environmental change. These results could assist the identification of typical phytoplankton associations in transitional water ecosystems determined by geomorphological and hydrodynamic characteristics, which is also in accordance with descriptions of associations in freshwater and marine habitats (Harris, 1987; Reynolds, 1997; Smayda, 2002). On the other hand, the low similarity between the two lagoons having comparable salinity, but different geographical location (Korission and Paredenitz) is due to a very different composition in the most dominant taxa, suggesting that eco-geographical factors significantly affect the composition of phytoplankton guilds.

The results of the present study seems to support the existence of a macro-ecological filter, which selects the species pool for different ecosystems, being characterized by abiotic factors that vary on large geographical scales. Species pool dynamics are subsequently influenced by an internal ecosystem filter (Blenckner, 2005), determined by biological constraints such as predation and competition and hydraulic forces, as well as by processes affecting local resource availability, such as land use in the catchment area, habitat type, habitat quality, and historical influences on the ecosystem (Rosenzweig, 1995). The internal ecosystem filter affects interactive relationships in the species pool, determining spatial fluctuations of phytoplankton abundance.

Our study confirms recent studies that microorganisms can show substantial geographical variation in biodiversity (Martiny *et al.*, 2006; Pommier *et al.*, 2007; Fuhrman *et al.*, 2008; Bryant *et al.*, 2008; Ptacnik *et al.*, 2010; Stomp *et al.*, 2011). However, these data were a reduced part of a larger dataset, and it would therefore be highly interesting to examine phytoplankton diversity in the worldwide lagoons subjected to different nutrient status, land use and geographical position. Such knowledge of the intra- and inter-habitat variability of the phytoplankton taxonomic structure is crucial for our understanding of aquatic biodiversity, and consequently for the maintenance of aquatic resources by means management and conservation plans.

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Appendix 1 - List of phytoplankton taxa identified in the three coastal lagoons.

COUNTRY	**TURKEY**		**GREECE**
LAGOON	**Akgöl**	**Paradeniz**	**Korission**
Bacillariophyta			
Bacillariophyceae			
Bacillaria paxillifera (O.F.Müller) T.Marsson 1901		●	●
Cocconeis scutellum Ehrenberg 1838			●
Cocconeis spp.	●		●
Campylodiscus biangulatus Greville 1862			●
Campylodiscus spp.	●		
Diploneis crabro (Ehrenberg) Ehrenberg 1854			●
Entomoneis alata (Ehrenberg) Ehrenberg 1845			●
Navicula transitans Cleve 1883	●	●	●
Navicula spp.	●	●	●
Pleurosigma spp.			●
Pseudo-nitzschia spp.		●	●
Surirella spp.			●
Bacillariophyceae pennales undet.			●
Coscinodiscophyceae			
Biddulphia biddulphiana (J.E.Smith) Boyer 1900			●
Chaetoceros debilis cf. *pseudocurvisetus*		●	
Chaetoceros pseudocurvisetus Mangin 1910		●	
Chaetoceros spp.		●	●
Cyclotella meneghiniana Kützing 1844	●		
Cyclotella spp.	●		
Guinardia striata (Stolterfoth) Hasle in Hasle & Syvertsen 1996			●
Leptocylindrus danicus Cleve 1889			●
Paralia sulcata (Ehrenberg) Cleve 1873		●	●
Proboscia alata (Brightwell) Sundström 1986		●	
Thalassiosira spp.	●		
Fragilariophyceae			
Ceratoneis closterium Ehrenberg 1839		●	●
cf. *Fragilaria* spp.			●
Grammatophora marina (Lyngbye) Kützing 1844			●
Grammatophora oceanica Ehrenberg 1840			●
Grammatophora spp.			●
Licmophora flabellata (Grev.)C.Agardh 1831			●
Licmophora sp.1			●
Licmophora sp. 2			●
Licmophora spp.			●
Rhabdonema adriaticum Kützing 1844			●
Striatella unipunctata (Lyngbye) C.Agardh 1832			●

Appendix 1 - Continued.

COUNTRY	**TURKEY**		**GREECE**
LAGOON	**Akgöl**	**Paradeniz**	**Korission**
Charophyta			
Conjugatophyceae			
Cosmarium laeve Rabenhorst 1868	●		
Cosmarium margaritiferum Meneghini ex Ralfs 1848	●		
Chlorophyta			
Chlorodendrophyceae			
Tetraselmis spp.		●	●
Chlorophyceae			
Acutodesmus acuminatus (Lagerheim) Tsarenko in Tsarenko & Petlovanny 2001			●
Coelastrum spp.	●		
Desmodesmus communis (E.Hegewald) E.Hegewald 2000	●	●	
Kirchneriella obesa (West) West & G.S.West 1894	●	●	
Kirchneriella spp.	●	●	
Monoraphidium contortum (Thuret) Komárková-Legnerová in Fott 1969	●		
Pediastrum boryanum (Turpin) Meneghini 1840	●		
Scenedesmus sp. 1	●		
Scenedesmus sp. 3	●		
Scenedesmus sp. 5			●
Scenedesmus sp. 8	●		
Schroederia setigera (Schröder) Lemmermann 1898	●		
Tetraedron minimum (A.Braun) Hansgirg 1888	●		
Tetraedron triangulare Korshikov 1953	●		
Tetraedron trigonum (Nägeli) Hansgirg 1888	●		
Tetrastrum glabrum (Y.V.Roll) Ahlstrom & Tiffany	●		●
Tetrastrum triangulare (Chodat) Komárek 1974	●		
Tetrastrum spp.	●		
Chlorophyceae undet. 1	●	●	
Prasinophyceae			
Pyramimonas spp.		●	●
Prasinophyceae undet. 2			●
Trebouxiophyceae			
cf. *Chlorella* sp.	●		
Crucigeniella rectangularis (Nägeli) Komárek 1974	●		
Crucigenia tetrapedia (Kirchner) Kuntze 1898	●		
Crucigenia spp.	●		
cf. *Eremosphaera* sp.	●	●	
Nephrocytium agardhianum Nägeli 1849	●		
Oocystis solitaria Wittrock 1879	●		
Oocystis sp. 1	●	●	
Oocystis sp.	●		

Appendix 1 - Continued.

COUNTRY	**TURKEY**		**GREECE**
LAGOON	**Akgöl**	**Paradeniz**	**Korission**
Cryptophyta			
Cryptophyceae			
Cryptomonas cf. *ovata*		●	
Plagioselmis prolonga Butcher ex G.Novarino, I.A.N.Lucas, S.Morrall 1994			●
Rhodomonas spp.			●
Cryptophyceae undet. 2	●		●
Cryptophyceae undet.	●	●	●
Cryptophyceae incertae sedis			
Leucocryptos marina (Braarud) Butcher 1967			●
Cyanobacteria			
Cyanophyceae			
cf. *Chroococcus* sp.		●	
Coelosphaerium spp.	●		
Merismopedia spp.	●		
Oscillatoria cf. *limosa*	●		
Snowella lacustris (Chodat) Komárek & Hindák 1988	●		
Woronichinia spp.	●		
Dinophyta			
Dinophyceae			
Akashiwo sanguinea (K.Hirasaka) G.Hansen & Ø.Moestrup 2000		●	●
Amphidinium carterae Hulburt 1957			●
Biceratium furca (Ehrenberg) Vanhoeffen 1897		●	
Ceratium teres Kofoid 1907		●	
cf. *Peridiniopsis pernardiforme*	●		
Gonyaulax polygramma Stein 1883		●	
Gonyaulax spp.		●	
Gymnodinium spp.		●	
Heterocapsa cf. *ovata*		●	
Heterocapsa pygmaea cf. *psammophila*		●	●
Heterocapsa rotundata (Lohmann) G.Hansen 1995		●	
Heterocapsa rotundata cf. *pseudotriquetra*			●
Heterocapsa sp.1		●	●
Heterocapsa spp.		●	●
Oblea spp.		●	
Oxytoxum longiceps Schiller		●	
Oxytoxum spp.			●
Podolampas palmipes Stein 1883		●	
Preperidinium meunieri (Pavillard) Elbrächter 1993		●	
Prorocentrum cordatum (Ostenfeld) Dodge 1975	●	●	●
Prorocentrum laevis cf. *faustiae*			●
Prorocentrum lima (Ehrenberg) F.Stein 1878		●	●

Appendix 1 - Continued.

COUNTRY	**TURKEY**		**GREECE**
LAGOON	**Akgöl**	**Paradeniz**	**Korission**
Dinophyta			
Dinophyceae			
Prorocentrum micans Ehrenberg 1834		●	
Prorocentrum scutellum Schröder 1900		●	●
Protoperidinium conicum (Gran) Balech 1974		●	
Protoperidinium divergens (Ehrenberg) Balech 1974		●	
Protoperidinium steinii (Jorgensen) Balech 1974		●	
Protoperidinium cf. *pallidum*			●
Protoperidinium sp. 3			●
Protoperidinium spp.			●
Scrippsiella cf. *trochoidea*		●	●
Scrippsiella trochoidea (Stein) Balech ex Loeblich III 1965		●	●
Dinophyceae athecate undet. 1 (>20µm)		●	●
Dinophyceae athecate undet. 2 (<20µm)		●	●
Dinophyceae thecate undet. 1 (>20µm)	●	●	●
Dinophyceae thecate undet. 2 (<20µm)	●	●	●
Euglenophyta			
Euglenophyceae			
cf. *Astasia* sp.		●	
Euglena proxima cf. *variabilis*	●	●	
Euglena spp.			●
Trachelomonas spp.	●		
Haptophyta			
Coccolithophyceae			
Syracosphaera pulchra Lohmann 1902			●
Coccolithophyceae undet. 3 (>20µm)		●	
Prymnesiophyceae			
Prymnesiophyceae undet. 5	●		
Prymnesiophyceae undet. 6			●
Ochrophyta			
Chrysophyceae			
Ollicola sp. 1		●	
Dictyochophyceae			
Dictyocha fibula Ehrenberg 1839			●
Protozoa incertae sedis			
Ebriophyceae			
Hermesinum adriaticum O. Zacharias 1906		●	
Other			
Phytoflagellates undet.	●	●	●
Phytoplankton undet. 12	●	●	●