Ecological indices as a tool for assessing pollution in El-Dekhaila Harbour (Alexandria, Egypt)

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Abstract

Statistical analyses of data concerning the phytoplankton standing crop and biomass were applied as a tool for assessing pollution in El-Dekhaila Harbour. Univariate and multivariate analysis showed a succession of three clusters associated with salinity and temperature variations. The first and third clusters comprised mainly diatoms and dinoflagellates. The second cluster, richer in species, was dominated by brackish water cyanophytes, chlorophytes and euglenophytes. The diversity index ranged from 0.08 to 2.41. A high diversity was associated with high evenness, reflecting the multidominance pattern of cluster (2). On the other hand, multiple correlations between salinity and standing crop, richness and evenness, were negative and significant, but positive with the diversity index. The ABC curve showed that the k-dominance curve for numerical abundance extends above that for the biomass when clusters 1 and 3 are dominant. Both curves coincide more or less for another segment of the curve but when cluster 2 becomes dominant the numerical abundance curve runs below that of the biomass. Such a pattern may indicate unpolluted or moderate to heavily polluted conditions in El-Dekhaila Harbour.

The present study reveals that the combination of univariate and multivariate analysis with the ABC curve provides a promising tool for the characterization of phytoplankton dynamics under stress conditions. On the other hand, the phytoplankton community in El-Dekhaila Harbour is stressed not by the inflow of brackish water but rather by the inflow of sea water. This is indicated by the higher diversity and evenness, and by the ABC curve during the dominance of cluster (2).

The complete text of the paper is available in PDF format at http://www.iopan.gda.pl/oceanologia/index.html

1. Introduction

Many semi-closed bays and coastal areas in the Mediterranean are exposed to land based pollution sources, mainly from agricultural, domestic and industrial effluents and/or river runoff. Changes to ecosystems as a result of pollution stress have led to the search for means of quantifying such changes. Two basic approaches for studying the impact of biological pollution are in use: measurements based on community structure, and measurements based on indicator organisms (Washington 1984).

The community structure approach has two aspects, namely, univariate and multivariate analysis. Univariate analysis uses diversity indices, which attempt to combine the data on abundance within a species in a community into a single number. The state of the community can then be understood from this number. The other approach is multivariate analysis, which is used to assess similarities among communities. Cluster analysis is indicative of the degree of similarity in species composition either between stations or at the same station over time. In this way it permits recognition of clusters of species or communities (FIR/MEDPOL/ALE/2 1991).

For aquatic ecosystems, indices of diversity are basically an approach to biological quality through the structure of the community. The indicator organism concept as an approach to water pollution assessment does not, however, represent community structure (Washington 1984), since the occurrence of an indicator species can reflect either clean or polluted conditions. Other biotic indices are likely to be specific for one particular type of pollution, as indicator organisms cannot be equally sensitive to all types of pollution (Beak 1965).

Another method was introduced by Warwick et al. (1987) for the detection of pollution-induced disturbance in marine communities. The distribution of numbers of individuals among species and the distribution of biomass among species in marine macrobenthic communities show a differential response to pollution-induced disturbance. Such a response can be clearly demonstrated by the comparison of k-dominance curves for abundance and biomass. These curves rank species in decreasing order of their abundance or total biomass on the x-axis (logarithmic scale) with the percentage of the total abundance of all species in the sample on the y-axis (cumulative scale). The technique used for this purpose is the abundance-biomass comparison (ABC) or k-dominance curve. This curve is widely used for the detection of pollution effects on macrobenthos (Warwick 1986, Warwick et al. 1987, Clarke 1990), but is not widely used for plankton.

The main objective of this work is to investigate the applicability of the ABC curve to the phytoplankton community and also to test the significance of some statistical parameters in providing an insight into the structure and dynamics of the phytoplankton communities under stress in El-Dekhaila Harbour. The k-dominance curve may also characterize the eutrophication status of an area (Ignatiades & Karydis 1990).

2. Material and methods

El-Dekhaila Harbour is located on the western side of Mex Bay (Fig. 1). It was constructed in 1986 for the export of manufactured iron and steel and the import of coal. It also plays an important role in the export and import of other goods such as minerals, ores, fertilizers, salts and grain. The harbour has a surface area of about 12.5 km^2 and a water depth ranging from 4 to 20 m. The harbour is indirectly subjected to a major inflow of mixed domestic, agricultural and industrial waste water (6.6×10^6 m^3 day^{-1}) flowing into Mex Bay a few kilometres to the east – the 'Umoum drain' (Fig. 1).

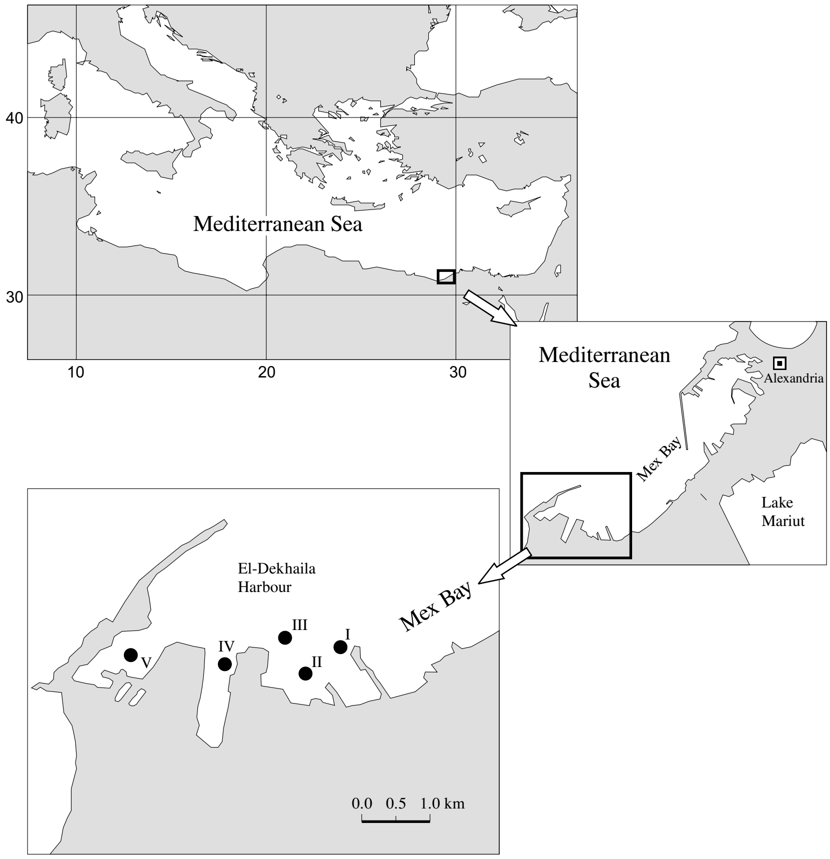

Fig. 1. Sample collection locations in El-Dekhaila Harbour during 1998–1999

In addition, maritime activities, the loading and unloading of unpacked grains and fertilizers on to and from ships, are a cause of direct pollution in the harbour (Abdel-Aziz 2001).

Surface phytoplankton and water samples were collected monthly from April 1998 to March 1999 at 5 stations (Fig. 1). Chlorophyll *a* was determined according to Strickland & Parsons (1972). Phytoplankton identification and enumeration were carried out in formalin-preserved subsamples using an inverted microscope following Utermöhl (1958). Salinity was determined after Strickland & Parsons (1972), and temperature was measured at each station.

Univariate analysis (mean and variance) was performed on Excel version 5. The multivariate analysis (diversity indices, cluster analysis and ABC curve) was done using the PRIMER computer program (developed at the Plymouth Marine Laboratory, UK).

The species richness (R) was calculated after Margalef (1958), the species diversity (H′) according to Shannon-Wiener (1949) and the species evenness (E) after Pielou (1977). Cluster analysis was carried out using the Bray-Curtis similarity index (Bray & Curtis 1957). The cluster analysis was applied to the dominant species.

The correlation analyses between salinity, diversity indices and standing crop were carried out using Excel version 5.

3. Results

A total of 107 species belonging to 4 major groups were recorded throughout the annual cycle. Diatoms were the most diversified (52 species), followed by dinoflagellates (38 spp.), chlorophytes (9 spp.) and cyanophytes (5 spp.). Two euglenophyte species and one dictyophyte were also recorded.

In spite of the large number of species, only six were perennial: *Cyclotella meneghiniana*, *Euglena acus*, *Prorocentrum minimum*, *Prorocentrum triestinum*, *Protoperidinium curvipes* and *Scrippsiella trochoidea*. With the exception of *E. acus*, all are pervasive and widespread in Egyptian Mediterranean waters (Mostafa 1985, Dorgham et al. 1987, Ismael 1998, Ismael & Halim 2001). Although perennial, *E. acus* is inversely related in abundance to salinity fluctuations.

The univariate analysis showed the dispersion distribution (patchiness), since the variance is larger than the mean ($S^2 > \mu$) and also increases with the mean. The raw data were therefore log-transformed. Since the patchiness distribution shown by univariate analysis says nothing about the constituents of the patches, multivariate analysis was used for the log-transformed data to identify the species clusters. The dendrogram revealed the occurrence of three main species clusters (Fig. 2, Table 1).

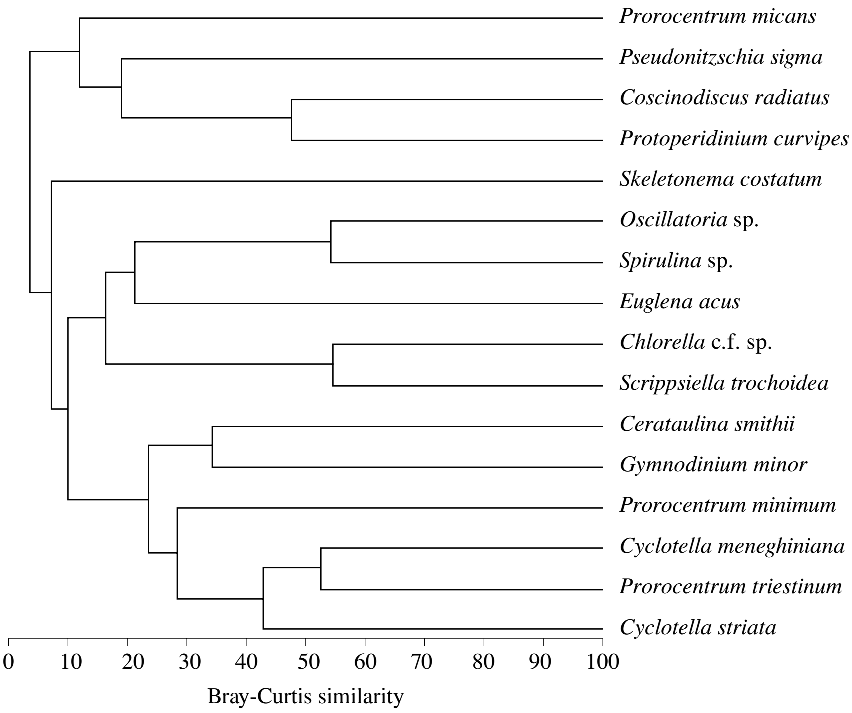

Fig. 2. Dendrogram for hierarchical clustering of 16 dominant species in El-Dekhaila Harbour during 1998–1999

Table 1. The species cluster tree in El-Dekhaila Harbour (1998–1999)

Cluster 1	Cluster 2	Cluster 3
Prorocentrum micans	*Oscillatoria* sp.	*Cerataulina smithii*
Pseudonitzschia sigma	*Spirulina* sp.	*Gymnodinium minor*
Coscinodiscus radiatus	*Euglena acus*	*Prorocentrum minimum*
Protoperidinium curvipes	*Chlorella* c.f. sp.	*Cyclotella meneghiniana*
	Scrippsiella trochoidea	*Prorocentrum triestinum*
		Cyclotella striata

Clusters (1) and (3) include only diatoms and dinoflagellates. Cluster (2) is richer in species and comprises cyanophytes, euglenophytes, chlorophytes and dinoflagellates. The appearance of the respective clusters is modulated by the physical conditions, each being more or less restricted to a range of salinity and temperature (Fig. 3).

Cluster (1) is restricted to April–May at a temperature of 21°C and a narrow salinity range, 31.9–32.3 PSU. The warm season from June to November is characterized by the dominance of brackish water species

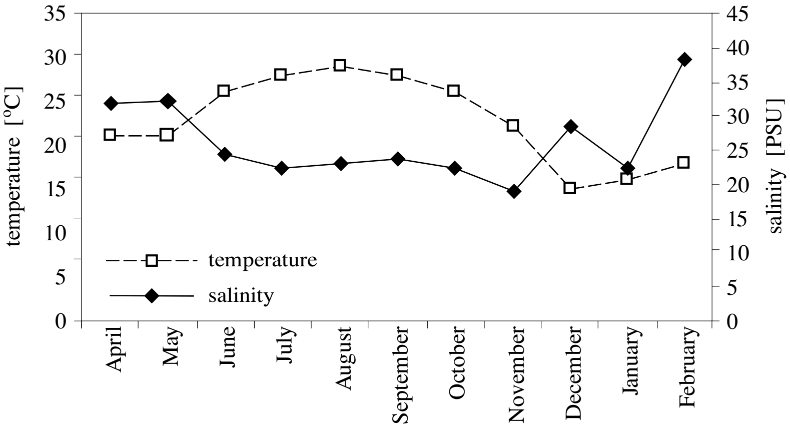

Fig. 3. Monthly variations of temperature [°C] and salinity [PSU] in El-Dekhaila Harbour during 1998–1999

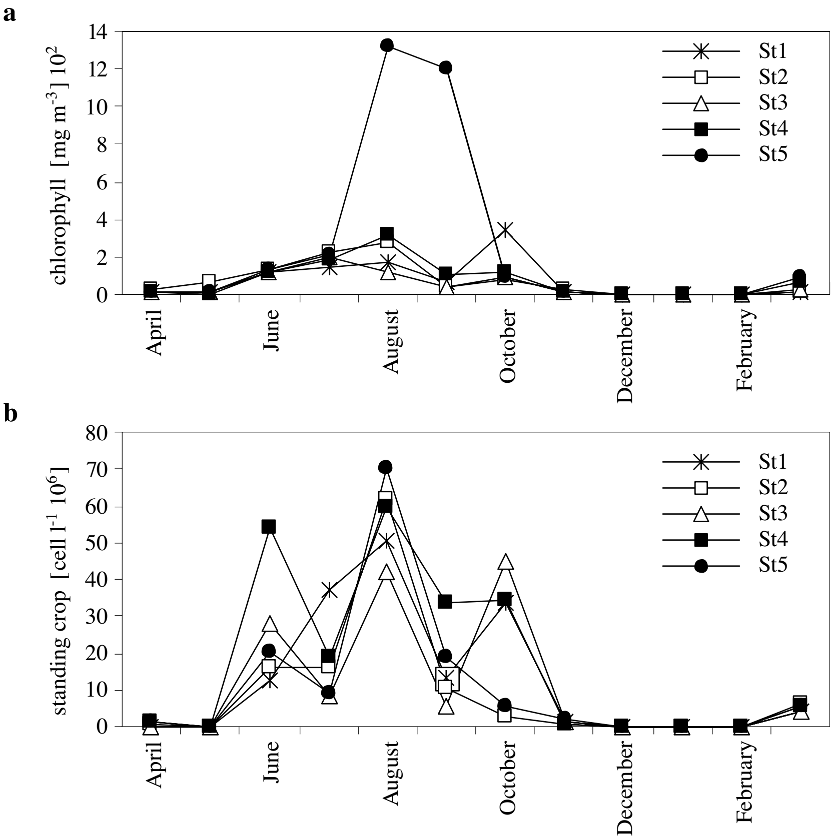

Fig. 4. Monthly variations of (a) Chlorophyll biomass [mg m^{-3}] and (b) phytoplankton standing crop [cell l^{-1}] in El-Dekhaila Harbour during 1998–1999

(cluster 2). Salinity is then at its minimum, 19–23.9 PSU at a temperature of 22 to 29°C. Cluster (3) is restricted to December–February at a lower temperature, 15–18°C, and a higher salinity range, 27.5 to 39.2 PSU (Fig. 3).

Large differences in the standing crop density are also observed between the respective clusters. Cluster (1) is characterized by a low standing crop (0.06×10^6 to 1.5×10^6 cell l^{-1}), cluster (2) corresponds to the blooming season (60×10^6 cell l^{-1}) and cluster (3) to the phase of lowest standing crop (0.004×10^6 to 0.32×10^6 cell l^{-1}). This is reflected by the chlorophyll concentration, where clusters (1) and (3) yielded a relatively low chlorophyll content (5.4 to 67 mg m^{-3} and from 20 to 86 mg m^{-3}, respectively), while cluster (2) yielded the highest chlorophyll concentration (39–1320 mg m^{-3}) (Fig. 4). Although the three communities were restricted to particular seasons, they displayed no spatial distribution, as they were present at all stations.

The diversity index (H′) in El-Dekhaila Harbour ranged from 0.08 to 2.41 for the different stations. The lowest diversity was recorded at station (3), not exceeding 1 indiv./bit (Table 2). On the other hand, diversity and evenness followed the same trend at most stations. High diversity was associated with high evenness, reflecting the multidominance pattern in cluster (2). Richness showed a different trend, decreasing with increasing diversity and evenness. The increase in richness was associated with decreasing salinity.

Table 2. Diversity index (H′) and evenness (E) in El-Dekhaila Harbour during 1998–1999 at the five stations

	Diversity index (H′)					Evenness (E)				
	St1	St2	St3	St4	St5	St1	St2	St3	St4	St5
April	1.74	0.60	0.81	1.23	0.8	0.62	0.19	0.10	0.44	0.25
May	1.87	2.15	0.79	1.4	1.88	0.72	0.86	0.17	0.53	0.75
June	0.99	1.36	0.21	0.39	0.97	0.29	0.40	0.70	0.12	0.32
July	0.81	1.13	0.56	1.25	1.65	0.28	0.36	0.27	0.47	0.54
August	1.19	0.99	0.28	1.22	1.31	0.44	0.36	0.68	0.43	0.52
September	1.94	1.78	0.46	1.9	1.22	0.65	0.64	0.36	0.62	0.49
October	1.79	2.0	0.32	1.54	1.57	0.66	0.68	0.64	0.47	0.54
November	1.68	1.98	0.42	2.41	2.18	0.49	0.68	0.44	0.76	0.68
December	1.52	2.17	0.56	2.21	1.99	0.53	0.69	0.38	0.86	0.90
January	1.61	2.22	0.83	2.1	2.29	0.90	0.92	0.13	0.91	0.84
February	1.54	2.13	0.76	2.23	1.96	0.7	0.78	0.17	0.78	0.79
March	0.33	0.08	0.14	0.43	0.52	0.10	0.03	0.86	0.14	0.18

The multiple correlations between salinity, diversity indices and standing crop showed a significant and negative correlation, except for the diversity index, where the correlation is positive at p = 0.05 and $R^2 = 0.52$:

Salinity = 37.9+1.98 (H′)−9.725 (E)−0.437 (R)−0.109 (Standing crop).

For the dominance biomass curve (ABC), species are ranked by order of importance on the x-axis (logarithmic scale) with percentage dominance on the y-axis (cumulative scale). The ABC curve for El-Dekhaila Harbour showed that the k-dominance curve for numerical abundance lies above that for the biomass for part of the curve, while both curves coincide more or less for another segment of the curve. The numerical curve runs below that of the biomass curve on the other segment (Fig. 5).

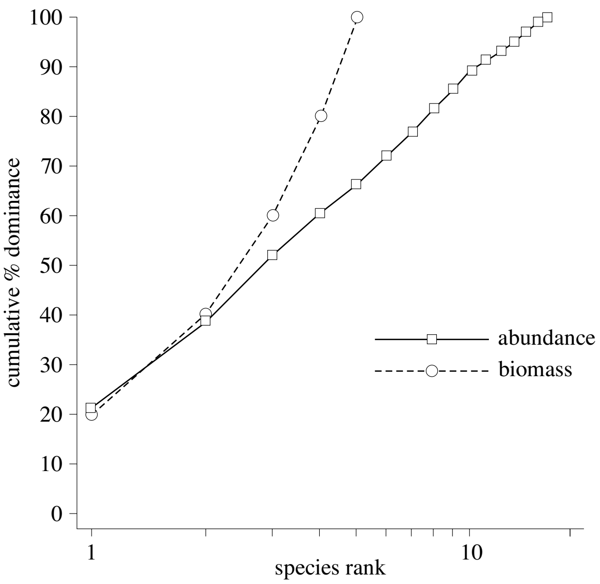

Fig. 5. K-dominance curves for species biomass and numbers in El-Dekhaila Harbour during 1998–1999

4. Discussion

The results show salinity to be the most important factor controlling the phytoplankton succession in El-Dekhaila Harbour. The increase in richness with decreasing salinity results from the introduction of brackish water species, in addition to the tolerant species already existing in the harbour.

The univariate analysis in El-Dekhaila Harbour showed that there was no clear relation between species richness and the diversity index. This is compatible with Reed (1978), who found that diversity indices were closely related to evenness, whereas species numbers (richness) were unimportant in determining species diversity for plankton and microbenthos. Although Balloch et al. (1976) found the diversity index (H′) to be a suitable indicator for water quality, Hughes (1978) concluded that this index was useful for community structure, but could not stand alone for assessing environmental quality. According to Margalef (1968), the diversity index, measured in bits per cell for populations of phytoplankton represented by samples of hundreds or thousands of cells collected by standard oceanographic sampling procedures, fluctuates around 2.5 bits in actively growing coastal populations. It is lower in estuaries, and is close to 3.5 and 4 in later stages of succession in more stable waters (Margalef 1967). In freshwater lakes the diversity ranges between 1 and 2.5 bits per cell in eutrophic lakes and up to 4.5 bits per cell in oligotrophic and dystrophic ones (Margalef 1964). Applying this criterion to phytoplankton diversity during the present study, it could be assumed that, with the exception of Station (3), El-Dekhaila Harbour is a eutrophic basin for most of the year, as the diversity index (H′) ranged from 0.08 to 2.4 indiv./bit.

The ABC approach is highly recommended by Warwick (1986), who stated that in 22 cases of comparison between species biomass and number curves, only one case has given a false impression of the pollution status of the benthic community. Warwick et al. (1987) suggested that the abundance/biomass comparison is a suitably abbreviated descriptor of the state of pollution and its effect on marine macrobenthos. The advantage of distribution plots such as the k-dominance curve is that the distribution of species abundances among individuals can be compared at the same time, since they have different units of measurements. This is not possible with diversity indices (FIR/MEDPOL/ALE/2 1991). With the exception of Ignatiades & Karydis (1990), who used k-dominance curves to describe temporal patterns for phytoplankton distribution in Saronicos Gulf, the ABC approach has not been applied to phytoplankton.

According to Warwick (1986), in unpolluted communities, the k-dominance curve for biomass lies above that for numbers. In moderately polluted communities, both curves roughly coincide, and in grossly polluted communities the numbers curve lies above the biomass curve. For El-Dekhaila Harbour, the ABC curve showed that the k-dominance curve for numerical abundance lies above the biomass for part of the curve when clusters (1) and (3) are dominant, but below it on the other part when cluster (2) is dominant. Such a pattern may indicate unpolluted or moderately to grossly polluted conditions in El-Dekhaila Harbour.

The above results appear to show that the combination of univariate and multivariate analysis with the ABC curve provides a promising tool for the characterization of phytoplankton dynamics under stressing conditions. All earlier studies in Mex Bay concluded that the phytoplankton community was stressed by the large and continuous outflow from El-Umoum effluents (Dorgham et al. 1987, Dorgham 1997, Mikhail 1997). The general conclusion of the present work, however, is that the phytoplankton in El-Dekhaila Harbour is not stressed by the inflow of brackish runoff from the El-Umoum outfall but rather by the occasional inflow of offshore sea water. A higher diversity and evenness obtained when cluster (2) became dominant, whereas diversity was lowest during April–May 1998 and March 1999, with clusters (1) and (3) dominant. On the other hand, the ABC curve highlighted stress during the phases of dominance of clusters (1) and (3), and moderate or no stress during the dominance of cluster (2). In this harbour the community is better adapted to the brackish than to the marine environment.

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