

Dataset and database biodiversity of plankton community in Lebanese seawater (Levantine Basin, East Mediterranean)

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Abstract

Oceanographic data were obtained from ship cruises conducted from 1965 until 2003 in the neritic and oceanic Lebanese waters (Levantine Basin). They include, in addition to Plankton community diversity and abundance, main hydrographic data such as temperature, salinity, dissolved oxygen, water transparency, chlorophyll a, nitrates and phosphates. The purpose of this work was to elaborate a dataset and database for the biodiversity of the plankton community in relation to the hydrological conditions of the area and the abundance of species populations. Spatial and temporal qualitative and quantitative distributions of the species and groups are strongly correlated to seasonal variations of hydrological parameters. The thermal annual cycle splits up in two different phases: a cold phase in winter (December-March) and a warm phase in summer (June-November), separated by a short spring inter-season. During the winter period, isothermal conditions prevailing in the 0-200 m water column are characterized with relative low temperature and salinity averages, poor plankton productivity and low biomass contrasting the high species diversity. The warm phase in summer is characterized by high surface water temperatures and salinity, accompanied with the formation of a thermocline in the layer 35-75m and a water layer stratification, which creates a hydro-thermal barrier avoiding exchange of water masses and vertical migration of organisms and low plankton biomass and diversity. A short spring period (April-June) is characterized by optimal hydrographic conditions that induce phytoplankton growth leading sometimes to little blooms, followed by high zooplankton production contrasting the low species diversity. During the long-term survey we noticed certain hydrological changes in the Levantine Basin, expressed by small rises in temperature ($\Delta T=0.4^{\circ}\text{C}$) and salinity ($\Delta S= 0.35\text{‰}$) and increasing migration. To date 400 phytoplankton species and more than 750 zooplankton taxa, were identified in the area, of which dozens of introduced exotic species are of Indo-Pacific origin. These changes induced some ecological evolutions in the marine ecosystems and are due to the regulation of the water level of the Nile by the Aswan High Dam by reducing the amount of freshwater outflow in the Mediterranean, and the deepening of the Suez Canal accelerates the northward current and thus facilitates the migration process. Global warming may also contribute to these hydrological changes in generating a certain “tropicalisation” of the Levantine Sea.

Keywords: Lebanese waters; Levantine Basin; Plankton dataset; Biodiversity.

Introduction

The Eastern Mediterranean, particularly the Levantine Basin, is the most impoverished and oligotrophic water body in terms of productivity and nutrient concentration (Krom *et al.*, 1991). There is a well-defined eastward trend in nutrient ratios over the entire Mediterranean that starts at the Gibraltar straits, and continues through the western basin, towards the eastern basin. The supply of nutrients to the Mediterranean is limited by inputs from the Atlantic Ocean and those of various rivers surrounding the sea (Hecht and Gertman, 2001). These authors have found that the surface layer to a depth of 150m had a nitrate concentration of less than $1\mu\text{mole.l}^{-1}$ and the maximum reached was 5.4 - $6.5\mu\text{mole.l}^{-1}$. Comparing the nutrient distribution and budget in the Mediterranean and the Red Sea, Souvermezoglou (1988) suggested that the Mediterranean receives 70% of its nutrient supply from the Atlantic, the rest of nutrients being provided by the rivers. The low concentration of nutrients, namely phosphates, nitrates and silicates induces low primary production due to poor chlorophyll content (Berman *et al.*, 1984). The strong evaporation and the shortage of freshwater input, makes of the Levantine Sea a concentration basin with a relative warm and high saline water body, where the temperature and salinity are the highest of the whole Mediterranean (Lacombe and Tchernia, 1972). The water masses mixing during homothermic winter period provide nutrients from the deep layers to the euphotic zone (Dugdale & Wilkerson, 1988; Ediger *et al.*, 1999). It has been demonstrated that the near-bottom chlorophyll-maxima are recorded in summer between 90 and 120m below the thermocline and above the sediments and over the continental shelf in the southeast Mediterranean off the Israeli coast (Townsend *et al.*, 1988); The bottom sediments can constitute the main source of nutrients for picoplankton and nanoplankton development and thus for chlorophyll-a and zooplankton production.

Very little was known about the Levantine Intermediate Water (LIW) and deep circulation in the Eastern Mediterranean until 1991. After the POEM results were revised and added to the Meteor expedition 1995, new findings were introduced regarding a big transition in the circulation of LIW. Malanotte-Rizzoli *et al.* (1998) have suggested that the LIW formed inside or in the periphery of Rhodes gyre is blocked in its westbound route by a three-lobe strong anticyclonical structure in the Southern Levantine, which induces a substantial LIW recirculation in the Levantine Basin itself.

The general circulation along the coast of Lebanon is dominant in northward direction during most of the year, in accordance with the general counterclockwise current gyre of the Eastern Mediterranean. This current is locally modified by the configuration of the coastline and the topography of the narrow continental shelf. This results in a series of clockwise directed eddies and small gyres associated with bays and headlands as well as with numerous submarine canyons incised in the continental shelf (Goedicke, 1972). Water movements along the coast are strongly associated with surface currents and seasonal meteorological factors. More detailed hydrographic data and its relation to plankton biodiversity were reported in previous work (Lakkis *et al.*, 1996; Lakkis, 1997).

The spatial and temporal variability in plankton communities is mainly correlated to seasonal hydro-climatic factors prevailing in the area. Seasonal changes in the quality

and quantity of plankton are very pronounced, whereas inter-annual fluctuations are more regular and show little variability (Lakkis and Novel-Lakkis, 1981).

The purpose of this paper is to highlight a plankton dataset and biodiversity in the Lebanese sector over a long-term survey 1965-2003, along with seasonal variations and inter-annual fluctuations.

Methods and materials

The study area extends over 150 km between the south of Lebanon ($33^{\circ}42' - 34^{\circ}28'N$) and offshore Tripoli city in the north ($35^{\circ}27' - 35^{\circ}31'E$), covering a total of 46 stations in the neritic waters and offshore in deep oceanic area (Fig. 1). Monthly, seasonally and annual cruises were carried out between 1965 and 2003. Surface and vertical plankton samples accompanied with hydrology measurements were taken, including plankton nets tows, temperature, salinity, dissolved oxygen, phosphate, nitrate, chlorophyll-*a*, and pH. Samples were taken at nine standard depths 0m, 10m, 25m, 35m, 50m, 75m, 100m, 150m, 200m.

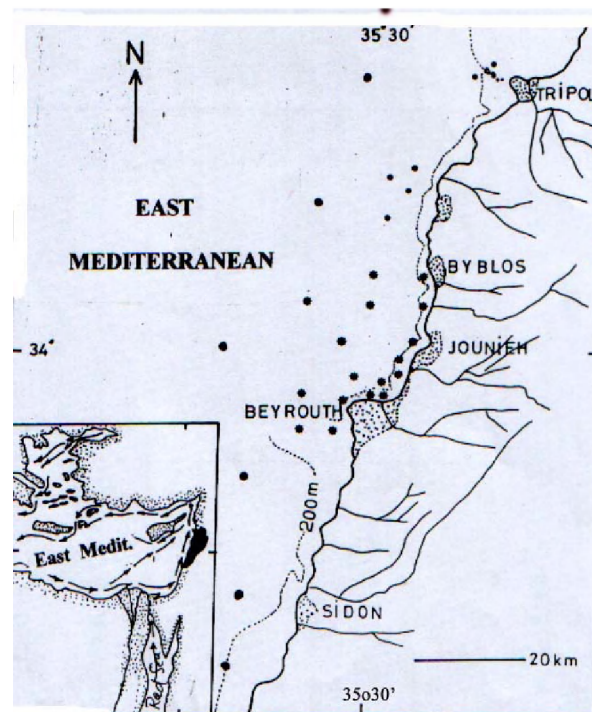


Fig. 1. Location of sampling stations along the coast of Lebanon during 1965-2003. Large spots: monthly and seasonally visited stations; small spots: irregularly or occasionally stations. Contour of the narrow continental shelf is indicated by dotted line. The insert indicates the general circulation in the Levantine Basin.

Monthly and seasonally cruises carried out during 38 successive years have provided a total of 2399 zooplankton samples and 1200 water samples for phytoplankton, chlorophyll-*a* and nutrient analysis (Figs. 2, 3). STD Hydro-bios electronic probe was used for measuring in situ temperature and salinity; and an Oxygen-meter and pH-meter probes were used for measuring dissolved oxygen and pH data. Niskin and Nansen reversing bottles were used to collect water samples for chemical analysis and CHL-*a* detection/analysis. Nitrate and phosphate were analyzed according to Strickland and Parsons (1972); while CHL-*a* was determined using Parsons (1969) for the determination of photosynthetic pigments in seawater. Vertical tows of coupled plankton nets of 50 μ (for microplankton) and 200 μ (macrozooplankton) were subject to qualitative and quantitative analysis.

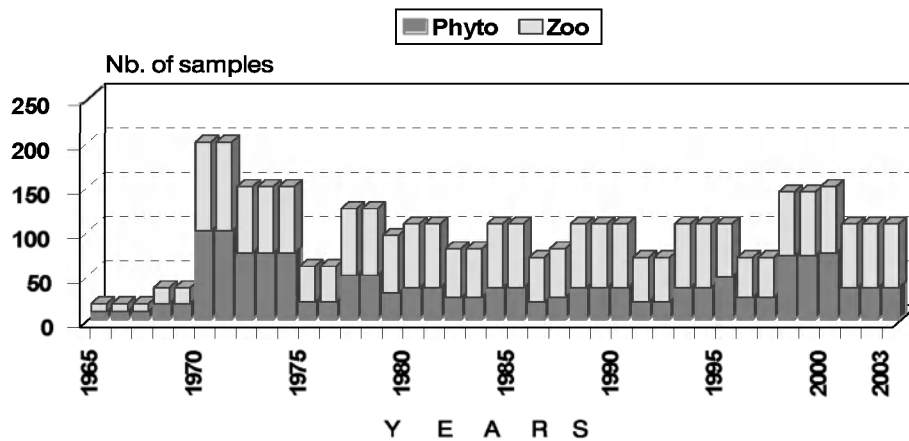


Fig. 2. Number of zooplankton samples (light column) and phytoplankton (dark) collected in the Lebanese seawaters during between 1965 and 2003.

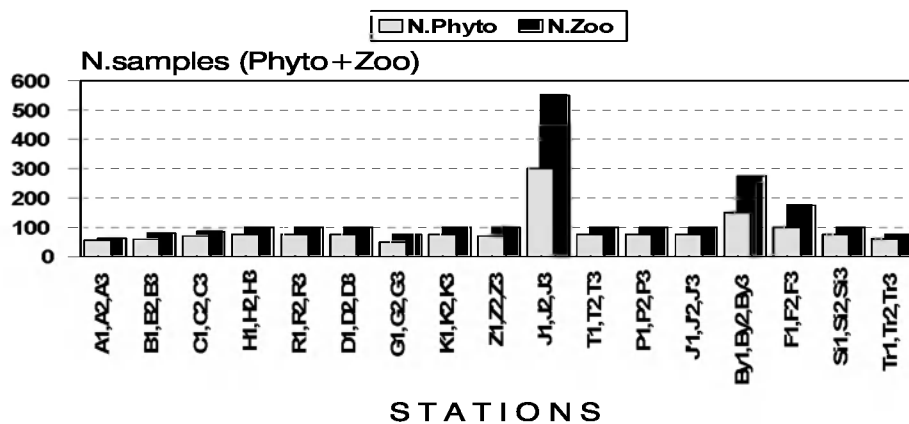


Fig. 3. Total Number of zooplankton samples (dark column) and phytoplankton (white) per station during 1965-2003.

Taxonomic identification was done up to species level; the abundance was reported as cells. l^{-1} for phytoplankton and chlorophyll a in mg.m^{-1} , whereas the zooplankton was reported as number of organisms per m^{-3} and/or cc.m^{-3} and mg.m^{-3} of dry weight of wet weight. Details of oceanographic data were reported in the IOC/EU project of MEDAR/MEDATLAS II (Maillard *et al.*, 2001; Lakkis, 2002).

Dataset

The plankton samples and hydrographic profiles taken during the long-term survey (1965-2003) constitute the basic elements for the Biodiversity database of Plankton community.

Results

Hydrological properties of the Lebanese seawater

Two annual thermal phases characterize the Levantine basin including Lebanese waters: a cold phase in winter (December-March) and a warm phase during the hot and dry long summer (June-November). A short spring inter-season separates the two periods.

Cold phase

The cold phase corresponds with the winter season (December-March); it is characterized by relative cold seawater (17°C) with isothermic conditions in the water column, due to mixing and turnover of water masses. Big amount of freshwater input from runoff and rivers reduce the surface salinity at offshore stations to its minimum in February-March (38.95 ± 0.41) (Fig.4).

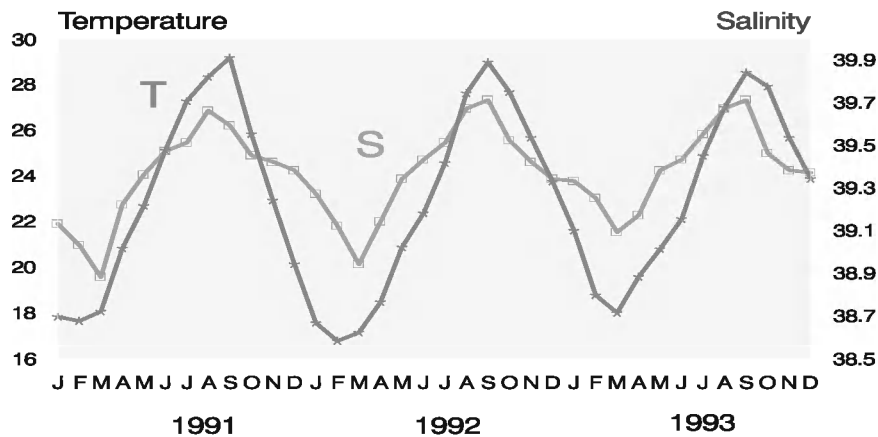


Fig. 4. Seasonal variations of Temperature and Salinity at surface offshore Lebanese seawater during three successive years at one offshore station J2.

Concentrations of nutrients reach their maximum levels in January ($\text{PO}_4=0.25 \mu\text{mole.l}^{-1}$; $\text{NO}_3=0.33 \mu\text{mole.l}^{-1}$); whereas $\text{CHL-}a$ is low during this period, averaging $0.09\pm0.04 \text{ mg.m}^{-3}$ for the season. Phytoplankton standing crop is very poor and zooplankton biomass is at lowest annual values, contrasting with high species diversity (Lakkis, 1997).

Warm phase

This phase coincides (if past tense, there should be past tense in cold phase and probably a year) with the hot long period of summer (June-November), during which the thermocline is formed between 35 and 75 m, accompanied by water column stratification. Surface water temperature increases to reach its maximum in August or September with a peak of 30°C . Salinity reaches a maximum of $39.62\text{‰} \pm 0.15$ in September at offshore stations, which is the highest value in the entire Mediterranean. Low phosphate and nitrate concentrations during this period, coincides with the lowest $\text{CHL-}a$ of the whole year ($0.07\pm\text{mg.m}^{-3}\pm0.05$). Dissolved oxygen at the surface drops to its lowest level in August ($5.72 \text{ ml.l}^{-1}\pm0.03$) due to rising temperature.

Spring Inter-season

This short phase corresponds to the spring season (April-June) and is characterized by optimal hydrological conditions suitable for phytoplankton growth, leading sometimes to a little bloom at coastal water with high $\text{CHL-}a$ values ($0.41\text{mg.m}^{-3}\pm0.12$). Water temperature varies between 21°C in April and 23°C in June, while moderate salinity varies between 39.35‰ and 39.42‰ respectively. Dissolved oxygen in the euphotic zone is correlated to high phytoplankton standing crop. Nutrient concentrations drop to minimum averages in June for phosphate ($0.05\mu\text{mole}\pm0.01$) and in May for nitrate ($0.17\mu\text{mole}\pm0.09$). This decrease is due to the use of nutrients by the microalgae for their growth.

Taxonomic Diversity of Plankton Community

Plankton community of the central Levantine Basin, although impoverished, remains diversified; most of Mediterranean groups of species are present. Several species of Indo-Pacific origin have migrated through the Suez Canal to establish permanent populations confined to the Eastern Mediterranean. Few of them have in mean time extended to the Western Basin.

Phytoplankton

About 400 phytoplankton species were found in the Lebanese waters, including 160 diatoms and 230 dinoflagellates. Some silicoflagellates were also identified. The composition of the phytoplankton populations varied in space and time. Several species occur permanently; they are found all year round, whereas many others are encountered only during some months of the year (Lakkis & Novel-Lakkis, 1981). The major taxa are given in Fig. 5 and Table III.

Table III: Taxonomical composition of Phytoplankton community.

Group	Families	Genera	Species
Bacillariophyceae	15	46	151
Dinoflagellata	14	33	227
Silicoflagellata	3	3	5
Ebriidae	2	2	2

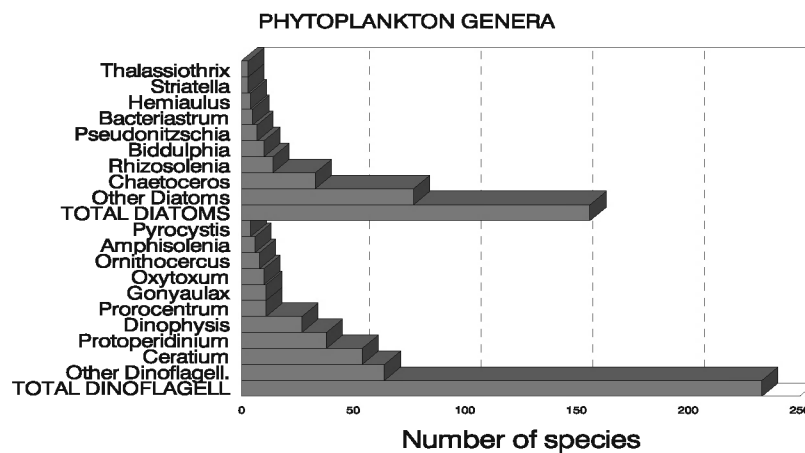


Fig. 5. Taxonomic Diversity of Phytoplankton community in Lebanese seawaters during 1965-2003.

The seasonal distribution of the most common and more frequent species is as follows:

Winter: *Chaetoceros curvisetus*, *Ch. pseudocurvisetus*, *Ch. decipiens*, *Leptocylindrus danicus*, *Skeletonema costatum*, *Pseudonitzschia fraudulenta*, *P. seriata*, *Cerataulina pelagica*, *Dinophysis caudata*, *Protoperidinium divergens*, *P. diabolus*.

Spring : *Ch. pseudo-curvisetus*, *Skeletonema costatum*, *Leptocylindrus danicus*, *L. minimus*, *P. fraudulenta*, *P. seriata*, *P. pungens*, *P. closterium*

Summer-Fall: *Chaetoceros affinis*, *Ch. brevis*, *Ch. didymus*, *Ch. Anastomosans*, *Ch. rostratus*, *Streptotheca thamesis*, *Rhizosolenia calcar-avis*, *Bacteriastrium elegans*, *Ceratium furca*, *C. pulchellum*, *Dinophysis caudata*, *Protoperidinium divergens*, *P. Diabolus*, *Dinophysis caudata*, *Prorocentrum micans*.

Monthly changes in species diversity and abundance of phytoplankton depend on hydro-climatic factors and hydrological conditions. At offshore stations, surface temperature ranges between 16°C in February, and a maximum of 30°C in August. Seasonal variability of salinity is small; it ranges between 39.29‰±0.49 in March and 39.62‰±0.34 during September). Nutrient concentrations display strong monthly variations at the surface, with a maximum in January for phosphate ($0.25\mu\text{mole}\pm 0.05$) and nitrate ($0.33\mu\text{mole}\pm 0.15$) and a minimum in June (phosphate) and May (nitrate). CHL-a displays great seasonal variations, the minimum average is recorded in September ($0.07\text{mg}\cdot\text{m}^{-3}$) and maximum in May ($0.39\text{mg}\cdot\text{m}^{-3}$) at open sea.

The annual cycle of phytoplankton displays two peaks: a major one in May-June and a 2nd less important one in October-November. In summer, during the water stratification, the plankton at the surface water is very poor in quantity as well as in diversity (Fig. 6). At 10-25 m the phytoplankton is more abundant and more diversified than at the surface. In winter the isothermic conditions and the turnover of water masses are not suitable for phytoplankton growth, which keeps densities at a low level.

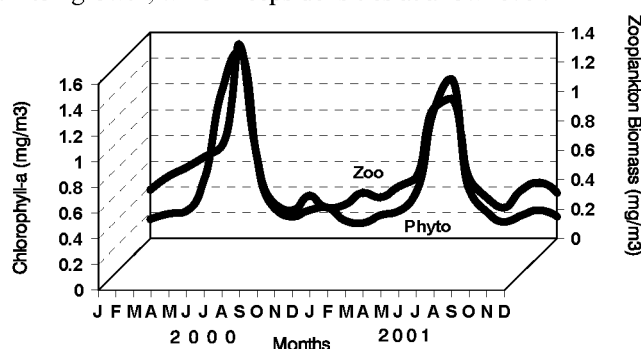


Fig. 6. Seasonal variations of chlorophyll a and Zooplankton at surface offshore station J2 during 2000-2001.

During spring (April-May) phytoplankton reach their maximum abundance ranging between 50.000 and 100.000 cells.l⁻¹. At the same time, the diversity is very low, because of the dominance of few species. In summer, following the breakdown of spring phytoplankton bloom, the cells density drops to 3000-10.000 cells.l⁻¹. Abundance of phytoplankton and chlorophyll-a shows a decreasing gradient from coastal waters towards offshore deep waters. Regarding the vertical distribution, the phytoplankton is abundant at the upper 50 meters and decreases drastically to disappear at 100m. However during summer and fall, the maximum depth for chlorophyll is recorded over the bottom sediment at 90-120 m due to source of nutrients from the regeneration of benthic organic substances.

Zooplankton

To date about 1000 zooplankton taxa were identified in the Lebanese seawaters, including all the planktonic groups from protozoans up to prochordates (Larvacea and Fish larvae). 250 microplankton species were found, of which 141 Tintinnids, 25

Foraminifera, 10 Acantharia, 25 Radiolaria Spumellaria, 30 Nasselaria, 6 Phaeodaria and 1 Heliozoa; many of them are of Indo-Pacific origin, present in the Red Sea.

Macrozooplankton includes all species from Hydromedusae up to Tunicates and fish larvae (Fig. 8, Table 4). The zooplankton community shows pronounced seasonal variations in diversity and abundance. A close phytoplankton-zooplankton relationship is always observed in the area (Fig. 7). The seasonal distribution of zooplankton is resumed as follows:

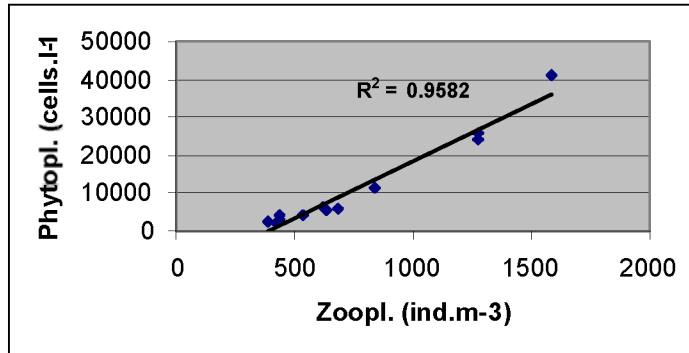


Fig. 7. Phytoplankton-Zooplankton relationship in the Lebanese waters during 2000 at offshore station J2.

Table 4. Taxonomical composition of Zooplankton community in the Lebanese seawaters during 1965-2003.

Group	N. species	Group	N. species
Foraminifera	12	Mysidaceae	4
Actinopoda	66	Cirripedia (larvae)	4
Tintiniidae	141	Decapoda (larvae)	110
Hydromedusae	68	Chaetognatha	10
Scyphozoa	5	Pteropoda	9
Siphonophora	28	Heteropoda	4
Copepoda	173	Polycheata (larvae)	8
Cladocera	6	Polycheata (adults)	4
Ostracoda	6	Appendicularia	15
Amphiopda	25	Thaliacea	6
Euphausiacea	5	Eggs & fish larvae	90

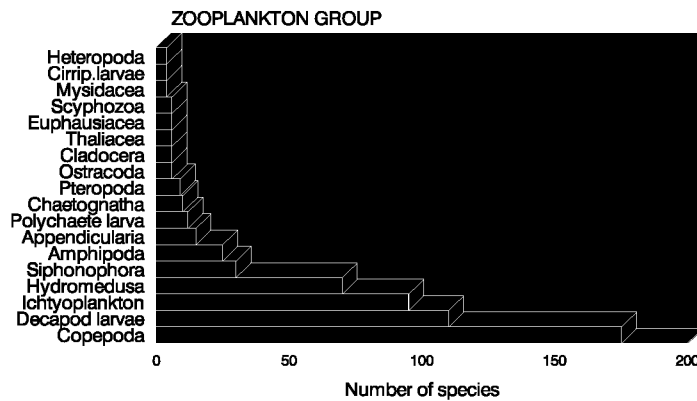


Fig. 8. Taxonomic Diversity of Zooplankton community in Lebanese seawaters during 1965-2003.

Winter: During the isothermic conditions, the zooplankton occurs in low abundances, but with high species diversity. Most of the species found at the surface are mesopelagic forms and are carnivorous, for example large Copepods, Siphonophora, Hydromedusae, Chaetognatha, etc...

Spring: With optimal temperature, and following the phytoplankton growth, the zooplankton starts to develop, namely herbivorous species reach the maximum of their abundance in May-June. Among those we mention phytoplankton filter feeders: Copepods, Appendicularia, Thaliacea, several small larvae.

Summer-Fall: After the break-down of the microalgae bloom in June-July, the abundance of zooplankton starts decreasing, to reach a minimum in August-September, coinciding with the stratification of water layers and the heavy thermocline which form a thermic barrier to the ascent of elements from the depth to the surface. Many groups became rare, whereas the meroplankton is enriched with various planktonic larvae of benthic organisms such as: Polychaeta Crustacea, Mollusca, Echinodermata and pelagic namely fish eggs and larvae, Crustacea and Cephalopoda larvae.

Exotic and Introduced species

36% of the dinoflagellates and 26% of diatom species present in the Levantine Basin including Lebanese sector, inhabit also the Red Sea; 45% of the planktonic fauna are common in the two marine Environments (Halim, 1969; Lakkis, 1980), most of them are considered as Lessepsian migrants (Table V). Migration process from the Red Sea into the Mediterranean, began after the opening of the Suez Canal in 1869. Previously to this period, few data on introduced species of fauna and flora of the area existed. More attention was given afterwards to the oceanography of the Eastern Mediterranean regarding the diversity and the impact of migration species (Por, 1978; Gurney, 1927).

Table V. Number of species in each planktonic group found in Lebanese waters. The number of exotic species, commonly found in the Red Sea and Levantine Basin.

Code	Group	Nb.species in Lebanon	Nb.species in common with Red Sea
DIA	Diatoms	160	40
DIN	Dinoflagellates	230	70
TIN	Tintinnids	141	40
FOR	Foraminifera	25	-
RAD	Radiolarian	25	?
HYD	Hydromedusae	74	11
SCY	Scyphomedusae	8	4
SIP	Siphonophores	28	18
PTE	Pteropoda	8	4
HET	Heteropoda	4	?
POL	Polychaetes & larvae	-	-
LCL	Cladocera	6	2
AMP	Amphipoda	25	7
COP	Copepoda	175	50
DEC	Decapod larvae	109	?
CHA	Chaetognatha	10	5
THA	Thaliacea	6	4
APP	Appendicularia	15	8
ICH	Ichthyoplankton	95	15

Inter-annual fluctuation

Variability between years of hydrology and plankton data are not very big; similar patterns in seasonal variations are observed from year to year depending on the parameters measured. The coefficient of variations for temperature between the years was 10% and for salinity 0.04% at the same stations. Inter-annual variability between the concentration of Chl.a was bigger than those for zooplankton biomass, respectively 25% and 15% (Fig. 9).

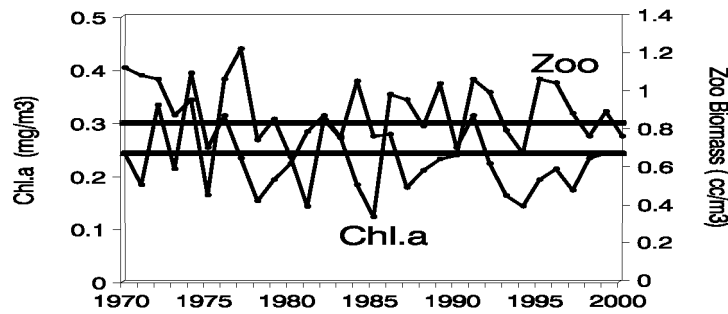


Fig. 9. Interannual fluctuations of Zooplankton biomass and Chl.a at surface seawater.

Discussion and conclusion

The eastern Mediterranean is a highly oligotrophic water body and a typical region of low productivity, due to limited nutrient supply in the euphotic zone (Ediger *et al.*, 1999). The hydrological and plankton time series data showed a clear regularity with minima and maxima, namely at surface layers. Seasonal variations of hydrological parameters and plankton in deep water are not as pronounced as at the surface. Inter-annual fluctuations are very similar year to year; on the other hand, they are more important between inshore and offshore waters. Vertical distributions of plankton data are more pronounced in the euphotic zone and neritic waters than in oceanic zone. These results are similar with those obtained in North East Mediterranean region, *e.g.* Iskenderoun Bay (Ylmaz and Tugrul, 1998). The extent of these variations is due mostly to hydro-climatic factors and nutrient cycles prevailing in the upper layers.

The water stratification and the heavy thermocline are more pronounced in the Levantine Basin than in other Mediterranean regions (Hecht, 1992). Vertical distribution of temperature is determined by the thermocline in summer and by isothermic conditions in winter; it has a great impact on vertical distribution of planktonic organisms. These spatial changes in plankton composition and abundance are significant between stations and between levels. Seasonal variation patterns of both phytoplankton and zooplankton are mostly similar between stations and between years, with a maximum in spring and a minimum late summer.

Over the 33 years of survey, we noticed certain changes in some hydrological parameters. During the last four decades we have observed 0.35‰, increasing salinity and 0.40°C temperature. This change is mainly due to the stop of the Nile flood after the building of the Aswan High Dam; the global warming might have some effect in this respect as well. During the last four decades, a certain “tropicalization” of the Levantine waters was observed (Lakkis *et al.*, 2003). This natural phenomenon is expressed by the increasing trend of the temperature and salinity that became close to those prevailing in the Red Sea. These hydrological changes have induced some ecological changes in the Levantine marine ecosystems, namely in the biodiversity following the Lessepsian migration of several marine species from the Red Sea to the Levantine basin.

Acknowledgements

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References

- Berman D.W., S.Z. El-Sayed., C.C. Trees and Y. Azov. 1984. Optical transparency, chlorophyll and primary productivity in the eastern Mediterranean near the Israeli coast. *Oceanologica Acta*, 7(3):367-372.
- Dugdale R.C. and F.P. Wilkerson. 1988. Nutrient sources and primary production in the Eastern Mediterranean. *Oceanologica Acta*, NS:179-184.
- Ediger D., S. Tugrul, C.S. Polat, A. Yilmaz and I. Salihoglu. 1999. Abundance and elemental composition of particulate matter in the upper layer of northeastern Mediterranean. *The Eastern Mediterranean as Laboratory Basin for the Assessment of Contrasting Ecosystems*:241-266.
- Goedicke T.R. 1972. Submarine Canyon on the central continental shelf of Lebanon. In: *The Mediterranean Sea: Natural Sedimentation Laboratory* D.J.Stanley Ed., 800p.
- Gurney R. 1927. Cambridge Expedition to the Suez Canal 1924. Copepoda and Cladocera of the Plankton. *Trans. Zool. Soc., London*, 22:139-173.
- Halim Y. 1969. Plankton of the Red Sea. *Oceanogr. and Marine Biology. Ann.Rev.*, 7:231-275.
- Hecht A. 1992. Abrupt changes in the characteristics of Atlantic and Levantine intermediate waters in the Southeastern Levantine basin 1992. *Oceanologica Acta*, 15(1):25-42.
- Hecht A. and I. Gertman. 2001. Physical features of the Eastern Mediterranean resulting from the integration of POEM data with Russian Mediterranean Cruises. *Deep Sea Research, Part I*, 48/8:1847-1876.
- Krom M.D., S. Brenner, I. Israilov and B. Krumgalz. 1991. Dissolved nutrients, performed nutrients and calculated elemental ratios in the south-East Mediterranean Sea. *Oceanologica Acta*. 14(2):189-194.
- Lacombe, H. and P. Tchernia. 1972. Caractères hydrologiques et circulation des eaux en Méditerranée, In: *The Mediterranean Sea; a Natural Sedimentation Laboratory*, edited by D.J. Stanley, Dowden, Hutchinson and Ross Stanley, 25-35.
- Lakkis S. 1971. Contribution à l'étude du Zooplancton des eaux libanaises. *Mar.Biol.* 11:138-148.
- Lakkis S. 1980. A comparative study of the plankton in the Red Sea and Lebanese waters. *Proc.Symp.Coast.Mar.Env. Red Sea,Gulf of Aden and Tropical W. Indian Ocean. (Khartoum)* Vol.2:541-559. UNESCO-ALECSO.
- Lakkis S. 1997. Long-time series of Hydrological and Plankton data from Lebanese waters (the eastern Mediterranean). *NOAA Technical Report NESDIS 87*:185-202.
- Lakkis S. 2002. Archiving and Rescue of oceanographic data since 1965 in the Lebanese water (Eastern Mediterranean). In: *Mediterranean and Black sea Database of Temperature and Salinity and Bio-chemical parameters Climatological Atlas. MEDAR/MEDATLAS II, 4CD, European commission (MAST)* .

- Lakkis S., A.E. Kideys, A.A. Shmeleva, E. Kovalev, E. Ünal and R. Zeidane. 2003. Comparison of Zooplankton biodiversity between Levantine basin and Black Sea, with reference to Alien species. Proceeding of the « Second International Conference on Oceanography of the Eastern Mediterranean and Black Sea: Similarities and Differences of two interconnected basins: 821-827.
- Lakkis S. and V. Novel-Lakkis. 1981. Composition, annual cycle and species diversity of the Phytoplankton in Lebanese coastal water. *Journal of Plankton Research*, 3(1):123-136.
- Lakkis S., G. Bitar, V. Novel-Lakkis and R. Zeidane. 1996. Etude de la Diversité Biologique du Liban. Flore et Faune Marines. PNUE & Min. Agric. Beyrouth, Liban, Publ. No 6:123p.
- Lakkis S., L. Jonsson, G. Zodiatis and D. Soloviev. 2003. Remote sensing data analysis in the Levantine Basin: SST and Chlorophyll-a distribution. Proceeding of the Second International Conference on Oceanography of the Eastern Mediterranean and Black Sea: Similarities and Differences of two interconnected Basins: 266-273.
- Maillard C., M. Fichaut, H. Dooley and Medar/Medatlas Group. 2001. Medar-Medatlas Protocol, Part I: Exchange format and quality checks for observed profiles. R.INT.TMSI/IDM/SISMER/SISOO-084.
- Malanotte-Rizzoli P., B. Manca, M.R. d'Alcala and A. Theocaris. 1998. The Eastern Mediterranean in the 80's and in the 90's. The Big Transition Emerged from POEM-BC Observational Evidence. Proceeding of NATO Advanced Research Workshop on the eastern Mediterranean as a Laboratory Basin for the Assessment of Contrasting Ecosystems. NATO Science Series; Kluwer Academic Publ.:1-7.
- Parsons T.R. 1969. The determination of photosynthetic pigments in sea-water. A survey of methods. Determination of photosynthetic pigments in sea-water, UNESCO:19-37.
- Por F.D. 1978. Lessepsian migration. The influx of the Red sea Biota into the Mediterranean by the way of the Suez canal. *Ecological Studies*. Springer Verlag, Berlin, N.York.
- Souvermezoglou E. 1988. Comparaison de la distribution et du bilan d'échanges de sels nutritifs en Méditerranée et en mer Rouge. *Oceanologica Acta, Océanographie pélagique méditerranéenne*, ed. H.J.Minas et P. Nival, No SP:103-109.
- Strickland J.D.H. and T.R. Parsons. 1972. A practical handbook of seawater analysis; 2nd ed. *Bull. Fish. Res. Board Can.*, vol 167, 311p.
- Townsend D.W., J. Christensen, T. Berman, P. Walline, A. Schneller and S. Yentsch. 1988. Near-bottom chlorophyll maxima in Southeastern Mediterranean shelf waters: upwelling and sediments as possible nutrient sources. *Oceanologica Acta*, No SP:235-244.
- Yilmaz A. and S. Tugrul. 1998. The effect of cold and warm-core eddies on the distribution and stoichiometry of dissolved nutrients in the northern Mediterranean. *Journal of Marine Systems*:253-268.