Asian Journal of Biology

5(2): 1-23, 2018; Article no.AJOB.38461
ISSN: 2456-7124

Plankton and Zoobenthos in the Southern Region of the Nile in Egypt: Community Structure, Relative Abundance and Diversity

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Authors' contributions

This work was carried out by the authors AME and IAI. The protocol was written by the authors AME and IAI. Designing of the field and laboratory investigations were performed by the authors AME and IAI. Management of literature searches was accomplished by the authors AME and IAI. The final manuscript was approved by the authors AME and IAI.

Article Information

DOI: 10.9734/AJOB/2018/38461
Editor(s):
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Complete Peer review History: http://prh.sdiarticle3.com/review-history/23367

Original Research Article

Received 27th November 2017
Accepted 5th February 2018
Published 27th February 2018

ABSTRACT

Major biological parameters along with nutrient concentrations of the Nile in Upper Egypt were analyzed during 2007 for a better understanding of community structure and diversity of the main functional groups of organisms. The abundance of plankton and zoobenthos was followed seasonally. Altogether 168 taxa (85 phytoplankton, 43 zooplankton and 40 zoobenthos) were encountered from the Nile in Upper Egypt. The combined contribution of chironomid larvae, Mollusca and Oligochaetae represented the abundant groups of the Nile zoobenthos throughout the study period. The results of this study suggested that the sediment contents of organic matter and $CaCO_3$, as well as water temperature and NO_3-N concentrations, seemed to be important in determining the abundance and biomass of zoobenthos. Most importantly, the results of this study will provide valuable information for river management. Simultaneously; alpha, beta, gamma and Shannon ($\grave{H}$) diversities of these communities were measured. Alpha and gamma diversities for

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phytoplankton were higher than those of zooplankton or zoobenthos. Shannon diversity index for the different groups was relatively low due to the less water retention of the lotic ecosystem. The composition similarity of the investigated samples and the weak rate of species displacement among sites were reflected by β diversity.

Keywords: Alpha; beta and gamma diversities; diversity index; functional groups; Nile water; upper Egypt; zoobenthos.

1. INTRODUCTION

Biodiversity of the aquatic habitats based on different estimated biotic indices can reflect community composition and describe the effect of water pollution on biotic communities [1,2]. Species composition and biotic interactions are directly responding to and influence community structure and function [3]. In this respect, [4] noticed that a set of complementary indices is required rather than using a single index for better explanations and comprehensive descriptions of biotic communities. Furthermore, the preferability of using multiple biological indices to reflect an overall picture of the aquatic ecosystem rather than using a single index was documented by [5].

Plankton and zoobenthos assemblages are regarded as the major functional groups of organisms in large rivers. Various local factors in addition to physicochemical and biological parameters appeared to be responsible for controlling the development and changes in the community structure of those assemblages [6].

The role of phytoplankton in such aquatic habitats is fundamentally vital and provides an important food resource to sustain other life forms. Diversity and abundance of river's phytoplankton are greatly related to the interaction of the river hydrology with different biotic and abiotic factors [7,8]. Consequently, riverine phytoplankton could be applied to ecological evaluation [9] and regarded as a valuable indicator of water quality [10]. Therefore, phytoplankton which constitutes autochthonous autotrophic production should be regarded as the most important feature of the large river ecosystems [11].

Zooplankton populations as primary consumers constitute an important biological element influencing the phytoplankton by grazing and in turn are consumed by predaceous zooplankton and other macroinvertebrates. Generally, in freshwater ecosystems, zooplankton community structure may reflect changes and indicate environmental pollution [12]. Due to their position in the food web, zooplankton has a relative importance of top-down and bottom-up control. They reflect the top-down regulators (fish), bottom-up factors (phytoplankton) and the status of the benthic fauna [13]. In addition, phytoplankton and zooplankton also form an important component of the diet for different planktivorous fish species. Furthermore, zoobenthos form another important food resource for fish and are able to be influenced by effects exerted by plankton.

Zoobenthos are among the most diverse and abundant constituents of the river biota where their production may exceed that of zooplankton [14]. They integrate the change in physical, chemical and ecological characteristics of their habitat and play a key role in the cycling of material and in energy flow. Thus, zoobenthos appeared to be critical when considered for ecological and biodiversity assessment [15].

The study of river zoobenthos for biological monitoring techniques was repeatedly described during the last few decades [16,17]. Freshwater macroinvertebrate species vary in their sensitivity to organic pollution [18] and subsequently, their presence or absence can be used to make inference about pollution loads. Biotic indices are numerical expressions combining a quantitative measure of species diversity with qualitative information on the ecological sensitivity of individual taxon [19]. Water-quality monitoring programs have been mainly based on the determination of physical and chemical parameters; in contrast, the biological assessment of rivers is very limited. While the study of zoobenthos as an impact indicator can reveal the occurrence of intermittent or unrecorded chemical pollution incident.

The Nile is one of the most important biologically diverse large African river ecosystems and its distinct hydrology may induce changes in biodiversity of plankton and zoobenthos. Consequently, the development of these communities, their species composition, and distribution pattern can reflect variations in seasonal succession, physical-chemical parameters and response to the industrial wastewater inputs. To the best of our knowledge, during the last few decades investigations concerning the Nile zoobenthos in Egypt were sparse. Most studies were taxonomic [20] or address small areas [21-25]. These works reported that the number of benthic macroinvertebrates in the Nile exceeded 50 species and the most abundant taxa were related to Mollusca, Insecta and Annelida.

The aim of this investigation was to document the major biological parameters of the main stream of the Nile in South Egypt. Those parameters in terms of composition, abundance and diversity of plankton and zoobenthos were investigated on the basis of qualitative and quantitative analyses. Hence, an additional link of the food chain in the large river ecosystems could be obtained.

2. STUDY AREA AND METHODS

2.1 Study Area

The study area is located in the upper part of the Nile in southern Egypt at Aswan district (24° 04` - 25º00` latitudes and 32º51` – 32º54` longitudes). Due to the relatively high industrial activities, the main stream of the Nile in this region receives wastewater discharged from agricultural drainage water, domestic wastes and industrial sewage from sugar cane and fertilizers factories. Mean annual value of water level is: 83.5 ± 2.12 m a.s.l. Current velocity fluctuations were around 1 $msec^{-1}$ with a mean annual value of 1.05 ± 0.35 $msec^{-1}$. The climate of this area is defined by aridity with annual precipitation of about zero mm and hot summer with high maximum temperature which often exceeded 45ºC.

2.2 Field Sampling and Laboratory Analyses

Twelve sites (Fig. 1) were selected in three locations for the present study, i.e. at each location, two sites along the west and two sites along the east side (one upstream and the other downstream of the wastewater discharge point).

Sampling was conducted over a one year period (2007) on a seasonal basis. Water temperature using an ordinary glass mercury thermometer calibrated to tens of a degree centigrade, transparency with a Secchi disc of 0.3 m diameter, pH value by a pH meter (Orion model 601/ digital ionalyzer, Orion, USA), conductivity, salinity with an Amber Science Inc. San Diego, CA, USA conductivity meter model 1062 and dissolved oxygen by an oxygen electrode (Jenway Oxygen meter, model 1070; Jenway, UK) were measured *in situ*. Water samples were collected using the water sampler Van-Dorn Bottle. Water contents of inorganic nutrients (NO_3^-, PO_4^-, SiO_2, SO_4^{2-}, Ca^{2+} and Mg^{2+}) and the sediment contents of organic matter were determined by methods described in [26]. For the sediment samples, calcium carbonate contents were determined using Collin-Calcimeter.

Phytoplankton biomass was presented by measurements of chlorophyll-*a* concentration. Chlorophyll-*a* was filtered through GF/C filters (47 mm; Whatman) and measured according to [27] with spectrophotometric measurements after extraction in 90% cold acetone. Numerical abundance of the Nile plankton was expressed as the number of both phytoplankton and zooplankton individuals (ind. L^{-1}). Aliquots of water samples were immediately fixed with 5% neutral formalin for preservation and further determinations of phytoplankton. After a sedimentation period of 48 hours in the laboratory, phytoplankton sub-samples were qualitatively and quantitatively determined microscopically. A counting cell of 0.1mL was used for enumeration of phytoplankton individuals. Zooplankton samples were collected with 50 µm mesh tow net. Samples were vertically hauled from 5 m to the surface at each sampling site. The samples were immediately fixed with formalin to a final concentration of 5%. In the laboratory, samples were concentrated, each concentrated original sample of 250 mL was mixed homogeneously and a one mL sub-sample was pipetted, and then poured into a counting cell where the different zooplankton individuals were identified and counted.

Duplicate samples of benthos were collected at each investigated site using Ponnar grab with an area of 225 cm^2. The living material of benthic organisms was immediately separated from the sediments by washing through a metallic sieve with a mesh size of 440 µm to sift the samples in the field. The separated groups were dried on filter paper and weighted after removing the shells of molluscs, and then the biomass was

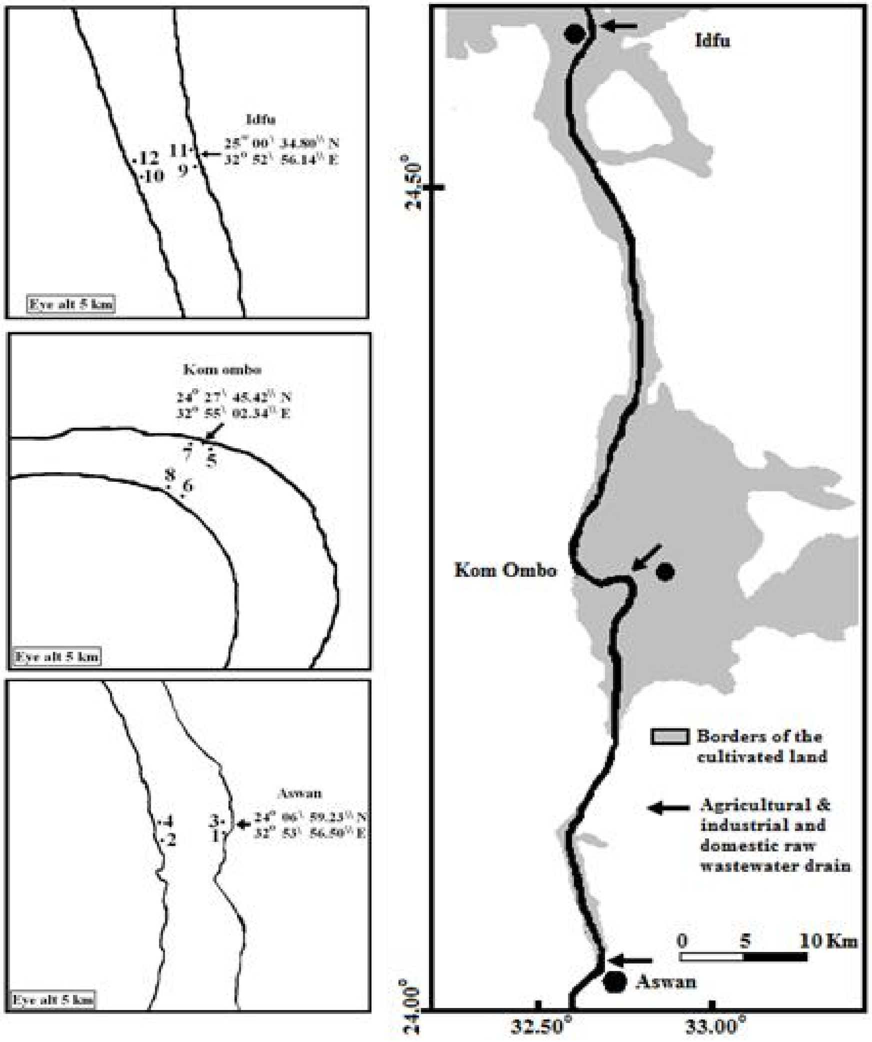

Fig. 1. Map showing the sampling sites along the main stream of the Nile.

estimated and expressed as gm^{-2}. Then, the samples were fixed with formalin solution at a final concentration of 5% to be preserved for further microscopic examinations. Numerical determinations were performed and presented as the number of individuals per square meter (ind. m^{-2}).

Phytoplankton species were identified according to the following manuals, keys and papers: [28-40]. In addition, zooplankton taxa were identified using the following principal taxonomic references: [41–57]. Furthermore, identification of zoobenthos were performed according to: [58,59] for insects; [60-63]; for identification of Oligochaetae: [64,65] for Mollusca; [66] was mainly used for identification of chironomid larvae.

2.3 Data Analysis

The relationship between abundance of the Nile zoobenthos and their environmental variables was assessed by calculating the simple linear correlation coefficient using MINITAB statistical software, INC, USA. Shannon-Wiener biodiversity index [67] was used to estimate community biodiversity. The calculations were layout by the following formula:

$$\dot{H} = - \Sigma Pi \ln Pi$$

Where pi is the relative abundance of i species calculated as the proportion of individuals of a given species to the total number of individuals in the community.

For each functional group of organisms; species richness as alpha diversity (α) was calculated at each investigated site in terms of the average number of species per sample, beta diversity (β) was calculated by measuring the species turnover as the ratio between the total number of species recorded for each site in the four sampling periods and its alpha diversity [68] and gamma diversity (γ) was estimated as the total number of species from all samples.

3. RESULTS

3.1 Water Quality and Plankton Communities

Table 1 displays the data of physical, chemical and biological analyses which were quantitated and reported for the Nile water throughout the study period. Temporal water temperature differences were relatively high. The decrease in water temperature in winter was accompanied by a considerable elevation in oxygen concentration and saturation levels as well as conductivity. Salinity, total hardness and pH showed invariably constant values during the entire investigation period. Transparency of the Nile water indicated good conditions for light penetration with relatively high Secchi Disc visibilities. The nutrient concentrations generally showed a wide range of variations with relatively recorded high differences between minimum and maximum levels. These variations reflected the seasonal development of the dissolved inorganic fractions of macronutrients (phosphorus and nitrogen). Levels of the dissolved silicate concentrations were well above concentrations usually accepted to restrain diatom growth. The maximum concentration appeared in summer, whereas the minimum was observed concomitantly as a consequence of uptake by diatoms in winter. Concentrations of SO_4^{2-} fluctuated between 7.61 and 16.85 mg L^{-1} due to biological activities or change in redox potential. The temporal difference in chlorophyll-*a* concentrations was obvious. Chlorophyll-*a* concentration peaked in autumn up to 16.29 μgL^{-1}. The lowest value of Chlorophyll-*a* concentration (2.23 μg L^{-1}) was observed in summer.

The representative plankton taxa are listed in Table 2. A total of 48 phytoplankton genera, 85 species, which belong to Cyanophyta (11 genus, 11species), Bacillariophyta (18 genus, 30 species), Pyrrophyta (2 genera, 2 species) and Chlorophyta (17 genus, 42 species) were recorded from the Nile water samples. Phytoplankton numerical abundance (10^4ind.L^{-1}) varied between 65.65 and 330.61 ind. L^{-1} with an average of 149.64 ind. L^{-1}. Bacillariophyta was the most abundant group followed by Cyanophyta. Chlorophyta comprised the most diverse group with respect to the number of genera and species, but they only accounted for about a mean value of 9.38% of the total phytoplankton density. Pyrrophyta was present throughout the year but never at high abundances. The most abundant species were the unicellular small centric; *Cyclotella meneghiniana* (38.88%) and the chain forming centric diatom; *Aulacoseira granulata* (23%) in addition to the filamentous cyanobacterium; *Planktolyngbya* sp. (8.77%).

Zooplankton community composed mainly of various taxa related to Rotifera, Cladocera, Copepoda, Ciliophora, Nemata and Platyhelminthes. Rotifers were the most represented group with a total of 25 taxa which were identified at the species level and one taxon at the genus level. For Copepoda, 3 species in addition to copepodite stages and Nauplius larvae were recorded. Besides, 2 genera, 7 species in addition to embryonic stages of Cladocerans were encountered. Furthermore, the rare zooplankton was represented by the scarcely recorded; Ciliophora, Nemata and Platyhelminthes. Numerically, Rotifers contributed 61.05% to the total zooplankton density, whereas Copepods and Cladocerans contributed 24.72% and 11.23%, respectively. The rare zooplankton (Ciliophora, Nemata and Platyhelminthes) collectively contributed about 3% of the total zooplankton population density. *Keratella cochlearis* dominated zooplankton community abundance throughout the study period. *Conochilus hippocrepis* was co-dominant. The relative densities of Cladoceran individuals were generally low with annual means of less than 5% of the total zooplankton density. Within the Copepods, Nauplius larvae and the copepodite stages were most common and contributed 11.89 and 6.84% to the total zooplankton population, respectively.

3.2 Zoobenthos

Forty taxa were recorded (Table 2) representing the community of the Nile zoobenthos in Upper Egypt. Twelve of those taxa were larvae of Chironomidae, 15 related to Mollusca and 4 to Oligochaetae. Besides, other rare fauna

Table 1. Mean values, standard deviation (SD), minimum and maximum levels of water physical, chemical and biological parameters along the main stream of the Nile in Upper Egypt during the investigation period

Parameters	**Mean values**	**SD**	**Range**	
			Minimum	**Maximum**
Temperature (°C)	20.25	0.64	15.00 (Wi)	25.0 (Su)
pH value	7.59	0.04	7.27 (Su)	7.84 (Sp)
Dissolved oxygen (mg L^{-1})	5.65	0.41	8.50 (Wi)	2.44 (Su)
Oxygen saturation (%)	64.08	4.50	29.83 (Sp)	94.34 (Wi)
Secchi depth (m)	4.30	0.67	2.75 (Au)	7.00 (Sp)
Electrical conductivity (µScm^{-1})	243.09	20.72	188.00 (Au)	395.00 (Wi)
Salinity (%)	0.10	0.01	0.08 (Au)	0.14 (Su)
Ca^{2+} (mg L^{-1})	30.09	1.57	20.00 (Wi)	38.48 (Su)
Mg^{2+} (mg L^{-1})	5.61	0.59	1.94 (Su)	8.75 (Au)
Total hardness (mg L^{-1})	35.69	1.33	24.80 (Wi)	42.05 (Su)
NO_3^- (µg L^{-1})	1377.54	454.26	393.23 (Su)	3264.72 (Sp)
PO_4^- (mg L^{-1})	41.33	9.14	9.99 (Sp)	101.80 (Au)
SiO_2 (mg L^{-1})	3.32	0.42	1.07 (Wi)	5.96 (Su)
SO_4^{2-} (mg L^{-1})	11.14	1.99	7.61 (Au)	16.85 (Su)
$CaCO_3$ (%)	2.02	1.34	0.57 (Au)	5.86 (Sp)
Organic matter (%)	3.40	2.26	1.28 (Wi)	10.21 (Sp)
Chlorophyll-*a* (µg L^{-1})	6.12	1.27	2.23 (Su)	16.29 (Au)
Total phytoplankton (10^4 ind.L^{-1})	149.64	12.14	65.65 (Sp)	330.61 (Au)
Cyanophyta (10^4 ind.L^{-1})	24.11	7.39	1.52 (Sp)	85.28 (Su)
Bacillariophta (10^4 ind.L^{-1})	108.23	11.49	29.94 (Su)	297.94 (Au)
Pyrrophyta (10^4 ind.L^{-1})	2.58	0.55	0.23 (Wi)	13.00 (Sp)
Chlorophta (10^4 ind.L^{-1})	14.03	2.46	3.72 (Su)	33.09 (Au)
Total zooplankton (10^4 ind.m^{-3})	2.67	1.84	0.64 (Wi)	6.6552 (Sp)
Rotifera (10^4 ind.m^{-3})	1.63	1.40	0.35 (Wi)	4.6728 (Sp)
Copepoda (10^4 ind.m^{-3})	0.66	0.38	0.06 (Au)	2.3628 (Su)
Cladocera (10^4 ind.m^{-3})	0.30	0.22	0.04 (Au)	0.9204 (Sp)
Rare forms (10^4 ind.m^{-3})	0.08	0.07	0.02 (Su)	0.3540 (Sp)
Total zoobenthos (10^4 ind.m^{-2})	0.48	0.67	0.02 (Wi)	3.74 (Sp)
Chironomid larvae (10^4 ind.m^{-2})	0.22	0.47	<0.01	2.97
Mullusca (10^4 ind.m^{-2})	0.13	0.18	<0.01	0.43
Oligochaetae (10^4 ind.m^{-2})	0.12	0.31	<0.01	2.07
Total rare fauna (10^4 ind.m^{-2})	0.17	0.02	<0.01	0.07

Seasons (in parentheses); Wi: winter, Sp: spring, Su: summer, Au: autumn, SD: standard deviation.

including Hirudinea, Platyhelminthes, Decapoda, unknown species of the larvae of Clucidae, nymph of Odonata, pupa of Chironomidae, nymph of Ephmeroptera, larvae of Trichoptera and Hemiptera (adult Corixidae) were also encountered.

Mean annual values of the total counts (4834 ind. m^{-2}) with a biomass of 15 gm^{-2} were recorded. The abundance of the Nile zoobenthos (Fig. 2) varied considerably among seasons with remarkable differences between east and west sites. At the west investigated sites, the densities of the Nile zoobenthos assemblages were of relatively higher values than those recorded at the east sites. Chironomid larvae and molluscs were abundant at the west sites; whereas, Oligochaete and chironomid larvae were more abundant at the east sites.

As regards the seasonal periodicity in the distribution of the Nile zoobenthos; Fig. 3 revealed that the highest density (mean values 37411 ind. m^{-2}) and biomass (56.8 gm^{-2}) was reached during spring at the northern investigated site (Idfu) due to the increased individual numbers of the chironomid larvae. Another peak (29650 ind. m^{-2}; 73.1 gm^{-2}), which was produced by increased individual numbers of Oligochaeta appeared during summer at the southern investigated site (Aswan).

Table 2. Average relative contribution (%) descriptive *taxa* to the total density of each functional group recorded along the main stream of the Nile in Upper Egypt during the investigation period

Phytoplankton	Author	%
Cyanophyta:		
Anabaena sp.	Bory de Saint-Vincent ex Bornet & Flahault	0.04
Anabaenopsis cunningtonii	Taylor	4.57
Chroococcus sp	. Nägeli	0.13
Gomphosphaeria sp.	Kützing	0.02
Merismopedia warmingiana	Lagerheim	1.24
Microcystis aeruginosa	Kützing	0.04
Oscillatoria sp.	Vaucher	0.50
Phormidium sp.	Kützing	0.29
Planktolyngbya sp.	Anagnostidis & Komárek	8.77
Planktothrix agardhii	(Gomont) Anagnostidis & Komárek	0.06
Spirulina sp.	Turpin	0.22
Bacillariophyta:		
Amphora ovalis	Kützing	0.15
Aulacoseira granulata	(Ehrenberg) Simonsen	23.00
Caloneis silicula	(Ehrenberg) Cleve	0.01
Cocconeis placentula	Ehrenberg	1.19
Cyclotella meneghiniana	Kützing Ehrenberg	38.88
Cymatopleura elliptica	(Brébisson) W. Smith	<0.01
C. solea	(Brébisson) W. Smith	0.07
Cymbella ventricosa	Kützing	0.79
Epithemia sorex	Kützing	0.02
Fragilaria ulna	(Nitzsch) Lange-Bertalot	4.20
Gomphonema acuminatum	Ehrenberg	0.01
G. olivaceum	(Hornemann) Brébisson	0.88
Gyrosigma acuminatum	Kützing	0.01
G. scalproides	(Rabenh) Cleve	0.01
Melosira varians	J. G. Agardh	1.37
Navicula bacillum	Ehrenberg	0.01
N. cryptocephala	Kützing	0.46
N. exigua	Gregory	0.73
N. gastrum	Ehrenberg	0.42
N. pupula	Kützing	0.05
N. rhynchocephala	Kützing	0.05
Nitzschia holsatica	Hustedt	0.42
N. parvula	W. Smith non Lewi	0.02
N. sigmoidea	(Nitzsch)	0.03
N. sp.	Hassall	0.15
Pinnularia sp.	Ehrenberg	<0.01
Rhoicosphenia curvata	(Kützing) Grun.	0.02
Rhopalodia gibba	(Ehrenberg) O. Müller	0.07
Surirella ovata	Kützing	0.12
S. robusta	Ehrenberg	0.07
Pyrrophyta:		
Ceratium hirundinella	(O. F. Müller) Dujardin	0.75
Peridinium sp.	Ehrenberg	0.95
Chlorophyta:		
Ankistrodesmus bibraianus	Korshikov	0.02

Phytoplankton	Author	%
A. falcatus	(Corda) Ralfs	1.35
A. spiralis	(Turpin) Lemmermann	0.23
A. stipitatus	(Chodat) Komárková-Legnerová	<0.01
Closterium aciculare	T. West	0.03
C. acutum	Brébisson	0.01
C. venus	Kützing	0.45
Coelastrum cambricum	Archer	0.21
C. microporum	Nägeli	0.06
C. reticulatum	(Danjeard) Senn.	0.27
Cosmarium botrytis	Meneghini	0.01
C. depressum	Lundell	0.04
Crucigenia rectangularis	(Nägeli) Gay	0.84
Dictyosphaerium pulchellum	Wood	0.90
Elakatothrix genevensis	(Reverdin) Hindák	0.53
Golenkinia radiata	Chodat	0.37
Kirchneriella lunaris	(Kirchner) Moebius	0.06
K. obesa	(W. West) Schmidle	0.06
Lagerheimia ciliate	(Lagerheim) Chodat	0.78
L. quadriseta	Lemmermann	0.08
Micractinium sp.	Fresenius	0.06
Oocystis solitaria	Wittrock	<0.01
O. sp.	A. Braun	0.04
Pediastrum biradiatum	Meyen	<0.01
P. boryanum	(Turpin) Meneghini	0.07
P. duplex	Meyen	0.01
P. simplex	Meyen	0.29
P. tetras	(Ehrenberg) Ralfs	0.02
Scenedesmus acuminatus	(Lagerheim) Chodat	0.12
S. acutus	Meyen	0.01
S. arcuatus	Lemmermann	<0.01
S. bijuga	(Turpin) Lagerheim	<0.01
S. ecornis	(Ehrenberg) Chodat	0.18
S. obtusus	Meyen	<0.01
S. quadricauda	(Turpin) Brébisson	0.30
S. sp.	Meyen	0.76
Schroederia setigera	(Schröder) Lemmermann	0.07
Staurastrum leptoclodum	Nordst	0.01
S. paradoxum	Meyen	0.68
Tetraedron caudatum	(Corda) Hansgirg	0.01
T. minimum	(A. Braun) Hansgirg	0.28
T. trigonum	Hansgirg	<0.01
Zooplankton		
Rotifera:		
Anuraeopsis fissa	Gosse	1.74
Asplanchna priodonta	Gosse	0.94
Brachionus angularis	Gosse	0.03
B. caudatus	Müller	0.03
B. calyciflorus	Pallas	0.93
B. patulus	Müller	0.66
B. rachionus angularis	Gosse	0.03
Cephalodella catellina	Müller	0.68
Conochilus hippocrepis	Schrank	8.71
C. hippocrepis (colonies)	Schrank	3.41
Euchlanis dilatata	Ehrenberg	0.07
Hexarthera mira	Hudson	0.06
Keratella cochlearis	Gosse	30.81

Phytoplankton	**Author**	**%**
K. procurva	Thorpe	0.06
K. tropica	Apstein	4.19
Lecane bulla	Gosse	1.88
L. depressa	Bryce	0.03
L. luna	Müller	0.94
L. lunaris	Ehrenberg	0.71
Lepadella ovalis	Müller	0.32
L. patella	Müller	0.30
Polyarthra vulgaris	Carlin	1.26
Proales sp.		1.26
Trichocerca chattoni	Beauchamp	0.17
T. longiseta	Schrank	2.43
T. similis	Wierzejski	0.47
Copepoda:		
Copepodite stages		6.84
Mesocyclops sp.	Claus	0.44
Nauplius larvae		11.89
Thermocyclops hyalinus	Sars	1.36
Thermodiaptomus galebi	Barrois	2.76
Cladocera:		
Alona intermedia	Müller	0.05
A. quadrangularis	Müller	0.47
Alona sp.		0.09
Bosmina longirostris	Müller	4.83
Ceriodaphnia cornuta	Sars	1.76
Ceriodaphnia sp.		0.01
Chydorus sphaericus	Müller	0.99
Daphnia barbata	Weltner	2.13
*Diaphanosoma excis*um	Sars	0.48
Embryonic stages of Cladocera		0.79
Other forms		
Ciliophora		0.28
Nemata		0.73
Platyhelminthes		2.01
Zoobenthos		
Chironomid larvae:		
Ablabesmyia sp.		0.06
Circotopus sp.		1.67
Chironomus sp.		0.27
Clinotanpus sp.		<0.01
Cryptochironomus sp		0.25
Dicrotendipes modestus		38.56
Microtendipes sp.		0.17
Nilodorum sp.		3.43
Orthocladius sp.		0.45
Polypedilum sp.		0.02
Procladius sp.		0.35
Tanytarsus sp.		0.10
Oligochaeta:		
Branchiura sowerbyi	Beddard	6.96
Hablotaxis sp.		0.02
Limnodirlus hoffmeisteri	Claparede	0.30
L. udekemianus	Claparede	17.53
Mollusca:		
Biomphalaria alexandrina	Ehrenberg	0.21
Bulinus truncatus	Audouin	1.61

Phytoplankton	**Author**	**%**
Bulinus sp.		0.03
Coleopatra bulimoides	Olivier	0.07
Corbicula fluminalis	Müller	0.06
Gabbiella senaariensis	Kuster	0.94
Gyraulus ehrenbergi	Beck	4.13
Helisoma duryi	Wetherbg	0.06
Lymnaea natalensis	Krauss	0.08
Melanoides tuberculata	Müller	0.26
Physa acuta	Darparnaud	1.37
Psidium pirothi	Jickeli	0.16
Spharium sp.		0.40
Theodoxus niloticus	Reeve	0.42
Valvata nilotica	Jickeli	16.65
Rare fauna:		
Adult of Hemiptera		0.02
Decapoda		0.45
Hirudinea		0.55
Larvae of Clucidae		0.74
Larvae of Trichoptera		<0.01
Nymph of Ephmeroptera		0.09
Nymph of Odonata		1.25
Platyhelminthes		0.19
Pupa of Chironomidae		0.11

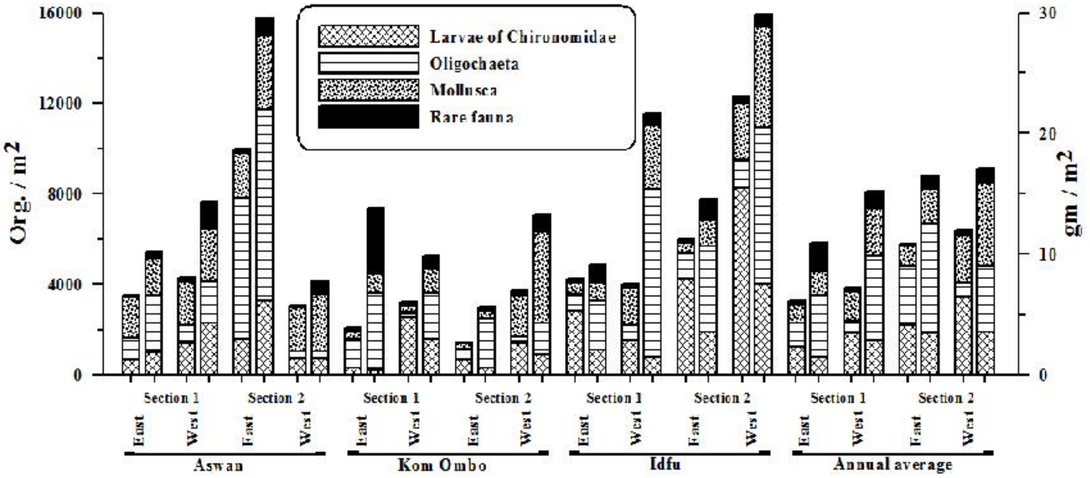

Fig. 2. Spatial distribution of zoobenthos along the mainstream of the Nile in Upper Egypt.
Aswan (Section 1 = sites 1 & 2, Section 2 = sites 3 & 4); Kom Ombo (Section 1 = sites 5 & 6; Section 2 = sites 7 & 8) and Idfu (Section 1 = sites 9 & 10; Section 2 = sites 11 & 12).

With respect to the different groups of the Nile zoobenthos, chironomid larvae followed by Mollusca constituted the main groups and oligochaetes ranked third in numerical importance. Spring was the most productive season for chironomid larvae at all investigated sites (Fig. 4). However, during summer and autumn, they remained low or totally disappeared in some sites. *Dicrotendipes modetus* was the most abundant species such that dominated the community of zoobenthos, with relatively high densities of 38.6 and 85.1% from the total population and chironomid larvae, respectively. Molluscs (Fig. 5) peaked during the spring– -summer period due to the development of high densities of *Valvata nilotica* which accounted for 16.6 and 62.9% of the total population and molluscs, respectively. Besides, *Gyraulus ehrenbergi* and *Bulinus truncatus* contributed 20.9% and 6.1% of the total molluscs, respectively.

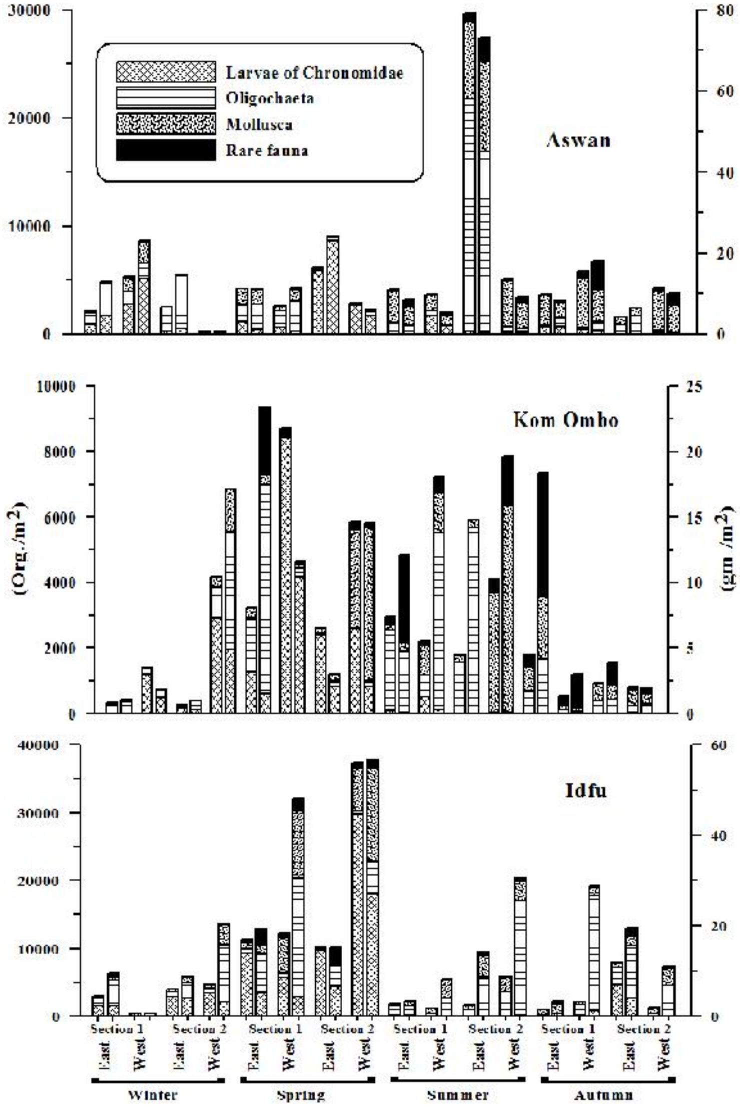

Fig. 3. Seasonal distribution of zoobenthos along the mainstream of the Nile in Upper Egypt

Oligochaetes varied considerably among the different sites during the investigated seasons (Fig. 6) with relatively higher values at the east sites compared with those reported for the west side. *Limnodrilus udekemianus* contributed for 17.5 and 70.6% of the total population and oligochaetes, respectively. The major occurrence of this species was recorded at the east sites. *Branchiura sowerbyi* was abundant during winter and ranked second in importance with 28.1% of the total Oligochaetes. In addition, the Oligochaetes; *Limnodrilus hoffmeisteri* and *Hablotaxis* sp. were scarcely encountered.

Some species of rare occurrence were recorded in different seasons. For instance, *Helobdella conifer* (Hirudinea) was recorded during spring and the Platyhelminthes, *Planaria* sp. during spring and summer. The crustacean, *Cardinea nilotica* was recorded during summer and autumn showing slight variations among sites. Besides, unidentified species belonging to five groups of aquatic insects were encountered comprising; the nymph of Odonata (*Zygoptera* and *Anisoptera*) in summer, the larvae of Clucidae in winter and spring, the nymph of Ephmeroptera during summer-autumn, Hemiptera, adult Corixidae in summer and the larvae of Trichoptera in autumn.

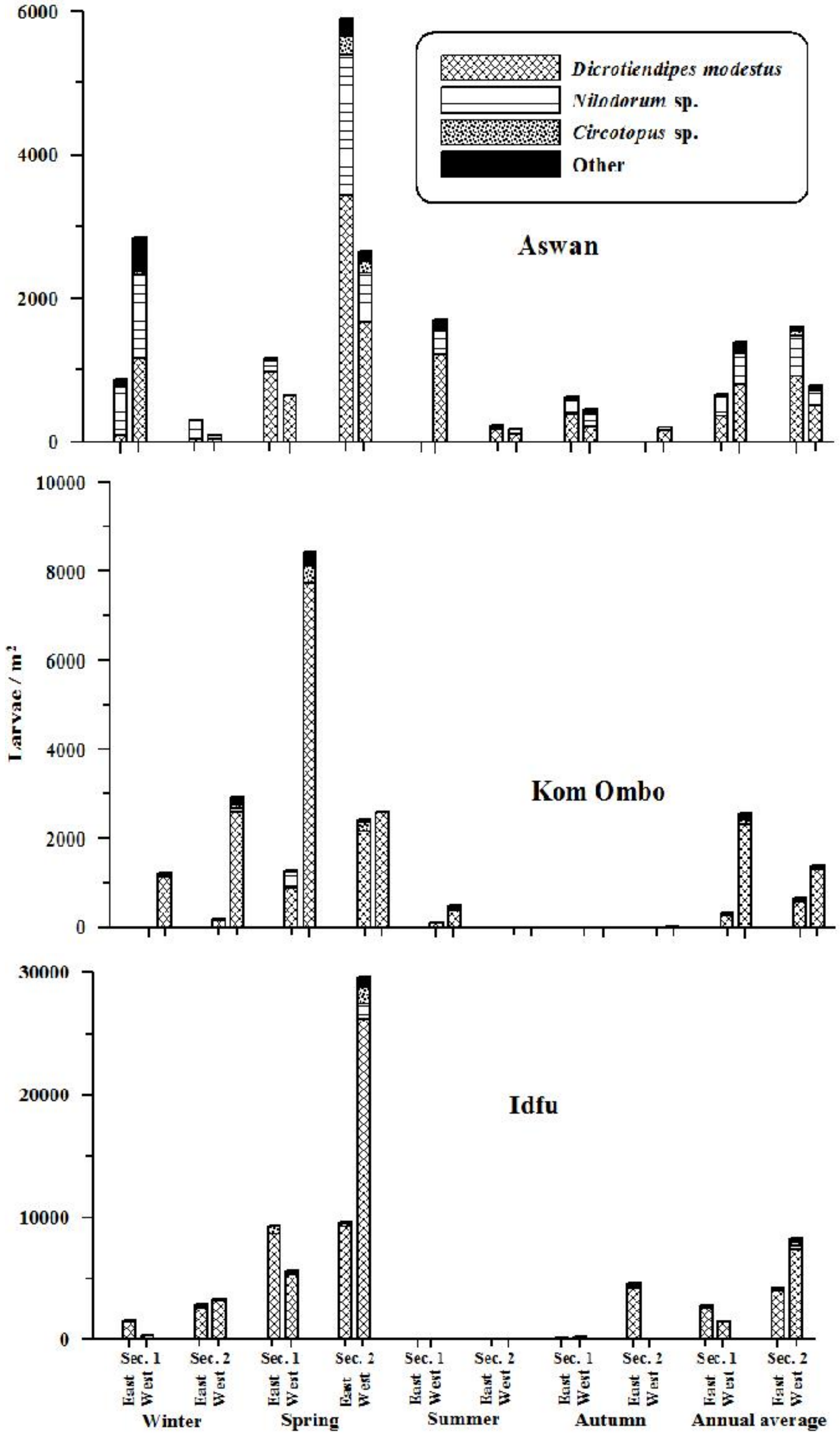

Fig. 4. Seasonal distribution of chironomid larvae in the different investigated sites along the mainstream of the Nile in Upper Egypt

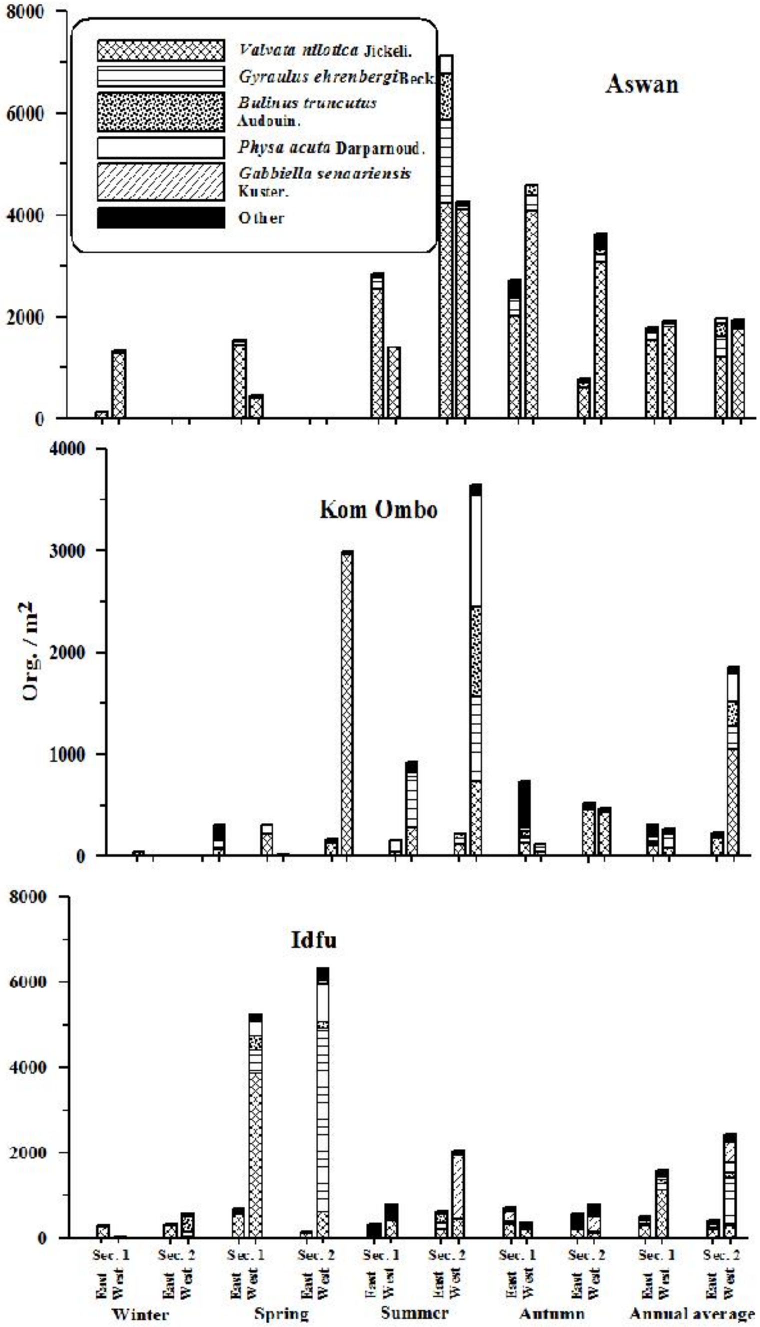

Fig. 5. Seasonal distribution of Mollusca in the different investigated sites along the mainstream of the Nile in Upper Egypt

Values within the range of significance valid for zoobenthos and variables of water and sediment are presented in Table 3. A strong significant correlation stands for the abundance measured as total counts or biomass of zoobenthos with the sediment contents of organic matter and $CaCO_3$. This was also emphasized by the dependence of zoobenthos on zooplankton density. The data concerning water temperature correlated closely with the total zoobenthos biomass and with the density or biomass of Mollusca.

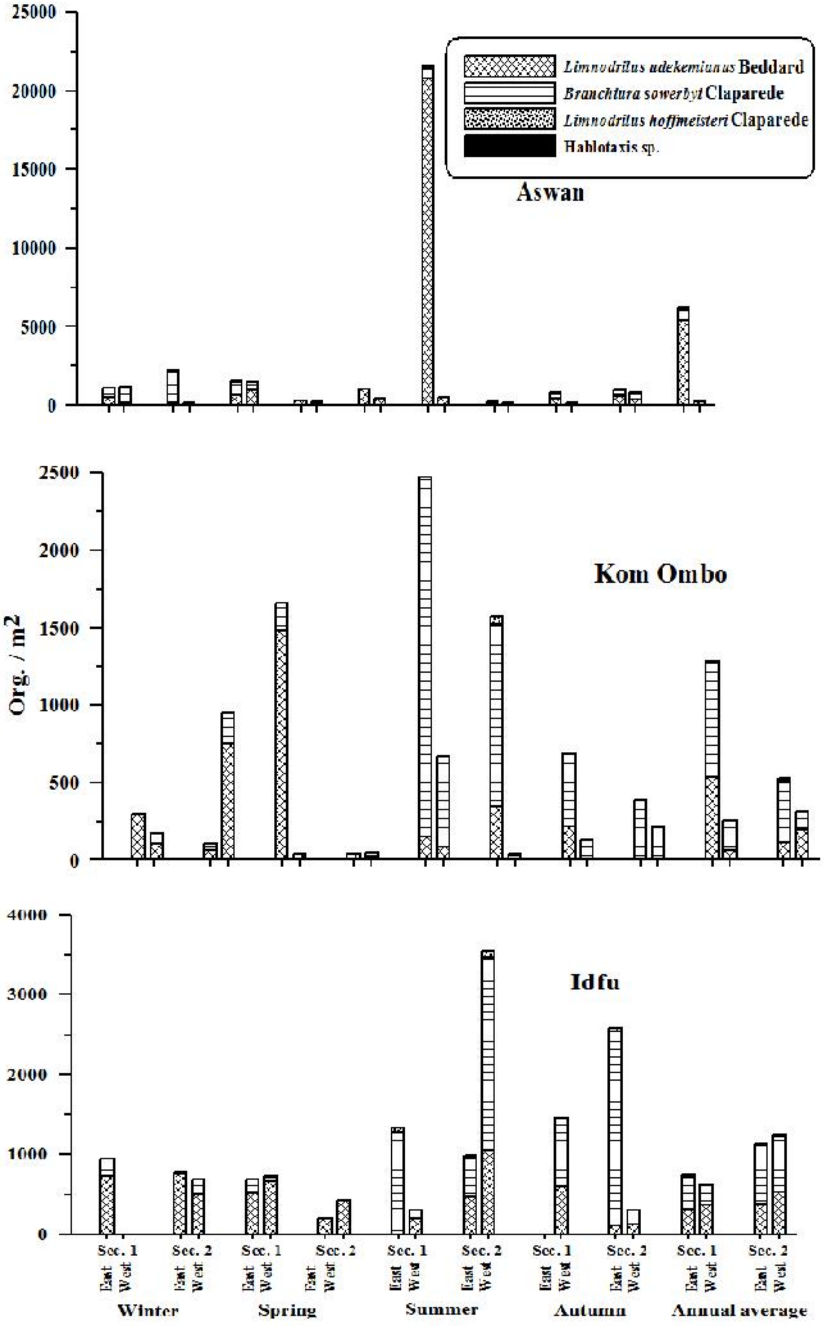

Fig. 6. Seasonal distribution of Oligochaetae in the different investigated sites along the mainstream of the Nile in Upper Egypt

3.3 Diversity

Total pool (γ diversity) of species of the different functional groups inventoried during this investigation (Table 4) was 85, 43 and 40 species of phytoplankton, zooplankton and zoobenthos, respectively. The highest levels of species richness (α diversity) were those of phytoplankton (27.17 – 33.25 species/ sample) followed by zooplankton (14.75 – 20.5 species/ sample). Zoobenthos had the lowest levels of species richness (5 - 10 species/ sample). The estimated values of Shannon index for phytoplankton were always higher than those for

Table 3. Significant correlations between zoobenthos and environmental parameters along the mainstream of the Nile in Upper Egypt during the investigation period

Relationship	*r*	*P*	Categories of depending
Zoobenthos			
Total counts - water temperature	0.489	0.015	+
Biomass - water temperature	0.462	0.023	+
Total counts – organic matter (%)	0.898	<0.001	+ + +
Biomass - organic matter (%)	0.884	<0.001	+ + +
Total counts – zooplankton density	0.434	0.034	+
Total counts – $CaCO_3$ ()	0.736	<0.001	+ + +
Biomass - $CaCO_3$ ()	0.690	<0.001	+ + +
Total counts - water temperature	0.489	0.015	+
Biomass - water temperature	0.462	0.023	+
Mollusca			
Biomass - water temperature	0.405	0.050	+
Chironomid larvae			
Total counts - NO_3-N	0.409	0.047	+

+: significant; + + +: strong significant.

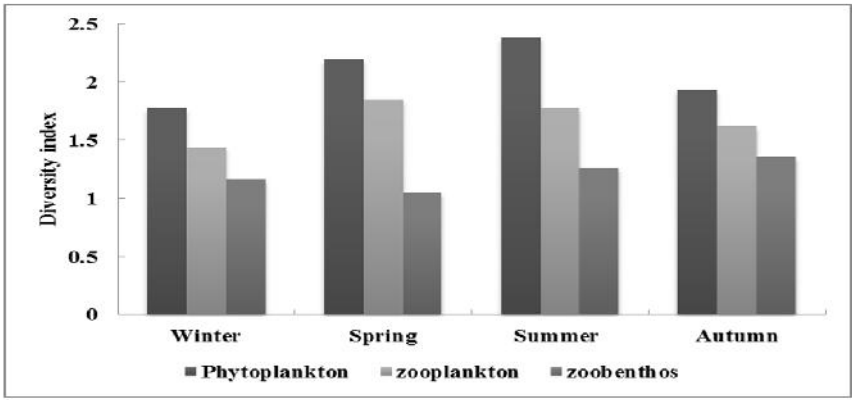

Fig. 7. Shannon index for the functional groups in different investigated seasons

the other functional groups. No wide range of seasonal variations in the diversity of the different functional groups was observed (Fig. 7). Diversity was typically the highest in summer for phytoplankton, in spring for zooplankton and in autumn for zoobenthos. The calculated values of species turnover (β diversity) for phytoplankton and zoobenthos were relatively higher than those of zooplankton. Regarding the whole system, the levels of beta diversity were; 2.07, 1.79 and 2.11 for phytoplankton, zooplankton and zoobenthos, respectively.

4. DISCUSSION

4.1 Plankton

The Nile phytoplankton community in Upper Egypt was characterized by high abundance of centric diatoms particularly the small unicellular; *Cyclotella meneghiniana* and the chain forming; *Aulacoseira granulata*. These diatoms dominated the community simultaneously or in an alternating manner with the filamentous cyanobacterium *Planktolyngbya* which attained peak abundance during summer. In this respect, phytoplankton of large rivers was found to be typically dominated by centric diatoms [69-72]. River's phytoplankton flora is characterized by species which are differently adapted to survive lotic conditions [73]. Main features of the phytoplankton community composition in large rivers show considerable biogeographic differences, since; it mainly depends on the geographic position of the river [74]. The Nile phytoplankton community structure appeared to be a typical feature of the Northern Hemisphere Rivers [75–77] and also for large rivers [78–80]. Phytoplankton flora of large rivers in the Northern Hemisphere often includes centric diatoms such as taxa from the genera *cyclotella* and most prominent *Aulacoseira* [81,82].

Table 4. Shannon (*H* '), alpha (α), beta (β) and gamma (γ) diversities recorded in different sites along the main stream of the Nile in Upper Egypt

Sites	Groups	*H* '	α	β	γ
	Phytoplankton				
1		1.98	33.25	1.80	60
2		2.04	27.17	2.32	63
3		2.05	27.33	2.27	62
4		2.01	28.50	2.07	59
5		2.19	33.17	2.05	68
6		2.17	31.33	1.92	60
		2.07	30.13	2.07	85
	Zooplankton				
1		1.39	20.25	1.83	37
2		1.63	17.50	1.89	33
3		1.91	20.50	1.76	36
4		1.82	17.25	1.57	27
5		1.69	17.00	1.88	32
6		1.59	14.75	1.83	27
		1.67	17.88	1.79	43
	Zoobenthos				
1					
E		1.39	8.00	1.88	15
W		1.38	8.75	2.06	18
2					
E		1.07	7.00	2.14	15
W		1.09	8.25	2.18	18
3					
E		1.09	6.00	2.17	13
W		1.22	6.25	2.08	13
4					
E		0.94	5.00	2.40	12
W		1.13	7.25	2.21	16
5					
E		1.28	8.25	2.18	18
W		1.33	8.50	2.24	19
6					
E		1.15	10.00	2	20
W		1.43	8.75	1.83	16
	Whole system	1.21	7.67	2.11	40

The relatively high share of the filamentous cyanobacteria; mainly consisting of the filamentous *Planktolyngbya* sp. within phytoplankton composition was determined for the summer season. These results were in agreement with earlier observations in the Nile system [83]. Similarly, the results of this study correspond with the observations that were reported in large rivers such as; Danube [84] and Spree [85] in Germany.

During this investigation, the Nile zooplankton community was mainly composed of various taxa related to the major groups namely; Rotifera, Cladocera and Copepoda. Those zooplankton groups appeared to be a typical feature of African freshwater bodies [86-88]. Rotifera was the dominant group with the highest number of recorded taxa. In this respect, the number of rotifer species was recorded to be higher than those of cladocerans or copepods in African water ecosystems [89]. Besides, similar combinations of typically planktonic zooplankton species were recorded in the Nile Basin [90]. These results go in agreement with the previous observations of the Nile water in Sudan [91] and in Egypt [92]. In general, the observations concerning the plankton community structure of this investigation correspond with the literature.

4.2 Zoobenthos

Zoobenthos related to Chironomidae, Mollusca and Oligochaetae were commonly reported from the Nile system in Egypt [21,22,24]. These groups dominated the zoobenthos community during the period of the present investigation. A change in the abundance of any of these groups was reflected in the total abundance of zoobenthos. In rivers, macro-benthic invertebrate qualities and quantities are largely influenced by a number of environmental factors [93,94], including physical, chemical and biological ones. The substrate status is also of great importance for regulating habitat complexity, food availability and refuge against predators and flow disturbance. The different substrate types can affect the accumulation of organic matter on the river bed [95]. Relative densities of clay, silt and sand as the main bottom sediment components in the investigated sites represented favorable conditions for the existence of multiple benthic taxa [96,97]. Besides, [22] found that the Nile molluscs are typical populations of the weedy and mud depositing habitats whereas, oligochaetes can survive in soft sediments as the case of the present study. In this respect, [15] indicated that environmental and spatial factors may act separately in structuring benthic assemblages.

The organic matter in the sediment provides an indication of the amount of settling on the bottom from the water column and it is used as an index of those available for the benthic community. In the present investigation, the increased amount of the organic matter contents in sediments during spring (avg. 4.04%) and summer (avg. 3.37%) were generally in concomitant with a parallel increase of macro-benthic invertebrate densities. Therefore, a strong significant correlation stands for the abundance measured as total counts and biomass of macroinvertebrates with the sediment contents of organic matter. This was also emphasized by the dependence of macro-benthic invertebrates on zooplankton density and to some extent on phytoplankton indicating that the organic matter may be an important relative to the Nile benthic fauna. Died phytoplankton and zooplankton cells deposited on the bottom of tropic rivers constitute the major food items for the macro-benthic invertebrates. In this respect, the importance of the availability of food supply and the physicochemical properties of the sediments were confirmed for the development of macro-benthic invertebrates in freshwater habitats [61]. Encrusting organisms were regarded as the main source of accumulating carbonates in the sediments of the Nile. The relatively high contents of $CaCO_3$ enhanced the development of bottom organisms in freshwater ecosystems. Therefore, this can explain the highly significant correlation stands for the total counts or biomass of the macro-benthic invertebrates and $CaCO_3$. These results clearly indicated that $CaCO_3$ is of marked importance for enhancement of the Nile benthic fauna. [98] found that the abundance of oligochaetes and molluscs was driven by Ca^{2+} contents.

Temperature is found to be a critical factor in controlling growth and spawning activities of certain biota in aquatic habitats. This has empirical support from the significant correlation that was established between water temperature and benthic fauna biomass and the density or biomass of molluscs. These results suggested that the survival and development of the Nile molluscs in the study area were apparently regulated by temperature. Similarly, [61] observed that the growth and reproduction of Mollusca were significantly dependent on water temperature.

The nutrient status of the freshwater habitats appeared to be governed by NO_3-N contents. In this investigation, the levels recorded for NO_3-N in the Nile water provided a suitable situation for the growth of zoobenthos. For instance, chironomid larvae were found to be mainly dependent on the NO_3-N concentrations. These observations were in accordance with the results obtained by [99]. In this context, [100] concluded that the diversity and composition of aquatic invertebrate communities could be determined by nutrients.

The effect of wastewater discharge on the abundance and species composition of the Nile macro-benthic invertebrate communities were recognized in the investigated sites during this study period. The total population densities of zoobenthos and of the main groups in all investigated sites of the west bank of the Nile were high when compared to those of the east bank. It is suggested that the observed differences between the west and east banks could be due to the dense population of macrophytes in the west bank sites. In addition, those sampling sites were not directly subjected to the effects of industrial and agricultural wastes. Some other groups of benthic fauna like a nymph of Ephmeroptera, larvae of Clucidae, pupae of Chironomidae, larvae of Trichoptera and Hemiptera (adult Corixidae) are highly affected by wastewater discharge to a degree that they are completely disappeared. This is in good agreement with [22] who recorded low density of bottom organisms in polluted areas. However, in the present study, the oligochaetes showed marked discrepancy and markedly increased in some polluted sites. Similarly, [17] observed that the areas polluted by industrial wastes were highly inhabited by oligochaetes. Concerning, the noticeable abundance of tubificids in organically polluted sites during this investigation could be explained on the basis of that the breakdown of organic matter can permit spectacular growth of tubificid.

Overall, the results obtained throughout this study period indicate that the investigated area of the River Nile with suitable substrate status, clear state, the acceptable range of water temperature and nutrients contribute to the abundance and diversity of macro-benthic invertebrates particularly at the west bank of the Nile. The combination of those variables was recognized as important factors for explaining local assemblages and variations among them [101].

4.3 Diversity

Diversity measures are frequently used to describe the biotic components of the aquatic habitats and regarded as good predictors of the status of these ecosystems [6]. The total pool of species observed in all sampling units within a system (γ diversity) is governed by the species richness (α diversity) of each community [102]. However, the species pool is depending on the number of samples and the taxonomic accuracy during analyses. In the present investigation, the sequence of the γ diversity and α diversity levels followed the order; phytoplankton, zooplankton and zoobenthos. These observations indicated that species richness could be considered as a simple way for diversity assessment. Thus, the more species are present in each compartment, the more different are the communities and the greater is the total number of species occurring in a certain geographic region.

Spatial biological variations are often described in terms of species turnover (β diversity). This is another useful measure between sampling sites within a geographical region [103]. Beta-diversity contrasts with the analysis of alpha-diversity, which is the amount of diversity (e.g. taxonomic richness) at a certain site [104,105]. Consequently, this index can show the degree of heterogeneity between compartments within a system like the sampling points in the present investigation. The similarity in the composition of the different communities (plankton or zoobenthos) may result in relatively high levels of beta diversity. The habitat heterogeneity was expected to be caused by wastewater disposal during this investigation. However, this was apparently not sufficient to influence the plankton and zoobenthos communities or it was difficult to be detected within short periods of time such as few months, the time corresponding to seasonal changes. Thus, the degrees of difference between sites expressed by β diversity reflected a relatively weak rate of species displacement along environmental gradients during the entire period of this investigation. Beta diversity appeared to be an important index for characterizing the diversity distribution along the main stream of the Nile in the investigated region. In this context, [106-108] have demonstrated the usefulness of beta diversity to explain variations in the composition of aquatic biota in river ecosystems. The use of alpha and beta diversity was emphasized as critical predictors in ecological and biodiversity assessment of the aquatic habitats [109].

Diversity can also be measured as Shannon index, which deals with the content of information that each species contributes to the whole community representing the number of species and their abundance. In the studied area, Shannon index (*Ȁ*) of the different functional groups was relatively low and did not exceed 2.17. This could be in part attributable to the less water retention of the lotic ecosystem and the increase in abundance may encourage competition interaction, which can act in decreasing the diversity. In general, the results of this investigation suggested that the combination of different biotic and abiotic factors could be regarded as possible drivers of the Nile plankton and zoobenthos diversity. In addition, wastewater disposal did not exert major influences on biodiversity. This could be explained by the ability of some dominant species for adaptation to the changing habitats and their capability of resisting pollution.

5. CONCLUSIONS AND RECOMMENDATIONS

The first key result of this investigation was a detailed taxonomic assessment of the phytoplankton and microzooplankton as well as macrozoobenthos community along the main stream of the Nile in Upper Egypt. Therefore, this study created baseline information for comparison with future studies. The second important result was that the inherent status of the diversity and food web interactions of the Nile water within the investigated area could be established. The data shown here are still only a snapshot of the environmental conditions, and several years' of data will be required for better understanding of the natural and man-made variability in hydrography and its effects on the biological communities in the Nile water ecosystem. Physical and chemical factors are of paramount importance in determining the composition of the biological communities with respect to the balance between functional groups of biota, with changes in discharge of industrial effluents to the river water. Importantly, for an assessment of potential climate change effects, future studies should also include laboratory investigations of the environmental tolerances of key riverine species. Only if these physiological parameters are known can the potential responses of these taxon groups to future environmental conditions be judged. At present, such data are still largely lacking and they should be investigated as part of well co-ordinated interdisciplinary investigations of the physics, chemistry and biology of the Nile water.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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