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Full Length Research Paper

Effects of Physico-Chemical Parameters on the Diversity and Abundance of Benthic Algae in an Agricultural Wetland in NDOP Plain, Cameroon

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Benthic algae are valuable tools in bio-monitoring pollution in wetland soils and water. The effects of physico-chemical parameters on the diversity and abundance of benthic algae were studied. Soil and water samples were collected from paddy fields following age gradient (34, 32, 22 and 5 years old). Physico-chemical properties and benthic algae diversity and abundance were analysed using standard methods. All the soils had pH values within the acidic range. Exchangeable potassium decreased with age of the paddy fields. Available phosphorus, pH, OM, and C/N ratio contributed to diversity and abundance of benthic algae. No significant ($P > 0.05$) relationship was observed between benthic diversity, total N and available phosphorus. Water from the five year old paddy field site was the most acidic. Potassium, Na^+, pH and salinity contributed positively to benthic diversity. Species richness and salinity were significantly correlated ($r= 0.986$, $P \leq 0.05$). Fifty three species were identified in 17 Families. Nitzschiaceae was the most abundant family and *Anacystis* sp. the most frequent species. The most common species were *Microcystis*, *Chlorococcus dispersus*, and *Nitzschia sigmoidea*. These may be used as bioindicators of pollution. The older fields had more eutrophic species while the younger ones had more oligotrophic species.

Keywords: Benthic algae, soil, water, diversity, physico-chemical parameters, pollution, wetland.

INTRODUCTION

Intensive farming has led to severe disturbance of watersheds throughout the world, resulting in fundamental changes in the structure and functioning of stream ecosystems (Lavoie *et al.*, 2004). Modern intensive agriculture is responsible for chemical and physical alterations such as increased contaminant and nutrient run off, increase in suspended solids due to erosion, and changes in discharge and channel morphology (Skinner *et al.*, 1997). Elevated concentrations of suspended sediments are also found in conjunction with elevated nutrient concentrations because many nutrients, such as phosphorus, commonly enter water adsorbed onto soil particles. Upon reaching the water, suspended soil particles can cause a rise in water temperature because suspended soil particles absorb solar energy that would otherwise have been reflected by water molecules.

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Consequently increased water temperatures are associated with both eutrophication and cyanobacteria blooms (Fujimoto *et al*., 1997; Kotak *et al*., 2000). These anthropogenic influences tend to modify the structure (abundance of organisms, diversity) and function of ecosystems. One main cause of the eutrophication, defined as organic matter production enhancement, is high dissolved nutrient concentration (Nixon, 1992). Increased nutrient and sediment loading can affect the functioning and biodiversity of aquatic ecosystems, requiring frequent monitoring of these systems.

Benthic algae have been identified as a valuable option for bio-monitoring of stream and river ecosystems (Hill *et al*., 2000). The traditional physico-chemical measurements used in water quality monitoring programmes, such as total phosphorus and suspended sediment load are important guides to environmental changes. However, they are only representative of short-term conditions found at the instant of sampling and do not provide information about the effects of these changes on biological communities. The need for a better comprehension of interactions between environmental quality and ecosystem integrity has increased the interest in finding biological indicators that provide a more accurate guide to changes in ecological conditions. More recently, this approach has been successfully applied to evaluate a variety of water quality problems (Winter and Duthie, 2000; Munn *et al*., 2002; Potapova *et al*., 2003). Periphytic communities provide an integrated measurement of water quality, as experienced by the aquatic biota, and have many biological attributes that make them ideal organisms for biological monitoring. Algae lie at the base of the aquatic food webs and therefore occupy a pivotal position at the interface between biological communities and their physico-chemical environment (Lowe and Pan, 1996). Furthermore, benthic algae have short life cycles and can therefore be expected to respond quickly to changes in environmental conditions (McCormick and Stevenson, 1998; McCormick and O'Dell 1996). Little or no study has been carried out to examine the potentials of algal bio-monitoring as affected by agricultural activities across the different age gradients on the Ndop wetland, where intensive rice farming has been a common practice since 1972. This wetland ecosystem is the most widely utilized plain in the north western region of Cameroon. *Zea mays* (maize), *Oryza sativa* (rice) and *Phaseolus vulgaris* (beans) are the main staple crops that are grown in this region. It is for this reason that the Upper Nun Valley Development Authority (UNVDA) was instituted in the region in 1970, as the main custodian of the wetland ecosystem (UNVDA, 1982). The natural hydrological regime of the wetland has resulted in the occurrence of many floodplain lakes, which are supplied with water from their own catchment areas bringing sediments (mud) from runoff which tend to bring nutrients from the surrounding environment. Many human-related alterations to the environment that act to degrade river ecosystems cause a shift in plant community composition as environmental conditions vary. Plant communities have also been shown to change in response to hydrologic alterations (Zedler & Kercher, 2004), nutrient enrichment (Johnson and Rejmankova, 2005), sediment loading and turbidity (Sager *et al*., 1998), metals and other pollutants. The effect of nutrient loading on species composition (both plants and animals) and the resultant structure and function of wetlands has been largely ignored when considering their ability to absorb nutrients (Verhoeren *et al*., 2006). Failure to understand interactions between nutrient loading and change in species composition may lead to underestimation of the impacts of these stresses. The abundance of these species may be due to nutrient availability (Page *et al*., 1982; Matson and Price, 1993). According to Scheffer (1998), benthic algae can be used to assess the pollution levels of this ecosystem. For this reason the present study seeks to evaluate the distribution, diversity and abundance of benthic algae communities on the Ndop wetland ecosystem as a tool for monitoring pollution across different age-gradient paddy-fields. This may form the baseline from which further comparison of the effects of nutrient load and other environmental stresses on such systems can be evaluated.

MATERIALS AND METHODS

Study Area

The study area, Ndop Plain, is located between latitudes 4 ^{0}48' N and 6^0 10' N and longitudes 10^0 14' E and 10 ^{0} 30 E (Figure 1). It is found in the Ngoketungia Division of the North West Region, Cameroon and is surrounded by 13 Villages. The area is a gentle undulating plain bounded by the Sabga and Wainama chain Hills (Koghan, 2004). It has a surface area of about 1,152 km^2, with an average population density of 104 inhabitants/km^2. The main economic activity in the area is agriculture, and more than 70 % of the people are involved in this activity. Due to the high productivity of soils from this region, the latter has become a focal point for diverse human activities and ethnic attractions. The mean annual temperature range is 27–33 ^{0}C, with a lot of cloud cover which helps to modify the temperature.

The rainy season is between mid-March to mid-November and the dry season starts from mid-November to mid-March. The highest rainfall has been recorded in July and August. Mean annual rainfall range is 330-2000 mm (SNEC, 2007). The rock types of this region are basically igneous and basaltic. Ndop plain falls within the savannah region of Cameroon and the vegetation is predominantly Sudan savannah. It is characterized by rich fauna and flora species (Kometa, 2006), although most of the natural vegetation has been destroyed by anthropogenic activities such as rice farming and other

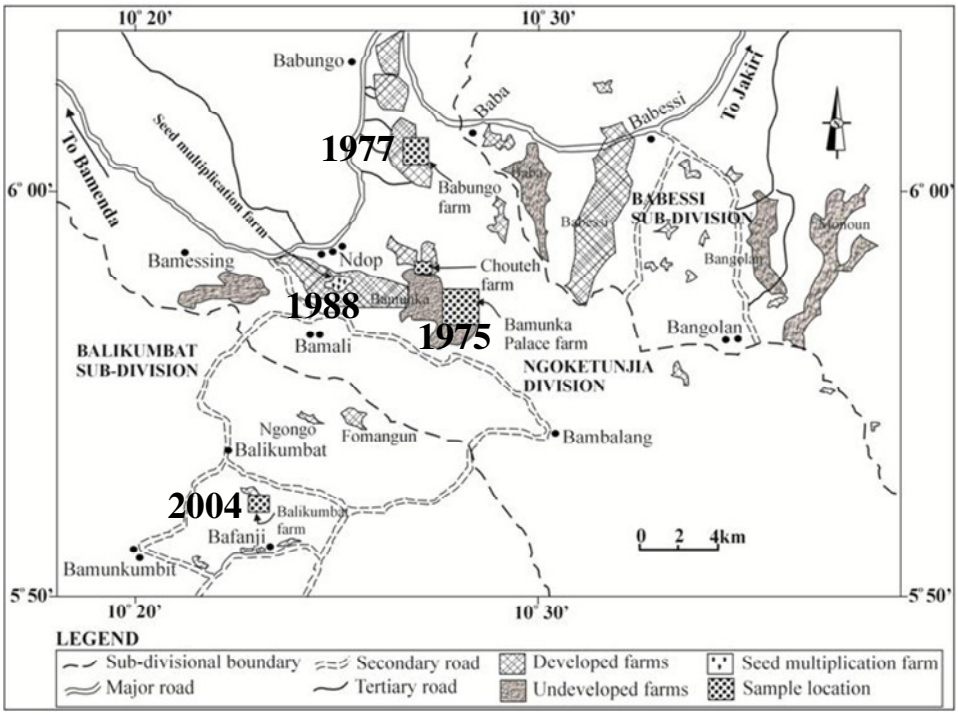

Figure 1. Selected sampling sites

agricultural activities, deforestation for settlements, fuel wood, and infrastructural development. Agriculture in most cases in this area is intensive and the agrochemicals used are mostly urea and NPK (20:10:10) fertilizers. According to SA Azomba (Upper Nun Valley Development Authority (UNVDA) Ndop, Cameroon, personal communication), a normal dose of chemical fertilizer application is 6 kg NPK/block (applied three to four weeks after planting) and 2kg/block for urea (applied during flowering). These correspond to 300 kg NPK /ha and 100 kg urea /ha (a block is 200 m^2).

Site selection

Four paddy field sites were selected for sampling to ensure that they span across the entire plain. The selection of the sites was based on the age gradient of the constructed rice farms and accessibility to the sites. These sites included the 1975 site (34 years old), the 1977 site (32 years old), the 1988 site (22 years old) and the 2004 site (five years old).

All sites were divided into contours of various sizes. Each contour was further divided into blocks of 10 m x 20 m (200 m^2). On each site, 3 transects of 20 m x 50 m (1000 m^2) were mapped out with two (2) blocks sampled per transect, giving a total of six (6) blocks/site, except for the five year old site, which had only one transect due to its small size and the inaccessibility of the area. A total of 20 blocks (sampling points) were mapped out and sampled. All sampling points were marked using the Global Positioning System (GPS). Sampling was carried out in December 2008 (Figure1).

Sample collection and handling

Using a hand trowel, three core soil samples were randomly collected from each block. Eighteen core soil samples (3 core samples x 6 blocks) each from the 34, 32 and 22 year old sites, and six core soil samples (3 core samples x 2 blocks) from the five year old site were uniformly mixed to give a bulk sample for each site (Figure 1). This gave a total of four bulk soil samples. Two portions, one for soil physico-chemical analysis and the other for benthic analysis, were collected from each bulk sample and stored in black polyethylene bags to avoid any further activities.

Surface water samples were collected from the different paddy–field sites (34, 32, 22 and five year old sites) in 0.5 L plastic containers. Before the samples were collected, the bottles were rinsed several times with the sample to be collected. The plastic containers were then put into a cooler containing ice blocks for onward transportation.

Conductivity and pH were determined during sampling using a Tracer pocket tester field conductivity meter, model pH/TDS/salts. Salinity was calculated from conductivity using the conversion factor described by Dohrman (2011).

Soil analysis

The soil samples were then air dried to a constant weight, according to Reddy et al. (1998) and transported for analysis. Each sample was then sieved through a 2-mm sieve and analysed in triplicate for pH, organic carbon (Org. C), exchangeable bases (Ca, Mg, K, Na), exchange acidity, total nitrogen (Tot. N) and available phosphorus (Av. P) in the University of Dschang Soil and Environmental laboratory using standard methods (APHA, 2005). The effective cation exchange capacity (ECEC) was calculated by summing the exchangeable bases and the exchange acidity while the organic matter (OM) was determined by multiplying the org. C by a factor of 1.729 (IITA, 1979).

Water analysis

The water samples were analysed for NO_3^-, PO_4^{3-}, K^+ and Na^+ in the University of Dschang Soil and Environmental laboratory using standard methods (APHA, 2005). Triplicate samples were analysed and the mean value for each parameter was calculated based on age gradient of the paddy-field site.

Benthic analysis

The soils for benthic analysis were centrifuged at 2500 rpm for 20 minutes (APHA, 2005) to accelerate sedimentation, and then decanted. A drop of each filtrate was then extracted and mounted on clean slides. Counting and identification of species were done using an Olympus BH-2 light microscope, equipped with Normaski optics at a magnification of 1000X (oil emersion). Slides for qualitative and quantitative analyses were prepared (in triplicate) and whole count method was employed, using Sedgwick Rafter Counting Chamber to determine their density. Identification of the benthic algae species followed relevant text books and articles (Compere, 1977; Lltis, 1980; Krammer and Lange-Bertalot, 1986, 1988, 1991, 2002; Gasse, 1980, 1986; Nguetsop, 1990; Nwankwo and Onyema, 2003; Nwankwo *et al*., 2003; John *et al*., 2005; Nguetsop *et al*., 2007; Bellinger and Siegee, 2010).

Statistical analysis

The variation of physico-chemical parameters, diversity and abundance of benthic algae at the different sites was determined using multivariate analysis (Principal Component Analyses, PCA), to rank the many factors under investigation based on the magnitude of their interactions during the growing and the off season period. Pearson Correlation was conducted to find out the physico-chemical factors that significantly affected species richness and diversity. One way analysis of variance (ANOVA) was used to evaluate the differences between the different alga divisions in the different paddy field sites. The ANOVA was conducted following positive tests for normality and homogeneity of variance.

Counting of algae was carried out as reported by Vollenweider (1974) and the number of species was then calculated using the following equation.

$$N_0/mL = \frac{C \times 1000}{A \times D \times F}$$

Where:

C = total number of organisms counted
A = area of field mm^2 (πr^2)
D = depth of field
F = number of fields counted

The Species Richness Index (D) according to Margalef, (1958) was used to evaluate the community structure. The equation below was applied and results were recorded to two decimal places.

$$D = (S - 1)/Log_e N$$

Where: *D* = Species richness index
S = Number of species in a population
N = Total number of individuals in S species.

Shannon-Weaver Diversity (H) and Sorenson's Indices:

Shannon Weaver Diversity Index of benthic algae species within the different sites was determined using:

$$H^1 = \sum (p_i)(\log_n P_i)$$ (Magaurran, 1988)

Where: H^1 = Index of species diversity (information content of sample, bits or individuals).
p_i = Proportion of total sample belonging to i^{th} species, and
i = Number of species.

Sorensen's similarity index:

Modified Sorensen's 1948 equation/method was used to show species similarity in the different sites in terms of species distribution.

It is expressed as: $$Cn = 2a / (2a + b + c)$$

Where: C_n = Sorensen's similarity coefficient
a,b,c, = number of individuals per sites.

Table 1. Physico-chemical parameters of soils in the different paddy fields

Parameter	Paddy field site ages (years)			
	34	32	22	05
pH(H_2O)	5.27	5.16	5.17	4.65
pH(KCl)	4.62	4.20	4.38	4.20
Ca (cmol/kg)	2.29	3.35	3.06	3.84
Mg (cmol/kg)	0.89	1.13	1.05	0.98
K (cmol/kg)	0.10	0.13	0.18	0.17
Na (cmol/kg)	0.06	0.06	0.06	0.06
Exchange acidity(cmol/kg)	0.02	0.06	0.03	0.04
ECEC(cmol/kg)	3.36	4.73	4.38	5.09
Org. C (%)	3.36	3.50	3.21	2.63
OM (%)	5.81	6.05	5.55	4.55
Tot. N (%)	0.27	0.25	0.33	0.38
C/N	12.4	14.0	9.73	6.92
Av. P (mg/kg)	14.4	13.8	14.6	11.9

RESULTS

Soil analysis

The pH values in both H_2O and KCl of the paddy fields in the Ndop plain were acidic, ranging from 4.65 to 5.27 and 4.20 to 4.62, respectively (Table 1). All the soils had low exchangeable bases. The quantity of Ca present in the soils ranged from 2.29 cmol/kg in the 34 year old site to 3.84 cmol/kg in the five year old site while the Mg present in the soils ranged from 0.89 cmol/kg in the 34 year old site to 1.13 cmol/kg in the 32 year old site. The 22 year old site had the highest K value (0.18 cmol/kg) while the lowest K value of 0.10 cmol/kg was recorded in the 34 year old site. Potassium levels decreased with the age of the paddy fields. The highest exchange acidity (0.06 cmol/kg) was observed in the 32 year old paddy field while the lowest value (0.02 cmol/kg) was recorded in the 34 year old site. The five year old site had the highest ECEC value (5.09 cmol/kg). There was a general decrease in ECEC with the age of the paddy field sites.

There was a general increase in the OM with age of the paddy fields, with the highest value (6.05 %) found in the 32 year old site. The five year old site had the lowest level (4.55 %) of OM. The C/N ratio ranged from 6.92 in the five year old site to 14.0 in the 32 year old site with an average value of 10.8.

Table 2 shows the results of the Principal Component Analysis of soil parameters, and benthic diversity and distribution following different age gradient. The principal component, PC1 explains 61.4% of the overall variance and PC2 explains 23.3 %, while PC3contributed only 15.3 % with the first two components contributing 84.7 %. Av. P, pH, OM, and C/N ratio were the vital factors that contributed to the diversity and abundance of benthic algae community in the Ndop wetland plain.

The Pearson correlation coefficients of the different soil parameters and species richness indices are presented in Table 3. There was a positive correlation between av. P and similarity ($r = 0.961$, $P \leq 0.05$), similarity and richness ($r = 0.951$, $P \leq 0.05$), Av. P and pH (H_20) ($r = 0.963$, $P \leq 0.05$), ECEC and evenness ($r = 0.939$, $P \leq 0.05$), Org. C and pH (H_20) ($r = 0.932$, $P \leq 0.05$) and ECEC and Ca ($r = 0.992$, $P \leq 0.05$). There was a significance negative correlation between pH (KCl) and evenness($r = -0.974$, $P \leq 0.05$), Tot. N and Org. C ($r = - 0.950$, $P \leq 0.05$), and Ca and pH (KCl) ($r = -0.951$, $P \leq 0.05$). There was no significant difference between Tot. N and diversity as well as Av. P and diversity.

Water analysis

The pH of water from the five year old paddy field was most acidic (pH = 2.7), while the 22 year old site was the most basic (pH = 7.4) (Table 4). The conductivity of the water ranged from 938 to 1905 µS/cm. Salinity of water ranged from 0.33 to 1.22 ppt. Nitrate and PO_4^{3-} levels

Table 2. Eigen value distribution analysis of the covariance matrix of soil parameters and benthic algae diversity in the different paddy fields

Eigenvalue	9.2104	3.4996	2.290
Proportion	0.614	0.233	0.153
Cumulative	0.614	0.847	1.000
Variable	PC1	PC2	PC3
pH(H_2O)	0.323	-0.108	-0.018
pH(KCl)	0.255	0.328	-0.105
Ca	-0.306	-0.200	0.019
Mg	-0.053	-0.527	0.015
K	-0.215	-0.155	-0.463
ECEC	-0.289	-0.258	-0.005
Org C	0.286	-0.233	0.155
OM	0.286	-0.232	0.155
Tot N	-0.261	0.173	-0.344
C/N	0.253	-0.212	0.333
Av. P	0.307	-0.111	-0.195
Richness (D')	0.235	-0.058	-0.457
Diversity (H')	0.165	-0.334	-0.396
Evenness	-0.217	-0.402	0.013
Similarity	0.293	0.006	-0.304

Table 3. Pearson correlation coefficients between soil parameters and species richness indices in the different paddy fields.

	pH(H_2O)	pH(KCl)	Ca	Mg	K	ECEC	Org C	Tot N	Av. P	Richness (D')	Diversity (H')	Evenness
pH(KCl)	0.638	-										
Ca	-0.833	-0.951*	-									
Mg	0.041	-0.733	0.519	-								
K	-0.560	-0.571	0.692	0.375	-							
ECEC	-0.760	-0.973*	0.992*	0.617	0.715	-						
Org C	0.932*	0.368	-0.636	0.295	-0.604	-0.552	-					
Tot N	-0.825	-0.332	0.598	-0.203	0.786	0.540	-0.950*	-				
Av. P	0.963*	0.641	-0.796	0.048	-0.341	-0.714	0.832	-0.652	-			
Richness (D')	0.740	0.596	-0.642	-0.024	0.051	-0.569	0.506	-0.24	0.892	-		
Diversity (H')	0.632	0.098	-0.247	0.523	0.277	-0.132	0.566	-0.285	0.773	0.839	-	
Evenness	-0.493	-0.974*	0.892	0.849	0.633	0.939*	-0.239	0.267	-0.463	-0.403	0.130	-
Similarity	0.880	0.767	-0.841	-0.165	-0.259	-0.780	0.659	-0.459	0.961*	0.951*	0.712	-0.603

*Significant at 0.05 level.

Table 4. Mean physico-chemical parameters of water in the Ndop wetland plain.

Sampling site age (years)	pH	Conductivity (uS/cm)	Salinity (ppt)	NO_3^-	PO_4^{3-}	K^+	Na^+
34	3.3	1570	0.89	195	721	5.54	3.1
32	2.8	1905	0.73	366	1603	2.2	3.6
22	7.4	938	1.22	329	1233	17.0	11.1
05	2.7	1370	0.33	136	510	3.9	4.1

Table 5. Eigen value distribution analysis of the covariance matrix of water parameters and benthic algae diversity in the different paddy fields.

Eigenvalue	6.8989	2.4553	1.6458
Proportion	0.627	0.223	0.15
Cumulative	0.627	0.85	1
Variable	PC1	PC2	PC3
pH	0.364	0.102	-0.192
Conductivity	-0.245	-0.368	0.393
Salinity	0.361	-0.009	0.248
NO3-	0.23	-0.505	0.071
PO43-	0.174	-0.564	0.08
K+	0.351	0.187	-0.2
Na+	0.338	0.064	-0.349
Richness (D')	0.362	0.096	0.213
Diversity (H')	0.357	-0.22	-0.002
Evenness	-0.04	-0.418	-0.583
Similarity	0.311	0.097	0.434

ranged from 136 to 366 mg/L and 510 to 1603 mg/L, respectively for the different paddy fields. Potassium and Na^+ ions ranged from 2.2 to 17.0 mg/L and 3.1 to 11.1 mg/L, respectively for the different paddy-fields.

A multivariate correlation analysis to determine the influence of water parameters on the benthic diversity and distribution showed that principal component, PC1, explains 62.7% of the overall variance and PC2 explains 22.3 % with PC3 contributing only 15.0% these first three cumulatively contributing 100% (Table 5). Potassium, Na^+, pH and salinity contributed positively to benthic diversity and density while conductivity contributed negatively.

The results of Pearson correlation coefficient between the water parameters and benthic diversity are presented in Table 6. There was a positive significant correlation between species richness and salinity ($r= 0.986$, $P \leq 0.05$), similarity and salinity ($r= 0.949$, $P \leq 0.05$), K^+ and pH ($r= 0.991$, $P \leq 0.05$), Na^+ and pH ($r= 0.976$, $P \leq 0.05$).

Benthics analysis

A total of 53 species were identified, belonging to 17 Families. The most abundant division was the Bacillariophyta (62.29%) followed by the Chlorophyta (16.98%), while the least were the Euglenophyta, Pyrrophyta, and Rhodophyta (1.87%). The standard errors of the different divisions were significantly different in the different paddy sites (Figure 2). A one way ANOVA showed a significant difference between the different algae divisions in the different paddy field sites with LSD of 1.628 (Table 7). The most abundant species were *Microcystis sp*

Table 6. Pearson correlation coefficients between water parameters and species richness indices in the different paddy fields.

	pH	Conductivity	Salinity	NO_3^-	PO_4^{3-}	K^+	Na^+	Richness (D)	Diversity (H')	Evenness
Conductivity	-0.831	-								
Salinity	0.825	-0.441	-							
NO_3^-	0.429	0.113	0.613	-						
PO_4^{3-}	0.269	0.268	0.477	0.985*	-					
K^+	0.991*	-0.890	0.788	0.303	0.136	-				
Na^+	0.976*	-0.855	0.698	0.417	0.271	0.963*	-			
Richness (D')	0.865	-0.560	0.986*	0.481	0.329	0.850	0.737	-		
Diversity (H')	0.842	-0.405	0.893	0.841	0.733	0.764	0.800	0.839	-	
Evenness	-0.021	0.068	-0.329	0.386	0.454	-0.097	0.176	-0.403	0.130	-
Similarity	0.668	-0.333	0.949*	0.424	0.295	0.655	0.491	0.951*	0.712	-0.603

*Significant at 0.05 level.

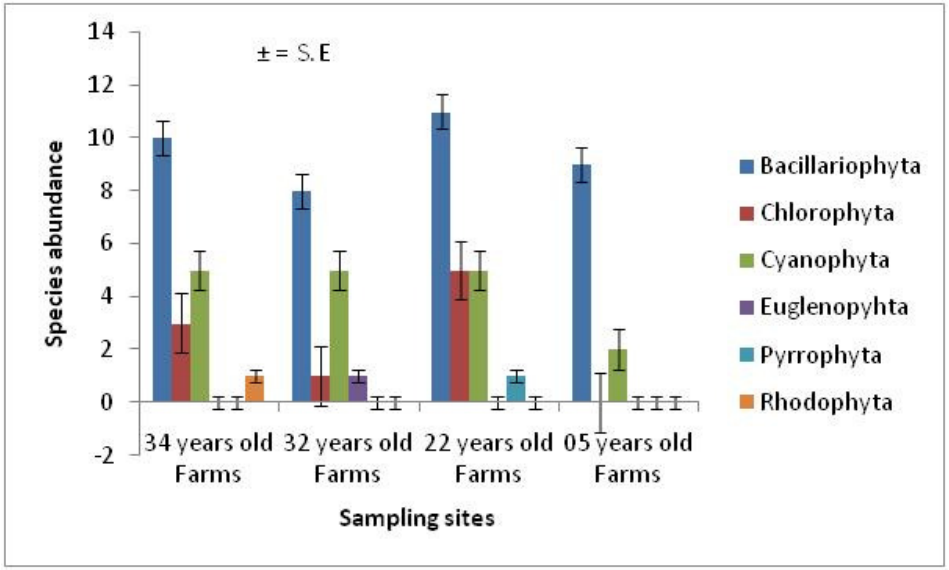

Figure 2. Frequency of benthic organisms across the study sites in the Ndop Plain

Table 7. One way analysis of variance showing significant different in the various algae division across sites with the least significant difference.

Source of variation	d.f.	s.s.	m.s	v.r.	Fpr.
Division	8	73.222	9.153	7.27	<0.001
Residual	27	34.000	1.259		
Total	35	107.222			
LSD		1.628			

(40.35% in the 34 years old site and 22.06% in the 32 years old site), *Chlorococcus dispersus* (17.21% in the 22 years old sites), while *Nitzschia sigmoidea* was 24.24% in the 05 years old site (Table 8). The least abundant species were *Scenedesmus granulates* (0.88%) and *Nitzschia harderii* (0.88%) in the 34 year old site, *Volvox* sp. (1.47%) and *Nitzschia accularis* (1.47%) in the 32 years old site; *Pinnularia bemiptera* (0.82%) and *Anomoeoneis vitra* (0.82%) in the 22 years old site, and *Anacystis* sp. (3.03%) and *Anabaena* sp. (3.03%) in the five years old site. The most frequent species were *Anacystis* sp. present in all the sites. *Nitzschia sigmoidea* and *Microcystis* sp. were also present in all sites (except the five year old site). The least frequent species were *Scenedesmus* sp. (present only on the 33 years old sites), *Pinnularia bemptrea* and *Nitzschia sigma* which were present only in the 22 year old site. The results showed that 54.72% of the species indicated eutrophic status, 9.43% mesotrophic, and 18.87% oligotrophic. Eutrophic species were found more in the older paddy field sites while the younger paddy field sites had more oligotrophic species.

Table 9 shows the Diversity Indices (DI) of the species, following the different age gradients. The 34 year old site had a DI of 2.27, with 20 species and an evenness of 0.77; the 32 year old site had a DI of 2.43, with 16 species and an evenness of 0.90; the 22year old site had DI of 2.66, with 23 species and an evenness of 0.86; and the five year old site had a DI of 2.11, with 12 species and an evenness of 0.88. The 22 year old site was therefore most diverse, while the five year old site was the least. Species diversity indices for the benthic organisms increased with increasing age, with 22 year old site being the most diverse.

DISCUSSION

Soils with pH values ranging from 4.0–5.3 are classified acidic (Yerima and Van Ranst (2005). Such soils are said to be toxic if they contain Al and Mn, but are deficient in Ca, and Mg. The low pH values in all the sites could be as a result of the application of acid forming fertilizers such as urea and other nitrogenous fertilizers. Fertilizers containing nitrogen in the form of ammonia, or in other forms subject to nitrification, will increase the acidity of the paddy fields. Wetland rice is a unique crop when compared to other agricultural crops in the sense that optimum yield of wetland rice could be achieved without the application of nitrogenous fertilizers. This is explained by the fact that the water in flooded fields is suitable for the growth of free-living, autotrophic nitrogen-fixing blue-green algae. The presence of anaerobic heterotrophic bacteria (*Clostridium* and *Azotobacter*) in anaerobic soils also contributes effectively to nitrogen fixation (Foth, 1984). These natural activities will also increase the acidity of the wetland soils. The low values of the exchangeable bases could be attributed to the fact that the present recommended farm management practice of ploughing back crop residue into the soils is not practiced in this area. Instead the crop residue is given as fodder to cattle or even burnt when dry. Fertilizer recommendations here is a blanket recommendation applied by broadcasting method, and this does not take into consideration the soil fertility test values, which should give proper fertilizer recommendations for each site. The low levels of Ca and Mg in the soils could be due to the absorption by benthic species. According to Baert *et al*., (1996), these parameters have an influence on the abundance and diversity of benthic species particularly Bacillariophyta whose cell walls need both calcium and silicon. The decrease in the K levels with age of paddy fields could be attributed to the supplying power of the soils as it has been shown that K levels decrease with continuous cropping (Tening et al. 1995). This was also reflected in the decrease of ECEC of the soils with age of paddy fields. Tening and Omueti (2000), Fonge *et al*. (2013) and Tening et al. (2013) reported that soils with low ECEC will be susceptible to low retention of nutrients which are easily transported into water. The C/N ratio is less than 15 in all the sites implying that mineralisation exceeds immobilisation (Foth, 1984). The non significant relationships between Tot. N and Benthic diversity as well as Av. P and benthic diversity could be due to the fact that their presence will enhance growth of all plant species thereby introducing plant competition. Hill *et al*. (2000) provided evidence that N and P were not significant

Table 8. Checklist of benthic algae, their abundance, relative abundance and trophic status following age gradient in the different paddy field sites

PHYLLUM	FAMILY	Scientific Names	Species abundance in the different age gradients.								Status
			34years old farm (1975)		32years old farm (1977)		22 years old farm (1988)		05 years old farm (2004)		
			Freq	RA (%)	Freq	RA (%)	Freq	RA (%)	Freq	RA (%)	
Bacillariophyta	Nitzschiaceae	*Nitzschia liebetruchii*	7	6.140	0	0	0	0	0	0	Eutro
Bacillariophyta	Nitschiaceae	*Nitzschia bacillariaeformis*	2	1.754	0	0	0	0	0	0	Eutro
Bacillariophyta	Nitschiaceae	*Nitzschia harderis*	1	0.877	3	4.412	0	0	0	0	Eutro
Bacillariophyta	Nitschiaceae	*Nitzschia frustulum*	2	1.754	0	0	0	0	0	0	Eutro
Chlorophyta	Desmidiaceae	*Scenedesmus grnulatus f. disciformis*	1	0.877	0	0	0	0	0	0	Meso
Bacillariophyta	Navicullaceae	*Navicula americana*	2	1.754	0	0	0	0	0	0	oligo
Bacillariophyta	Nitzschiaceae	*Nitzschia sigmoidea*	7	6.140	9	13.235	0	0	8	24.242	Eutro
Bacillariophyta	Bacillariophyceae	*Rhopalodia constricta*	2	1.754	0	0	16	13.115	0	0	NC
Cyanophyta	Cyanophyceae	*Anabaena azollae*	4	3.509	0	0	0	0	0	0	Meso
Bacillariophyta	Fragilariaceae	*Diatom* sp.	3	2.632	0	0	0	0	0	0	Eutro
Euglenopyhta	Euglenaceae	*Euglena* sp.	0	0	2	2.941	0	0	0	0	Eutro
Bacillariophyta	Nitzschiaceae	*Nitzschia dubiiformis*	2	1.754	0	0	0	0	0	0	Eutro
Bacillariophyta	Nitschiaceae	*Nitzschia augulata*	7	6.140	0	0	0	0	0	0	Eutro
Cyanophyta	Cyanophyceae	*Microcystis* sp.	46	40.351	15	22.059	11	9.016	0	0	Eutro
Cyanophyta	Cyanophyceae	*Anacystis* sp.	8	7.018	4	5.882	6	4.918	1	3.030	Eutro
Cyanophyta	Cyanophyceae	*Anacystis cyanea*	7	6.140	0	0	5	4.098	0	0	Eutro
Chlorophyta	Cladophoraceae	*Grammatophora* sp.	2	1.754	0	0	0	0	0	0	Meso
Rhodophyta	Lemaneaceae	*Lemanea* sp.	1	0.877	0	0	0	0	0	0	NC
Chlorophyta	Monostromataceae	*Monoraphidium setiforme*	4	3.509	0	0	0	0	0	0	NC
Cyanophyta	Nostocaceae	*Anabaena* sp.	0	0	9	13.235	0	0	1	3.030	Meso
Bacillariophyta	Diplonieceae	*Diplonies finnica*	0	0	3	4.412	0	0	0	0	NC
Bacillariophyta	Navicullaceae	*Navicula gibbula*	0	0	7	10.294	0	0	0	0	oligo
Bacillariophyta	Nitschiaceae	*Navicula elginesis*	0	0	3	4.412	0	0	0	0	oligo
Bacillariophyta	Cymbellaceae	*Gomphonema teresgtinum*	0	0	2	2.941	0	0	0	0	Eutro
Bacillariophyta	Nitzschiaceae	*Nitzschia acicularis*	0	0	1	1.471	0	0	0	0	Eutro
Chlorophyta	Volvocaceae	*Volvox* sp.	0	0	1	1.471	0	0	0	0	Eutro
Cyanophyta	Oscillatoriaceae	*Oscillatoria splendida*	0	0	2	2.941	9	7.377	0	0	Eutro

Table 8. Continue

Bacillariophyta	Naviculaceae	*Navicula salinarum*	0	0	3	4.412	0	0	0	0	oligo
Chlorophyta	Chlorellaceae	*Chlorella* sp.	0	0	0	0	2	1.639	0	0	Eutro
Chlorophyta	Conjugaceae	*Spirogyra* sp.	0	0	0	0	6	4.918	0	0	Eutro
Bacillariophyta	Nitschiaceae	*Nitzschia hungariea*	0	0	0	0	12	9.836	3	9.091	Eutro
Chlorophyta	Chlorophyceae	*Chlamydomonas* sp.	0	0	0	0	5	4.098	0	0	Eutro
Bacillariophyta	Naviculaceae	*Navicula gregaria*	0	0	0	0	2	1.639	0	0	oligo
Cyanophyta	Cyanotheceae	*Cyanothece aeruginosa*	0	0	0	0	2	1.639	0	0	NC
Bacillariophyta	Anomoeoneiceae	*Anomoeoneis vitrea*	0	0	0	0	1	0.820	0	0	NC
Chlorophyta	Chloroccoccaceae	*Chlorococcus dispersus*	0	0	0	0	21	17.213	0	0	Eutro
Chlorophyta	Chlorophyceae	*Sticbococcus* sp.	0	0	0	0	2	1.639	0	0	NC
Bacillariophyta	Navicullaceae	*Pinnularia bemiptera*	0	0	0	0	1	0.820	0	0	oligo
Bacillariophyta	Navicullaceae	*Navicula secreta*	0	0	0	0	1	0.820	0	0	oligo
Bacillariophyta	Cymbellaceae	*Cymbella mesiana*	0	0	0	0	3	2.459	0	0	NC
Bacillariophyta	Nitzschiaceae	*Nitzschia sigma*	0	0	0	0	1	0.820	0	0	Eutro
Bacillariophyta	Surirellaceae	*Surirella* sp.	0	0	0	0	1	0.820	0	0	Meso
Pyrrophyta	Gymnodiniaceae	*Peridinium subsalsum*	0	0	0	0	1	0.820	0	0	Eutro
Bacillariophyta	Nitzschiaceae	*Nitzschia palustris*	0	0	0	0	2	1.639	0	0	Eutro
Bacillariophyta	Nitschiaceae	*Nitzschia closterium*	0	0	0	0	12	9.836	0	0	Eutro
Bacillariophyta	Navicullaceae	*Navicula exigua*	0	0	0	0	0	0	5	15.152	oligo
Bacillariophyta	Nitschiaceae	*Naviculac lementis*	0	0	0	0	0	0	2	6.061	oligo
Bacillariophyta	Nitzschiaceae	*Nitzschia cylindra*	0	0	0	0	0	0	7	21.212	Eutro
Bacillariophyta	Navicullaceae	*Navicula pseudosilicula*	0	0	0	0	0	0	1	3.030	oligo
Bacillariophyta	Nitzschiaceae	*Nitzschia hybrida*	0	0	0	0	0	0	2	6.061	Eutro
Bacillariophyta	Nitschiaceae	*Nitzschia nana*	0	0	0	0	0	0	2	6.061	Eutro
Bacillariophyta	Achnanthaceae	*Cocconeiss chuette*	0	0	0	0	0	0	1	3.030	NC
Cyanophyta	Nostoceae	*Nostoc linkia*	6	5.263	4	5.882	0	0	0	0	Eutro

Table 9. Benthic Diversity Indices

SITES	Richness (D')	Diversity (H')	EXP H'	Hmax	Evenness	Similarity indices
34years	3.801	2.273	9.717990	2.944439	0.772296	0.506
32years	3.318	2.422	11.33692	2.708050	0.896610	0.336
22years	4.371	2.657	14.25671	3.091042	0.859654	0.532
05years	2.860	2.110	8.247226	2.397895	0.879887	0.178

environmental variables for evaluating the use of periphyton assemblage data, as an index of biotic integrity

The low pH of water from the paddy fields is not unusual as anthropogenic activities around the wetland area bring in a lot of nitrogenous compounds which undergo hydrolysis in water thereby increasing the acidity of the water. Principal component analyses in the different sites showed that K^+, Na^+, pH and salinity are vital abiotic factors that contribute in ecosystem management (Mosisch *et al*. 1999; Lavoie *et al*. 2004). The strong interaction between species diversity and salinity in the dry season is not uncommon as it has been reported that dry conditions elevate salinity and create conditions suitable for the survival of benthic alga species (Onyema *et al*. 2003; Martin *et al*. 2011).

The 22 year old site had the most abundant species, while the five year old site had the least. The former was also the richest in terms of species and the most diversed, followed by the 32 year old site, while the five year old site was the least diversed. Diversity decreases with the age of the farms, except for the 22 year old site which corresponded with the high NO_3^- and and PO_4^{3-} loads that lead to eutrophication. Bacillariophyta and *Nitzschia* sp. were the most abundant division and species, respectively. This showed that the water is eutrophic (Bellinger and Siege, 2010). *Nitzschia* sp. is an indicator of eutrophic environment (Schneider and Lindstrøm, 2011). The presence of cyanobacteria could be attributed to the shallow nature of most of the sites having large amounts of organic matter, except for the five year old site, which was still a young farm. *Anabaena circinalis*, *Microcystis aeruginosa, M. wesenbergii, M. viridis,* are typical blue-green algae that indicate eutrophication, while the presence of *Scenedesmus* sp. is a sign of strong eutrophication (Rosén, 1981). *Microcystis aeruginosa* was the most common species in all the sites, meaning that all the sites were showing some signs of pollution. Many strains of *Microcystis* are known to produce cyanobacterial hepatotoxins, termed microcystins (Yasuno *et al*. 2000). These toxins are soluble peptides which damage the livers of higher animals (Codd and Poon, 1988; Watanabe *et al*. 1991) and are lethal or harmful to many kinds of aquatic organisms (Penaloza et al., 1990). Therefore, the control of microcystin-produced by *Microcystis* is an important environmental and public health issue. Hamma and Park (2005) suggested that the major source of variation of Microcystin content of *Microcystis* bloom seems to be related to changes in dominance of *Microcystis* morphospecies. Hamma *et al*. (2008) reported that high nutrient concentration could promote the dominance of toxic *Microcystis*. Our results showed that concerted action is now needed to monitor nutrient levels in order to prevent more serious *Microcystis* blooms in such important agro-ecological sites.

CONCLUSION

The diversity and abundance of the diatoms and Cyanophyta show a polluted environment, especially since the nitrate and phosphate levels in water were more than the EPA values. However this is not reflected in the soil, suggesting low resident time. The high *Microsystis* sp. abundance is of concern with reference to farmers and animal health hence the sources of pollutants need to be addressed in this wetland.

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