UNIVERSITY OF CAPE COAST

OBSERVATIONS ON THE BENTHIC MACROINVERTEBRATE AND FISH COMMUNITIES OF THE KAKUM ESTUARY WETLAND IN GHANA

BY

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DECLARATION

Candidate's Declaration

I hereby declare that this thesis is the result of my own original work and that no part of it has been presented for another degree in this university or elsewhere.

Candidate's Signature..................................... Date.....................................

Name: Isaac Okyere

Supervisors' declaration

We hereby declare that the preparation and presentation of the thesis were supervised in accordance with the guidelines on supervision of thesis laid down by the University of Cape Coast.

Principal Supervisor's Signature.............................. Date............................

Name: Prof. John Blay

Co – Supervisor's Signature...................................... Date...............................

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ABSTRACT

The environmental conditions, composition of benthic macrofauna, and richness, diversity, as well as food habits and aspects of reproductive biology of fish species in the Kakum Estuary wetland (located 2 km west of Cape Coast, Ghana) were studied from July 2009 to February 2010 in an effort to broaden our knowledge of the biodiversity and ecological value of wetland ecosystems. Sampling was conducted on five pools in the wetland.

Oligochaeta and Diptera (chironomid larvae) were the only benthic organisms present, presumably because of the ephemeral nature of the environment. During the dry season, the organisms declined significantly in abundance and densities and later disappeared, possibly due to the continuously increasing salinity which rendered the environment stressful to the organisms.

Twelve families of eighteen genera comprising eighteen fish species were collected, of which *Aplocheilichthys spilauchen* (43.31%), *Sarotherodon melanotheron* (18.12%) and the freshwater shrimp *Macrobrachium macrobrachion* (12.37%) were dominant. Results suggested that marine and freshwater fishes use the wetland as nursery and feeding grounds. The fish communities included planktivorous, carnivorous and omnivorous ones. *Kribia kribensis* and *Porogobius schlegelii* had high fecundities suggesting that they provide little or no parental care while *S. melanotheron* and *A. spilauchen* had low fecundities which were attributable to their adaptations for ensuring survival of their spawn. Some recommendations have been made including restriction on fishing during the wet season to avoid exploitation of juvenile fishes.

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DEDICATION

This work is wholly dedicated to my father Mr. Samuel Asiedu.

TABLE OF CONTENTS

Content Page

Content	Page
DECLARATION	ii
ABSTRACT	iii
ACKNOWLEDGEMENTS	iv
DEDICATION	v
LIST OF TABLES	ix
LIST OF FIGURES	x
LIST OF PLATES	xiii
LIST OF APPENDICES	xiv
CHAPTER ONE: INTRODUCTION	1
Objectives	8
CHAPTER TWO: MATERIALS AND METHODS	9
Study area	9
Measurement of aquatic environmental factors	14
Benthic macroinvertebrate sampling	14
Fish sampling and measurements	15
Analysis of fish data	16
Analysis of benthic invertebrate data	18
CHAPTER THREE: RESULTS	20

Surface area and depths of pools 20

Monthly changes in aquatic environmental parameters 22

Variations in composition of benthic macroinvertebrates 30

Variations in density of invertebrate fauna 32

Fish species occurrence in pools 41

Fish species richness and diversity 41

Similarity of fish communities 44

Monthly composition of fish species 45

Pooled data on fish composition in the wetland 59

Size distribution of the three most common species in the wetland 62

Food habits of the fishes in the wetland 67

Aspects of the reproductive biology of some fishes 82

CHAPTER FOUR: DISCUSSION 88

Conditions in the wetland 88

The macrozoobenthic community 92

The fish community 94

Food habits of the fishes 97

Breeding habits of the fishes 102

CHAPTER FIVE: CONCLUSIONS AND RECOMMENDATIONS 104

Conclusions 104

Recommendations 107

REFERENCES 109

APPENDICES 121

LIST OF TABLES

Table		Page
1	Surface area of pools in the Kakum Estuary wetland	20
2	Density of benthic invertebrates in Pool I in the Kakum Estuary wetland from July to October 2009	35
3	Density of benthic invertebrates in Pool II in the Kakum Estuary wetland from July to October 2009	36
4	Density of benthic invertebrates in Pool III in the Kakum Estuary wetland from July to October 2009	37
5	Density of benthic invertebrates in Pool IV in the Kakum Estuary wetland from July to November 2009	38
6	Density of benthic invertebrates in Pool V in the Kakum Estuary wetland from July to October 2009	39
7	Occurrence of fish species in the Kakum Estuary wetland in pools	42
8	Species richness and diversity indices for fish communities of the five pools in the wetland	43
9	Sorensen’s similarity index for the pairs of fish communities	44
10	Size range of fish species sampled (all pools) from the Kakum Estuary wetland	66
11	Sex ratio of *Aplocheilichthys spilauchen* in pools in the wetland	82
12	Fecundity of four species in the Kakum Estuary wetland	83

LIST OF FIGURES

Figure		Page
1	Map of Ghana showing the Kakum Estuary wetland	10
2	Changes in the depth of pools in the Kakum Estuary wetland from July 2009 to February 2010	21
3	Monthly changes in temperature in Kakum Estuary wetland pools from July 2009 to January 2010	23
4	Changes in salinity of pools in the Kakum Estuary wetland from July 2009 to January 2010	24
5	Monthly increase in conductivity in pools in the Kakum Estuary wetland from July 2009 to January 2010	25
6	Monthly rise in turbidity of Kakum Estuary wetland pools from July 2009 to January 2010	27
7	Monthly fluctuations in dissolved oxygen content of pools in the Kakum Estuary wetland from July 2009 to January, 2010	28
8	Monthly variations in pH of Kakum Estuary wetland pools from July 2009 to January 2010	29
9	Percentage composition of benthic macroinvertebrates in the five pools in Kakum Estuary wetland from July 2009 to January 2010	31
10	Monthly mean density of benthic macroinvertebrates in five pools in Kakum Estuary wetland from July 2009 to January 2010	33
11	Monthly percentage composition of fish species in Pool I in the Kakum Estuary wetland from July 2009 – January 2010	46

12 Overall percentage composition of fish species in Pool I in the Kakum Estuary wetland 47

13 Monthly percentage composition of fish species in Pool II in the Kakum Estuary wetland from July 2009 – January 2010 49

14 Overall percentage composition of fish species in Pool II in the Kakum Estuary wetland 50

15 Monthly percentage composition of fish species in Pool III in the Kakum Estuary wetland from July 2009 – January 2010 52

16 Overall percentage composition of fish species in Pool III in the Kakum Estuary wetland 53

17 Monthly percentage composition of fish species in Pool IV in the Kakum Estuary wetland from July 2009 – January 2010 55

18 Overall percentage composition of fish species in Pool IV in the Kakum Estuary wetland 56

19 Monthly percentage composition of fish species in Pool V in the Kakum Estuary wetland from July 2009 – January 2010 58

20 Overall percentage composition of fish species in Pool V in the Kakum Estuary wetland 60

21 Percentage composition of fish species in the Kakum Estuary wetland 61

22 Length-frequency distribution of *Aplocheilichthys spilauchen* in five Kakum Estuary wetland pools 63

23 Length-frequency distribution of *Sarotherodon melanotheron*

	in four Kakum Estuary wetland pools	64
24	Length-frequency distribution of *Macrobrachium macrobrachion* in four Kakum Estuary wetland pools	65
25	Frequency and composition of different food items in the diet of *Aplocheilichthys spilauchen* in the Kakum Estuary wetland pools	68
26	Frequency and composition of food items consumed by *Sarotherodon melanotheron* in Kakum Estuary wetland pools	71
27	Occurrence and composition of different food items in the diet of *Liza falcipinnis* in the Kakum Estuary wetland pools	73
28	Frequency and composition of different food items in the diet of *Tilapia zillii* in the Kakum Estuary wetland pools	75
29	Composition of prey items in the diet of *Hemichromis fasciatus* in the Kakum Estuary wetland	77
30	Composition of food items in the diet of *Kribia kribensis* in the Kakum Estuary wetland	79
31	Composition of food items in the diet of *Porogobius schlegelii* in the Kakum Estuary wetland	80
32	Regression plot of fecundity-total length relationship of *Aplocheilichthys spilauchen*	85
33	Regression plot of fecundity-body weight relationship of *Aplocheilichthys spilauchen*	86
34	Ova diameter frequency distribution of *Aplocheilichthys spilauchen* from the Kakum Estuary wetland	87

LIST OF PLATES

Plate		Page
1	Portions of the Kakum Estuary wetland during the wet season	12
2	Portions of the Kakum Estuary wetland during the dry season	13

LIST OF APPENDICES

Appendix		Page
A	Averages of environmental parameters of the five Kakum Estuary wetland pools sampled from July 2009 to February 2010	121
B	Size distribution of fish species from Pool I in the Kakum Estuary wetland	125
C	Size distribution of fish species from Pool II in the Kakum Estuary wetland	126
D	Size distribution of fish species from Pool III in the Kakum Estuary wetland	127
E	Size distribution of fish species from Pool IV in the Kakum Estuary wetland	128
F	Size distribution of fish species from Pool V in the Kakum Estuary wetland	129

CHAPTER ONE

INTRODUCTION

The term ‘wetland’ generally groups together a wide range of habitats that share common features, the most important of which is continuous, seasonal or periodic standing water or saturated soils. Classification of wetlands has been a problematic task, with the commonly accepted definition of what constitutes a wetland being among the major difficulties and a controversial starting point (Scott & Jones, 1995). Two main scientifically-based and in a way comprehensive wetlands classification systems which have gained broad acknowledgement are the classification system provided by Cowardin, Carter, Golet and LaRoe (1979) for the needs of the US government, and the classification adopted by the Ramsar Convention on Wetlands (Ramsar Convention Secretariat, 2007).

Cowardin *et al.* (1979) defines wetlands by plants (hydrophytes), soils (hydric soils), and frequency of flooding. Ecologically related areas of deep water, traditionally not considered wetlands, are included in their classification. The scheme classifies wetlands into Systems, which are further divided into smaller Subsystems, Classes, Subclasses, and Dominance Types. Systems form the highest level of the classification hierarchy; five are defined: Marine, Estuarine, Riverine, Lacustrine, and Palustrine. Marine and Estuarine Systems each have two Subsystems, Subtidal and Intertidal; the Riverine System has four

Subsystems, Tidal, Lower Perennial, Upper Perennial, and Intermittent; the Lacustrine has two, Littoral and Limnetic; and the Palustrine has no Subsystems. Within the Subsystems, Classes are based on substrate material and flooding regime, or on vegetative life form.

The classification system set up by Cowardin *et al*. (1979) did not include many wetland types that have resulted from human activities. To avoid the weak point of this classification system, the Ramsar Convention on Wetlands developed a new and more comprehensive wetland classification system (adopted in 1990 and modified in 1996), known as “the Ramsar Classification System for Wetland Type” (Ramsar Convention Secretariat, 2007), and this is the only attempt made to establish a global system for classifying wetlands (Scott & Jones, 1995). The wetlands are classified into three major classes: Marine-coastal wetlands, Inland wetlands and Human-made wetlands. These are further subdivided by the type of water: fresh, saline, brackish and alkaline; and may be further classified by the substrate type of other characteristics.

The Ramsar Convention (1971) defines wetlands as "areas of marsh, fen, peat land or water, whether natural or artificial, permanent or temporal, with water that is static or flowing, fresh, brackish or salt, including areas of marine water, the depth of which at low tide does not exceed six metres". Therefore, the categories of wetland ecosystems under the “Ramsar Classification System for Wetland Type” include wide variety of habitats such as marshes, peat lands, floodplains, rivers, lakes, coastal areas such as salt marshes, mangroves, seagrass beds, coral reefs and other marine areas no deeper than six metres at low tide, as well as human-made wetlands such as waste-water treatment ponds and reservoirs (Ramsar Convention Secretariat, 2007).

The need for a better understanding of the role of biodiversity in the functioning of aquatic ecosystems has been raised by several authors (Little, Reay & Grove, 1988; Ryan & Ntiamoa-Baidu, 2000; Scherer-Lorenzen, 2005; Duarte, Macedo & Fonseca, 2006). Humbert and Dorigo (2005) have indicated that ecosystem functioning depends on several factors including biodiversity and a multiplicity of interactions between the physical, chemical and biological determinants. According to Lévêque (1995), several studies attribute ecosystem function largely to processes such as storage and transfer of matter and energy at different temporal and spatial scales. Scherer-Lorenzen (2005) also argues that the function of an ecosystem is highly dependent on the functional traits of the organisms involved as well as the abiotic environment. In agreement with Scherer-Lorenzen (2005), Humbert and Dorigo (2005) pointed out that knowledge of the functional traits of biodiversity and ecological interaction between the biotic and abiotic environments is crucial for informed management decisions.

Wetland ecosystems provide essential services and these have been enumerated by Ryan and Ntiamoa-Baidu (2000), to vary from ecological to socio-economic. Ecologically, they function in storage of runoff, denitrification and detoxification of polluted water, prevent shoreline erosion, and serve as breeding and feeding grounds for diverse animals such as mammals, birds, reptiles, and fishes. Furthermore, wetlands provide socio-economic services such as fisheries and eco-tourism.

Due to these vital and valuable ecological and socio-economic services, the management of wetlands and their resources has been a prime concern in international, national and local environmental management conventions, policies and projects over the last four decades (Masundire, 1994; Ramsar Convention Secretariat, 2007). In line with this, over 1840 wetlands worldwide have been designated as Ramsar sites (internationally important wetlands) under the Ramsar Convention (Ramsar Convention Secretariat, 2007) and are being managed and protected with financial aid from international organisations such as the Global Environment Facility (GEF) and the World Bank. In Ghana, Ramsar sites are being managed under the Coastal Wetlands Management Project (CWMP) with support from the Global Environment Facility (Ryan & Ntiamoa-Baidu, 2000).

Yankson and Obodai, (1999) have reported the occurrence of over one hundred estuaries and lagoons and their watersheds along the 550 km coastline of Ghana. However, only five lagoons and their watersheds namely Muni-Pomadze lagoon (9,461.12 hectares), Densu delta (5,892.99 hectares), Sakumo lagoon (1,364.35 hectares), Songor lagoon (51,113.33 hectares) and Keta lagoon (101,022.69 hectares) are being managed as Ramsar sites (Willoughby, Grimble, Ellenbroek, Danso & Amatekpor, 2001; Quashie & Oppong, 2006). Apart from these wetlands, the other coastal wetlands are relatively smaller and considered publicly owned resources with apparently no regulation on the use of their resources (Attuquayefio & Gbogbo, 2001). Against this background, concerns have been raised (Gbogbo, 2007; Attuquayefio & Gbogbo, 2001) about managing a few wetlands and their resources as Ramsar sites to the neglect of the majority because of their smaller size as this has serious implications for their resources. There is therefore the need to consider management of other coastal wetlands in Ghana. It is however important that baseline information on the ecological health of these wetland ecosystems is acquired on which sound management decisions can be made.

Through the initiatives of the CWMP, detailed studies have been conducted on the hydrology (Tumbulto & Bannerman, 1995), flora (Oteng-Yeboah, 1994) and fauna (Gordon, 1995; Koranteng, 1995; Koranteng, Ofori-Danson & Entsua-Mensah, 2000; Ryan & Attuquayefio, 2000; Raxworthy & Attuquayefio, 2000) of the Ramsar sites as a prerequisite for sound management of these sites. On the other hand, there is a dearth of information on the ecology and socio-economic value of the smaller wetlands. Ghana being signatory to the Ramsar Convention, it is pertinent to promote the management and wise use of the smaller wetlands through the assessment and monitoring of wetland conditions and resources.

Even though the Ministry of Lands and Forestry is implementing the policy on National Wetlands Conservation Strategy (Ministry of Lands and Forestry, 1999; Ministry of Lands and Forestry, 2005) which aims at extending management interventions to encompass a greater number of unmanaged wetlands, the impact of this policy has remained imperceptible since its enactment. Towards this end, Attuquayefio and Gbogbo (2001) and Gbogbo (2007) have investigated the fauna and other aspects of such unmanaged wetlands as the Mukwe and Laiwi lagoons in the Greater Accra Region of Ghana, purposely to promote their management. The present study seeks to investigate the benthic macroinvertebrate and fish fauna of an unmanaged wetland in Ghana to prioritise issues of ecological concern and also to encourage management interventions.

Although the composition, diversity, biomass and density of benthic macrofauna of some wetland ecosystems in Ghana have been reported (Blay & Dongdem, 1996; Gordon, 2000; Yankson & Akpabey, 2001; Lamptey & Armah, 2008), these investigations focused on lagoons and estuaries, with no consideration for the adjoining coastal marshes. There is thus a dearth of information on the biodiversity of such ecosystems in Ghana, and the impacts of abiotic factors on their macroinvertebrate communities. Considering the fact that wetlands are dynamic systems with varying hydrological conditions (Acharyya & Mitsch, 2001), and these changes in water quality, periods of anoxia and accumulating organic matter directly affect the macroinvertebrate and fish communities (Craft, 2000), it is pertinent to understand the effects of the changing conditions on the aquatic fauna in a given locality.

Among the fauna of wetland ecosystems, benthic macroinvertebrates have been extensively used for the assessment of the ecological integrity as well as biomonitoring of wetland habitats (Acharyya & Mitsch, 2001; Mekong River Commission, 2010). This is because they manifest a distinct response to changes in the aquatic environment, thus serving as promising indicators of hydrologic stress and aquatic ecosystem health in general (Nazarova, Semenov, Sabirov, Efimov & Yu, 2004). Their sedentary nature, ubiquitous distribution and lifecycles of measurable duration allow for both long term and short term analyses (Rosenberg & Resh, 1993). In addition, benthic macrofauna are easy and inexpensive to sample and easy to identify with already established diversity and monitoring indices (Acharyya & Mitsch, 2001). The composition and density of benthic macrofauna community was therefore used in this study relative to the assessment of wetland habitat conditions. Among others, this information would be useful in determining the ecological health of the wetland and also facilitate its biomonitoring.

Assessment of the fish community was important for several compelling reasons. Coastal wetlands are among the most biologically productive but least understood ecosystems in the world (Ryan & Ntiamoa-Baidu, 2000). In Ghana, they are reported to be the most diverse aquatic habitats (Gordon *et al*., 1998). The smaller coastal wetlands which are greater in number with a wider geographical distribution have been neglected in terms of management and regulatory interventions. This is partly due to a lack of adequate knowledge on the ecology of these wetlands that could advance the understanding of their contributory functions (Attuquayefio & Gbogbo, 2001; Gbogbo, 2007).

For countries in West Africa that are signatory to the Ramsar Convention, this study provides an important insight of fish assemblages and diversity of fish biota, and will thus encourage studies to cover a greater number of such wetlands in the sub-Region. Most importantly, this work was necessary to broaden knowledge of the ecological importance of unmanaged wetlands to Ghana's fisheries, as coastal wetlands are reportedly important breeding, nursery and feeding grounds for juveniles of commercially important marine fishes (Jin, Fu, Zhong, Li, Chen & Wu, 2007; Green, Smith, Earley, Hepburn & Underwood, 2009).

Objectives

The work investigates the diversity of fish and benthic macroinvertebrate fauna, and some aspects of the biology of fishes occurring in the Kakum Estuary wetland near Cape Coast (Ghana) in an effort to provide baseline information on the biodiversity, ecological values and ecological health of the wetland to promote the making of informed decisions for management and wise use the wetland and its resources.

The specific objectives were to:

i. monitor monthly changes in conditions in pools in the wetland (depth, temperature, salinity, conductivity, turbidity, dissolved oxygen and pH).
ii. investigate the richness, composition, density and diversity of benthic macroinvertebrate communities in the wetland
iii. study composition, richness, diversity, aspects of reproduction and food habits of the fish community

CHAPTER TWO

MATERIALS AND METHODS

Study area

The Kakum estuary wetland is a coastal marsh located about 2 km west of Cape Coast in the Central Region of Ghana (approximately 5^{o} 6^{l} N; 1^{o} 18^{l} W) and is associated with the Kakum River Estuary which lies to the west of the wetland (Figure 1). The vegetation in the area is dominated by three main grasses: the saltwater couch *Paspalum vaginatum* (Poaceae), the sedge-grass *Cyperus articulatus* (Cyperaceae) and the bulrush *Typha australis* (Typhaceae) which is limited to the south-eastern sector of the wetland. Patches of the date palm *Phoenix dactylifera* (Palmae) occur along the southern and middle portions, and the thatch grass *Imperata cylindrica* (Poaceae) and coconut trees *Cocos nucifera* (Palmae) fringe the stretch of sandy beach separating the wetland from the Atlantic Ocean.

Three communities namely Duakor, Apewosika and Amamoma border the eastern and northern zones of the wetland, while the western portion is bordered by mangroves which extend from the Kakum River estuary.

The resources of the wetland are exploited by the nearby inhabitants for diverse purposes. Mud is excavated for building huts which are roofed with the thatch grass *I. cylindrica* and the sedge-grass *Cyperus articulatus* is harvested to weave mats; the fruits of the coconut tree are sold; while the fronds are used for

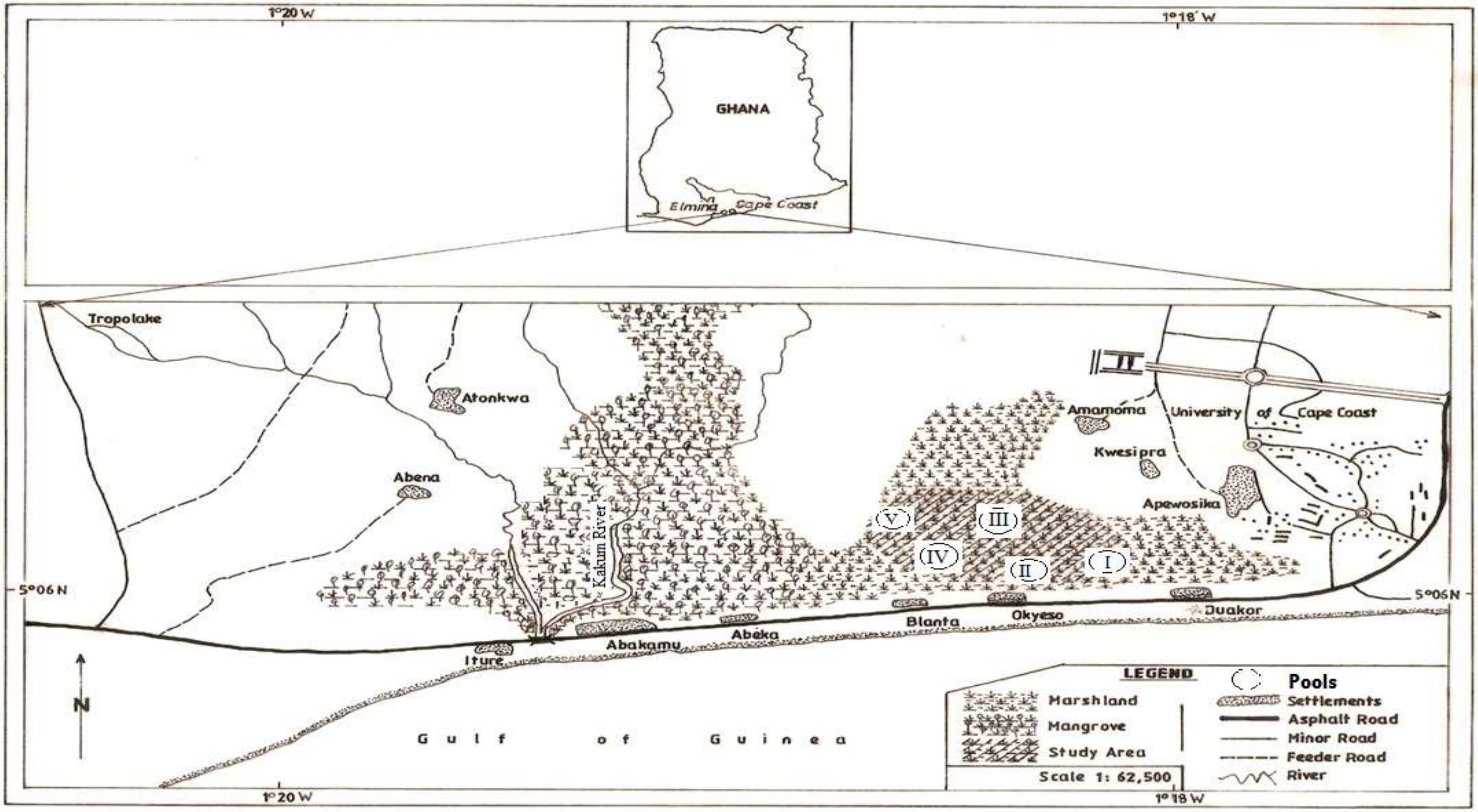

Figure 1: Map of Ghana showing the Kakum Estuary wetland

fencing. Annual temperatures around Cape Coast range between 24ºC and 32ºC with relative humidity ranging between 70% and 90%, and average annual rainfall of 1400 mm (Asamoah, 1973). The area experiences bimodal rainfall regime with peak in May-June and September. Dry periods (harmattan) are experienced between November and March. In the rainy or wet season (from May to September) flood waters from the Kakum River inundate the wetland (Plate 1a-b), and fish become abundant. The fish are exploited mainly on a subsistence scale. The area is characterized by isolated natural pools during the dry season (from October to late March) (Plate 2a-b) which are appear brownish in colour.

The study was conducted from July 2009 to February 2010. Five relatively large pools in the wetland were selected for the study. These pools were selected to ensure as prolonged sampling as possible since it became known from some local fishermen interviewed during a reconnaissance survey that the smaller pools dry up rapidly during the dry season while the larger ones could persist into the peak of the season. The surface area of each pool was determined at the beginning of the study. The area of a near square or rectangular pool was estimated as the product of the length and width, and the area of approximately circular pools was calculated from the formula $A = \pi r^2$ where A= surface area of pool, r = radius of pool and π = 22/7.The deepest part of each pool was measured once a month using a meter rule.

a. The wetland in early June 2009 prior to flooding

b. The flooded wetland in late June to early July 2009

Plate 1: Portions of the Kakum Estuary wetland during the wet season

a. Pool I after the flood

b. Dry bed of Pool I in November 2009

Plate 2: Portions of the Kakum Estuary wetland during the dry season

Measurement of aquatic environmental factors

Measurement of parameters of the aquatic environment, and collection of benthic fauna and fish were undertaken between 20th and 22nd of each month between the hours of 10:00 GMT and 13:00 GMT to ensure consistent monthly sampling, and each pool was sampled till it dried up. Temperature, salinity and conductivity were recorded with a YSI Incorporated (Model 63) meter by immersing the probe into the pool. Temperature was measured to the nearest 0.1 ^{o}C, salinity to the nearest 0.1 ‰ and conductivity to the nearest 1 μS/cm. Turbidity was determined using turbidimeter (*TOA* Model TB-1A) and pH with a portable pH meter (Corning Incorporated Model 220). Dissolved oxygen content of pools was also determined using a HACH test kit Model *FF2* following Winkler's titrametric method.

Three measurements of each physicochemical parameter were taken at different points in each pool on a sampling date and the average value calculated.

Benthic macroinvertebrate sampling

Three replicate samples of pool sediments were collected with an Ekman grab (15 cm × 15 cm) each month for studies on the benthos. The samples were screened in the field using a set of sieves of mesh sizes 4000 μm, 2000 μm and 500 μm, and the animals retained in the sieves were preserved in 10% formalin for detailed examination in the laboratory. Prior to sorting, a pinch of Bengal rose dye was added to the samples to stain the organisms to enhance their visibility. The macrofauna found were examined under a dissecting microscope and identified with the aid of laboratory manuals (Yankson & Kendall, 2001; Hauer &

Lamberti, 2006). Counts of the different taxonomic groups in the samples were recorded separately for further analysis.

Fish sampling and measurements

A pole-seine net (7 m long and 1.5 m deep) with stretched mesh size of 5mm was used for monthly fish sampling. This particular net was used because of the small size, shallowness and soft bottom of the pools; another reason was to ensure the capture of small fishes. The fishes were preserved in 10% formalin soon after capture to arrest post mortem digestion of stomach contents and transported to the laboratory for further examination. The fish were sorted and identified to their families and species using manuals and keys on finfishes and shellfishes in Ghana and West Africa (Rutherford, 1971; Schneider, 1990; Dankwa, Abban & Teugels, 1999; Paugy, Lévêque & Teugels, 2003), and the number of individuals belonging to each species from the pools was recorded.

The total length (TL) and standard length (SL) of finfish; carapace width (CW) of crab and body length (BL) of shrimp specimens were measured to the nearest 0.1 cm and the body weight (BW) of the finfish as well as the shellfish (shrimps and crabs) was determined to the nearest 0.01g. All finfish were dissected to determine the sex and gonad weight (to the nearest 0.01 g), and the content of the stomach was examined using a dissecting microscope where necessary.

Ripe ovaries were preserved in 10% formalin for studies on the fecundity and ova diameter measurements. Eggs were teased from the ovarian tissue in a petri dish and the immature ova were separated from mature ones prior to counting the latter. The whole count method was employed in determining the fecundity of fish species with fewer number (< 1000) of ripe eggs in the ovaries eggs) and the sub-sampling method (Bagenal & Braum, 1978) was used for fish producing a large number (> 3000) of ripe eggs. With the sub-sampling method, the weight of the paired ovaries (W_1) was determined. Four sub samples (two from each ovary) were taken and weighed and the average weight of the sub samples (W_2) was calculated. The number of eggs in each sub sample was then counted and the average (N_2) was computed. The absolute fecundity (Fec) was estimated as $\frac{W_1}{W_2} \times N_2$.

Analysis of fish data

Fish samples from the pools were analyzed for species richness, diversity, species composition, size distribution, and food and habits. Also, sex ratio, fecundity and spawning frequency of some species were determined.

Diversity of the fish communities was ascertained by the Shannon-Wiener index (H′) given as:

$H' = -\sum_{i=1}^{s} P_i(lnP_i)$ (Krebs, 1999),

where *s* is the number of species in the community and

P_i is the proportion of individuals belonging to species *i* in the community

The evenness or equitability component of diversity was calculated from Pielou's index given as:

$J' = H'/H_{max}$ (Pielou, 1966) where $H_{max} = \ln s$.

The degree of similarity between the fish communities in the different pools was determined as:

$C_s = \frac{2j}{a+b}$ (Krebs, 1999),

where C_s is Sorensen's index which ranges from 0 (dissimilar) to 1 (completely similar),

j is the number of species common to a given pair of pools, and

a and b are the number of species occurring in either of the pair.

Size distribution of the most abundant species in the five pools was analyzed at 1cm class intervals to establish their modal sizes.

Stomach contents were analyzed using the "points" and the frequency of occurrence methods (Hyslop, 1980; Lima-Junior & Goitein, 2001). The "points" method gives the bulk contribution of each food item to the total food consumed while frequency of occurrence expresses the number of stomachs in which each food item occurs as a percentage of all stomachs containing food. Points were awarded each stomach according to its degree of fullness; 10 points for full stomach, 5 for half and 2.5 for quarter filled stomach. Empty stomachs were excluded from the analysis. The total number of points awarded to each stomach was subdivided among the food items present according to their relative contribution to the total stomach content. The percentage composition of each of the food items was determined by summing up the points awarded to the item and divided by the total points awarded to all stomachs containing food, and the resulting value expressed as a percentage.

Sex ratio of the species was calculated as the ratio of the number of males to females, and a *Chi-squared* test (Zar, 1999) was used to verify the significance of numerical differences between the sexes. A regression analysis was used to establish the relationship between fecundity and total length; and fecundity and body weight.

The diameter of eggs of 5 female specimens of *Aplocheilichthys spilauchen* (Poeciliidae) was measured with stage micrometer to the nearest 0.1 mm to determine the possible frequency of spawning of the species.

Analysis of benthic invertebrate data

The monthly percentage numerical composition of the different taxa of macrobenthos in the community was calculated. Due to the small number of grab samples (n= 3), counts of individuals belonging to each taxon in a sample were log transformed (Elliott, 1977) to ensure that the estimates truly represent the populations means and confident limits. Where all three samples contained organisms, the number of individuals, x, belonging to each group of invertebrates was transformed as $\log_{10} x$, and where zero counts occurred, $\log_{10}(x+1)$ was used for the transformation. The arithmetic mean of the transformed counts was then calculated, and the derived mean (= geometric mean) which is the mean number of individuals of each taxon per dredge area (225 cm^2 = 0.0225 m^2) was computed as the antilog of the mean of transformed counts. The derived mean value was converted to mean number of individuals per 1 m^2 by multiplying this number by a factor of 44.4.

To compute the 95% confidence limits, the variance of transformed counts was first calculated as $\frac{\sum(\log_{10} x - \bar{y})^2}{n-1}$ where $\bar{y}$ is the arithmetic mean of transformed counts and n is the sample size. The 95% confidence limits were computed as the antilog of $\bar{y} \pm\ t\sqrt{\frac{variance\ of\ transformed\ counts}{n}}$, where t is a tabular statistical value at the 5 % level of probability.

CHAPTER THREE

RESULTS

Surface area and depths of pools

The pools had a characteristically brownish appearance. The estimated surface area of the pools sampled is presented in Table 1. Pool V was the largest with surface area measuring 2680 m^2, which is about three and half times larger than Pools I, III and IV (surface areas 779 m^2, 759 m^2 and 754 m^2 respectively), and four times the size of Pool II (661 m^2).

Table 1: Surface area of pools in the Kakum Estuary wetland

Pool	Surface area(m^2)
Pool I	779
Pool II	661
Pool III	759
Pool IV	754
Pool V	2680

There was a gradual decline in depth of the pools from the wet season months to the dry season months (Figure 2). Although the pools were generally shallow (< 100 cm deep), Pool V was about twice deeper than the others throughout the study period. In July 2009, the maximum depth of Pools I, II, III and IV were 47.0 cm, 45.0 cm, 45.3 cm and 48.5 cm respectively whereas Pool V was 98.3 cm deep. In the subsequent months, the pools progressively reduced in depth. By October 2009, the pools were less than half their initial depth. Pool I, IV, II and III, and V dried out completely in November, December, January and February respectively.

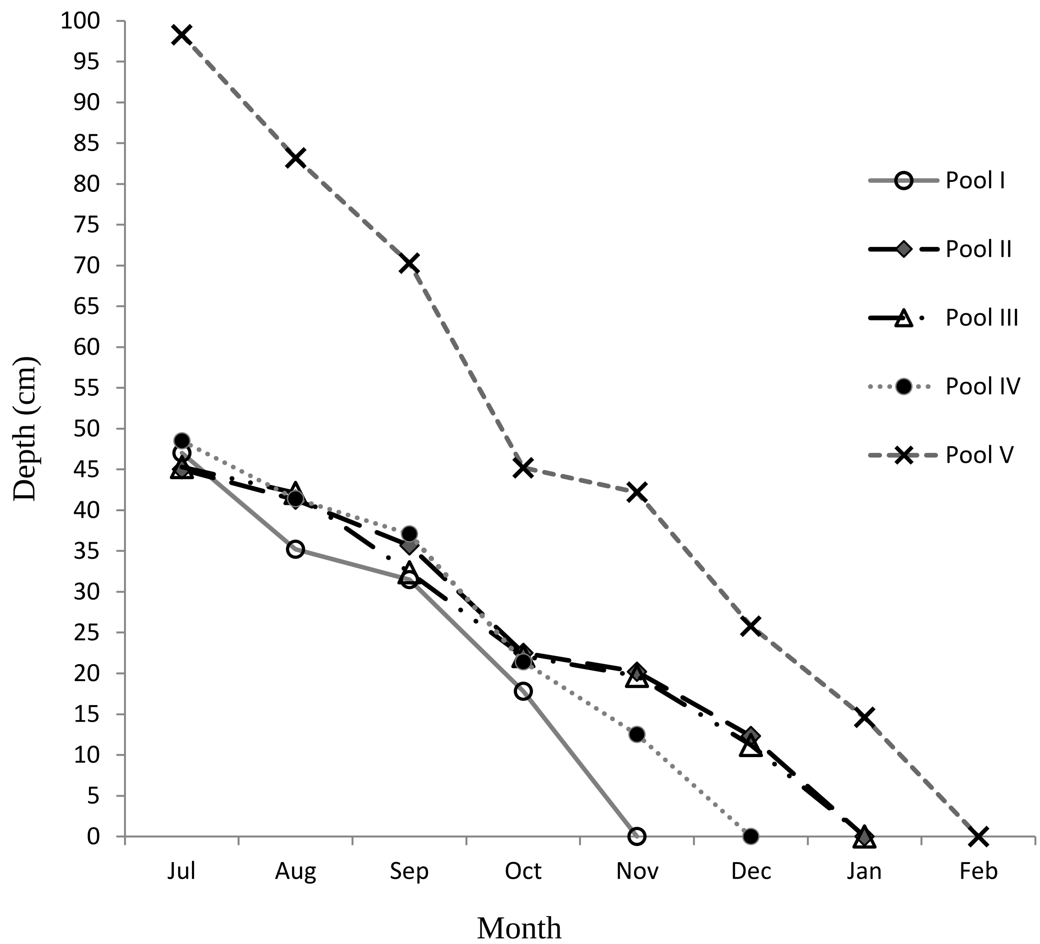

Figure 2: Changes in the depth of pools in the Kakum Estuary wetland from July 2009 to February 2010

Monthly changes in aquatic environmental parameters

Temperature

Monthly water temperatures in the five pools and their variations were very similar (Figure 3).The lowest temperature was recorded in July, ranging from 27.9 ^{o}C in Pool V to 30.7 ^{o}C in Pool IV. Temperatures continued to increase reaching 43.6 ^{o}C, 42.9 ^{o}C and 42.1 ^{o}C in Pool V, III and II respectively in December. The temperature in Pool V, the only remaining pool in January 2010, was 46.6 ^{o}C.

Salinity

The monthly salinities of the pools (Figure 4) did not differ much, with values ranging from 0.7 ‰ to 1.0 ‰ in July 2009, and increasing steadily during the study period. In January 2010, salinity in Pool V reached 5.7 ‰ before drying up.

Conductivity

As illustrated in Figure 5, conductivity was generally low at the beginning of the study, measuring1,503 µS/cm in Pool I and 2,302 µS/cm in Pool III in the month of July 2009. There was a steady increase in conductivity throughout the study period, with values reaching11,930 µS/cm, 11,520 µS/cm and 11,387 µS/cm in Pool III, V and II respectively in December 2009, and 12,777 µS/cm in Pool V in January 2010.

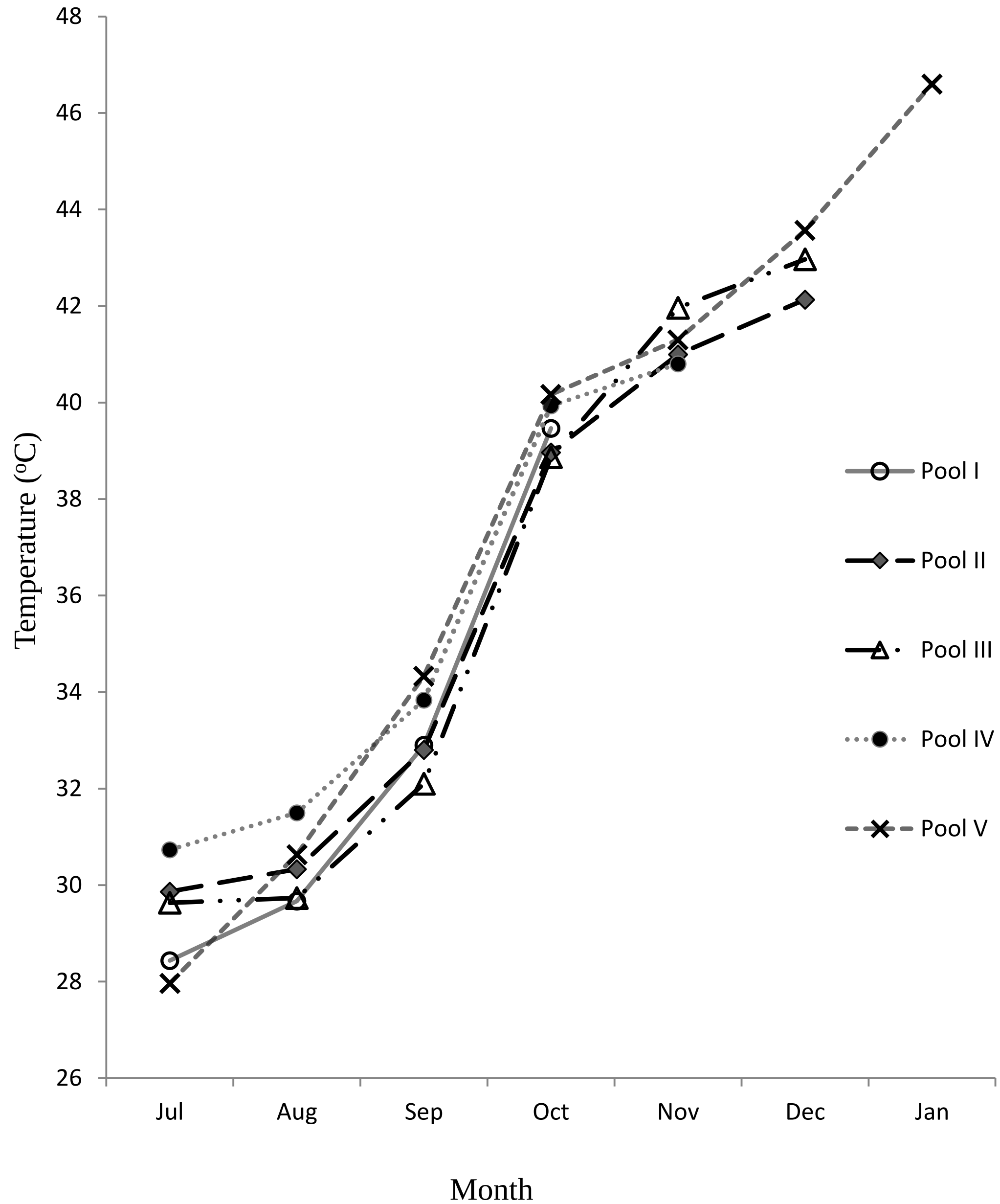

Figure 3: Monthly changes in temperature in Kakum Estuary wetland pools from July 2009 to January 2010

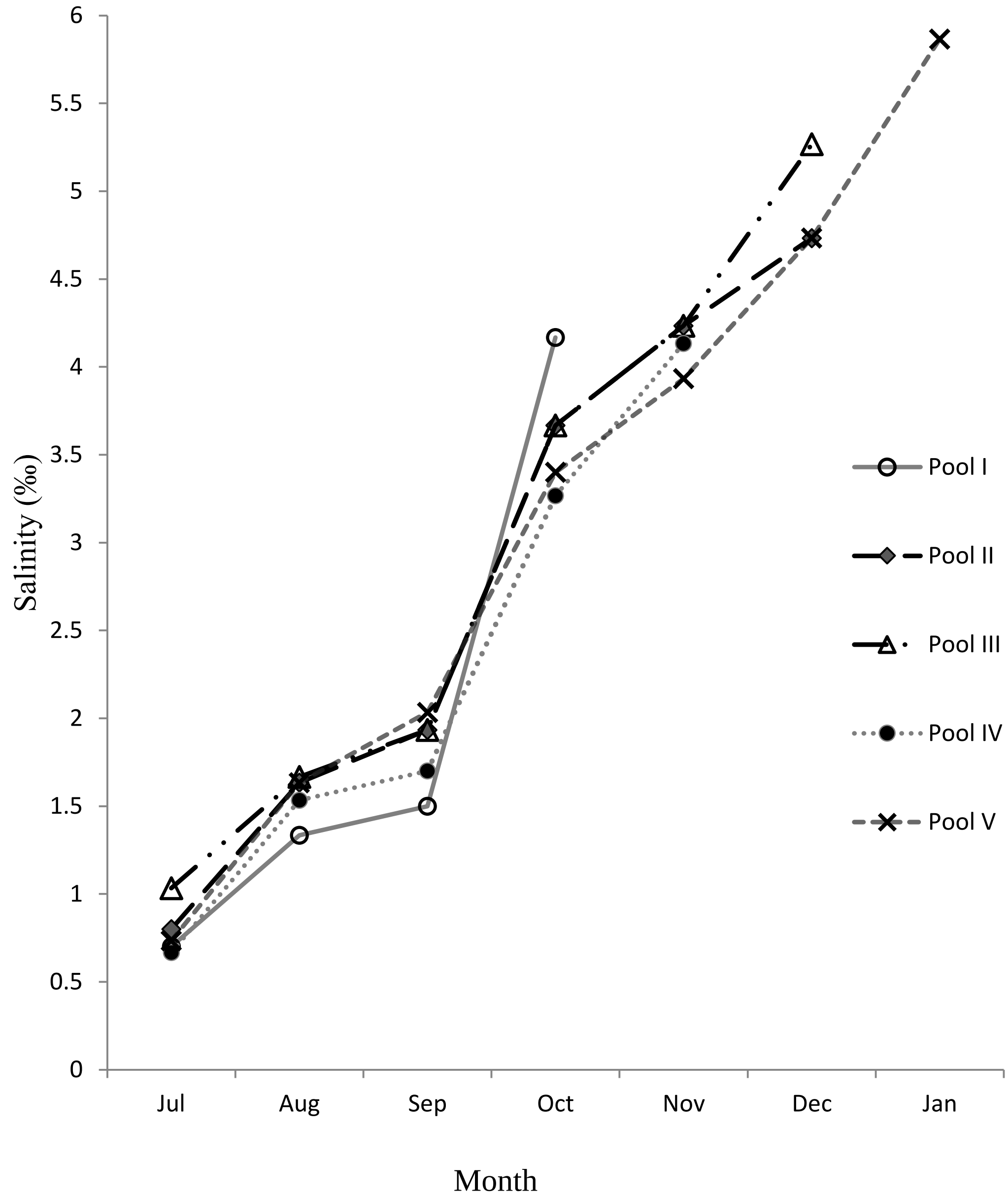

Figure 4: Changes in salinity of pools in the Kakum Estuary wetland from July 2009 to January 2010

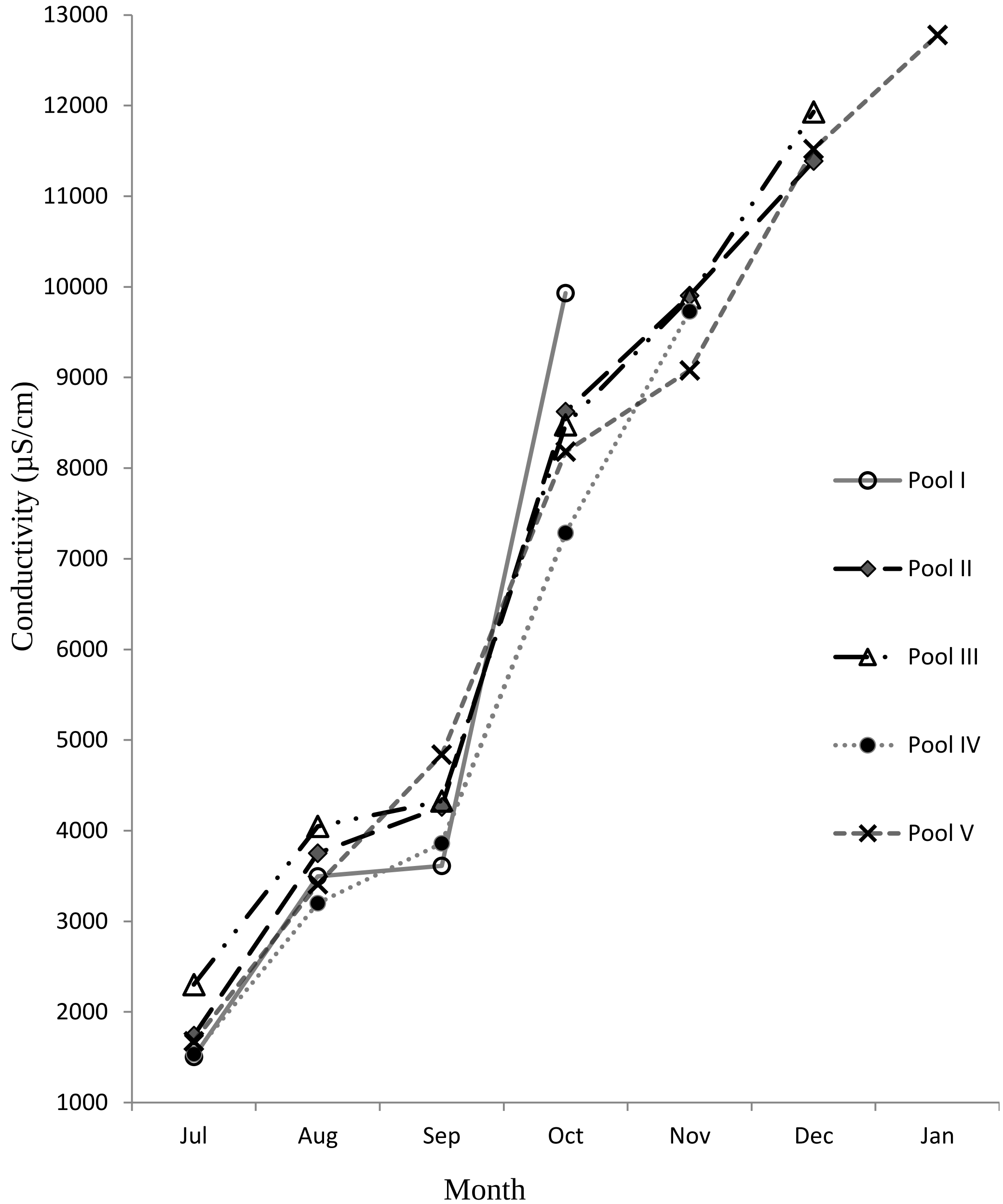

Figure 5: Monthly increase in conductivity in pools in the Kakum Estuary wetland from July 2009 to January 2010

Turbidity

Like the other parameters, turbidity of the waters increased during the period of study (Figure 6).The pools were less turbid in July 2009 with values ranging from 78 ppm in Pool II to 91 ppm in Pool IV, but became more turbid in the later months when turbidity reached between 258 ppm in Pool III and 301 ppm in Pool V in December 2009, and 304 ppm in Pool V in January 2010.

Dissolved oxygen content

Dissolved oxygen (DO) concentration generally declined during the first two months of the study but increased thereafter (Figure 7). The DO concentration in Pool V was higher and remained fairly stable compared to the other pools; its DO ranged between 5.0 mg/L and 5.7mg/L throughout the study period. In the other pools however, the oxygen content varied between 3.5 mg/L in Pool II and 4.0 mg/L in Pool IV in July 2009, dropping to 2.7, 2.4 and 2.3 mg/L in Pool II, I and III respectively in September. Thereafter, DO concentration increased progressively, reaching 5 mg/L in December 2009 in the existing pools.

pH

Monthly pH values did not vary much between pools and the trend of change was similar for all pools. The pools were slightly acidic to neutral in July-August 2009 but became alkaline from September onwards (Figure 8) where pH values were greater than 7.0. In January 2010, pH reached 8.62 in Pool V which was the only existing pool.

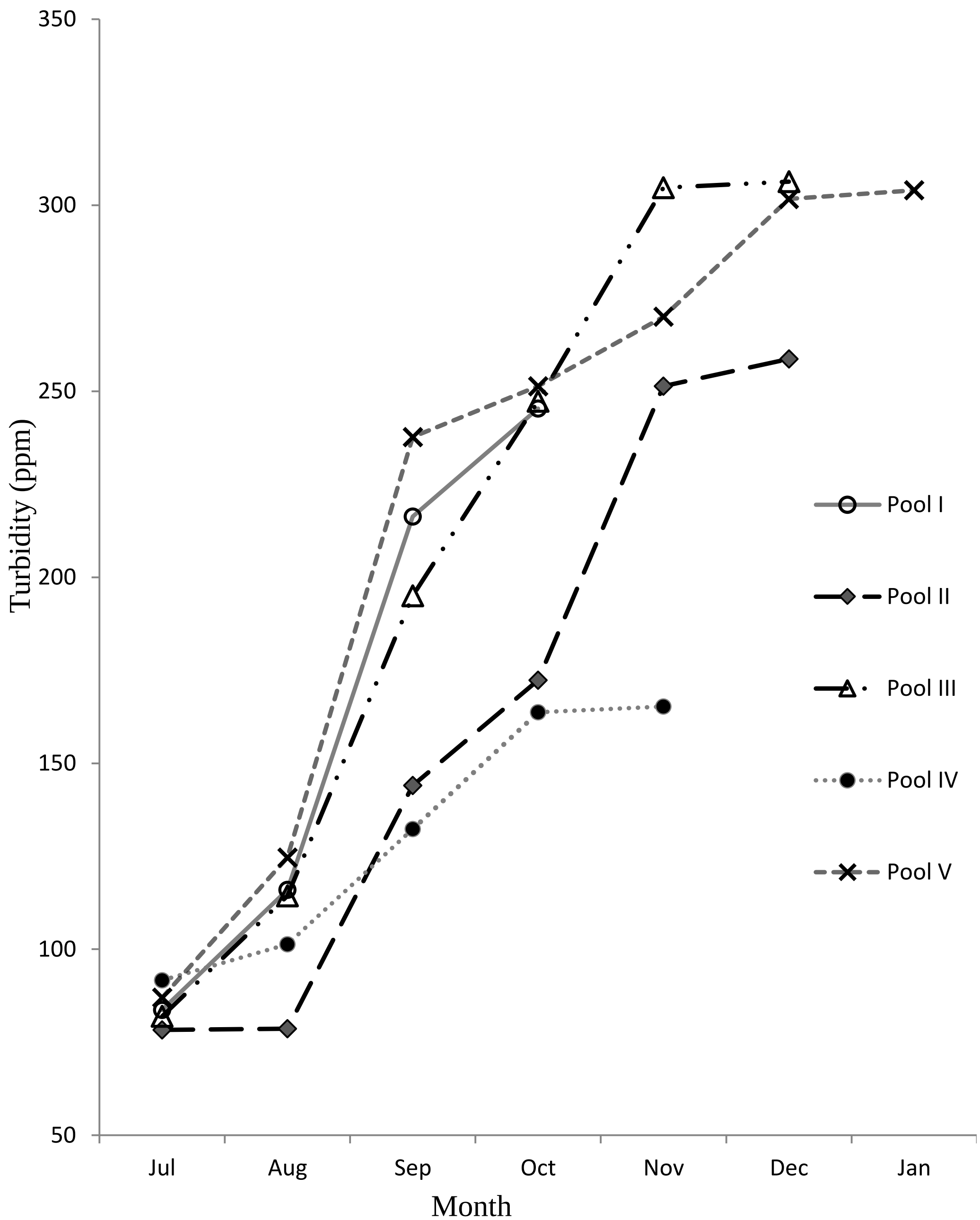

Figure 6: Monthly rise in turbidity of Kakum Estuary wetland pools from July 2009 to January 2010

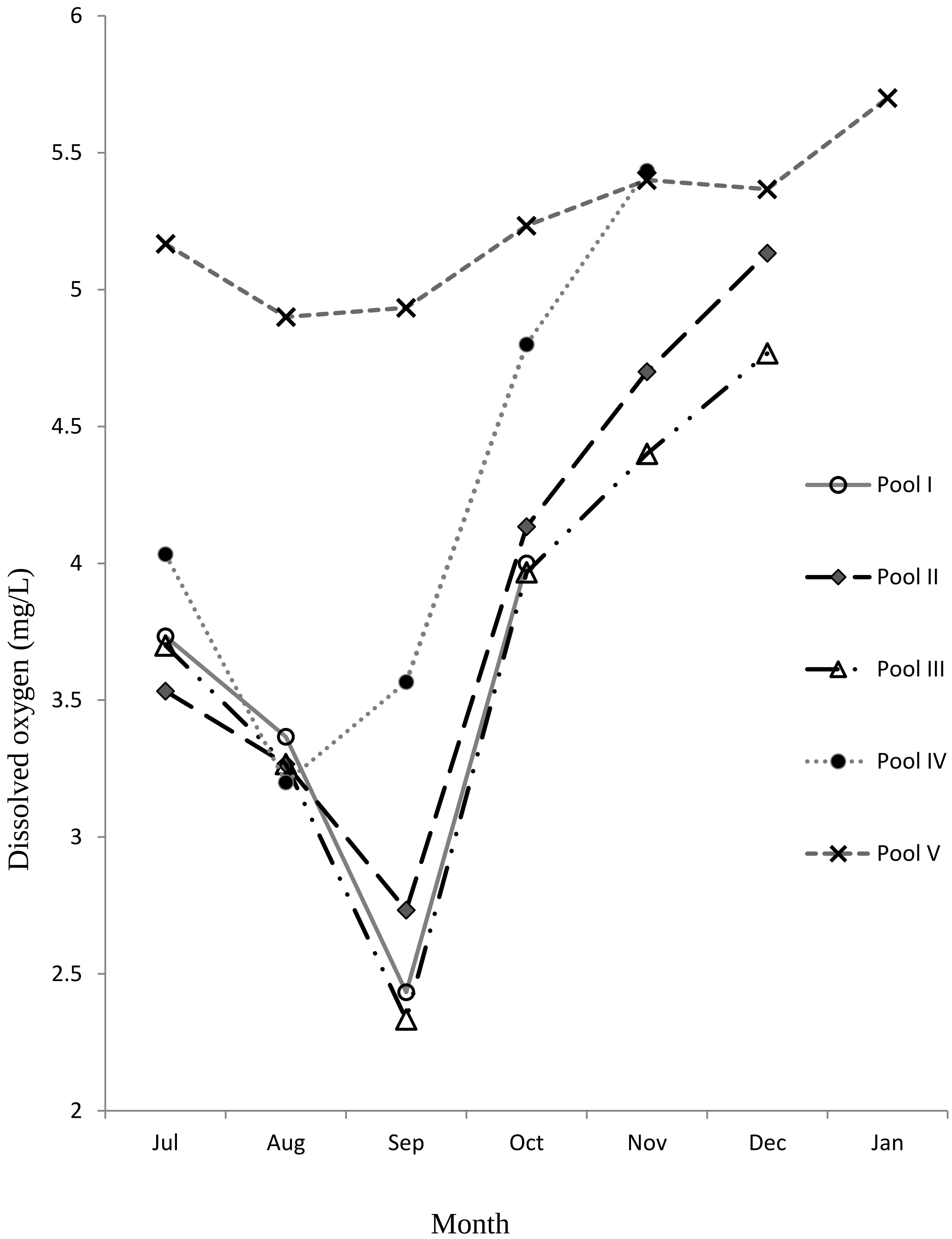

Figure 7: Monthly fluctuations in dissolved oxygen content of pools in the Kakum Estuary wetland from July 2009 to January, 2010

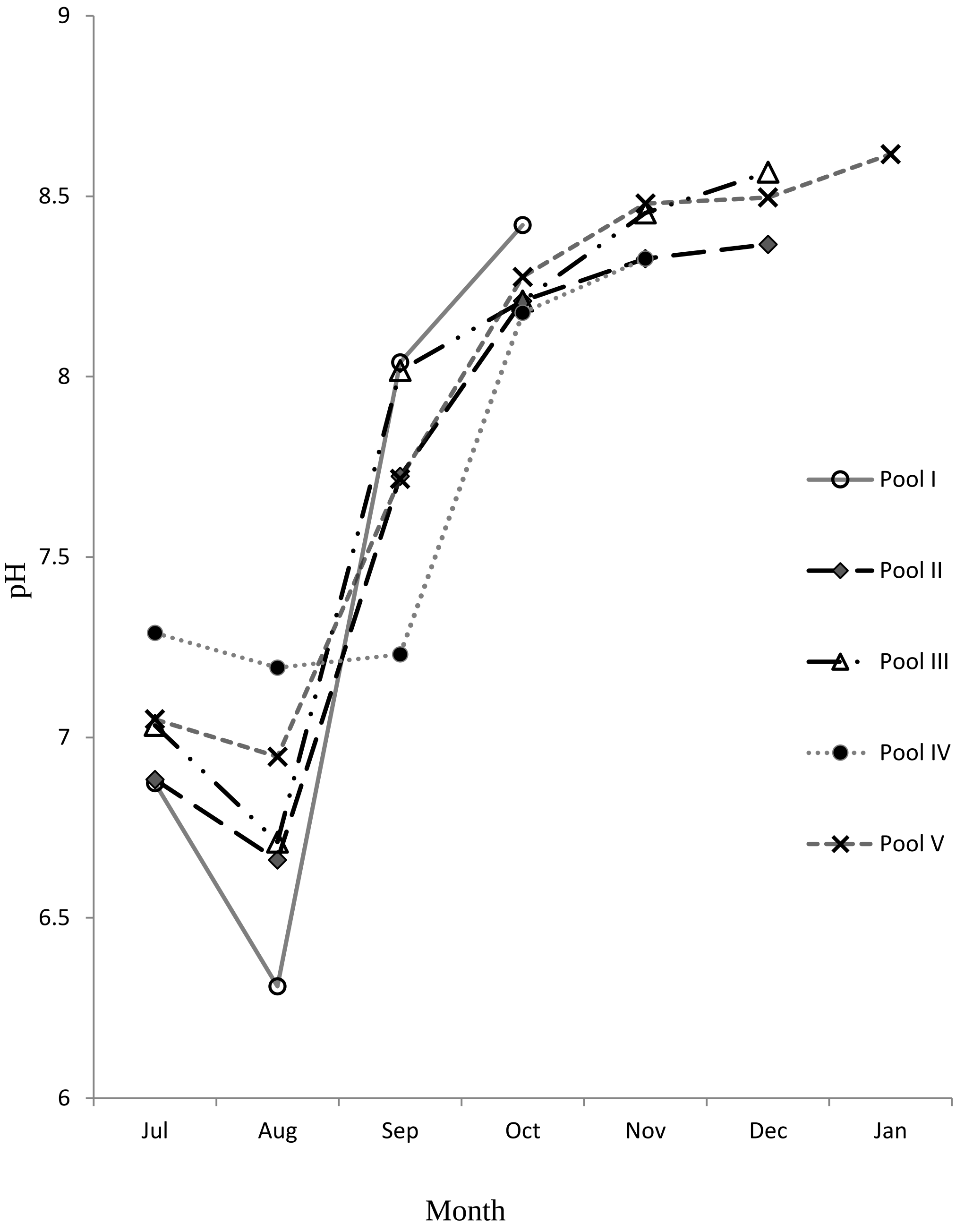

Figure 8: Monthly variations in pH of Kakum Estuary wetland pools from July 2009 to January 2010

Variations in composition of benthic macroinvertebrates

Figure 9 illustrates the monthly composition of the macrozoobenthos in the five pools. The Diptera (larvae of the family Chironomidae) and Oligochaeta were the only representative groups in the benthos.

In Pool I, the composition of dipterans varied from 77.08% to 88.68% between July and September, but it dropped to 9.76% in October. Oligochaetes varied in composition from 11.32% to 22.92% in July – September, and increased to 90.24% in October.

Diptera constituted 70% to 78.57% of invertebrates sampled from Pool II from July to September while Oligochaeta constituted between 21.43% and 35.59%. Only two invertebrate specimens were collected in October, one of which was an oligochaete and the other a dipteran. No organism was found thereafter till the pool dried in January 2010.

The dipteran composition in Pool III ranged from 80% to 89.74% between July and September while oligochaetes had a composition ranging between 10.26% and 20% during the same period. All seven specimens found in October were oligochaetes and no benthos was found for the rest of the study period.

As occurred in the other pools, chironomid larvae (Diptera) dominated the samples in Pool IV in July-September with composition varying from 66.67% to 89.83%, but declined drastically to 3.57% in October and disappeared thereafter. On the other hand, oligochaetes were low in abundance between July and September with composition ranging from10.17% to 33.33%, but increased to 96.43% in October after which only 2 were recorded in November.

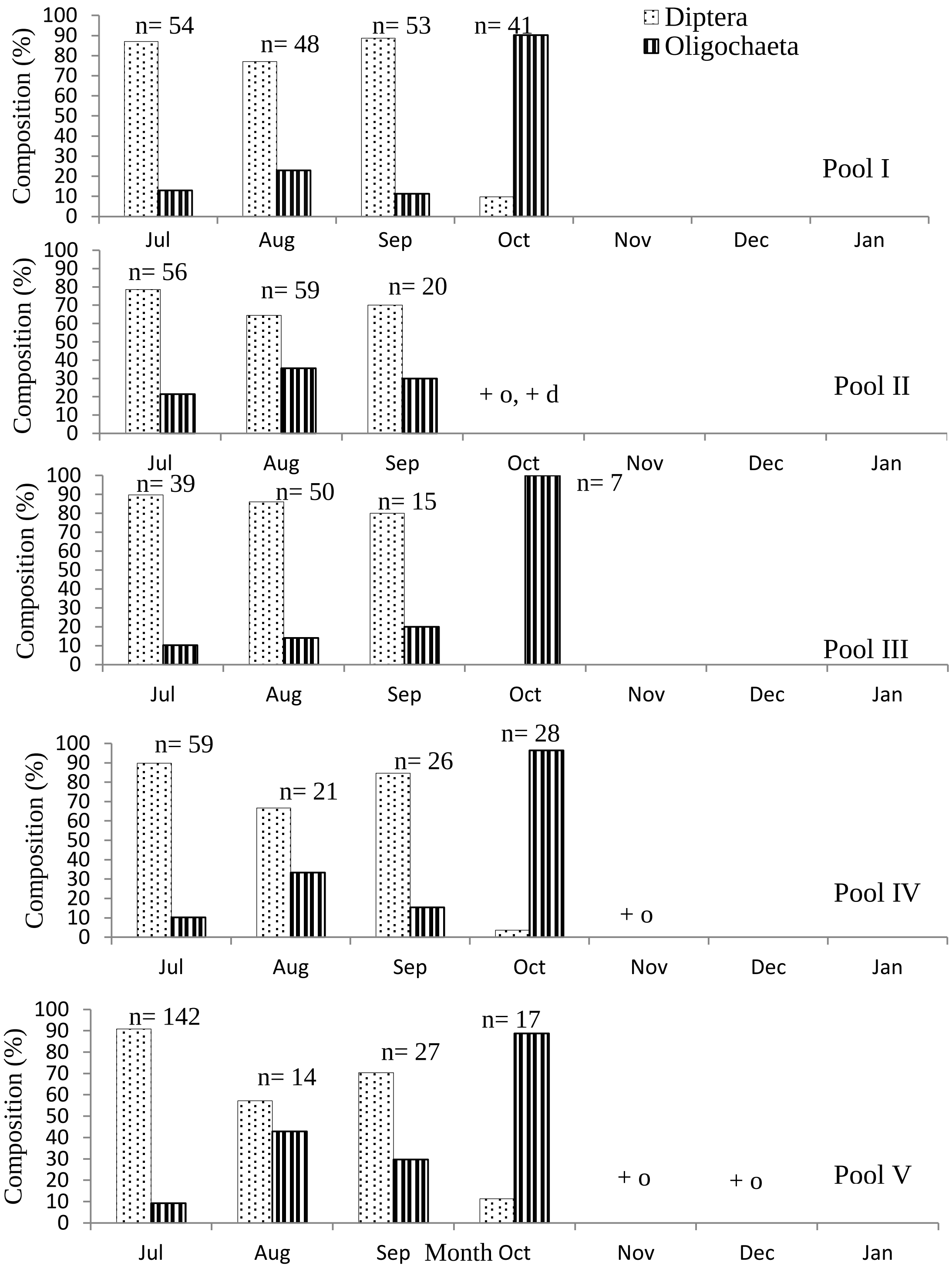

Figure 9: Percentage composition of benthic macroinvertebrates in the five pools in the Kakum Estuary wetland from July 2009 to January 2010 (n = number of benthic invertebrates, + o = 1 – 3 oligochaetes, + d = 1 dipteran)

Dipterans comprised 57.14% to 90.85% of the benthic invertebrates in Pool V from July to September, and only 11.7% in October 2009. Oligochaetes were lowly represented in the first three months, constituting between 9.15% and 29.63% of the benthos, but increased to 88.23% in October. Afterwards, only oligochaetes were found in the pool, with 3 individuals in November, and one specimen in December.

Variations in density of invertebrate fauna

Figure 10 illustrates changes in the densities (mean number of individuals per meter square) of the two benthic invertebrate taxa, and a summary of the density estimates and their 95% confidence limits is provided in Tables 2– 6.

The mean density of dipterans in pool I ranged from 258 individuals/m^2 to 648 individuals/m^2 in July – September, after which it declined significantly to 71 individuals/m^2 in October. Oligochaete density varied from 81 individuals/m^2 to 112 individuals/m^2 from July to September, and increased to 476 individuals/m^2 in October.

In Pool II, dipteran density declined progressively from 520 individuals/m^2 in July to 56 individuals/m^2 in October. Oligochaetes varied from 155 to 206 individuals/m^2 in July –August, and reduced to 81individuals/m^2 in September and 56 individuals/m^2 in October, and disappeared thereafter.

In Pool III, the mean density of Diptera was 516 individuals/m^2 and 632 individuals/m^2 in July and August respectively, but this dropped to 161 individuals/m^2 in October. Oligochaetes fluctuated between 56 individuals/m^2 and 89 individuals/m^2 from July to October.

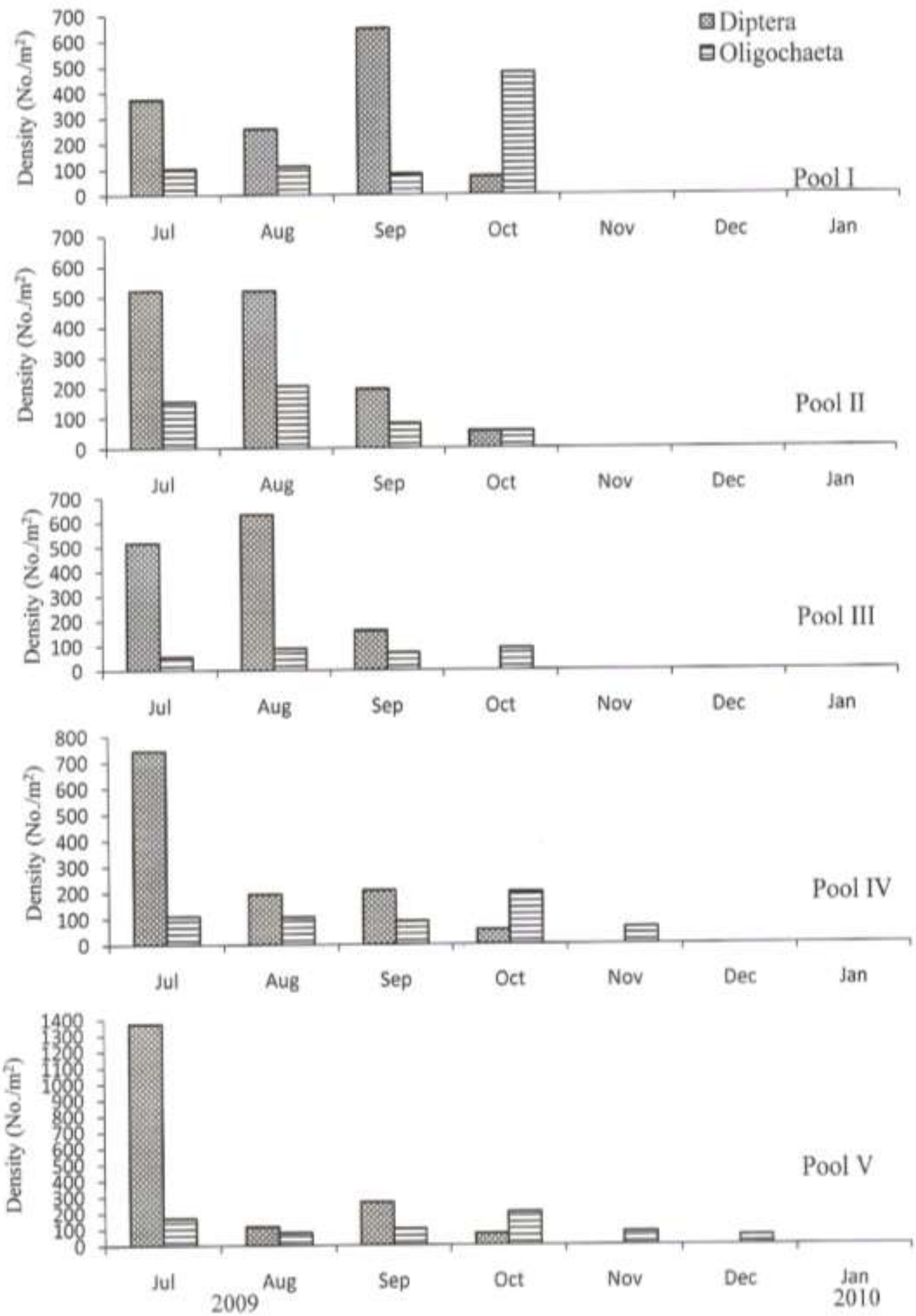

Figure 10: Monthly mean density of benthic macroinvertebrates in five pools in Kakum Estuary wetland from July 2009 to January 2010

The density of Diptera in Pool IV also decreased gradually during the study, from 744 individuals/m^2 in July to 208 individuals/m^2 in September and 56 individuals/m^2 in October. Between July and September, the density of Oligochaeta ranged from 89 individuals/m^2 to 110 individuals /m^2. It however increased to 201 individuals/m^2 in October, dropping to 64 individuals/m^2 in November.

The mean density of dipterans in Pool V reduced significantly from 1,375 individuals/m^2 in July to 117 individuals/m^2 in August, and further declined to 71 individuals/m^2 in October; no specimens were found for the rest of the study period. The monthly mean density of oligochaetes fluctuated between 81 individuals/m^2 and 203 individuals/m^2 from July to November, and declined to 56 individuals/m^2 in December 2009.

Table 2: Density of benthic invertebrates in Pool I in the Kakum Estuary wetland from July to October 2009

Month/ Benthic invertebrate group	Total no.	Derived mean (no./225cm^2)	Variance	Derived 95 % CL		Mean Density (no./m^2)	Density (No./m^2) 95% CL	
				Min	Max		Min	Max
July								
Diptera	47	8.42	0.64	0.0867	818.536	374	4	36343
Oligochaeta	7	2.29	0.01	1.2921	4.05659	102	57	180
August								
Diptera	37	11.91	0.02	5.2969	26.7116	528	235	1184
Oligochaeta	11	2.52	0.21	0.1832	34.6609	112	8	1539
September								
Diptera	47	14.62	0.04	4.6468	45.8024	648	206	2034
Oligochaeta	6	1.82	0.06	0.4476	7.37768	81	20	328
October								
Diptera	4	1.59	0.12	0.2188	11.5156	71	10	511
Oligochaeta	37	1.03	0.07	2.36	48.6965	476	105	2162

CL = Confident Limit

Table 3: Density of benthic invertebrates in Pool II in the Kakum Estuary wetland from July to October 2009

Month/ Benthic invertebrate group	Total no.	Derived mean (no./225cm^2)	Variance	Derived 95 % CL		Mean Density (no./m^2)	Density (No./m^2) 95% CL	
				Min	Max		Min	Max
July								
Diptera	44	11.7	0.16	1.19	115.2	519	53	5114
Oligochaeta	12	3.48	0.08	0.69	17.53	154	31	778
August								
Diptera	38	11.7	0.04	3.73	36.72	519	165	1630
Oligochaeta	21	4.63	0.33	0.17	123.7	205	8	5492
September								
Diptera	14	4.38	0.035	1.5	12.77	194	67	567
Oligochaeta	6	1.82	0.058	0.46	7.206	81	20	320
October								
Diptera	1	1.26	0.03	0.47	3.393	56	21	151
Oligochaeta	1	1.26	0.03	0.47	3.393	56	21	151

CL = Confident Limit

Table 4: Density of benthic invertebrates in Pool III in the Kakum Estuary wetland from July to October 2009

Month/ Benthic invertebrate group	Total no.	Derived mean (no./225cm^2)	Variance	Derived 95 % CL		Mean Density (no./m^2)	Density (No./m^2) 95% CL	
				Min	Max		Min	Max
July								
Diptera	35	11.6	0.003	8.31	16.19	515	369	719
Oligochaeta	4	1.26	0.03	0.47	3.393	56	21	151
August								
Diptera	43	14.2	0.005	9.69	20.87	631	430	926
Oligochaeta	7	2	0.09	0.36	11.13	89	16	494
September								
Diptera	12	3.63	0.058	0.92	14.41	161	41	640
Oligochaeta	3	1.59	0.12	0.22	11.52	70	9.7	511
October								
Diptera	0							
Oligochaeta	7	2	0.091	0.36	11.23	89	16	499

Table 5: Density of benthic invertebrates in Pool IV in the Kakum Estuary wetland from July to November 2009

Month/ Benthic invertebrate group	Total no.	Derived mean (no./225cm^2)	Variance	Derived 95 % CL		Mean Density (no./m^2)	Density (No./m^2) 95% CL	
				Min	Max		Min	Max
July								
Diptera	53	16.7	0.03	6.21	45.05	743	276	2000
Oligochaeta	6	2.47	0.13	0.31	19.4	109	14	861
August								
Diptera	14	4.38	0.035	1.5	12.77	194	67	567
Oligochaeta	7	2.41	0.183	0.21	27.85	107	9.3	1236
September								
Diptera	22	4.67	0.244	0.28	78.83	207	12	3500
Oligochaeta	4	2	0.091	0.36	11.23	89	16	499
October								
Diptera	1	1.26	0.03	0.47	3.393	56	21	151
Oligochaeta	27	4.51	0.375	0.14	149.9	200	6	6658
November								
Oligochaeta	2	1.44	0.076	0.3	6.981	64	13	310

Table 6: Density of benthic invertebrates in Pool V in the Kakum Estuary wetland from July to October 2009

Month/ Benthic invertebrate group	Total no.	Derived mean (no./225cm^2)	Variance	Derived 95 % CL		Mean Density (no./m^2)	Density (No./m^2) 95% CL	
				Min	Max		Min	Max
July								
Diptera	129	30.9	0.215	2.18	437.9	1370	97	19443
Oligochaeta	13	3.83	0.074	0.81	18.14	170	36	805
August								
Diptera	8	2.62	0.01	1.48	4.644	116	66	206
Oligochaeta	6	1.82	0.058	0.46	7.206	80.7	20	320
September								
Diptera	19	6	0.031	2.19	16.43	266	97	729
Oligochaeta	8	2.29	0.1	0.38	13.97	102	17	620
October								
Diptera	2	1.59	0.03	0.59	4.275	70.5	26	190
Oligochaeta	15	4.58	0.048	1.31	16.03	203	58	712

(**Table 6** *continued*)

Month/ Benthic invertebrate group	Total no.	Derived mean (no./225cm^2)	Variance	Derived 95 % CL		Mean Density (no./m^2)	Density (No./m^2) 95% CL	
				Min	Max		Min	Max
November								
Diptera	0							
Oligochaeta	3	1.82	0.058	0.46	7.206	80.7	20	320
December								
Diptera	0							
Oligochaeta	1	1.26	0.03	0.47	3.393	55.9	21	151

Fish species occurrence in pools

The occurrence of fish species in the pools studied is summarized in Table 7. A total of 18 species belonging to 18 genera and 12 families were sampled from the pools, of which *Aplocheilichthys spilauchen* (Poeciliidae) was the most abundant comprising 43.31% of the 1810 fish specimens collected. Six species, namely *Hemichromis fasciatus, Sarotherodon melanotheron, Tilapia zillii* (Cichlidae), *Kribia kribensis* (Eleotridae), *Liza falcipinnis* (Mugilidae), *Aplocheilichthys spilauchen* (Poeciliidae), and two shellfish namely the freshwater shrimp *Macrobrachium macrobrachion* (Palaemonodae) and the swimming crab *Callinectes amnicola* (Portunidae) occurred in all the five pools. The goby *Porogobius schlegelii* (Gobiidae) was taken from four pools while the African catfish *Clarias gariepinus* (Clariidae) and the eleotrid *Eleotris senegalensis* (Eleotridae) were encountered in three pools. The fishes sampled from two pools were the West African lady fish *Elops lacerta* (Elopidae), the African pike *Hepsetus odoe* (Hepsetidae) and *Odaxothrissa mento* (Clupeidae). Two species of gobies, *Bathygobius soporator* and *Periophthalmus barbarous*, the cyprinid *Barbus sp*., and one eleotrid *Dormitator lebretonis* were each found in one of the pools.

Fish species richness and diversity

The number of species, genera and families, and the diversity indices for the fish communities in the pools are presented in Table 8. Species richness was highest in Pool V where 15 species belonging to 15 genera and 10 families were recorded. Pool III had 12 species from 12 genera and 10 families, and Pools I and II each had 12 species belonging to 12 genera and 9 families. The lowest species

Table 7: Occurrence of fish species in the Kakum Estuary wetland in pools

		Pool				
Family	**Species**	**I**	**II**	**III**	**IV**	**V**
CICHLIDAE	*Hemichromis fasciatus*	+	+	+	+	+
	Sarotherodon melanotheron	+	+	+	+	+
	Tilapia zillii	+	+	+	+	+
CLARIIDAE	*Clarias gariepinus*	+	+	-	-	+
CLUPEIDAE	*Odaxothrissa mento*	-	-	+	-	+
CYPRINIDAE	*Barbus* sp.	-	-	+	-	-
ELEOTRIDAE	*Kribia kribensis*	+	+	+	+	+
	Eleotris senegalensis	+	+	-	-	+
	Dormitator lebretonis	-	-	-	+	-
ELOPIDAE	*Elops lacerta*	-	+	-	-	+
GOBIIDAE	*Porogobius schlegelii*	+	+	+	-	+
	Bathygobius soporator	-	-	-	+	
	Periophthalmus barbarus	-	-	-	-	+
HEPSETIDAE	*Hepsetus odoe*	+	-	+	-	-
MUGILIDAE	*Liza falcipinnis*	+	+	+	+	+
POECILIIDAE	*Aplocheilichthys spilauchen*	+	+	+	+	+
PALAEMONIDAE	*Macrobrachium macrobrachion*	+	+	+	+	+
PORTUNIDAE	*Callinectes amnicola*	+	+	+	+	+

+ denotes present; - indicates absent

richness was recorded from Pool IV where 9 species belonging to 9 genera and 7 families were encountered.

From the Shannon-Wiener index of diversity estimates, Pool V had the highest species diversity (H′ = 2.7), followed by Pools I, II and III (H′ = 2.5), while Pool IV had the lowest diversity (H′ = 2.2).

Concerning the equitability, the values ranged from 0.6 (Pools I and IV) to 0.7 (Pools II, III and V) indicating that the individual numbers were fairly evenly distributed among the different species in the fish communities in all the pools.

Table 8: Species richness and diversity indices for fish communities of the five pools in the wetland

Pool	No. of families	No. of genera	No. of species	*H′*	*J′*
Pool I	9	12	12	2.5	0.6
Pool II	9	12	12	2.5	0.7
Pool III	10	12	12	2.5	0.7
Pool IV	7	9	9	2.2	0.6
Pool V	10	15	15	2.7	0.7

H′= Shannon-Wiener index; *J′*=Equitability index

Similarity of fish communities

Table 9 presents the results of the similarity in pairs of fish communities in the wetland. Similarity values ranged from 0.7 to 0.9 suggesting that there was a high similarity among the fish communities in the pools, with the communities in Pools I and II being the closest, and Pools IV and V communities recording the least similarity.

Table 9: Sorensen's similarity index for the pairs of fish communities

	Pool I	Pool II	Pool III	Pool IV	Pool V
Pool I					
Pool II	0.917				
Pool III	0.833	0.750			
Pool IV	0.762	0.762	0.762		
Pool V	0.815	0.889	0.741	0.667	

Monthly composition of fish species

Pool I

Figure 11 illustrates the monthly percentage composition of fish species in Pool I. Six species were sampled from the pool in July 2009, with *Aplocheilichthys spilauchen* (Poeciliidae) being dominant (84.72%), followed by *Kribia kribensis* (Eleotridae) (9.72%) while the remaining four species, *Sarotherodon melanotheron* (Cichlidae), *Clarias gariepinus* (Clariidae), *Hepsetus odoe* (Hepsetidae) and *Macrobrachium macrobrachion* (Palaemonidae) constituted 1.4% each. Two species were caught in August with *Aplocheilichthys spilauchen* constituting 96.20% and *Liza falcipinnis* (Mugilidae) also constituting 3.80% of the community. *A. spilauchen* (58.30%) dominated the catches in September while the crab *Callinectes amnicola* (Portunidae) and the shrimp *Macrobrachium macrobrachion* (Palaemonidae) had compositions of 33.30% and 8.30% respectively. In October, *Tilapia zillii* (Cichlidae) was the most abundant of the 6 species sampled, making up 57.81% of the fishes collected while the compositions of *L. falcipinnis* and *Hemichromis fasciatus* (Cichlidae) were 20.31% and 15.62% respectively. The compositions of *C. amnicola*, *Eleotris senegalensis* (Eleotridae) and *Porogobius schlegelii* (Gobiidae) varied between 1.56% and 3.12%. The overall percentage composition of fish species in Pool I is presented in Figure 12.

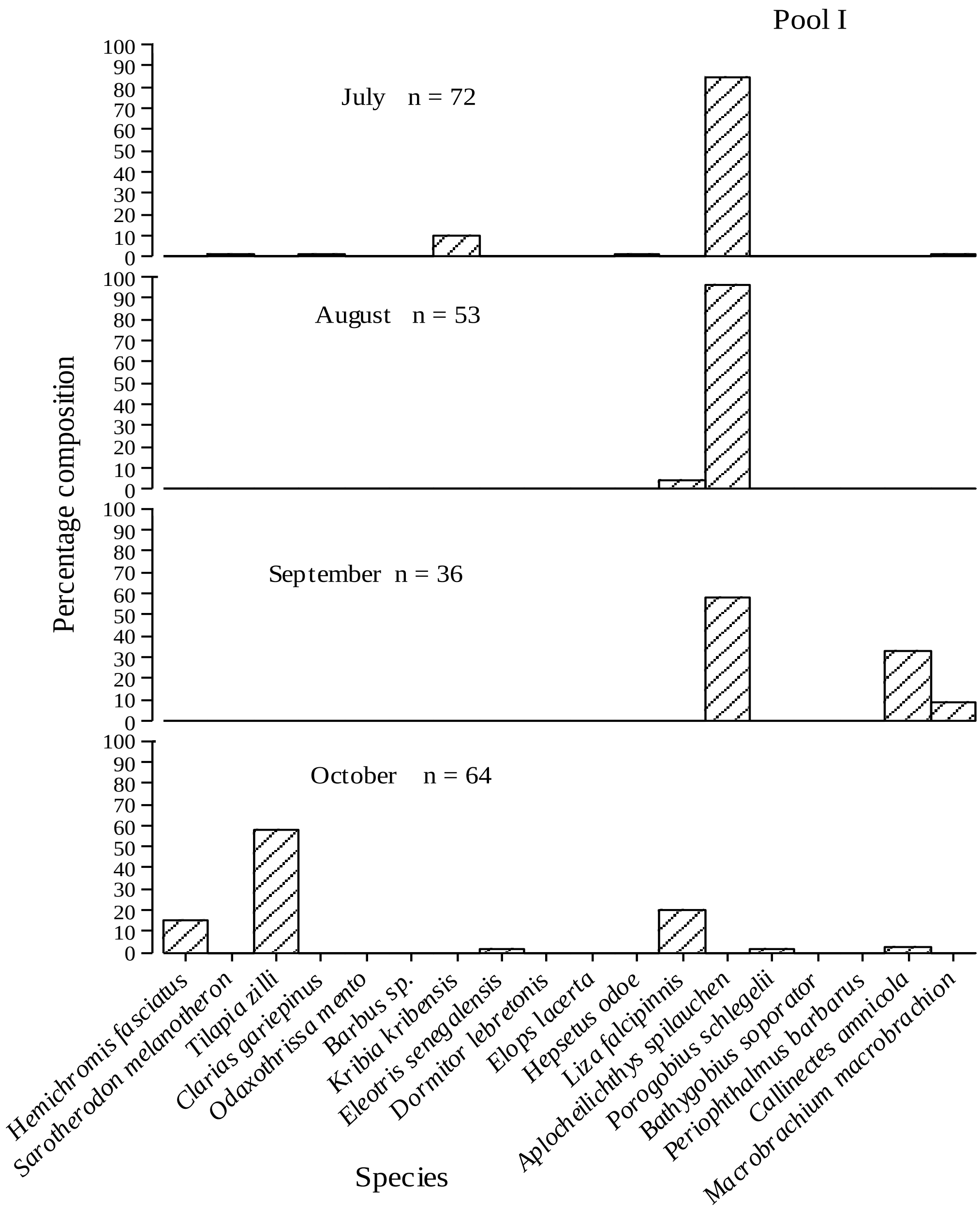

Figure 11: Monthly percentage composition of fish species in Pool I in the Kakum Estuary wetland from July 2009 – January 2010

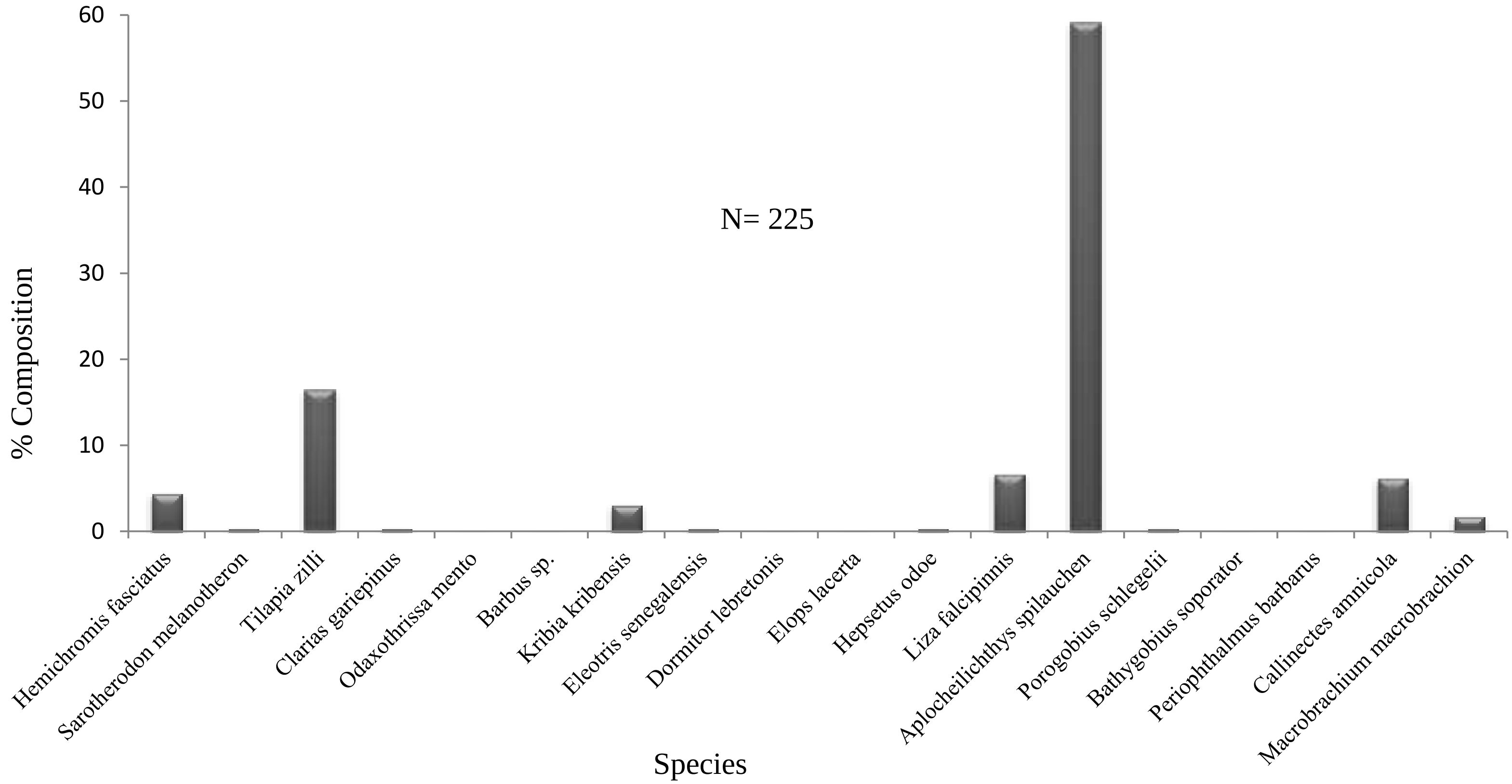

Figure 12: Overall percentage composition of fish species in Pool I in the Kakum Estuary wetland

Pool II

Two species were caught in Pool II in July 2009 of which *A. spilauchen* composition was 94.74% and the sickle fin mullet *L. falcipinnis* had a composition of 5.26% (Figure 13). Similarly, *A. spilauchen* was the most abundant fish in August, constituting 72.30% of the community. Other species caught were *K. kribensis* (10.80%), *M. macrobrachion* (7.70%), *T. zillii* (4.60%), *C. gariepinus* (3.10%) and *L. falcipinnis* (1.50%). In September, seven species were encountered of which 70.50% were *A. spilauchen* and 8.60% were *Porogobius schlegelii*. The cichlid *T. zillii* and the shrimp *M. macrobrachion* both had a composition of 7.4% while the composition of the remaining three species namely *Callinectes amnicola*, *L. falcipinnis* and *Elops lacerta* were 3.70%, 1.20% and 1.20% respectively. *K. kribensis* dominated the ten species collected in October, making up 26.55% of the community. *A. spilauchen*, *T. zillii* and *M. macrobrachium* constituted 20.35%, 19.47% and 11.50% respectively, while the composition of *P. schlegelii*, *H. fasciatus*, *L. falcipinnis* and *Sarotherodon melanotheron* varied between 3.54% and 5.31%. Other species present were *Eleotris senegalensis* (2.65%) and *C. amnicola* (1.77%). Two species were found in November of which *S. melanotheron* dominated with a composition of 87.23 % while *T. zillii* comprised 12.77% of the catch. *S. melanotheron* was also the most encountered species in December 2009, constituting 78.26% of the community. *K. kribensis* (13.04%) and *M. macrobrachion* (8.69 %) were the other species collected. Figure 14 illustrates the overall percentage composition of fish species in Pool II.

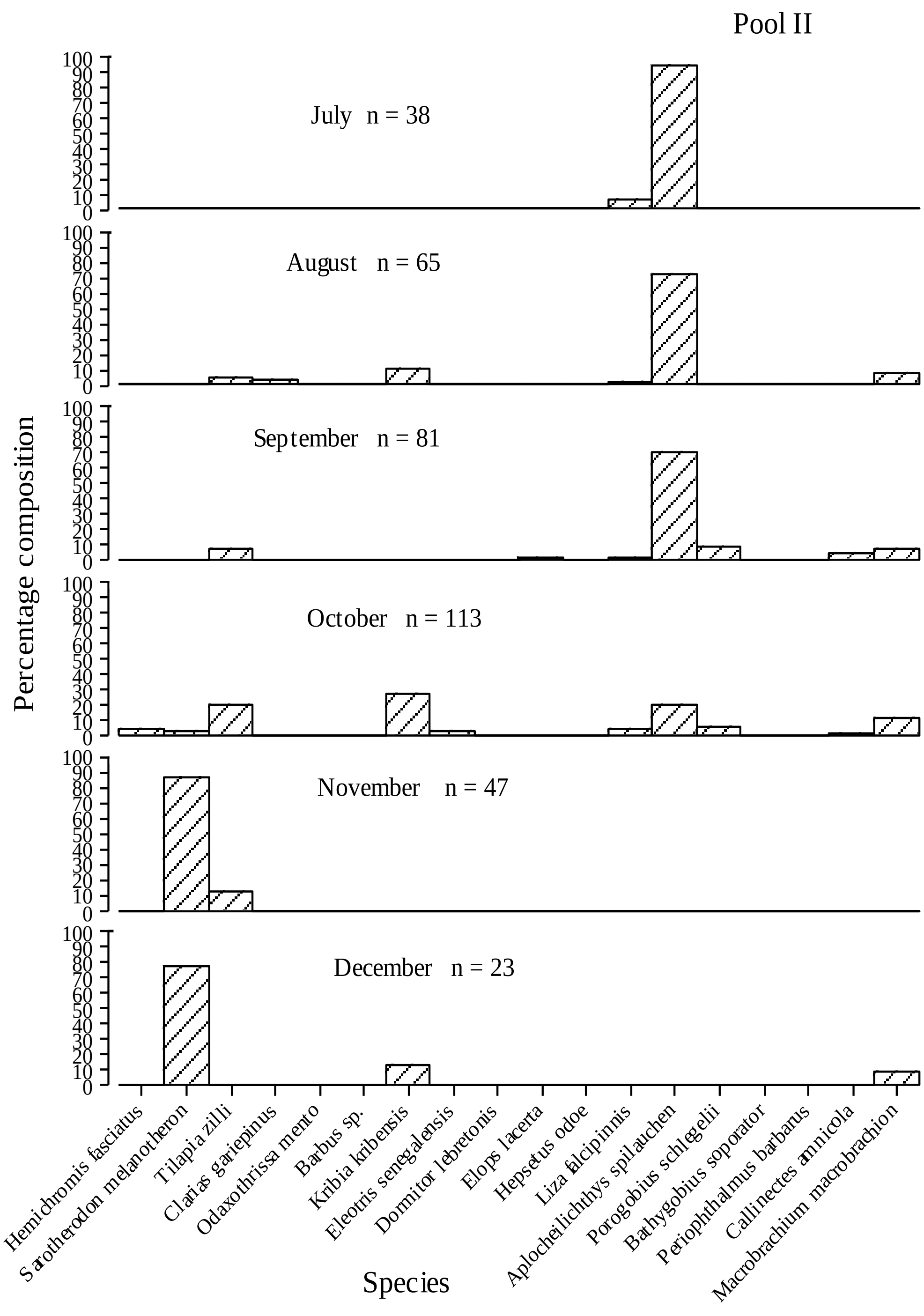

Figure 13: Monthly percentage composition of fish species in Pool II in the Kakum Estuary wetland from July 2009 – January 2010

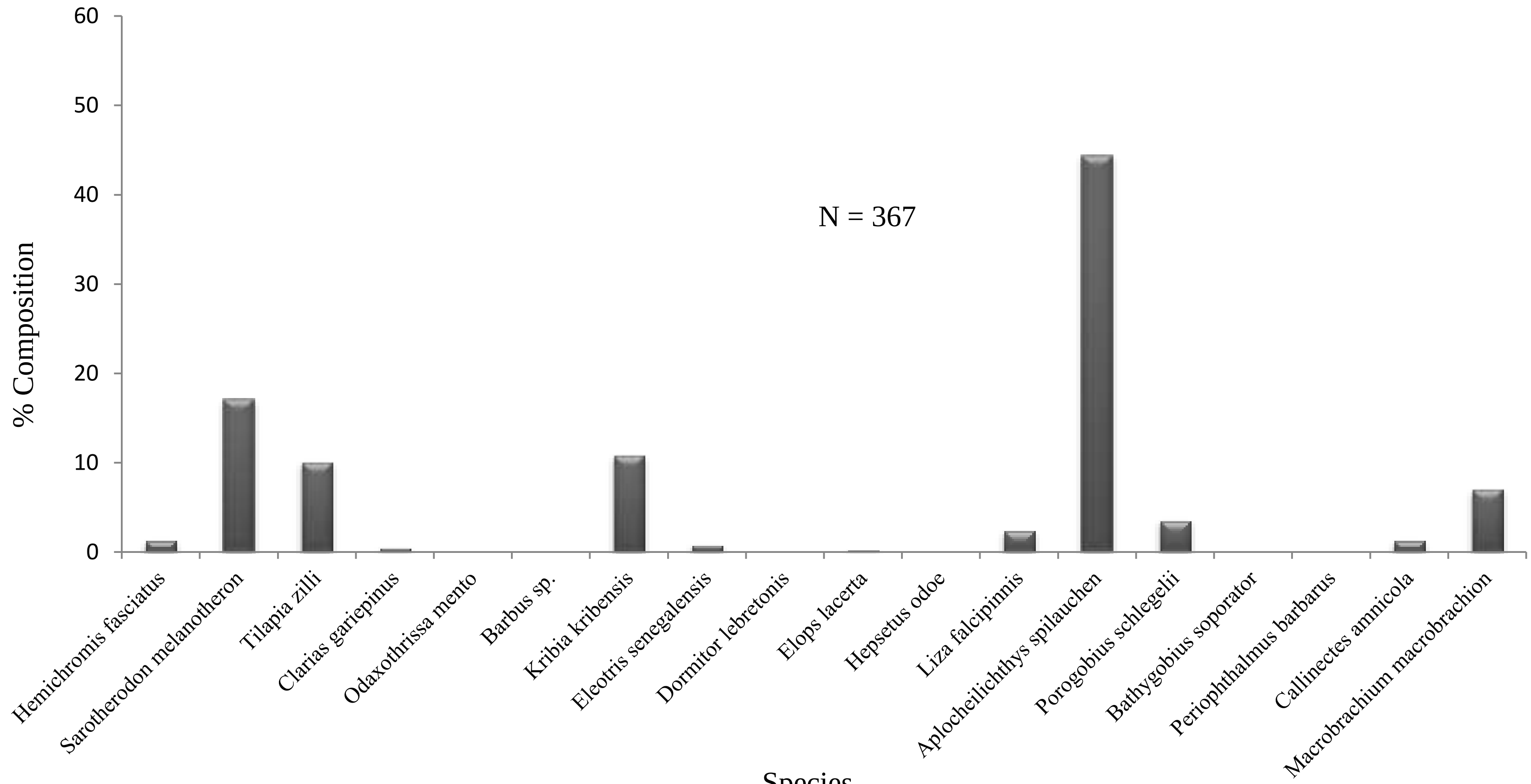

Figure 14: Overall percentage composition of fish species in Pool II in the Kakum Estuary wetland

Pool III

The composition of fish species in Pool III (Figure 15) shows that *A. spilauchen* was the dominant (84%) of the three species present in July. The other two species were the freshwater clupeid *Odaxothrissa mento* (12%) and *L. falcipinnis* (4%). Similarly, *A. spilauchen* dominated the fish community in August, making up 48.39% of the seven species collected. *Barbus* sp. comprised 29.03% while *P. schlegelii*, *M. macrobrachion* and *L. falcipinnis* made up between 4.30% and 9.68% of the catch. *T. zillii* and *C. amnicola* represented 1.07% each. Of the eight species caught in September, 39.93% were *M. macrobrachion*, 25.58% were *A. spilauchen*, 11.63% were *P. schlegelii* and 9.30% were *Barbus* sp. Both *H. fasciatus* and *T. zillii* had compositions of 4.65%, and *Hepsetus odoe* and *L. falcipinnis* constituted 2.32% of the sample. In October, *M. macrobrachion* was the most abundant of the nine species sampled, constituting 53.46% of community while *A. spilauchen* followed with 13.86%. Both *P. schlegelii* and *L. falcipinnis* had compositions of 5.94%, and *S. melanotheron* constituted 4.95% of the sample. The remaining four species namely *H. fasciatus, T. zillii, K. kribensis* and *C. amnicola* made up 3.96% each. Four species were recorded in November of which *S. melanotheron* dominated by 60.83% and *M. macrobrachion* made up 30.19%. The other species were *P. schlegelii* (7.55%) and *A. spilauchen* (1.89%). *S. melanotheron* was the only species caught in December 2009. The overall percentage composition of fish species in Pool III is presented in Figure 16.

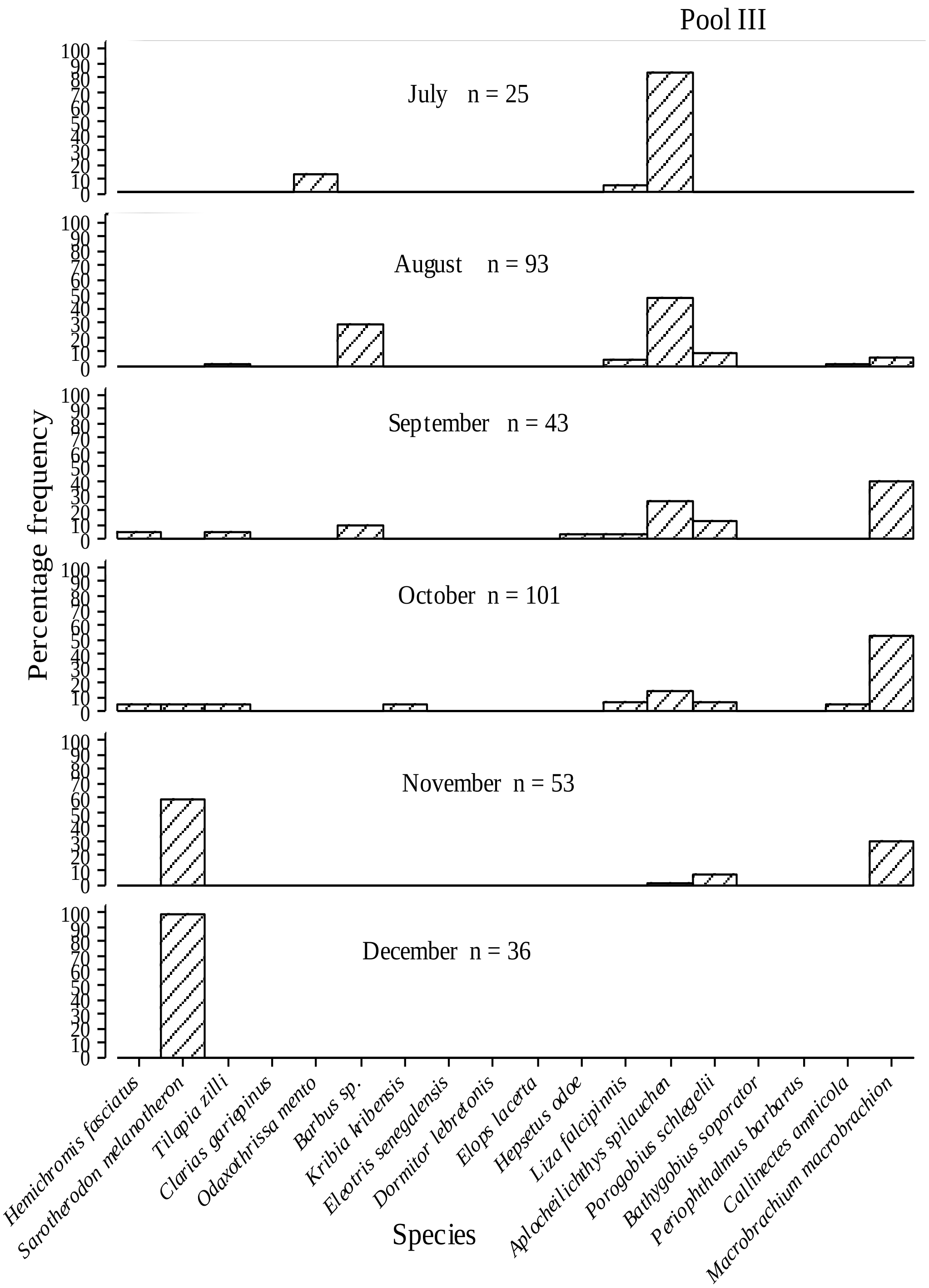

Figure 15: Monthly percentage composition of fish species in Pool III in the Kakum Estuary wetland from July 2009 – January 2010

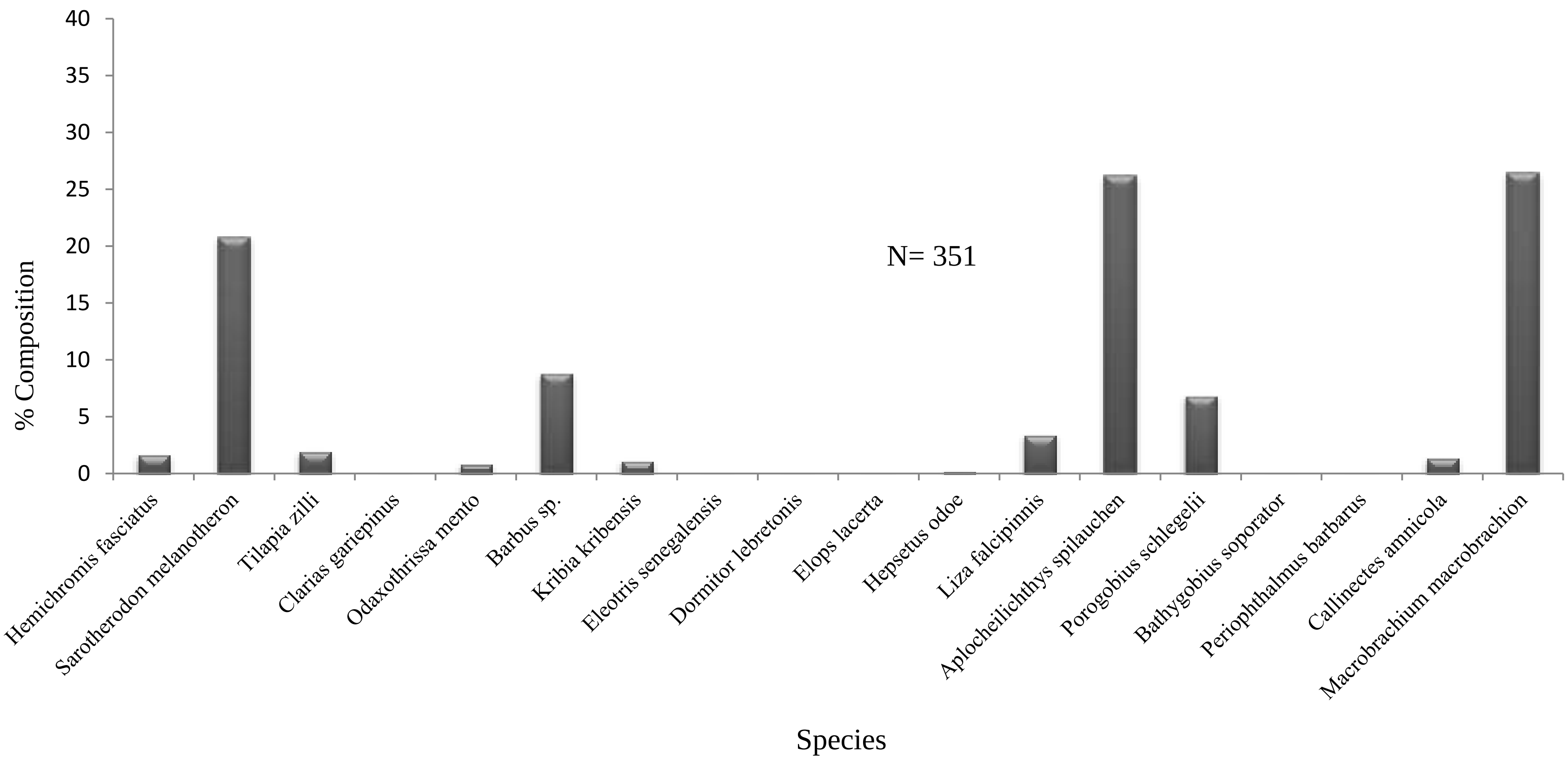

Figure 16: Overall percentage composition of fish species in Pool III in the Kakum Estuary wetland

Pool IV

In Pool IV (Figure 17), *A. spilauchen* was the most encountered fish in July, comprising 92.31% of the four species collected. *C. amnicola, T. zillii,* and *M. macrobrachion* constituted 4.61%, 1.54% and 1.54% respectively. Similarly in August, 92.86% of the four species caught were *A. spilauchen*, and 3.57% were *C. amnicola*. *Dormitator lebretonis* (Eleotridae) and *T. zillii* both composed 1.76% of the sample. Seven species were encountered in September dominated by *A. spilauchen* with a composition of 70.59%. The two shellfishes, *M. macrobrachion* and *C. amnicola* constituted 13.23% and 10.29% respectively of the catch while the three cichlids, *S. melanotheron*, *H. fasciatus* and *T. zillii*, and the goby, *Bathygobius soporator* made up 1.47% each of the sample. In October, eight species were recorded from the community of which *A. spilauchen* had the highest composition of 27.59%, followed by *K. kribensis* with 22.41%, and *H. fasciatus* and *S. melanotheron* each of which had compositions of 17.24%. Other species caught in October were *T. zillii* (8.62%), *C. amnicola* (3.45%), *L. falcipinnis* (1.72%) and *M. macrobrachium* (1.72%). The community was dominated by *S. melanotheron* in November where it made up 72% of the four species present. The other species recorded were *M. macrobrachion, K. kribensis* and *H. fasciatus* with compositions of 22%, 4% and 2% respectively. Figure 18 illustrates the overall percentage composition of fish species in Pool IV

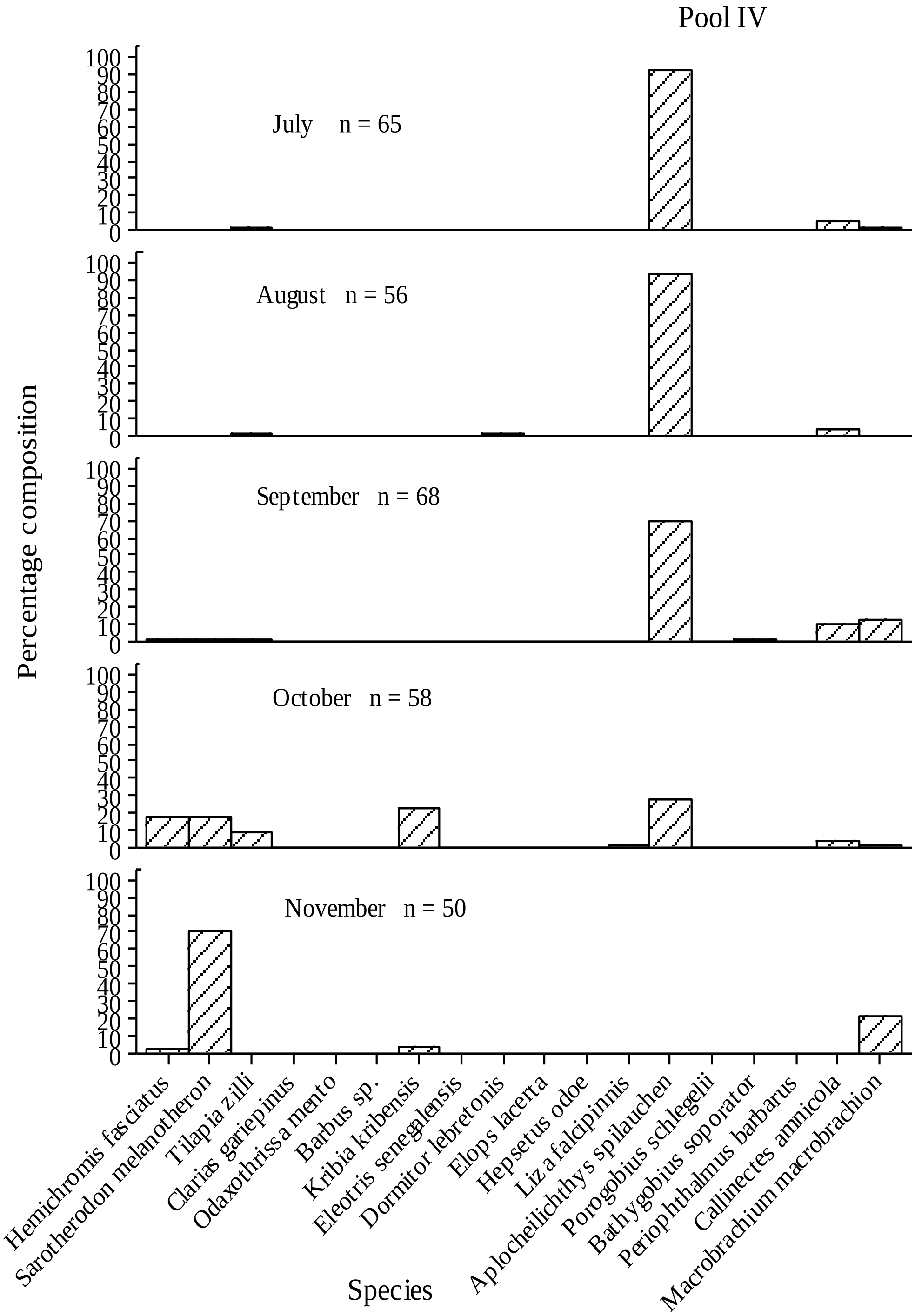

Figure 17: Monthly percentage composition of fish species in Pool IV in the Kakum Estuary wetland from July 2009 – January 2010

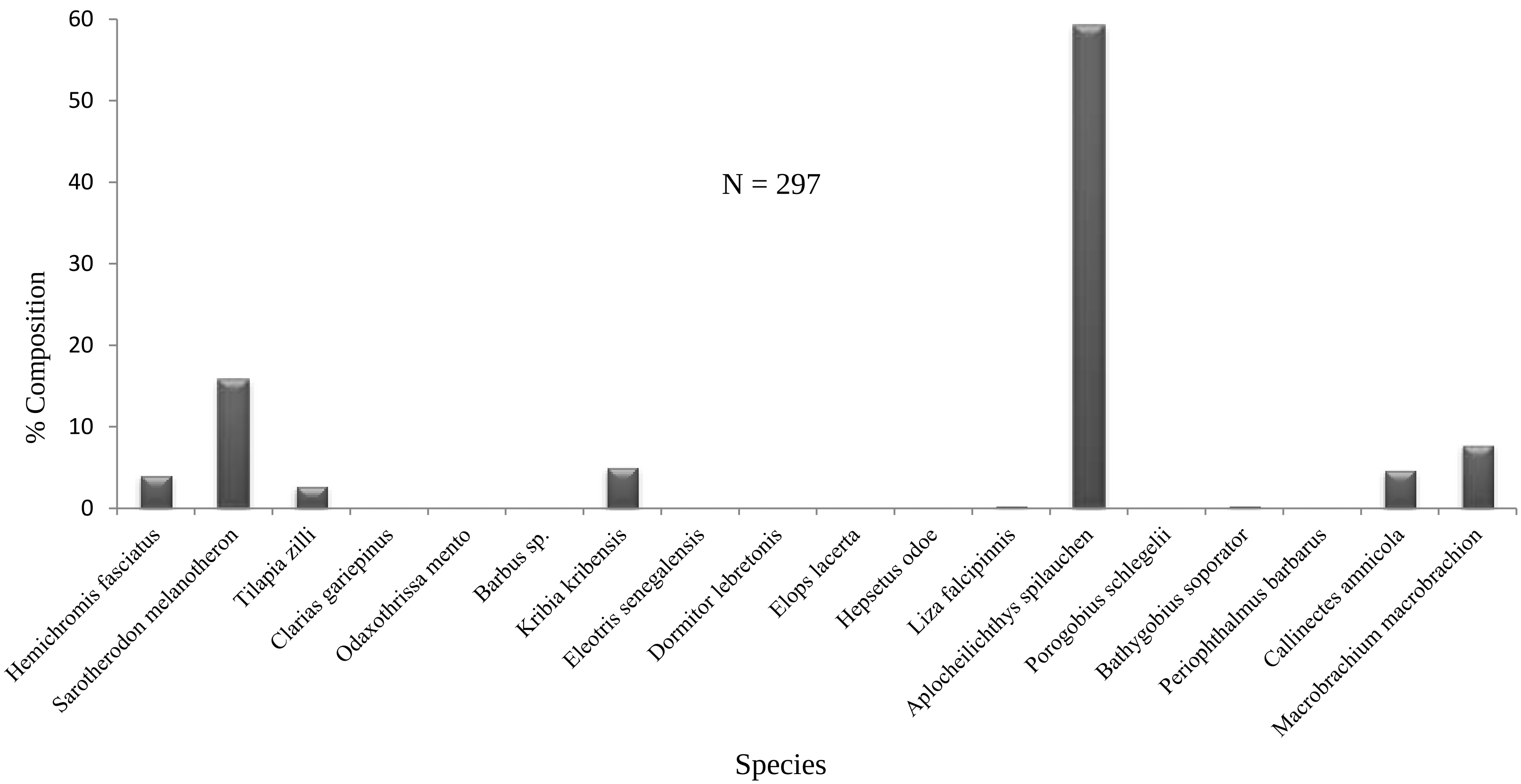

Figure 18: Overall percentage composition of fish species in Pool IV in the Kakum Estuary wetland

Pool V

The community in Pool V was made up of nine species in July (Figure 19), and as in the other pools, *Aplocheilichthys spilauchen* was highly dominant scoring 78.61% of the total fish caught. The remaining species, namely *M. macrobrachion*, *T. zillii*, *Callinectes amnicola*, *Odaxothrissa mento*, *H. fasciatus*, *Clarias gariepinus*, *L. falcipinnis* and *S. melanotheron* varied in composition from 0.59% to 6.36%. In August, eight species occurred and was again dominated by *A. spilauchen* (41.84%), followed by *S. melanotheron* (32.65%). The shrimp *M. macrobrachion* and *T. zillii* made up 9.18% and 7.14% respectively while *C. amnicola*, *H. fasciatus*, *P. schlegelii* and *C. gariepinus* constituted between 1.02% and 4.08% of the fish sample. Of the ten species present in September, *A. spilauchen*, *M. macrobrachion* and *S. melanotheron* were the abundant fishes, consisting of 36.28%, 26.55% and 17.70% respectively, while *T. zillii* comprised 8.85%. The compositions of *C. amnicola*, *P. schlegelii*, *Eleotris senegalensis*, *H. fasciatus*,*C. gariepinus* and *K. kribensis* varied between 0.88% and 4.42%. In October, *S. melanotheron* and *M. macrobrachion* dominated the community where they scored 29.63% and 27.78% respectively. Next in abundance were *K. kribensis* (16.67%), *Elops lacerta* (11.11%) and *T. zillii* (7.41%). Three species including *A. spilauchen* were present in very low abundance (< 4%). The fish collected in November was dominated by *S. melanotheron*, comprising 49.33% of the sample. *Elops lacerta* composed 18.67% of this sample, while *M. macrobrachion*, *K. kribensis* and *C. amnicola* followed with compositions of 10.67%, 8% and 6.67% respectively.

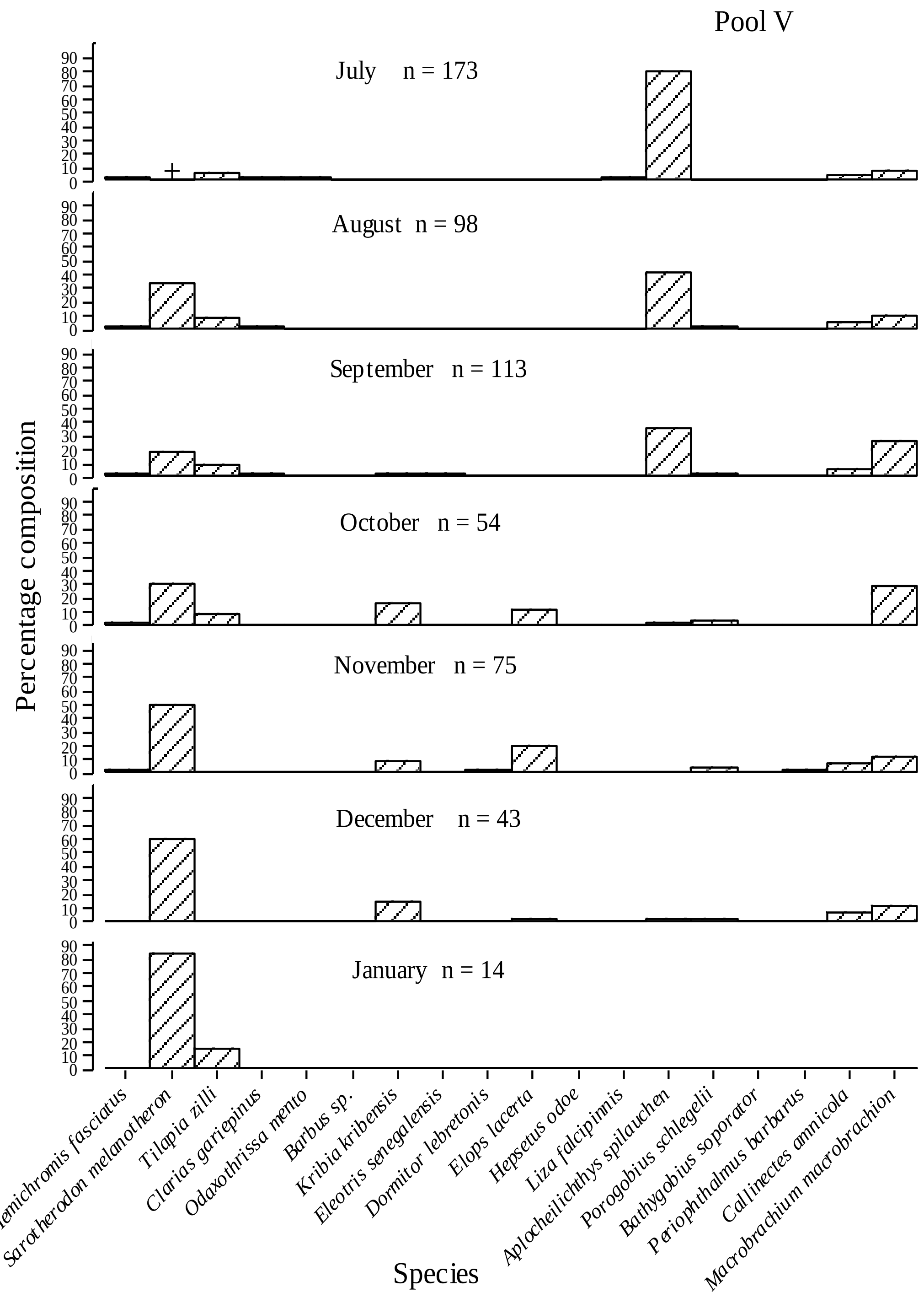

Figure 19: Monthly percentage composition of fish species in Pool V in the Kakum Estuary wetland from July 2009 – January 2010 (+ indicates < 1 %)

Four other species (i.e. *H. fasciatus, Domitator lebretonis, P. schlegelii* and *Periophthalmus barbarous*) occurred sparingly (< 2%). *S. melanotheron* remained the most common of the seven species sampled in December 2009, making up 60.46% of the community. *K. kribensis*, *M. macrobrachion* and *C. amnicola* constituted 13.95%, 11.62% and 6.98% respectively of the sample, while the remaining three species *namely E. lacerta, A. spilauchen* and *P. schlegelii* were very low in composition (< 3% each). Only two species were present in the community in January 2010 of which 85.71% were *S. melanotheron* while the remaining 14.28% were *T. zillii.*

Figure 20 shows the overall percentage composition of the species in Pool V. The poecilid fish *Aplocheilichthys spilauchen* was dominant, followed by *S. melanotheron* and the freshwater shrimp *Macrobrachium macrobrachion.*

Pooled data on fish composition in the wetland

Figure 21 presents the pooled percentage composition of the 18 species in the entire wetland community. Of the eighteen species in the wetland, *Aplocheilichthys spilauchen* (Poeciliidae) was dominant, comprising 43.31% of the fish community. This was followed by the lagoon tilapia *Sarotherodon melanotheron* (Cichlidae) with a composition of 18.12% and the freshwater shrimp *Macrobrachium macrobrachion* (Palaemonidae) which composition was 12.37%. *Tilapia zillii*, *Kribia kribensis* and the crab *Callinectes amnicola* comprised 6.68%, 4.68% and 3.31% of the community respectively, while *Porogobius schlegelii*, *Hemichromis fasciatus*, *Liza falcipinnis*, *Barbus* sp. and *Elops lacerta* varied in composition from 1.2% to 2.60%. The remaining seven

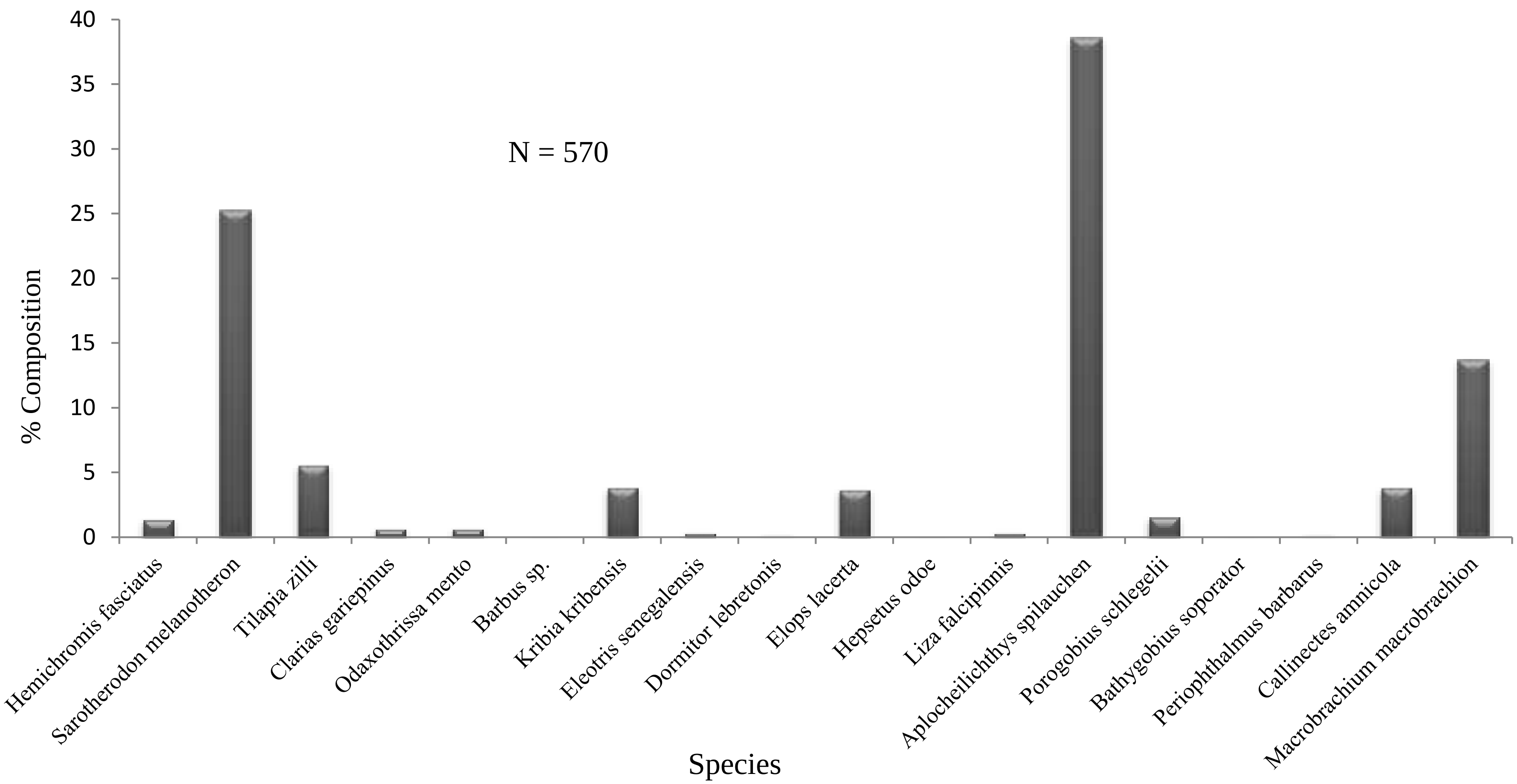

Figure 20: Overall percentage composition of fish species in Pool V in the Kakum Estuary wetland

species namely *Odaxothrissa mento, Bathygobious soporator, Periophthalmus barbarus*, *Hepsetus odoe*, *Dormitator lebretonis*, *Eleotris senegalensis* and *Clarias gariepinus* occurred sparingly in the community (< 1% each).

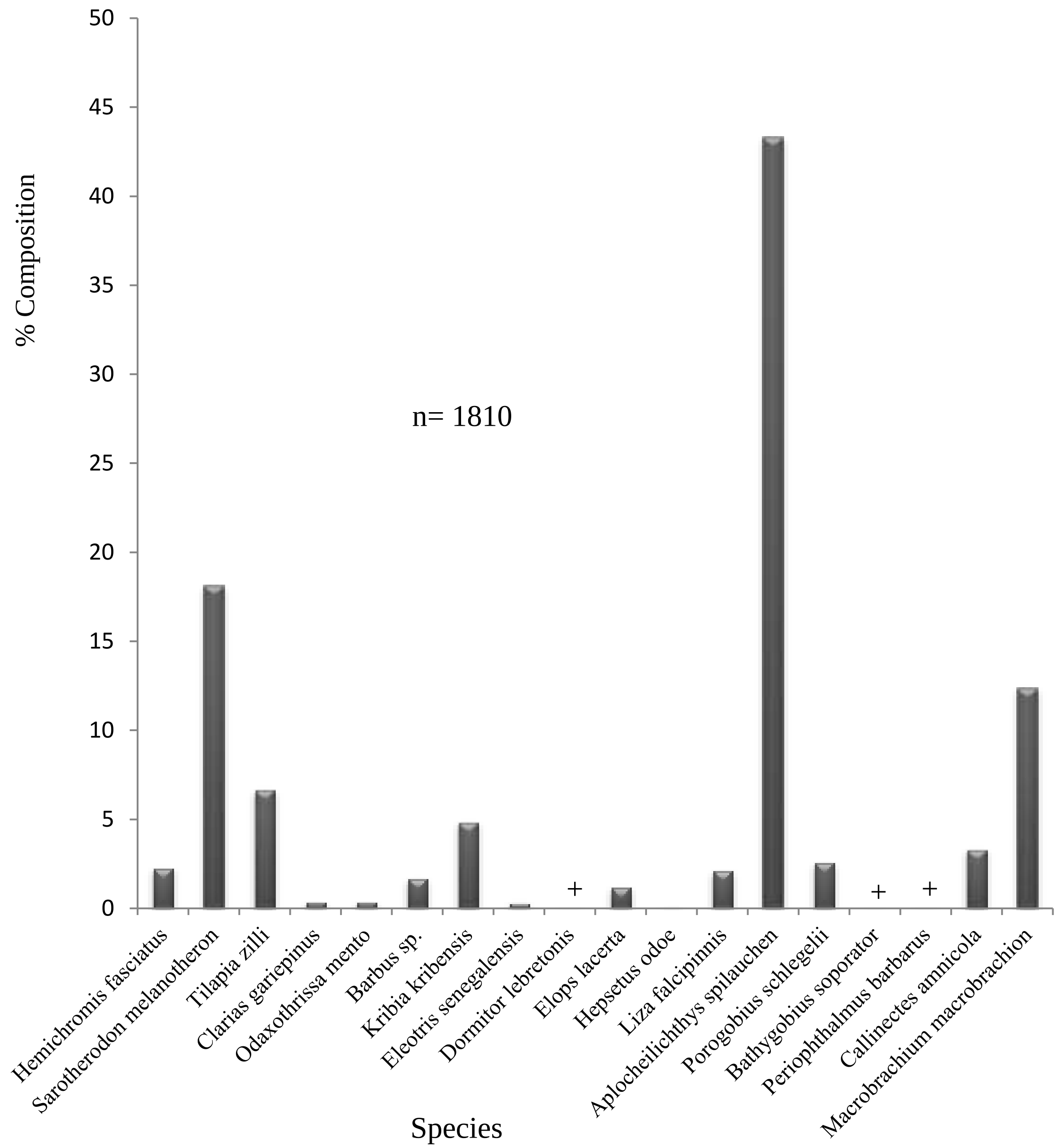

Figure 21: Percentage composition of fish species in the Kakum Estuary wetland (+ indicates < 1 %)

Size distribution of the three most common species in the wetland

The length-distributions of the dominant species in the community *Aplocheilichthys spilauchen*, *Sarotherodon melanotheron* and *Macrobrachium macrobrachion* in each of the pools is illusrated in Figures 22, 23 and 24. The range of sizes as well as the modal lengths of the different species in the wetland combined is presented in Table 10, and details for each pool is presented in Appendices 2 – 6.

Aplocheilichthys spilauchen

Specimens ranged in length from 2.3 cm to 5.6 cm TL, and individuals of the 3.0–3.9 cm class dominated the populations in all pools (Figure 22).

Sarotherodon melanotheron

Specimens of this fish measured 1.3 to 12.3 cm TL. Only 2 specimens were sampled from Pool I and were therefore excluded from the analysis. The modal size of the species in the other pools was 2.0- 2.9 cm TL (Figure 23).

Macrobrachium macrobrachion

A body length range of 2.0 to 10.7 cm was recorded for this prawn species. Only 4 individuals were sampled from Pool I and therefore the length distribution was not analysed. In Pool III, none of the sizes was clearly dominant in the population. However, the class 7.0-7.9 cm had the highest composition in Pool II, while the most common individuals measured 2.0-2.9 cm in Pool IV, and 3.0-3.9 cm was the modal size of the prawn in Pool V (Figure 24).

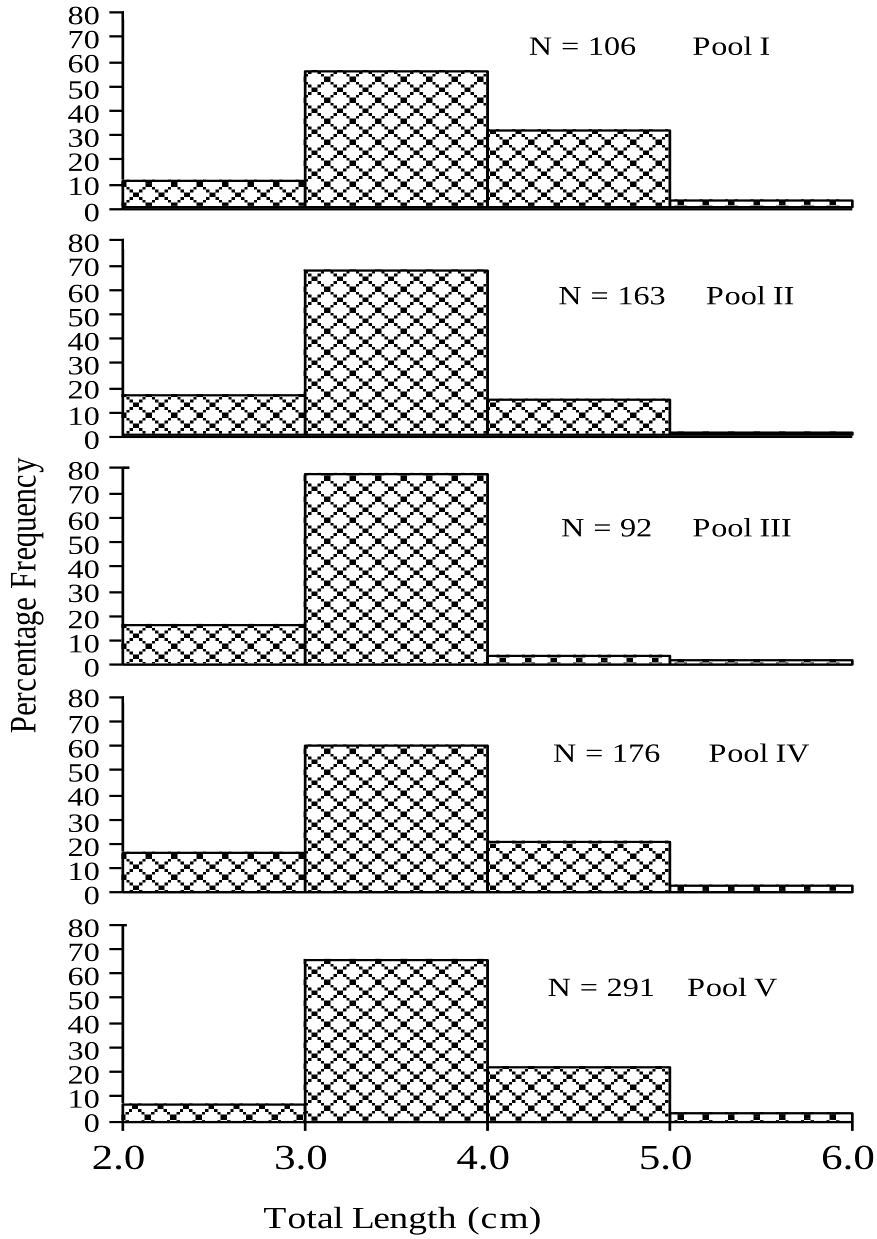

Figure 22: Length-frequency distribution of *Aplocheilichthys spilauchen* in five Kakum Estuary wetland pools (n = number of individuals)

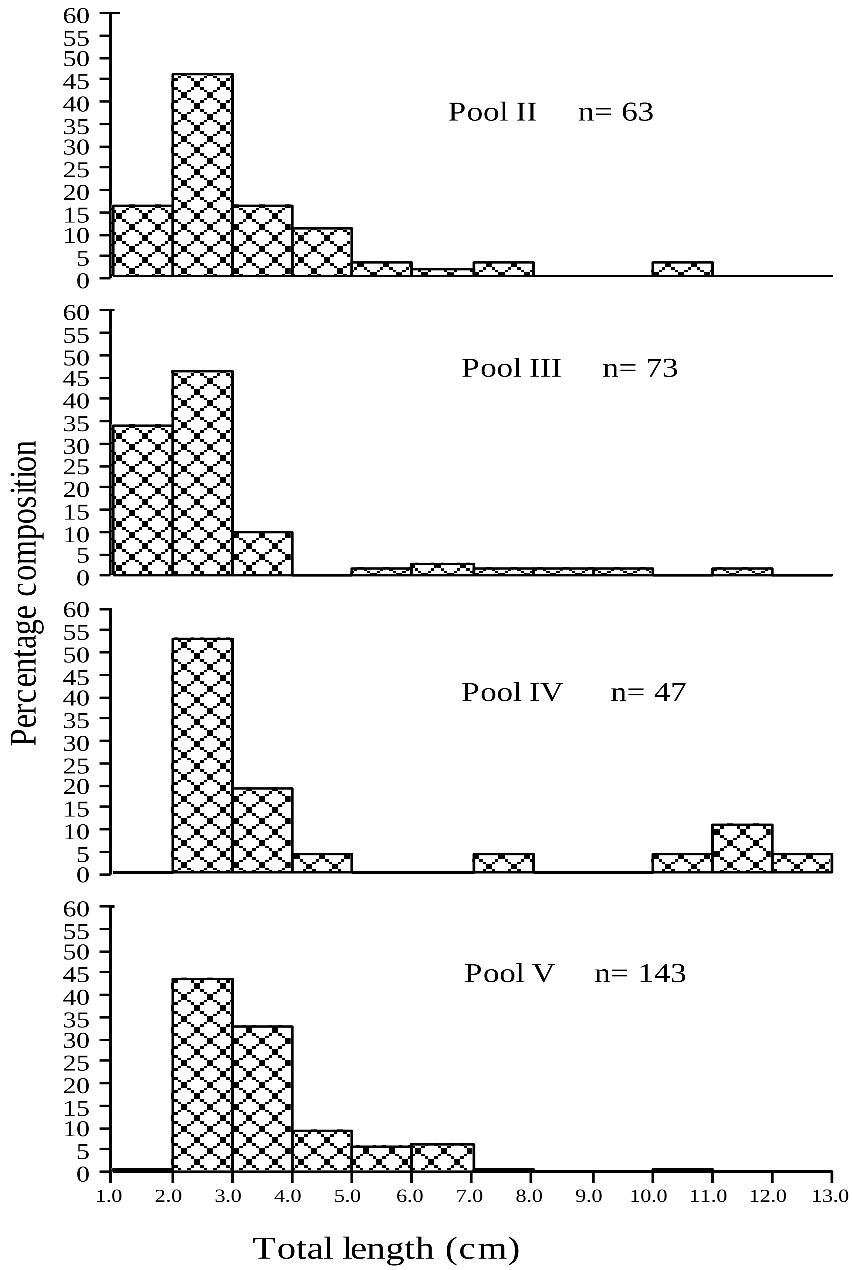

Figure 23: Length-frequency distribution of *Sarotherodon melanotheron* in four Kakum Estuary wetland pools (n = number of individuals)

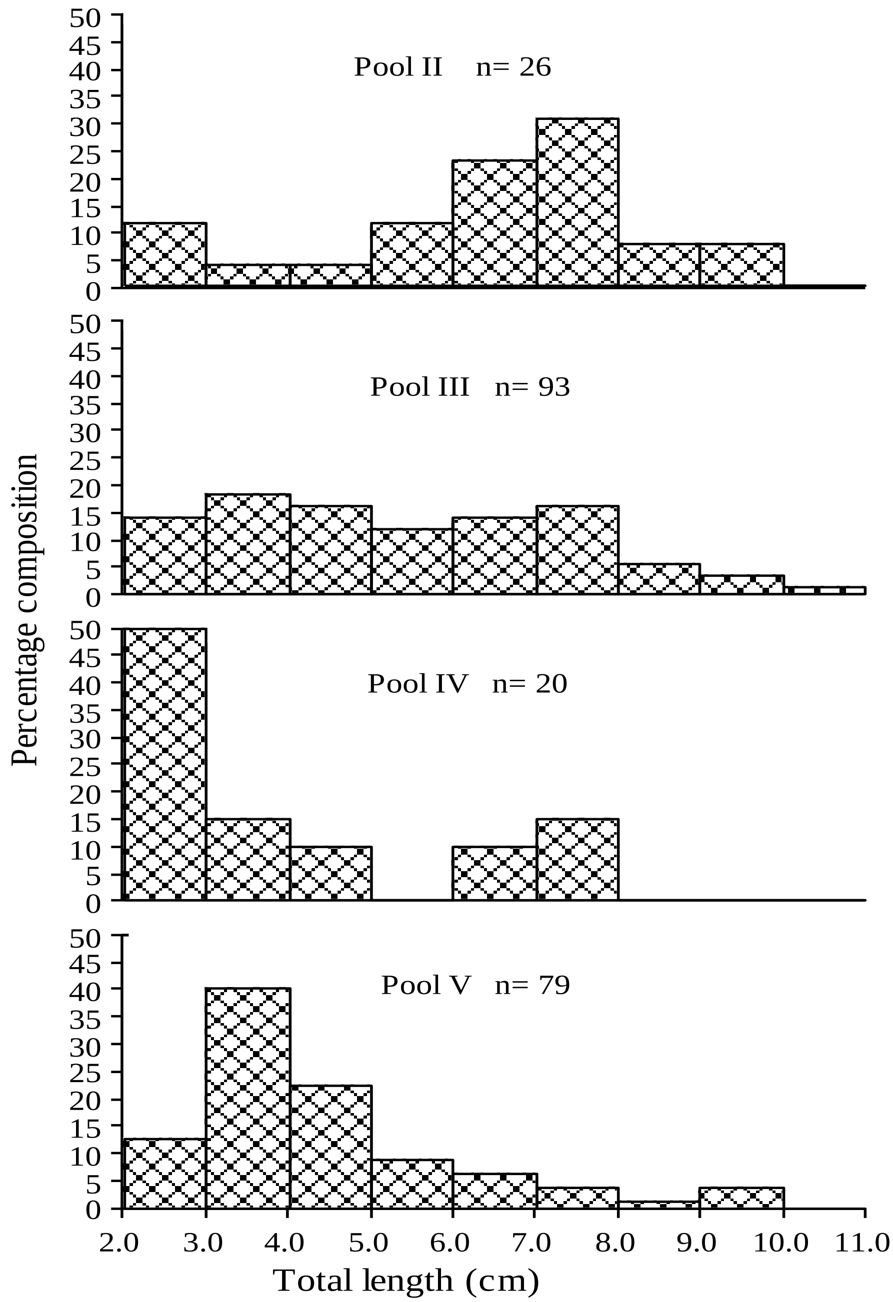

Figure 24: Length-frequency distribution of *Macrobrachium macrobrachion* in four Kakum Estuary wetland pools (n = number of individuals)

Table 10: Size range of fish species sampled (all pools) from the Kakum Estuary wetland

		TL(cm)			
Species	No.	Min	Max	Modal class	Composition
Hemichromis fasciatus (FW)	41	3.5	12	3.0-3.9	62.4 %
Tilapia zillii (FW)	121	1.4	6.9	2.0-2.9	69.6%
Clarias gariepinus (FW)	7	10.4	24.1	-	-
Odaxothrissa mento (FW)	7	8	16.6	-	-
Barbus sp.(FW)	31	3.1	4.7	3.0-3.9	43.2%
Kribia kribensis (FW)	88	3.6	6.2	5.0-5.9	68.4%
Eleotris senegalensis (FW/BW)	6	3.4	6.3	-	-
Dormitator lebretonis (FW/BW)	1	-	-	-	-
Elops lacerta (M)	22	3.8	8.8	6.0-6.9	60.2%
Hepsetus odoe (FW)	2	-	19.5	-	-
Liza falcipinnis (M/BW)	39	6.2	13.6	7.0-7.9	63.3%
Porogobius schlegelii (FW/BW)	47	4.1	8.1	5.0-3.9	42.3%
Bathygobius soporator (M/BW)	1	-	-	-	-
Periophthalmus barbarus (BW)	1	-	-	-	-
Callinectes amnicola (M/BW)	60	1.0*	7.2*	1.0-1.9*	73.2%

FW, freshwater; BW, brackishwater; M, marine; (*) Carapace width

Food habits of the fishes in the wetland

Aplocheilichthys spilauchen

A total of 784 specimens of this species were examined from the wetland; 133, 163, 92, 176 and 220 from Pools I – V respectively of which 3 from Pool II and 6 from Pool V had empty stomachs. Debris, insects and insect larvae were the main food of the fish (Figure 25).

In Pool I, 97% of the specimens fed on unidentified adult insects which constituted 33.1% of their diet. Unidentified insect larvae occurred in the diet of 78% and made up 30.4% of the food. Debris was eaten by 89% and contributed 20.1% of the bulk food while chironomid larvae were eaten by 40% of the fish and had a composition of 12.1%. Copepods were the least consumed prey (ingested by 5.4% of the fish and composed 4.3% of the food).

The most consumed food of the population in Pool II was unidentified insect larvae (83.4% and 42.1% by occurrence and composition respectively). Unidentified adult insects were ingested by 73.3% of the specimens and constituted 29.1% of the eaten prey while 80.6% took debris which made up 14.2% of the diet. Chironomid larvae and copepods had occurrence of 56.8% and 7.5% respectively, both of which accounted for 7.4% of the ingested items.

The specimens examined from Pool III fed frequently on adult insects and unidentified insect larvae (each with occurrence of 76%), and these items had compositions of 36.14% and 25.23% respectively. Debris was consumed by 60.9% of the specimens and constituted 21.21% of their food while chironomid

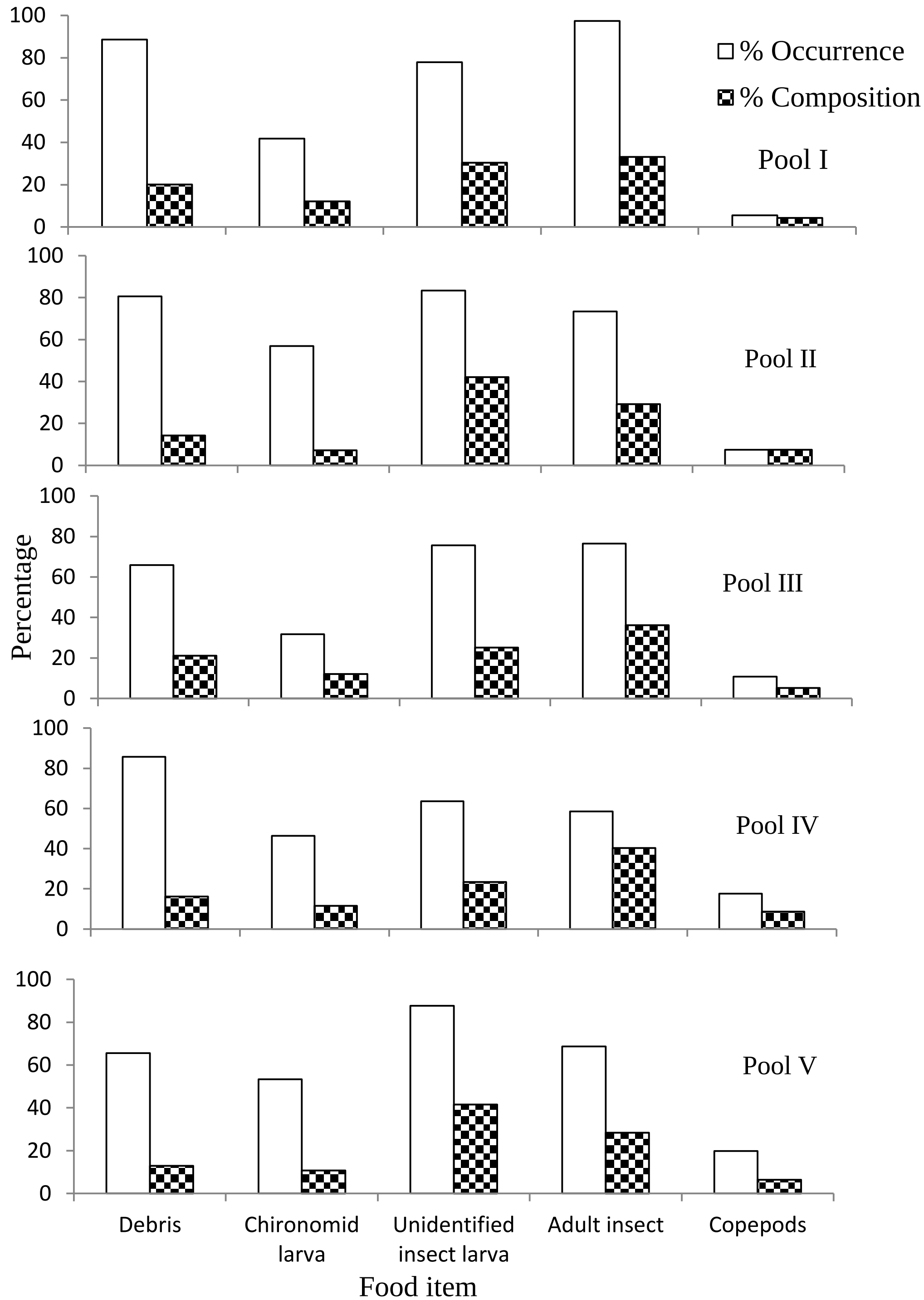

Figure 25: Frequency and composition of different food items in the diet of *Aplocheilichthys spilauchen* in the Kakum Estuary wetland pools

larvae (31.7% and 12.12% by occurrence and composition respectively) and copepods (10.8% and 5.3% by occurrence and composition respectively) were lowly eaten by the fish.

Debris was encountered in the diet of 85.1% of the specimens from Pool IV, but made up 16.3% of the bulk food. Adult insects and unidentified insect larvae had occurrence of 58.5% and 63.5% respectively, and compositions of 23.35% and 40.26% respectively while chironomid larvae were preyed on by 46% of the fish and accounted for 11.52% of the consumed prey. Copepods were the selected by 17.6% of the sample and constituted 8.64% of the diet.

In Pool V, 87.63% of the specimens preyed on unidentified insect larvae which made up 33.1% of the diet. Unidentified adult insects were found in the stomachs of 68.7% and made up 28.4% of food consumed, and debris was selected by 65.57% and formed 12.89% of the bulk food. Chironomid larvae were taken by 53.41% of the fish and contributed 10.72%, with copepods having the lowest occurrence of 19.81% and composition of 6.46%.

Sarotherodon melanotheron

As shown in Figure 26, stomach contents identified in the diet of this species include species of blue-green algae, green algae and diatoms. *Anabaena* spp., *Oscillatoria* spp., *Chroococcus* sp. and *Microcystis* sp. were the main blue-green algae consumed, while the green algae found were mostly filamentous types such as *Spirogyra* sp., desmids (e.g. *Closterium* sp. and *Scenedesmus* sp.), and other unicellular forms (eg. *Pediastrum* sp. and *Staurastrum* sp.). The most common diatoms found were species of *Navicula*, *Rhizosolenia*, *Gyrosigma* and

Stephanodiscus. Debris was also present in the food of the fishes, while copepods and rotifers as well as macrozoobenthos such as oligochaetes and chironomid larvae, and also fish scales, occurred in the diet of few specimens.

Only 1 specimen was collected from Pool I which fed on diatoms and blue-green algae.

Diatoms were the most important item consumed by all the 63 specimens caught from Pool II and accounted for 58.2% of their diet. Debris occurred in the stomachs of 76% of the specimens and constituted 21.4% of the food while green algae (33% by occurrence) and blue – green (25.4% by occurrence) contributed 9.5 % and 4.7 % respectively. Less than 10 % of the fish preyed on rotifers and zoobenthos and these made up less than 5 % of their food.

In Pool III, 73 specimens were examined of which the stomachs of 2 were empty. Diatoms were encountered in every stomach containing food and had a composition of 50.8%, followed by debris (64.8% and 26.1% by occurrence and composition respectively). Green and blue – green algae had occurrence of 31% and 14% respectively, and constituted 8.4% and 5.8% respectively. The occurrence as well as the composition of zooplankton, zoobenthic and other food items varied between 1% and 5%.

Of the 47 specimens examined in Pool IV, diatoms, debris, green and blue – green algae had occurrence of 100%, 65.9%, 55% and 48.9% respectively, and compositions of 54.7%, 14.4%, 16.1% and 6.6% respectively. The remaining prey were ingested by less than 10% of the fish and each constituted less than 4 % of the food eaten.

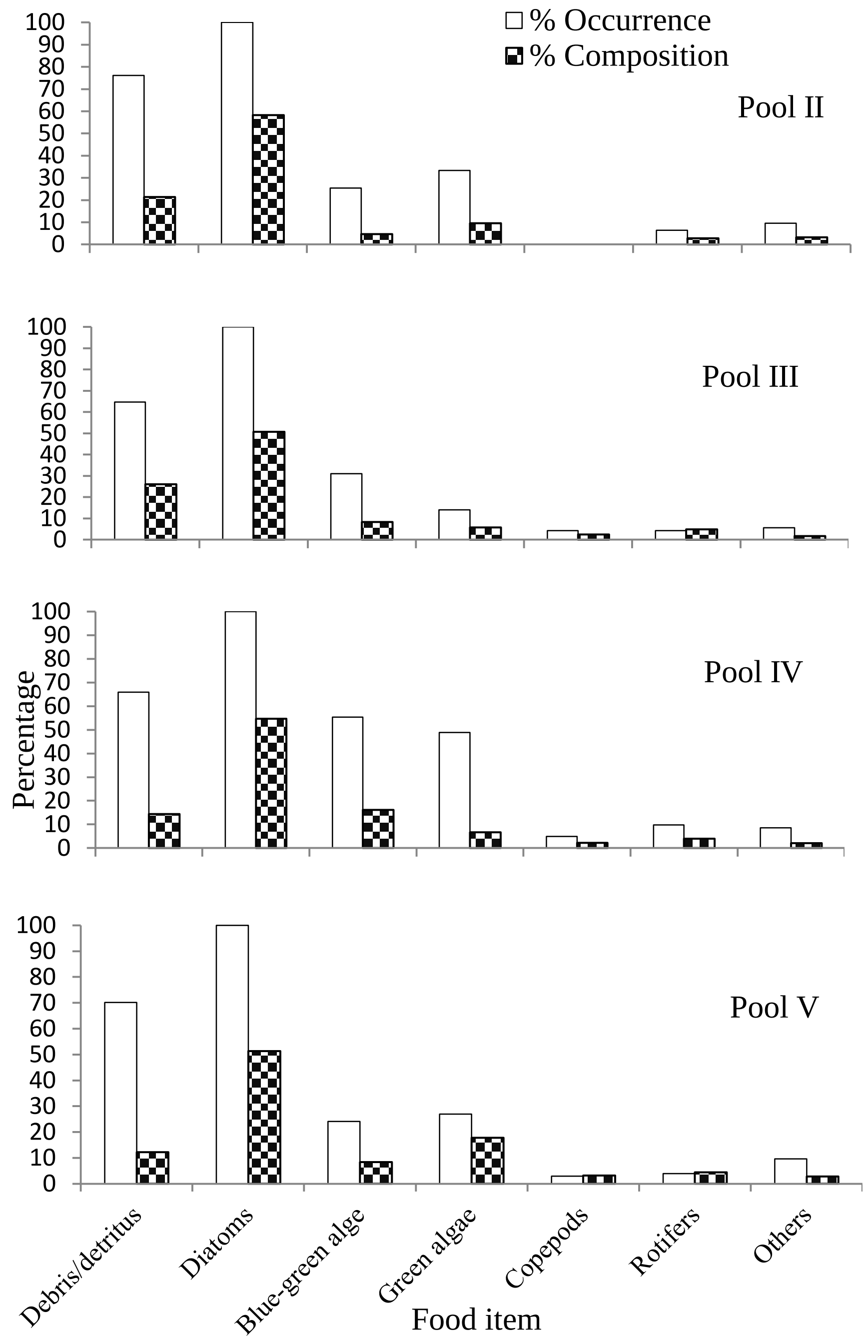

Figure 26: Frequency and composition of food items consumed by *Sarotherodon melanotheron* in Kakum Estuary wetland pools

A total of 144 specimens were sampled from Pool V of which 5 had empty stomachs, and diatoms (100% by occurrence and 51.3% by composition) were the main food consumed by the population. Debris was frequently ingested (70%) but made up 12.24% of the ingested food while green algae (27% by occurrence) and blue – green algae (24% by occurrence) accounted for 17.7% and 8.4% respectively. Less than 10% of the specimens fed on copepod, rotifers and benthic invertebrates, and these items together constituted 10% of the diet.

Liza falcipinnis

The occurrence and composition of the various food items consumed by the *L. falcipinnis* populations in the wetland is illustrated in Figure 27. Blue – green algae (eg. *Oscillatoria* spp. and *Anabaena* spp.), diatoms (e.g. *Closterium* sp. and *Rhizosolenia* sp.) and green algae such as *Pediastrum* sp. and *Scenedesmus* sp. were the main items identified. Debris as well as copepods, rotifers and macrobenthic fauna such as oligochaetes and chironomid larvae, and also fish scales were also found in the food of some specimens.

The most important food eaten by the 15 specimens examined from Pool I were diatoms (100% by occurrence, 41.6% by composition) and debris (80% and 30.34% by occurrence and composition respectively). Blue-green algae, green algae and copepods had occurrence of 26.6%, 46.7% and 40% respectively, and compositions of 8.32%, 4.74% and 7.14% respectively. Few specimens preyed on rotifers and other zooplankton (<20 %) and these constituted less than 5% of the ingested diet.

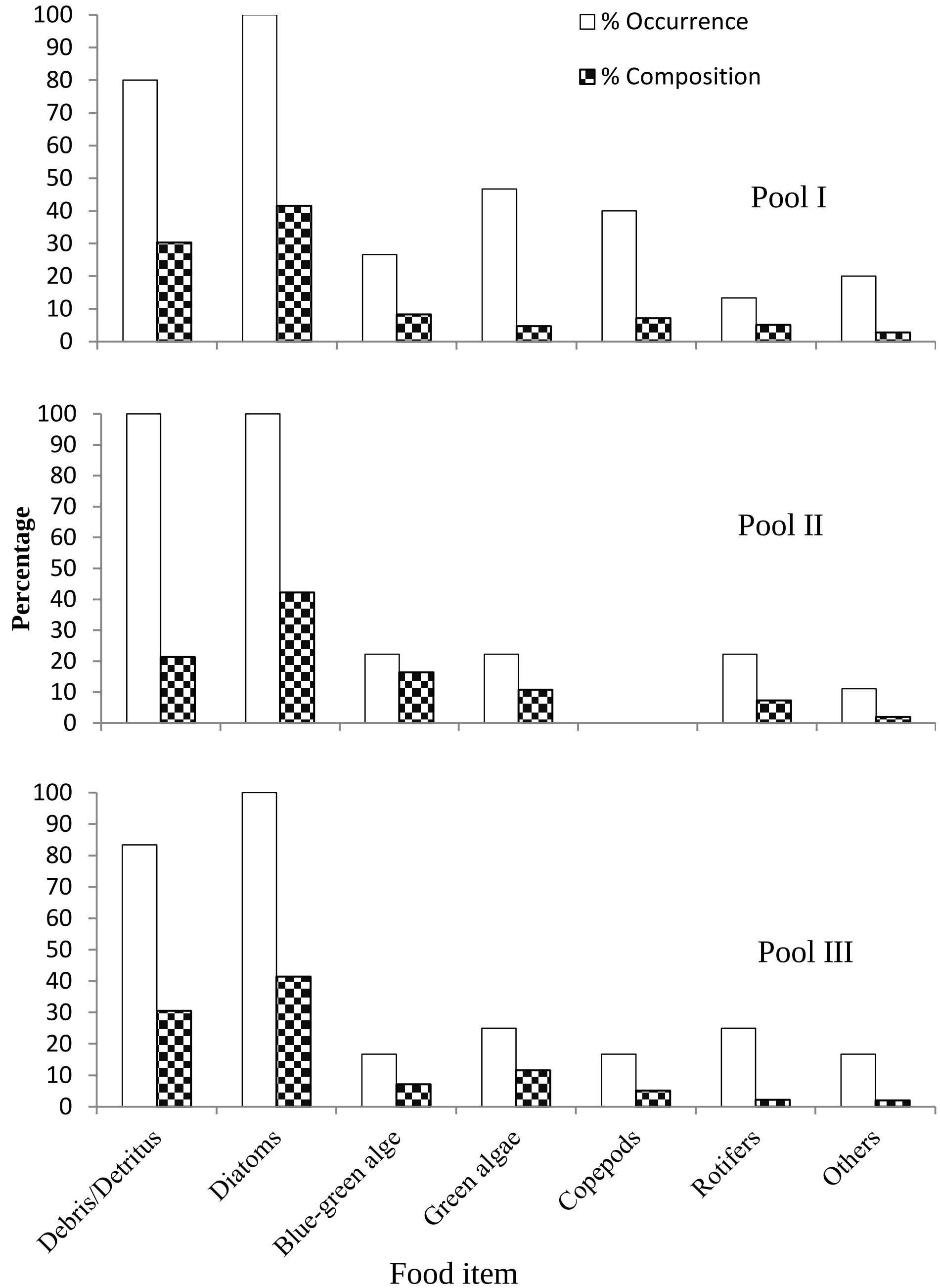

Figure 27: Occurrence and composition of different food items in the diet of *Liza falcipinnis* in the Kakum Estuary wetland pools

All the 9 specimens collected from Pool II ingested diatoms and debris, with these items making up 42.2% and 21.3% respectively of the diet. Each of blue – green algae, green algae and rotifers occurred in 22.2% of the stomachs examined, and had compositions of 16.4%, 10.8 % and 7.26% respectively, while other items such as zoobenthos and fish scales together had 11% and 2% by occurrence and composition respectively. None of the fish ate copepods.

The 12 individuals sampled from Pool III fed principally on diatoms (100% by occurrence, 41.41% by composition) and debris (83.3% by occurrence and 30.57% by composition). The occurrence of the remaining items varied between 16% and 25% while the composition varied from 2% to 11.6%.

One individual was taken from Pool IV and two from Pool V all of which fed on diatoms, green algae and debris.

Tilapia zillii

A total of 121 specimens were examined from the five pools; 37 from each of Pools I and II, and 7, 8 and 32 from Pools III, IV and Pool V respectively, of which none had an empty stomach. Plant material, debris and algae, especially diatoms and filamentous green and blue-green algae, were the main component of the food of the fish (Figure 28).

Plant material (98% by occurrence) and algae (100% by occurrence) were the most frequently ingested food of the fish in Pool I, constituting 51.5% and 34.1% respectively of the consumed food. This was followed by debris with occurrence of 53.4% and composition of 10.6% while copepods and rotifers were ingested by 6.65% and 9.95% of the specimens respectively, and made up 1.61% and 2.21% respectively of the consumed food.

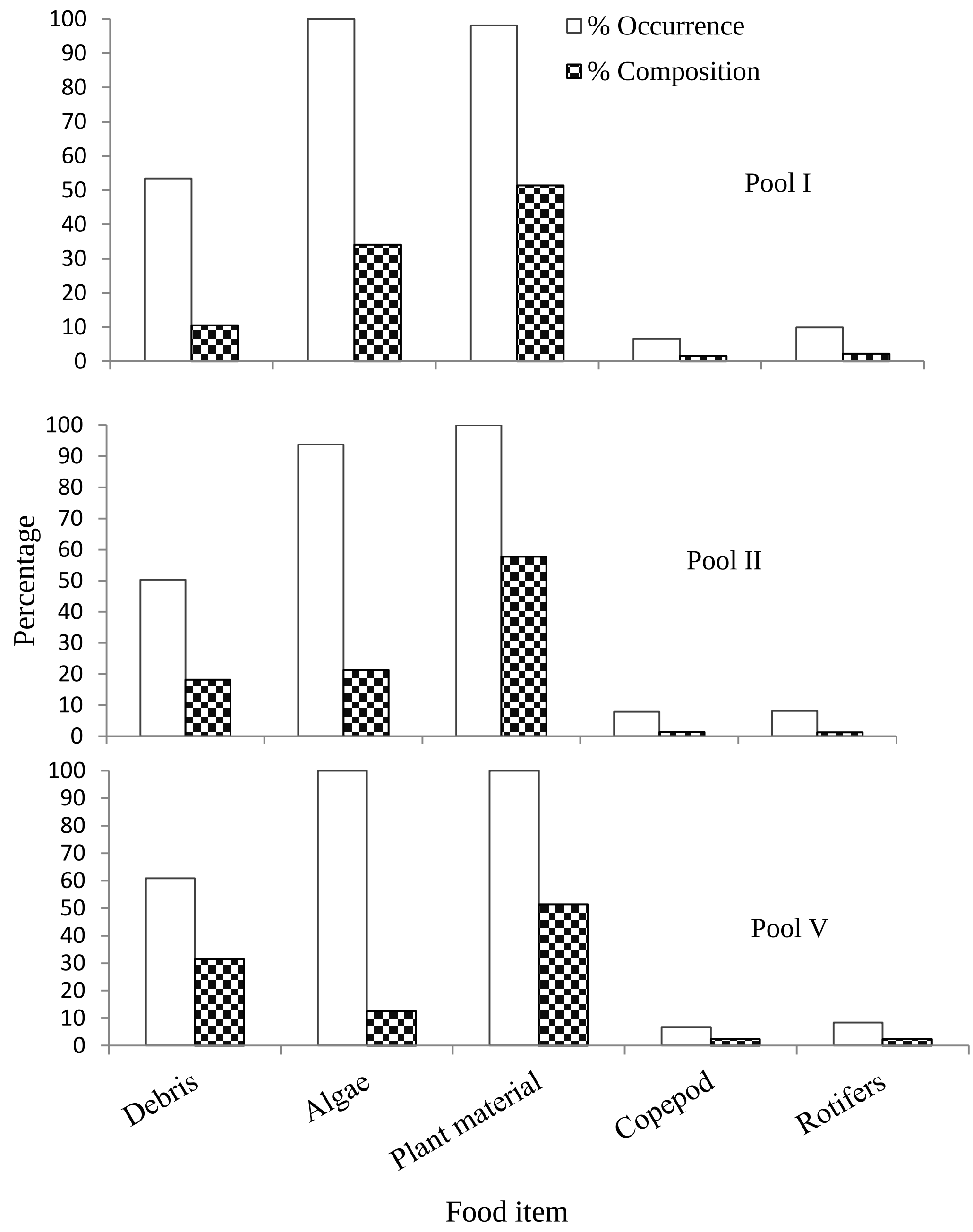

Figure 28: Frequency and composition of different food items in the diet of *Tilapia zillii* in the Kakum Estuary wetland pools

Similarly, the specimens collected from Pool II also fed mostly on plant material (100% by occurrence and 57.7% by composition), algae (93.7% by occurrence and 21.3% by composition) and debris (50.3% by occurrence and 18.2% by composition). Copepods and rotifers were the least selected food, occurring in the diet of fewer than 10% of the tilapia and constituting less 3% of the food eaten prey.

In Pool IV, all the fish took plant materials and algae, with plant materials making up 51.4 %, and algae making up 12.5% of the food. Approximately 60.8% fed on debris, and it constituted 31.41% of the bulk food while fewer than 10% of the fish preyed on copepods and rotifers, with each of these items constituting less 5% of the food ingested prey.

Hemichromis fasciatus

The samples of *H. fasciatus* from the five pools were combined for the analysis due to the small number of individuals (< 15) collected from each pool. A total of 41 specimens (10, 5, 6, 12 and 8 from Pools I – V respectively) were examined and the species preyed widely on insect larvae, fragments of adult insects, shrimps, fish fry, fish scales and copepods (Figure 29). Among the items encountered, insect fragments (75.6% by occurrence) and fish fry (95.1%) were the most common prey, constituting 28.97% and 30.84% respectively of the diet. Insect larvae (principally chironomid larvae) were found in the stomachs of 68.2% of the specimens and composed 17.2% of the food while shrimps ingested by 58% of the fish made up 12.6% of prey ingested. Each of fish scale and copepods, as well as algae (e.g. diatoms, green and blue-green algae) and debris made up very little component (< 10% occurrence and < 4% composition) of the consumed food.

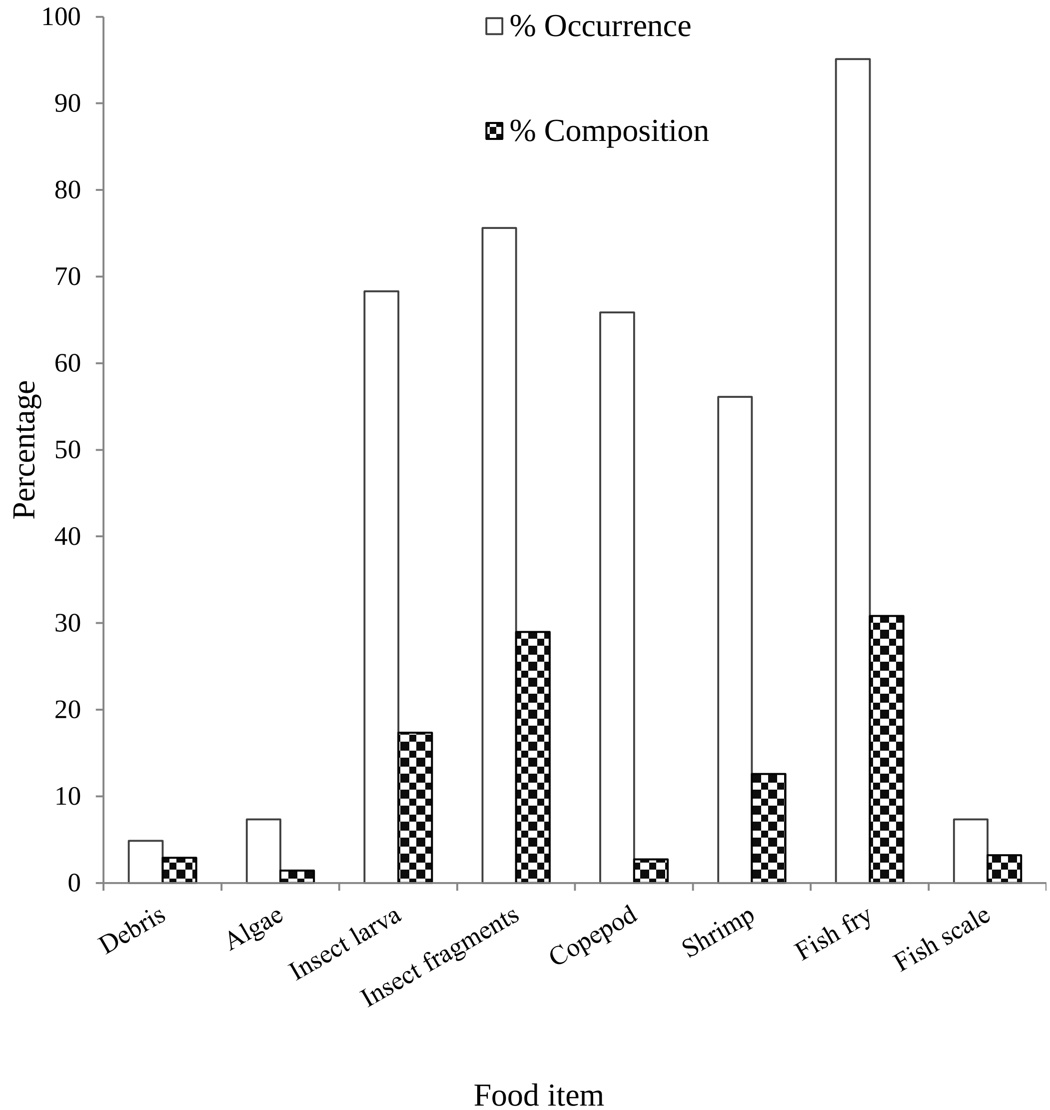

Figure 29: Composition of prey items in the diet of *Hemichromis fasciatus* in the Kakum Estuary wetland

Kribia kribensis

Data on the food of this fish was also combined for the analysis due insufficient specimens caught from some pools. Of the 88 *K. kribensis* specimens sampled from the five pools (7, 40, 4, 15 and 22 for Pools I – V respectively), 2 had empty stomachs. As shown in Figure 30, debris, insect larvae (chironomid larvae), copepods and annelids (oligochaetes) were the food items taken by the fish and were encountered in all stomachs containing food, with copepods being the most eaten prey which made up 33.5% of the food. Chironomid larvae were the next highly consumed prey with composition of 27.2% while oligochaetes (annelid) comprised 22.6% of the ingested food. About 16.7% of the stomach content was debris.

Porogobius schlegelii

Specimens of *P. schlegelii* sampled from the pools totalled 41, all of which fed mainly on copepods, annelids, and debris. Copepods were the most ingested prey which formed almost 48 % of the bulk content of the stomach (Figure 31). Debris (34%) and oligochaetes (16%) also formed a very important component of the food of the fish while fish scales were encountered in less than 5% of the specimens and constituted 2% of the total consumed food.

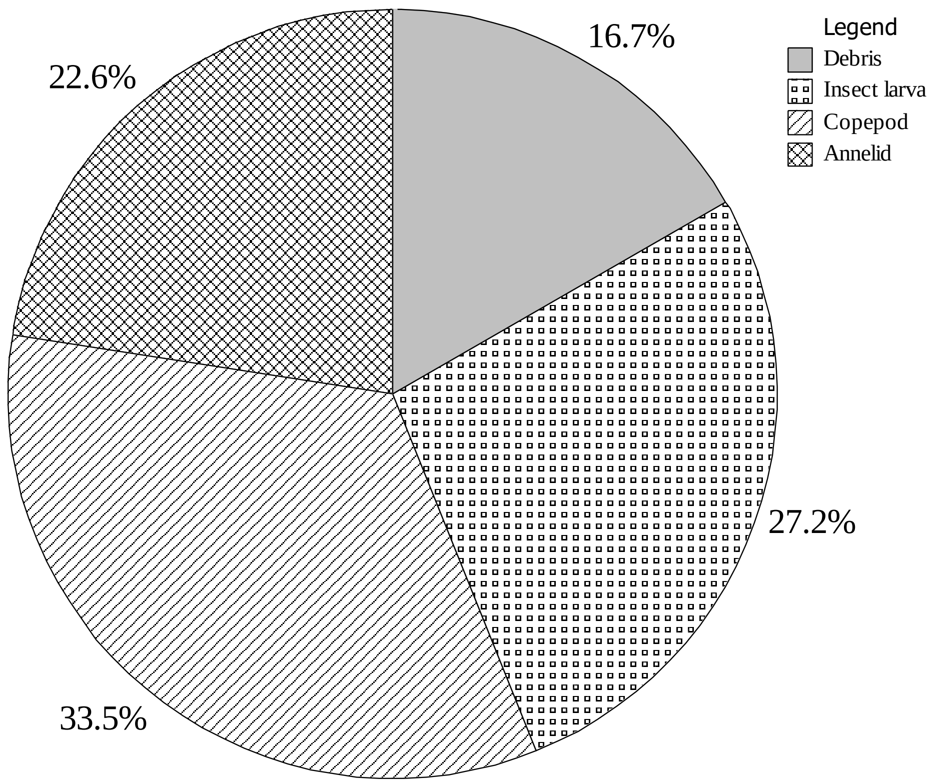

Figure 30: Composition of food items in the diet of *Kribia kribensis* in the Kakum Estuary wetland

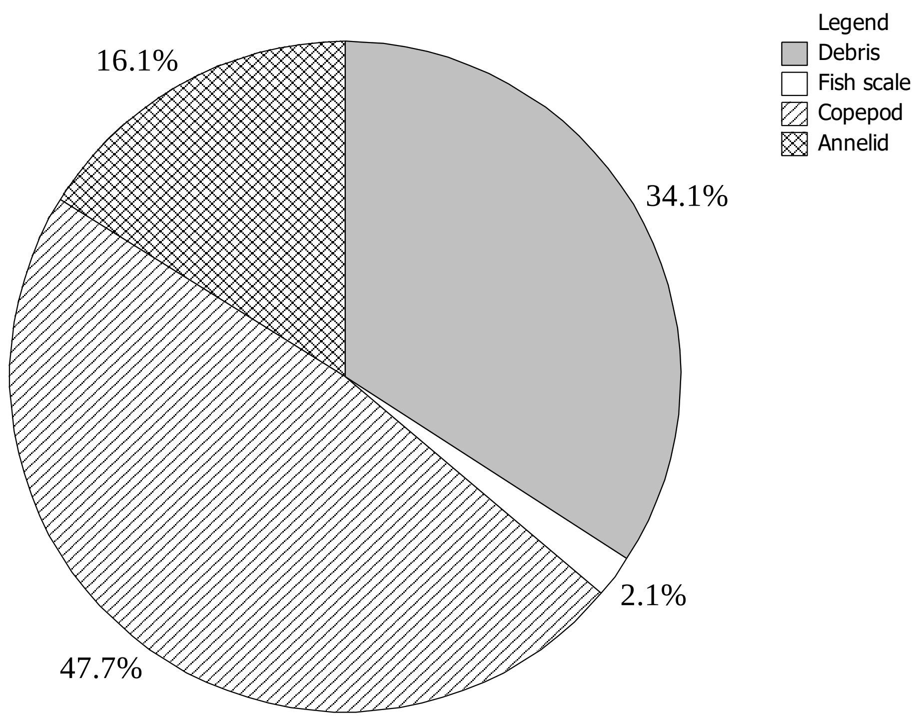

Figure 31: Composition of food items in the diet of *Porogobius schlegelii* in the Kakum Estuary wetland

Other species

Debris or detritus (60 % by composition) and chironomid larvae (40 % by composition) were the only food consumed by all the 31 specimens of *Barbus sp.* Sampled from Pool III. Of the one specimen each of the gobies *Periophthalmus barbarus* (caught from Pool V) and *Bathygobius soporator* (collected from Pool IV), only copepods were found in the stomach of the former while the latter fed on detritus, chironomid larvae and copepods. Similarly, debris and copepods were the only items eaten by the one specimen of *Dormitator lebretonis* (Eleotridae) caught from Pool V while all the 6 individuals of *Eleotris senegalensis* examined (1, 3 and 2 specimens from Pools I, II and V respectively) fed on chironomid larvae, copepods, debris and oligochaetes with these items making up 36.4 %, 28.2 %, 21.3 % and 14.1 % respectively of the bulk food.

Fragments of adult insects and juvenile shrimps were the only components of the food of the 7 individuals of the clupeid *Odaxothrissa mento* sampled from Pools III and V in the wetland, with each food item constituting about 50 % of the diet. *Elops lacerta* (1 specimen from Pool II and 21 from Pool V) preyed exclusively on juvenile shrimps and fish fry (each made up 50 % of the diet), and the 1 specimen of the West African pike *Hepsetus odoe* from each of Pools I and III ingested only fishes. A total of 7 specimens of the catfish *Clarias gariepinus* were caught from Pools I, II and V all of which consumed fishes (40 % by composition), chironomid larvae (19 % by composition), plant materials (20 % by composition), algae (8 % by composition) and debris (13 % by composition).

Aspects of the reproductive biology of some fishes

Sex ratio

Aplocheilichthys spilauchen was the only species with sufficient samples for analysis of sex ratio. Results show that females of the species outnumbered the males by one and half to almost twice in all the pools (Table 11), although the differences were not significant in Pools II and III (χ^2 = 3.06 and 1.09, P > 0.05). When data from all the pools are combined however, females significantly outnumbered the males (χ^2= 28.57, P < 0.05).

Table 11: Sex ratio of *Aplocheilichthys spilauchen* in pools in the wetland

Pool	N	Male	Female	M:F	χ^2	$P_{(0.05)}$
Pool I	48	17	31	1:1.82	4.08	S
Pool II	64	25	39	1:1.56	3.06	NS
Pool III	23	9	14	1:1.55	1.09	NS
Pool IV	80	27	53	1:1.96	8.45	S
Pool V	128	44	84	1:1.91	12.50	S
Overall	**343**	**122**	**221**	**1:1.81**	**28.57**	**S**

NS= not significant, S= significant

Fecundity

The gravid females encountered in the samples belonged to four species and the range of their total lengths and absolute fecundities is presented in Table 12. The eleotrid *Kribia kribensis* ranged from 4.1 cm to 7.2 cm TL and had fecundity of 7,406 to 16,831 eggs. Fecundity estimates for the goby *Porogobius schlegelii* specimens measuring 5.2 cm to 7.6 cm TL were between 3,366 and 12,118 eggs. Specimens of the lagoon tilapia *Sarotherodon melanotheron* measured 10.7 cm to 12.3 cm TL and their fecundity ranged from 111 to 226 eggs while *Aplocheilichthys spilauchen* which measured 3.6 cm to 5.4 cm had an absolute fecundity range of 2 to 44 eggs.

Table 12: Fecundity of four species in the Kakum Estuary wetland

Species	N	Range of total length (cm)	Range of absolute fecundity
Aplocheilichthys spilauchen	81	3.6-5.4	2 - 44
Sarotherodon melanotheron	6	10.7-12.3	111 - 226
Porogobius schlegelii	7	5.2-7.6	3,366 - 12,118
Kribia kribensis	8	4.1-7.2	7,406 - 16,831

N = number of gravid females

The relation between the total length (TL, cm) and fecundity (Fec) of *A. spilauchen* (Figure 32) is described by the linear equation:

Fec. = 9.148TL (cm) - 26.05 (r = 0.45)

while the relation between the body weight (BW, g) and fecundity (Fec) (Figure 33) is described by the linear equation:

Fec. =12.63BW (g) + 0.417(r = 0.48).

Ova diameter frequency

The frequency distribution of the diameter of eggs from 5 specimens of *A. spilauchen* is presented in Figure 34. Three modes or peaks were observed for each of the five specimens. Ova measuring 0.65 mm constituted one mode (the first mode) in the ovary of all five specimens. Ova of diameter 0.96 mm formed another mode (the second mode) in two of the specimens; while in the remaining three, the second mode was constituted by ova measuring 1.05 mm. Eggs measuring 1.35 mm in diameter made up the third mode in four of the specimens while those of size 1.45 mm constituted the third mode in one specimen.

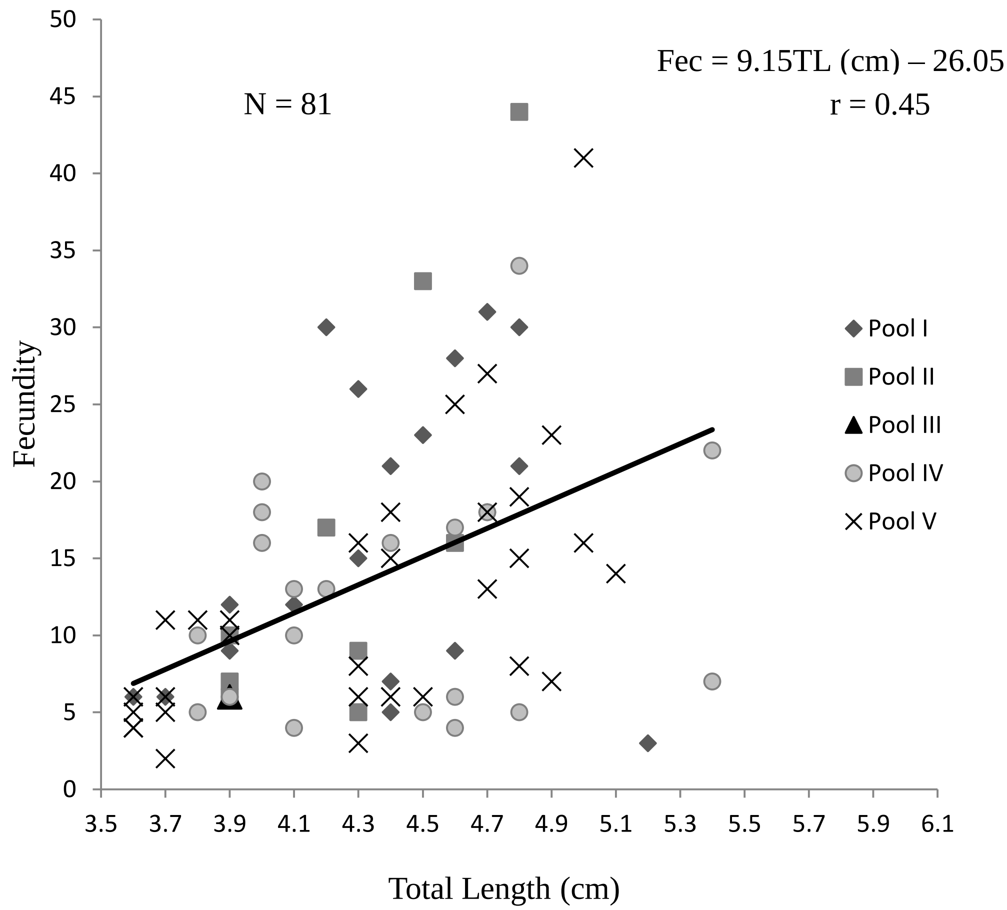

Figure 32: Regression plot of fecundity-total length relationship of *Aplocheilichthys spilauchen* (n = number of females)

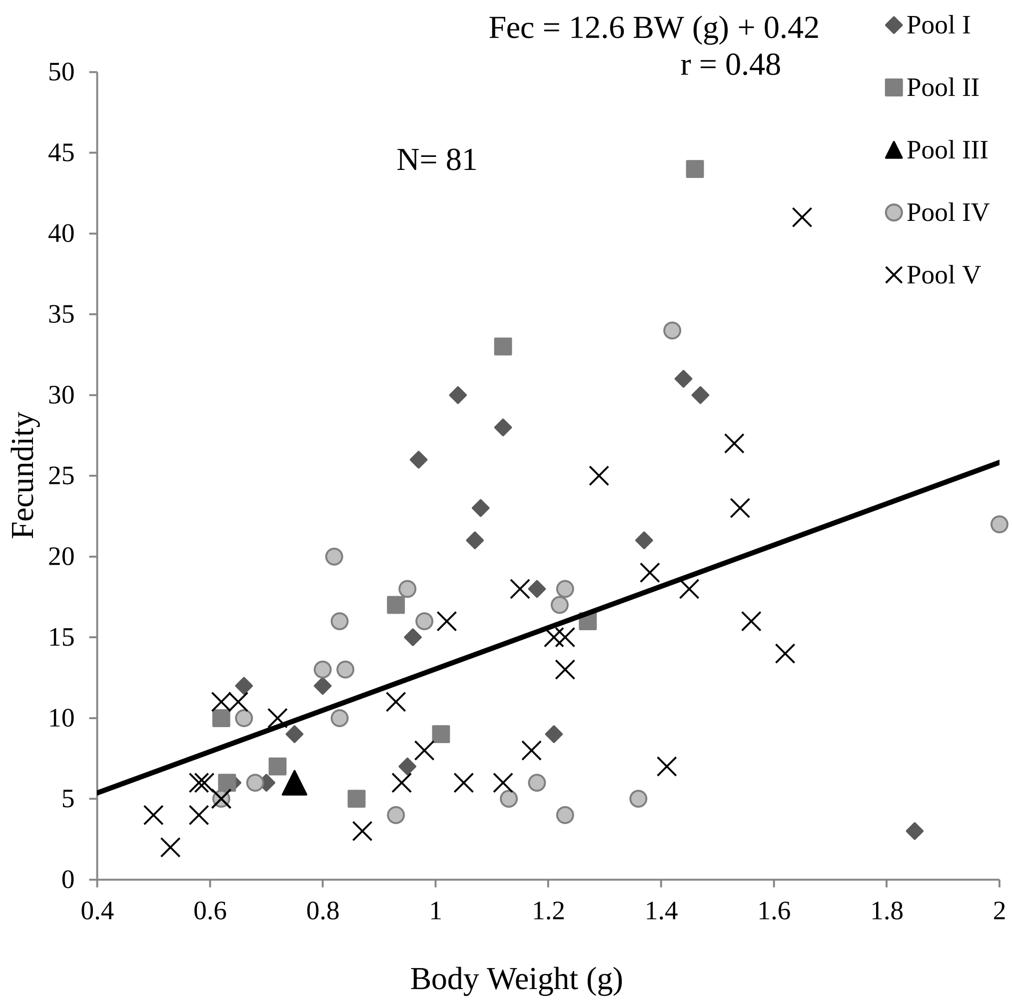

Figure 33: Regression plot of fecundity-body weight relationship of *Aplocheilichthys spilauchen* (n = number of females)

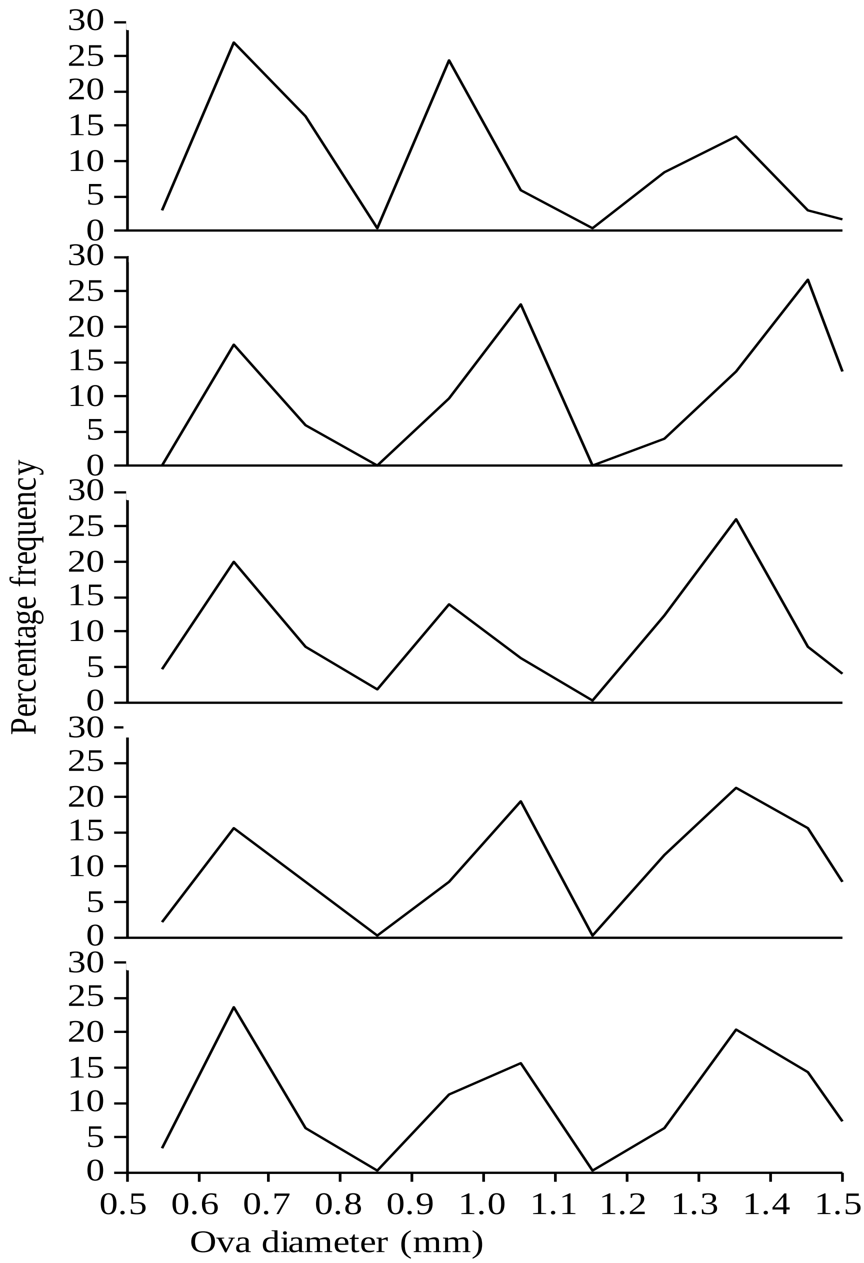

Figure 34: Ova diameter frequency distribution of *Aplocheilichthys spilauchen* from the Kakum Estuary wetland

CHAPTER FOUR

DISCUSSION

Conditions in the wetland

Results of the environmental parameters represent averages on the sampling dates (only one day in each month) and this limited further estimation of variations such as standard deviation or standard error of the mean for the months. For this reason, interpretation of the results should be done with caution.

The Kakum Estuary wetland is a highly dynamic and seasonal environment. Pools are formed in the dry season, and during the wet season the area is inundated by the flood waters of the Kakum River. The characteristic brownish coloration of the pools could be due to generation of ferric compounds.

The scarcity of information on the physico-chemical parameters of such ephemeral pools of coastal wetlands limits the comparison of the present study with other studies on similar habitats. Nevertheless, most of the results on the aquatic environmental parameters recorded are similar to reports on limnological conditions of floodplain pools associated with some major rivers and brackish water habitats in Africa (Welcomme, 1975; Little *et al.*, 1988).

Generally, evaporation from a given surface is greatest during periods of warm, dry and windy conditions. In the present study, the pools reduced in volume and dried up in the latter part of the study possibly as a result of the sustained increase in water temperature of the pools which may have enhanced their evaporation. This is similar to the observation of Chunlan, Gaodi and Heqing (2007) who found temperature as the major factor responsible for the shrinking and drying up of Baiyangdian Lake wetland in China. Other factors such as the incessant winds from the Atlantic Ocean over the pools and the fact that the pools were generally shallow (< 1 m deep) also played significant role.

The salinities recorded in the pools which ranged from 0.7 ‰ in the wet season to 6 ‰ in the dry season suggest that the pools were brackish. The increasing salinity and conductivity of pools during the study period has also been reported by Welcomme (1975) for floodplain pools along some major rivers in Africa. It has been found that there is a general tendency for salinity and conductivity to be higher in the dry season than the wet season. It has further been explained that this does not necessarily mean a reduction in the total quantity of salts during the floods, but a dilution due to the greater quantity of freshwater in the system (Holden and Green, 1960 cited in Welcomme, 1975). Therefore, as the water gradually evaporated due to rise in temperatures, the salt content (salinity) became concentrated resulting in an increase in conductivity of the pools.

Concerning turbidity in the pools, Babey (undated) has mentioned clouding by suspended plankton as the major source of turbidity in ponds. In addition, it has been reported that the main location of phytoplankton production within a river-floodplain system appears to be in the lagoons or pools after separation from the river (Welcomme, 1975). It is therefore likely that the continuous increase in turbidity observed in all the pools occurred as a result of phytoplankton production. Furthermore, the higher turbidity recorded during the latter months of the study is similar to Welcomme's observation in the pools of the floodplains, where maximum phytoplankton production appears to occur in the dry season.

The dissolved oxygen content of the pools generally ranged from 2.5 mg/L in the wet season to about 5 mg/L in the dry season, except in Pool V where the values did not fall below 4 mg/L throughout the study. The cause of lower oxygen levels in ponds and lakes during the rainy season has been attributed to higher amount of oxygen consumed as a result of decomposition of plant and animal materials deposited into these systems (Babey, undated; Almeida, Barthem, Viana & Charvet-Almeida, 2009). Also, the rise in the dissolved oxygen content during the latter period of the study agrees with a reported observation that depending on the locality, wind action or photosynthetic activity of aquatic plants can generate higher oxygen levels in floodplain pools in the dry season (Holden & Green, 1960; quoted in Welcomme, 1975). Perhaps, high rate of decomposition of organic materials carried into the wetland through the Kakum River, surface runoff and organisms killed by inundation of the wetland caused a reduction in the oxygen content during the wet season. However, increasing phytoplankton density due to enhanced photosynthetic activities in the pools coupled with a strong wind action over the shrinking shallow pools may have caused the increased oxygen content during the latter periods of the study.

Regardless of the increases observed, it would appear that oxygen content of the pools in the wetland is generally low as the values recorded from most of the pools were usually less than 5 mg/L. When compared with the polluted Fosu lagoon in Ghana, the oxygen concentrations at the surface of the lagoon (which range from 6 mg/L to 14 mg/L) (Blay & Dongdem, 1996) is even higher than that of Pool V which had the relatively higher DO. The seemingly low oxygen content of the pools may be due to pollution by effluents from the nearby communities.

The pools were slightly acidic to neutral (pH around 6.5 to 7.5) in the wet season but were alkaline (8 to 8.5) after the rains. According to Welcomme (1975), pH is generally lower in floodplain pools during the floods due to a similar condition in the river channels. In the dry season however, it varies in the pools depending on pH of the local soil (Welcomme, 1975). The Kakum River with which the wetland is associated has been reported to be acidic (Bosque-Hamilton, Nana-Amankwaa & Karikari, 2004). The lower pH recorded in the wet season is therefore attributable to high input of water from the Kakum River which flooded the wetland prior to commencement of the study, and the alkaline conditions in the dry season probably resulted from the influence of the local soil. This notwithstanding, the values recorded during the study period fall within the pH range of 6.5 to 9.0 given by Pillay (2004) as desirable for fish growth.

The observed variations in the environmental parameters of the wetland agrees with Acharyya and Mitsch (2001) that wetlands are dynamic ecosystems with fluctuating water levels, periods of oxygen stress and hydric soils with varied hydrological conditions. Furthermore, Craft (2000) observed that changes in water quality, periods of anoxia and accumulating organic matter directly affect the macroinvertebrate and fish communities. Therefore, the observed changes in the aquatic environment would have a diverse influence on the life of the aquatic fauna in wetland.

The macrozoobenthic community

Oligochaetes and dipteran larvae (chironomid larvae) were the only benthic fauna present in the wetland pools. These were abundant in the wet season but gradually declined in abundance and density, and completely disappeared later during the study (after October 2009). Results of the study concur with reports on the composition and abundance of macroinvertebrate communities of Muni lagoon (Gordon, 2000) and Keta lagoon (Lamptey & Armah, 2008) in Ghana. These authors reported salinity as the major factor determining the diversity and abundance of macroinvertebrates in these brackish habitats; with high invertebrate diversity and abundance occurring in the wet season when salinities are low, and low diversity and abundance in the dry season when high salinities prevail. The increasing salinity of the pools from July 2009 to January 2010 may have been responsible for the steady decline in density and subsequent disappearance of benthic macrofauna from the pools.

Investigations carried out on tolerance of freshwater invertebrates to changes in water salinity revealed that the upper limit for freshwater oligochaete species varied from 6 ‰ to 8 ‰ (Berezina, 2004), and that for freshwater midge larvae also revolved around a similar range (Bervoets, Wils & Verheyen, 1996; Berezina, 2004) beyond which they could not osmoregulate and hence died. Obviously, the lower salinities of the Pools from July to September (< 2 ‰) was far below the maximum tolerance limits discussed above and hence suitable for development of the oligochaete and chironimid communities. However, as salinities rose above 4 ‰ from October onwards, the organisms may have faced the problem of being unable to osmoregulate due to increased ionic content of the water (Berezina, 2004) leading to their extermination.

Dipterans were highly dominant during the first three months of the study after which oligochaetes also became dominant but for only a month or two and at lower densities prior to drying of the pools. This might suggest that the oligochaetes could tolerate slightly higher salinities than the chironomids. Nonetheless, the environment became stressful to both organisms as the dry season progressed.

The diversity, distribution, richness and abundance of macroinvertebrate community of wetlands give important clues about their functional status or ecological health (Hart, Johnson, Johnson & Mitsch, 1996). The poor richness of the benthic fauna community, together with the invertebrate taxa making up the community raise questions about the ecological health of the Kakum Estuary wetland.

Chironomid larvae or midge larvae have been used as indicators of pollution (Coffman & Ferrington, 1996; Jenderedjain, Hakobyan & Jenderedjian, 2007). According to Foote (1987), larvae of some species of midges have the blood pigment, haemoglobin, in their hemolymph which allows them to survive in low-oxygen, and often heavily-polluted environments.

Certain species of oligochaetes have also been reported to tolerate some extent of pollution and tend to be dominant in polluted aquatic habitats but scarce in unpolluted environments (Lafont, Camus & Rosso, 1996). For this reason, they are also used as indicators of pollution. In the polluted Musaözü Dam Lake (Turkey), these two taxa together constituted 73% of the benthic invertebrate fauna (Arslan, Ilhan, Şahin, Filik, Yilmaz & Öntürk, 2007).

The occurrence of these organisms as the only benthic fauna in the wetland might therefore suggest that this habitat is polluted. It could also be the result of the ephemeral nature of the habitat.

Compared with Fosu lagoon, the Kakum Estuary wetland has poorer representation of benthic invertebrate fauna as the former supports seven species of benthic macrofauna comprising four species of gastropods and three species of insect larvae, including chironomids (Blay & Dongdem, 1996). The poor diversity of macrobenthos could limit development of the fish community since benthic macroinvertebrates constitute an important link in the trophic relationships among various communities in aquatic ecosystems.

The fish community

Of the 18 fish species inhabiting in the wetland, three species, i.e. *Aplocheilichthys spilauchen* (Poeciliidae), *Sarotherodon melanotheron* (Cichlidae) and *Macrobrachium macrobrachion* (Palaemonidae) were dominant and together they made up over 73 % of the community. This community structure is similar to reports by some earlier researchers which indicate dominance of a few species in the total fish biomass of brackishwater habitats (Quinn, 1980; Little *et al*., 1988; Green *et al.*, 2009).

Results of the present study showed that the fish community included freshwater, brackishwater and marine species. Salinity has been recognised as a key factor influencing the occurrence and composition of species in brackishwater habitats in the tropics and subtropics (Little *et al*., 1988; Wright, 1986 cited in Blay, 1997) because of species differences in salinity tolerance. However, this parameter could not be linked with the presence or absence of any of the species in the pools, presumably because salinity was similar among the pools. Rather, the continuous increase in salinity may have accounted for the remarkable decline in the number of species in the communities after October 2009 when high mortality of freshwater fish species was observed. The communities were later dominated by the euryhaline black-chinned tilapia *Sarotherodon melanotheron* in the pools which lasted into the dry season.

The relatively larger size of Pool V, coupled with its relatively higher oxygen content seem to be the factors that might account for its corresponding highest fish species richness and diversity. However, no relationship was seen between the recorded environmental parameters and the low number of species which occurred in Pool IV. Also, the slight differences between the species evenness of the communities may be attributed to the fact that a number of species present in the communities were represented by a small number of individuals, a few of which dominated in large numbers. In spite of these disparities, the closeness of the diversity indices is reflected in the communities being very similar and this is buttressed by the high similarity index values (C_s>

0.6; values for the index range from 0 – dissimilar, to 1 - completely similar), possibly as a result of the prevailing highly similar environmental conditions.

The 18 species belonging to 12 families recorded in the Kakum wetland is lower than that of the nearby Kakum River Estuary where Blay (1997) reportedly found 28 species belonging to 14 families. Apparently, because of its permanent connection to the sea, more species enter the estuary than the adjacent wetland where most fishes enter only during the wet season when it is flooded by the Sweet River and the Kakum River.

Coastal wetlands serve as important breeding and nursery grounds for commercially important fishes. Reports on the structure of fish communities of salt marshes along the Essex coastlines (UK) (Green *et al.*, 2009) and a salt marsh intertidal creek in the Yangtze River Estuary (China) (Jin *et al*., 2007) showed that juveniles of commercially important species dominated the catches from the marshes. These workers therefore reiterated the importance of salt marshes as nursery habitats, and the need for increased conservation of such habitats.

The Kakum estuarine wetland similarly appears to serve different important purposes for different fishes at different life stages. The black-chinned tilapia *Sarotherodon melanotheron* which is the mainstay of the fishery of many West African lagoons (Blay, 1998), and the second most abundant fish in the wetland was represented by a large number of small individuals mostly 2.0-2.9 cm in total length and far smaller than the 4.6 cm SL (= 5.5 cm TL) estimated as the maturity length (Lm_{50}) for the *S. melanotheron* population in the adjacent estuary (Blay, 1998). It is likely that the larger adults were fished out leaving juvenile fishes in the pools. For the shrimp *Macrobrachium macrobrachion* which was the third most dominant species in the wetland and also an important food resource exploited by the nearby inhabitants, not only was there a high number of immature individuals, there was also a considerable number of gravid females in some pools which might explain the variations in its modal representation in the pools.

Besides these commonly encountered fishes, juveniles of marine fishes including the swim crab *Callinectes amnicola* (Portunidae), *Liza falcipinnis* (Mugilidae), *Elops lacerta* (Elopidae), *Porogobious schlegelii* (Gobiidae) and *Bathygobius soporator* (Gobiidae) which have been reported in the Kakum River Estuary (Blay, 1997) were also encountered in the wetland. This suggests that the wetland is highly utilized as feeding grounds by juvenile marine fishes, while freshwater species use it as breeding, nursery and feeding grounds

Food habits of the fishes

The general scarcity of literature on details of food habits of some of the non-commercially important fishes examined, together with the fewer individuals caught for some species (<10), limit a fair and effective comparison of the feeding ecology of some fish populations in the Kakum estuarine wetland with populations elsewhere.

The main constituents of the diet of *Aplocheilichthys spilauchen* in the pools were debris, insect larvae (chironomid and unidentified larvae), copepods and unidentified adult insects, with copepods forming a very small portion of the food. Due to the high association of chironomid larvae with debris and other bottom organic matter which serve some nutritional importance to it (Foote, 1987), it is highly possible to find large quantities of debris in the diet of fishes which feed on chironomid larvae. With the exception of debris, adult insects and insect larvae were also highly consumed as reported by Dankwa *et al*. (1999) while small amount of copepods were eaten.

The diet of *Sarotherodon melanotheron* in the Kakum Estuary wetland did not differ markedly from that of populations in the Sakumo Lagoon in Ghana (Ofori-Danson & Kumi, 2006) and Eleiyele reservoir (Ayoade & Ikulala, 2007) and Awba Reservoir (Ugwumba & Adebisi, 1992) in Nigeria, except that these populations fed on a wider range of algae and zooplankton.

The sickle fin mullet *Liza falcipinnis* in the pools also fed on similar items taken by mullet populations in Benya lagoon, Ghana (Blay, 1995), and River Pra and River Volta estuaries, Ghana, (Dankwa, Blay & Yankson, 2005). However, the lagoon and estuarine populations ingested a broader spectrum of food items including red algae, molluscan larvae, polychaetes and nematodes which were absent in the diet of the population in the wetland.

Such a relatively narrow spectrum of food suggests the unavailability of a number of their dietary items in the wetland. Probably, pollution of the wetland, unfavourable salinities and droughts have inhibited the development of communities of such benthic fauna as polychaetes and nematodes, hence their absence in the diet of the fishes.

Samples of *S. melanotheron* and *L. falcipinnis* collected from three locations in Nigeria (Tarkwa bay, Ikoyi fish ponds and Lagos lagoon) were found to exploit the same food resource but exhibited trophic divergence in that the cichlid consumed mainly blue-green algae while the mullet ingested more diatoms, possibly as a means of minimizing or preventing interspecific competition, considering the abundance of food (Ugwumba, 1988). Results of the present study however show that these two species exploited the same food resource in the pools, eating mainly diatoms, with a lower consumption of green and blue-green algae. Conceivably, such complete trophic overlap which could potentially result in competition occurred as a consequence of a relatively higher abundance of diatoms in the pools than the other algae.

Concerning the other cichlids in the Kakum wetland, *Tilapia zillii* fed mainly on plant materials, and considerably on algae and debris, confirming their macrophagous food habits reported by Dankwa *et al.* (1999). The dietary prey consumed by *Hemichromis fasciatus* varied from insect larvae and fragments of adult insects to shrimps and fish fry which is similar to the observations of Dankwa *et al*. (1999) that the species is a minor-piscivore. Comparatively, the food consumed by the populations in Tarkwa bay and the Lagos lagoon in Nigeria (Ugwumba, 1988) consisted principally of fish. Such difference in the variety of prey consumed by the wetland population and those in Nigeria could be related to the availability, abundance and diversity of their potential prey in their respective environments.

Fishes of the family Eleotridae and Gobiidae are known carnivores (Dankwa *et al*., 1999) and this predatory habit was manifested in the diet of the three eleotrids (*Eleotris senegalensis, Dormitator lebretonis* and *Kribia kribensis*) as well as the three gobies (*Porogobious schlegelii*, *Bathygobious soporator* and *Periophthalmus barbarus*). Although *K. kribensis* and *P. schlegelii* exploited similar resource (copepods, oligochaetes and debris), the former additionally consumed chironomid larvae to a considerable extent (27 % of diet) while the latter ingested fish scales but at very low preference (2 %). This could suggest trophic divergence among the species to reduce or avoid interspecific competition.

Unlike the four species of eleotrids in freshwater streams of the Caribbean coast (Costa Rica) which had diets dominated by shrimps and fishes (Winemiller & Ponwith, 1998), those in Kakum did not consume such items despite their abundance in the pools. This might suggest that although eleotrids are generally predatory, the prey items vary among the different species.

Blay (1996) identified eleven items in the food of *P. schlegelii* population in the Fosu lagoon (Ghana) including detritus, fish scales, copepods, algae, rotifers, fish fry, insect larvae and some plant materials. In the present study however, only the first three items, together with oligochaetes, were eaten by the Kakum wetland population while other predatory fishes fed on the other items. Considering the presence of several macrophagous species in the wetland pools compared to the lagoon where *P. schlegelii* is the only macrobenthophagous fish present (Blay & Asabre–Ameyaw, 1993, quoted in Blay & Dongdem, 1996), it is conceivable that the consumption of such narrow range of prey could be related to a resource partitioning mechanism to reduce competition.

Odaxothrissa mento (Clupeidae) fed on adult insects and juvenile shrimps while *Elops lacerta* (Elopidae) preyed on juvenile shrimps and fish fry indicating that both are carnivorous. The cyprinid *Barbus* sp. ingested debris and chironomid larvae suggesting that the species is detritivorous. Unfortunately, the dearth of information on the food habits of these three species constrains the comparison of the dietary items as well as food spectrum of the populations in the Kakum Estuary wetland with others elsewhere. Nevertheless, this study could serve as a reference point for future studies on the food habits of these species in Ghana and other West African countries.

Based on the observed food habits of the finfish species in the wetland, they could be classified into the trophic guilds used in Esteves, Lobo and Faria (2008) and Green *et al.* (2009). *Sarotherodon melanotheron*, *Tilapia zillii* and *Liza falcipinnis* can be categorised as microherbivore-detritivores while *Barbus* sp., *Kribia kribensis*, *Eleotris senegalensis*, *Dormitator lebretonis*, *Porogobius schlegelii*, *Bathygobius soporator* and *Periophthalmus barbarus* may be classified as invertivore-detritivores. The only fish that belongs to the insectivore feeding guild is *Aplocheilichthys spilauchen*. The minor – piscivore guild includes *Hemichromis fasciatus, Odaxothrissa mento* and *Elops lacerta* while *Hepsetus odoe* fed exclusively on fish and would therefore be categorised as piscivore. The diet of the catfish *Clarias gariepinus* consisted wide range of items from plant to animal matter and would therefore be classified as omnivore.

Breeding habits of the fishes

In fish species, egg production has been found to relate to the degree of parental care and survival rates. Fecundity is low in species that provide a moderate or high degree of care for their eggs and larvae, while those that provide little or no parental care often have high fecundity (Fuiman, 2002).

The relatively high fecundity of the goby *Porogobius schlegelii* and the eleotrid *Kribia kribensis* (absolute fecundity range = 3,366-16,831 eggs) primarily suggests that the two species give either little or no parental care to their eggs and larvae. It is therefore not surprising that Winemiller and Ponwith (1998) found eleotrids cannibalising on their progeny, as their high fecundity would ensure their continuous survival despite the high vulnerability and the possible consequence of high mortality of their eggs, larvae and juveniles. Certainly, producing such large number of offspring without parental protection in these small pools would be of advantage to the piscivorous fishes such as *Elops lacerta*, *Hemichromis fasciatus* and *Hepsetus odoe* which fed greatly on fish and fish fry as well as shrimps. This could in one way or the other contribute to ensuring a trophic balance as well as maintaining population balance in the community.

The low fecundity of *S. melanotheron* (111 – 226 eggs per female) is attributable to its paternal oral brooding habit (Trewavas, 1983) which ensures a high degree of survival of their brood.

Holden and Reed (1991) and Dankwa *et al.* (1999) have reported that the eggs of *Aplocheilichthys spilauchen* can withstand long periods of desiccation when seasonal pools dry up, and still hatch when water becomes available in the next wet season. This could also explain the relatively low fecundity of the species since high survival of their spawn would be ensured.

There was a significant difference in the sex ratio of the *A. spilauchen* population in the wetland (χ^2= 28.57, P < 0.05), with females out - numbering males by almost 2:1 which might compensate for the low fecundity of the species, thereby increasing the total egg production. Only a few males would therefore be of relevance in the population since a single individual produces several spermatozoa to fertilize the eggs produced.

There was a weak linear positive correlation between fecundity and total length as well as fecundity and body weight of *A. spilauchen* (r < 0.5), implying that number of eggs produced is not clearly related to body size. This might be due to the small size range of the species.

The three successive modes observed in the ova diameter frequency distribution of *A. spilauchen* might indicate that spawning is continuous in the species. Monthly length – frequency distribution could have further provided information on the spawning frequency of the species.

CHAPTER FIVE

CONCLUSIONS AND RECOMMENDATIONS

Conclusions

The Kakum Estuary wetland is a highly dynamic environment, with isolated pools which are formed after the area is inundated in the wet season, and dry up with the progress of the dry season. The water temperature, salinity, conductivity and turbidity of the pools were lower during the wet season, but increased continuously as the dry season progressed. The pools were slightly acidic to neutral in the wet season but were alkaline in the dry season. The dissolved oxygen content of the pools varied between 2 mg/L and 5 mg/L during the study period.

Oligochaetes and dipteran larvae (chironomid larvae) were the only benthic invertebrate macrofauna present in the Kakum Estuary wetland pools, and their abundance and densities were higher in the wet season but declined significantly during the dry season after which they disappeared. This possibly occurred as a result of the continuously increasing salinity which posed osmoregulation problems and rendered the environment stressful to both organisms. The occurrence of these organisms as the only benthic fauna in the wetland might suggest that the habitat is polluted. The ephemeral nature of the habitat could also account for the observed poor richness of benthic fauna community of the wetland.

A total of 18 fish species comprising freshwater (e.g. *Barbus* sp., *Kribia kribensis*, *Aplocheilichthys spilauchen*, *Hepsetus odoe*, and *Macrobrachium macrobrachion*), brackishwater (e.g. *Sarotherodon melanotheron* and *Periophthalmus barbarus*) and marine fishes (e.g. *Liza falcipinnis*, *Elops lacerta* and *Callinectes amnicola*) belonging to 18 genera and 12 families were collected from the wetland, of which three species namely *Aplocheilichthys spilauchen* (Poeciliidae), *Sarotherodon melanotheron* (Cichlidae) and *Macrobrachium macrobrachion* (Palaemonidae) were dominant and together they made up 73.8 % of the community.

Although the species richness as well as diversity values for the fish communities in the pools were very close, Pool V had the highest richness (15 species belonging to 15 genera and 10 families) as well as the highest diversity (H′ = 2.7). Furthermore, there was a high similarity among the fish communities in the pools, possibly as a result of the prevailing highly similar environmental conditions.

The presence of gravid females of some freshwater fishes such as *A. spilauchen*, *Kribia kribensis* and *M. macrobrachion* and in the pools together with the occurrence of a high number of juvenile individuals of marine species such as *Liza falcipinnis*, *Elops lacerta* and *Callinectes amnicola* in the samples, suggest that the wetland is highly utilized as feeding grounds by juvenile marine fishes while freshwater species use it as breeding, nursery and feeding grounds.

Results of the food habits of the fishes showed that the communities were made up of detritivorous, planktivorous, insectivorous, invertevorous, omnivorous and piscivorous fishes. However, the range of food items taken by the fish populations in the wetland was narrower than that reported for other populations in Ghana and elsewhere. Such a relatively narrow spectrum of food may be due to the unavailability of a number of their dietary items in the wetland.

The absolute fecundities of *Kribia kribensis* and *Porogobius schlegelii* ranged from 7,406 to 16,831 eggs and 3,366 to 12,118 eggs respectively, while that of *Sarotherodon melanotheron* and *Aplocheilichthys spilauchen* ranged from 111 to 226 eggs and 2 to 44 eggs respectively. Conceivably, *K. kribensis* and *P. schlegelii* provide little or no parental care for their progeny, hence the high fecundities which would ensure survival of their spawn despite their high vulnerability. For *S. melanotheron* and *A. spilauchen*, their low fecundities could be dues to their adaptations for ensuring survival of their spawn.

The females of *A. spilauchen* population in the wetland significantly out-numbered the males by almost 2:1 which might compensate for the low fecundity of the species, since a single individual would produce several spermatozoa to fertilize the eggs produced. A regression analysis of fecundity and body size of *A. spilauchen* showed that fecundity is not clearly related to body size. Also, three successive modes were observed in the ova diameter frequency distribution of *A. spilauchen* which might indicate that spawning is continuous in the species.

Although the Kakum estuary wetland is not a Ramsar site, it is an important area that should be conserved by all means since fishes from freshwater, brackishwater and marine source utilize it possibly as breeding, nursery and feeding grounds. It is hoped that the information provided in this work will be useful to the National Wetlands Conservation Strategy policy as part of the prerequisites needed for planning and management of the lower reaches of River Kakum; one of the target areas under the policy.

Recommendations

It is evident from the present study that the Kakum Estuary wetland is used as breeding, nursery and feeding grounds by juvenile marine fishes. This suggests the need to restrict fishing in the pools prior to their separation from the Kakum River channel.

However, this regulation cannot be effectively implemented without the active involvement of the local opinion leaders such as the assemblymen of Duakor and Abakam, as well as the caretakers of Okyeso and Blanta since they are the authorities in effective control of the affairs of users of the wetland. It is therefore advisable that the country's fisheries policy and National Wetlands Conservation Strategy should consider this recommendation for implementation in cooperation with the local authorities in a co-management effort.

It is suggested that there should be control of any discharge of effluents draining into the wetland from the adjacent villages. It might therefore be necessary to construct proper drainage systems through which the wastes could be channelled into the sea which is a bigger sink for organic waste, given the proximity of the area to the Atlantic Ocean.

Levels of some inorganic pollutants (e.g. mercury and lead) in the wetland should be monitored to investigate their toxicity levels which could be used to advice on the use of the resources.

Lastly, the amphibian, reptile and bird communities of the wetland should be studied to broaden our knowledge of the biodiversity of the Kakum estuary wetland and its importance to these communities.

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APPENDICES

Appendix A: Averages of environmental parameters of the five Kakum Estuary wetland pools sampled from July 2009 to February 2010 (each value is an average of three measurements)

Depth

	Average depth (cm)				
Month	Pool I	Pool II	Pool III	Pool IV	Pool V
Jul	47.0	45	45.3	48.5	98.3
Aug	35.2	41.3	42.1	41.4	83.2
Sep	31.5	35.7	32.4	37.1	70.3
Oct	17.8	22.5	22.1	21.4	45.2
Nov	0	20.2	19.7	12.5	42.2
Dec		12.3	11.2	0	25.8
Jan		0	0		14.6
Feb					0

Temperature

	Average temperature (ºC)				
Month	Pool I	Pool II	Pool III	Pool IV	Pool V
Jul	28.4	29.9	29.6	30.7	28
Aug	29.7	30.3	29.7	31.5	30.6
Sept	32.9	32.8	32.1	33.8	34.3
Oct	39.5	39.0	38.9	39.9	40.2
Nov		41.0	42	40.8	41.3
Dec		42.1	43		43.6
Jan					46.6

(Appendix A *continued*)

Salinity

	Average Salinity (‰)				
Month	Pool I	Pool II	Pool III	Pool IV	Pool V
Jul	0.7	0.8	1	0.7	0.7
Aug	1.3	1.6	1.7	1.5	1.6
Sept	1.5	1.9	1.9	1.7	2.0
Oct	4.2	3.7	3.7	3.3	3.4
Nov		4.2	4.2	4.1	3.9
Dec		4.7	5.3		4.7
Jan					5.9

Conductivity

	Average Conductivity (µS/cm)				
Month	Pool I	Pool II	Pool III	Pool IV	Pool V
Jul	1503	1740	2302	1534	1677
Aug	3496	3750	4046	3200	3408
Sept	3611	4261	4326	3859	4839
Oct	9932	8623	8478	7284	8181
Nov		9902	9879	9729	9079
Dec		11387	11931		11520
Jan					12778

(Appendix A *continued*)

Turbidity

Month	Average Turbidity (ppm)				
	Pool I	Pool II	Pool III	Pool IV	Pool V
Jul	84	78	82	92	87
Aug	116	79	114	101	125
Sept	216	144	195	132	238
Oct	245	172	247	164	251
Nov		251	305	165	270
Dec		259	306		302
Jan					304

Dissolved oxygen concentration

Month	Average DO (mg/L)				
	Pool I	Pool II	Pool III	Pool IV	Pool V
Jul	3.7	3.5	3.7	4.0	5.2
Aug	3.4	3.3	3.3	3.2	4.9
Sept	2.4	2.7	2.3	3.6	4.9
Oct	4.0	4.1	4.0	4.8	5.2
Nov		4.7	4.4	5.4	5.4
Dec		5.1	4.8		5.4
Jan					5.7

(Appendix A *continued*)

pH

Month	Average pH				
	Pool I	Pool II	Pool III	Pool IV	Pool V
Jul	6.87	6.88	7.03	7.29	7.05
Aug	6.31	6.66	6.71	7.19	6.95
Sept	8.04	7.72	8.02	7.23	7.72
Oct	8.42	8.21	8.21	8.18	8.28
Nov		8.33	8.45	8.33	8.48
Dec		8.37	8.57		8.5
Jan					8.62

Appendix B: Size distribution of fish species from Pool I in the Kakum Estuary wetland

			TL(cm)			BW(g)
Family/Species	**No.**	Min	Max	Mode	Min	Max
CICHLIDAE						
Hemichromis fasciatus	10	3.1	7.9	3.5	0.46	7.45
Sarotherodon melanotheron	1		4.3			1.66
Tilapia zillii	37	2.1	6.4	2.9	0.16	4.57
CLARIIDAE						
Clarias gariepinus	1		14.3			24.41
ELEOTRIDAE						
Kribia kribensis	7	4.1	5.7	5.3	0.75	1.63
Eleotris senegalensis	1		7			3.44
HEPSETIDAE						
Hepsetus odoe	1		10.1			7.79
MUGILIDAE						
Liza falcipinnis	15	5.6	12.8	9.1	1.95	18.34
POECILIDAE						
Aplocheilichthys spilauchen	106	2.5	5.6	3.4	0.13	2.16
GOBIIDAE						
Porogobius schlegelii	1		6.5			2.6
PORTUNIDAE						
Callinectes amnicola	14	0.4*	8.1*	2.3*	0.29	47.14
PALAEMONIDAE						
Macrobrachium macrobrachion	4	4.3	7.5		0.94	5.52

Asterics (*) denotes Carapace width

Appendix C: Size distribution of fish species from Pool II in the Kakum Estuary wetland

		TL(cm)			BW(g)	
Family/Species	**No.**	Min	Max	Mode	Min	Max
CICHLIDAE						
Hemichromis fasciatus	5	3.1	9.6		0.42	12.91
Sarotherodon melanotheron	63	1.3	10.2	2.9	0.1	28.29
Tilapia zillii	37	2.1	7.3	2.2	0.14	9.81
CLARIIDAE						
Clarias gariepinus	2	15.8	32.2		30.3	288.45
ELEOTRIDAE						
Kribia kribensis	40	3.4	7.2	5.8	0.3	4.1
Eleotris senegalensis	3	7.3	8.8		4.14	7.8
ELOPIDAE						
Elops lacerta	1		4.3			0.31
MUGILIDAE						
Liza falcipinnis	9	3.9	12.6		0.73	18.95
POECILIDAE						
Aplocheilichthys spilauchen	163	2.3	5	3.4	0.07	1.61
GOBIIDAE						
Porogobius schlegelii	13	4	7.6	7.1	0.61	4.39
PORTUNIDAE						
Callinectes amnicola	5	1.8*	3.3*	*	0.43	3.17
PALAEMONIDAE						
Macrobrachium macrobrachion	26	2.2	9.3	6	0.1	12.13

Asterics (*) denotes Carapace width

Appendix D: Size distribution of fish species from Pool III in the Kakum Estuary wetland

		TL(cm)			BW(g)	
Family/ Species	**No.**	Min	Max	Mode	Min	Max
CICHLIDAE						
Hemichromis fasciatus	6	3.3	8.5		0.54	8.76
Sarotherodon melanotheron	73	1.3	11.2	1.4	0.1	26.87
Tilapia zillii	7	2.5	7		0.3	5.72
CLUPEIDAE						
Odaxothrissa mento	3	9.5	17.2		7.04	44.66
CYPRINIDAE						
Barbus sp.	31	3.1	4.7	3.7	0.32	1.18
ELEOTRIDAE						
Kribia kribensis	4	4.6	7		2.51	3.28
HEPSETIDAE						
Hepsetus odoe	1		19.5			78.38
MUGILIDAE						
Liza falcipinnis	12	2.8	14.1	13	0.24	27.6
POECILIDAE						
Aplocheilichthys spilauchen	92	2.4	5.1	3.1	0.14	1.43
GOBIIDAE						
Porogobius schlegelii	24	3.4	7	5.8	0.36	3.54
PORTUNIDAE						
Callinectes amnicola	5	6.4*	1.7*		0.59	29.3
PALAEMONIDAE						
Macrobrachium macrobrachion	93	2	10.7	3.1	0.12	14.32

Asterics (*) denotes Carapace width

Appendix E: Size distribution of fish species from Pool IV in the Kakum Estuary wetland

		TL(cm)			BW(g)	
Family/ Species	**No.**	Min	Max	Mode	Min	Max
CICHLIDAE						
Hemichromis fasciatus	12	2.8	4.1	3.1	0.34	1.09
Sarotherodon melanotheron	47	2.1	12.3	2.6	0.02	37.86
Tilapia zillii	8	2.8	5.7		0.43	3.62
ELEOTRIDAE						
Kribia kribensis	15	3.2	7.2	3.2	0.26	3.62
Dormitator lebretonis	1		4.5			0.35
MUGILIDAE						
Liza falcipinnis	1		10.5			11.12
POECILIDAE						
Aplocheilichthys spilauchen	176	2.3	5.4	3.1	0.08	2.12
GOBIIDAE						
Bathygobius soporator	1		5.8			1.88
PORTUNIDAE						
Callinectes amnicola	14	1.6*	6.9*	2.4*	0.37	24.27
PALAEMONIDAE						
Macrobrachium macrobrachion	20	2.2	7.8	2.6	0.06	7.24

Asterics (*) denotes Carapace width

Appendix F: Size distribution of fish species from Pool V in the Kakum Estuary wetland

		TL(cm)			BW(g)	
Family/ Species	**No.**	Min	Max	Mode	Min	Max
CICHLIDAE						
Hemichromis fasciatus	8	3.5	12	6.1	0.7	25.75
Sarotherodon melanotheron	143	1.4	10.5	3.2	0.05	22.55
Tilapia zillii	32	1.4	6.9	5.1	0.23	6.78
CLARIIDAE						
Clarias gariepinus	4	10.4	24.1		9.3	128.11
CLUPEIDAE						
Odaxothrissa mento	4	8	16.6		3.24	35.04
ELEOTRIDAE						
Kribia kribensis	22	3.6	6.2	5.7	0.5	3.1
Eleotris senegalensis	2	3.4	6.3		0.36	2.93
Dormitator lebretonis	1		6.7			3.89
ELOPIDAE						
Elops lacerta	21	3.8	8.8	6.9	0.07	4.08
MUGILIDAE						
Liza falcipinnis	2	6.2	9.9		3.04	10.7
POECILIDAE						
Aplocheilichthys spilauchen	221	2.4	5.1	3.4	0.15	2.22
GOBIIDAE						
Porogobius schlegelii	9	4.1	8.1	7.2	0.61	4.7
Periophthalmus barbarus	1		6.5			2.85
PORTUNIDAE						
Callinectes amnicola	22	1.0*	7.2*	1.4*	0.05	27.03
PALAEMONIDAE						
Macrobrachium macrobrachion	79	2.2	9.4	4.2	0.08	11.13

Asterics (*) denotes Carapace width