UNIVERSITY OF CAPE COAST

FACTORS INFLUENCING THE RANGE SHIFT OF PLANT SPECIES IN WETLANDS IN NORTHERN REGION (GHANA), WITH A NOTE ON THE FISH AND BIRD COMMUNITIES

BY

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DECLARATION

Candidates's Declaration

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

Candidate's signature:..

Date:...................................

Name: COLLINS AYINE NSOR

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.

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ABSTRACT

The study examined the role of anthropogenic disturbances, temperature, precipitation and evapotranspiration in the range shift of aquatic plants, fish and bird communities in six wetlands. It was conducted over a 2-year period. The dominance ratio approach was used to determine the range shift of plants. Ordination techniques were used to determine the influence of environmental factors on biological data-set. Of the 40 species of plants sampled, obligate species constituted 35%, while facultative wetland species and obligate upland species were 40% and 27.5% respectively. Animal dung assessment showed that 14 seedlings identified were the same species as those sampled among the 40 species. Plant diversity and evenness distribution did not differ significantly (F = 2.27, $p>0.05$) in the wet and dry seasons. Plant range shift was largely influenced by farming practices, bushfire and grazing. These variables correlated significantly ($p<0.05$) with axis I and axis II, and accounted for 61.29% of the total variance in species range shift. Field survey indicated the declining abundance of *Pistia stratiotes* and was attributed among others to sensitivity to environmental disturbances. Fish diversity and abundance was slightly higher in the dry season than in the wet season. Bird densities and diversity (F = 4.101, $p<0.05$) were significantly higher in the wet season than in the dry season. Influence of temperature on precipitation, over the last 50-years, was not significant (R^2 = 0.354; $p>0.05$). Plant range shift and variations in fish and bird diversity may be attributed more to human-led activities than the impacts of climate change and variability.

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DEDICATION

I dedicate this thesis to my late father (Mr. Gerald Adongo Nsor) and mother (Mrs. Paula Akurugu Nsor) for their care and support.

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CHAPTER ONE

INTRODUCTION

Background to the Study

Observations of range shifts in line with climate change have been well documented in northern European countries, where observed records for many herbaceous cover, birds, butterflies and tree species date back to the mid-1700s (Parmesan, 2006). Since then, a number of global biome models have been developed and used to predict and evaluate the changes in vegetation distribution likely to occur with a changing climate in both terrestrial and aquatic systems (Huntley, 1991). Apart from the effects of climate change causing a shift in species range, competition for nutrient utilization and degradation of hydrologic condition linked to human activities, also play a vital role in shifting species outside their range. Craft, Vymazal & Richardson (1995) observed that over time, plant species composition in wetlands may shift as native species decline and are replaced by species that take advantage of high nutrient levels to increase growth. Nutrient enrichment mostly results in replacement of uncommon or rare species by species tolerant of high nutrient loadings (e.g., *Phragmites autralis*) (Chambers, Meyerson & Saltonstall, 1999). The possibility that anthropogenic disturbances can cause range shift of species, calls for a thorough assessment between environmental drivers and climate variables, since wetlands in this Region have been poorly studied either, from a phenological (Dunne, Harte & Taylor, 2003) or geographical range shift approach (Parmesan, 2006; VanGrunsven et al. 2007).

Research Justification

Wetland ecosystems contribute significantly to human well-being. This include: fish and fiber, water supply, water purification, climate regulation, flood attenuation, coastal protection, recreational opportunities and tourism (Millennium Ecosystem Service, 2005). They serve as a haven for "*keystone*" species which are sensitive to impacts of climatic variability and anthropogenic disturbances. Globally, wetlands have been reportedly lost or under severe threat, in spite of the numerous international Ramsar agreement and National policy intervention framework, to promote the sustainable exploitation and management of their resources. The cause of this drawback is partly traced to lack of enforcement of policy framework or inconsistency in policy direction towards the management of wetlands by different governments and the high poverty levels. A number of scientific studies have attributed recent species range shift to impacts of climatic variability (Walther et al. 2002; Walther et al. 2005) although general consensus on this issue still remain elusive among many scientists, since species range shift may be local to regional-specific due to variations in climate. While some researchers argue that climate change impacts are solely responsible for species range shift at the local to regional and global scales, (Iverson, 1944) others are of the view that environmental disturbances are the major drivers of concern (Machinski, 2001; Ceschin et al. 2009). Though increases in air temperature could potentially alter the thermal tolerance level of some wetland species, it cannot be concluded that this is due only to increases in temperature. Since there is the possible contribution of some anthropogenic in altering the morphology of species, replacement of native species with upland species and restrict species distribution.

Wetlands in Northern Region were considered for this study because scientific information on the general biodiversity status is simply unavailable or poorly studied, compared to the coastal wetlands (e.g., Sakumo lagoons, Muni, Mukwe and Ehunli wetlands) that have attracted lots of scientific studies, with much emphasis on the impacts of environmental drivers (Wuver, Attuqueyefio & Enu-Kwesi, 2003) and climate change pattern on freshwater, oceans and species responses (Armah, Wiafe & Kpelle 2005; Ashton, 2009). Reconnaissance survey and field interaction among some indigenous members (herbalists and wetland users) in Northern Region, have indicated observed changes in plant species composition either through reduction in spatial distribution or complete extinction in the last two decade in wetlands systems (Mr. Mahama Chimsa- Kukobila Assemblyman *pers comm*). The observation on changes in species composition is simply unscientific and therefore not certain whether this is linked to changing climate or environmental disturbances. This calls for the need to investigate in order to establish the major causes of this phenomenon. Increase in daily temperatures in Northern Ghana over the last 30 years (from 1931-1960) (Ontoyin, 1993; Yelfari, 1993) and from 30-35^{0}C to 38-46^{0}C between 1980 and 2008 (Ghana Meteorological Service, 2009) coupled with high poverty levels (~ 85%) (UN Report, 2010) among Northern extraction, have in part pushed significant number of the indigenes to landscape edges where they are compelled to over exploit wetland resources as an alternative source of livelihood. The surge in temperature among other things may have caused the observed erratic rainfall pattern in recent times, with a resultant effect on low food production. Thus many Northern households have resort to the use of wetland zones as an alternative source of crop production, livestock grazing and fuel wood and thatch material harvesting. It is therefore possible that increase in human-led disturbances coupled with climatic variability impacts on wetlands biodiversity, could be responsible in the reduction of endemic species while aiding the colonization of nearby dry land species. But Richardson & Bond (1991) and Hulme (2003) suggest that the interaction between disturbance regime and biotic factors may possibly override climatic variables in explaining species distribution. This was confirmed by the Millennium Ecosystem Service Report (2005) which noted that anthropogenic disturbances can cause more rapid deterioration and loss of wetlands biodiversity than natural causes. Ceschin et al. (2010) concluded by citing an example of a decreased in species richness, composition and structure in the last 30 years in the Tiber River- Rome as a result of human influences.

Therefore gaining a deeper understanding of factors accounting for wetland species loss, especially plants may help minimize or reverse the trend among wetlands in Northern Region. On the hand, since most wetland species are noted for their sensitivity to changes in their habitat conditions (Avisar & Fox, 2012) it will be vital to have a suite of some plant or animal species that can serve as indicator to either current or future climatic thresholds or anthropogenic disturbances (Rutherford et al. 1999). Rutherford et al. (1999) therefore recommended the need to identify a suite of sensitive indicator species which can reveal the effects of changes in different aspects of the physical environment, such as temperature and drought. Rutherford et al. (1999) concluded that most of the predicted species such as *Bolusanthus speciosus*, *Combretum apiculatum* and *Sesamnothamnus lugardii* and *Prosopis* sp. (Richardson & Bond, 1991) that will reduce in number, shift or become extinct from their geographical ranges, at the regional and local scales are largely terrestrial plant species. Armah et al. (2005) listed five plant species (*Conocarpus erectus, Thespesia populnea, Acrostichum aureum, Phoenix reclinata, Sesuvium portulacrastrum* and *Phylloxerus vermicularis*) associated with coastal mangrove wetlands that may be at risk to sea-level rise. No such assessment on freshwater ecosystems in relation to temperature, precipitation and evapotranspiration impacts has been made in Northern Guinea Savanna wetlands.

Apart from the availability of 50-years of temperature and precipitation data and 48- years of potential evapotranspiration data in Northern Region, there is no historical biogeographic information for the same period on the aquatic plants of wetlands. The absence of well documented data on species will probably make it difficult to determine whether current species have indeed shifted from their range, reduced or remained unchanged to their habitats. This study will focus on current anthropogenic disturbances and climate change indicators to determine their respective role in the range shift of species. On bird assemblage, apart from a baseline study to determine the types of birds in Kukobila wetland (Obodai & Nsor, 2009) no study has been carried out to establish their population, diversity and factors accounting for their seasonal variations from different wetlands. This therefore suggests the need to investigate in detail the current state of bird assemblage among the six different and to use the outcome of the study as a baseline for future seasonal population monitoring. Since most human-led activities such as wildfires, farming, grazing and harvesting of plant materials are seasonally driven, this study will examine plant range shift along an environmental gradient in the dry and wet seasons. The outcome of this study will be used as a baseline for future reference, since there is no data for comparison.

Research Aim

The aim of this study is to determine factors that account for the range shift of aquatic plants and propose appropriate mitigation and adaptive strategies. To achieve this study, the following specific objectives were outlined:

(a) Identify the factors which account for the range shift of aquatic plants as well as their diversity and pattern of distribution,

(b) Evaluate the relationship between physico-chemical parameters/ anthropogenic activities on fish diversity and pattern of distribution,

(c) Determine the factors influencing the spatial variation of bird species,

(d) Examine the historical trend of temperature, precipitation and evapotranspiration record over the last 50 years in relation to the state of the wetlands biodiversity and

(e) Propose the needed conservation measures to promote the functional state of the wetlands for sustainable use.

CHAPTER TWO

REVIEW OF RELATED LITERATURE

Influence of Anthropogenic Drivers on the Range Shift, Composition and Distribution of Aquatic Plants

Kath, Brocque & Craig-Miller (2010) found that wet and dry periods were an important factor in determining diversity of the plant communities. Consequently, variations in the intensity and frequency of the hydro period can have potential long term effects on community diversity and structural distribution and modification of the physical state of wetlands (Kath et al. 2010).

Akpene (2001) define bushfires as ‘fires set to bush with an intended purpose, but which get out of control, spread quickly and devastate non-target areas’. Bushfires can occur through human activities and natural ignition through blazing heat and lightening of dry biomass. The human-led bushfires which cause significant damage to the environment is estimated to be 98% of all the bushfires recorded in Ghana (Gboloo, 1998) and largely regarded as one of the leading causes of deforestation in West Africa. For example, the clearing of fertile lands using bushfires in Ghana and most other African countries (Hall & Swaine, 1981; Korem (as cited in Wuver et al. 2003) has greatly affected the vegetation structure of ecosystems. These phenomena, consequently pose severe threat to wetland biodiversity over long term. Wuver et al. (2003) indicated how indiscriminate bushfires have severely damaged the biodiversity of Muni-Pomadze wetland in the Central Region of Ghana. Hackney & de la Cruz (1981) observed the decrease in the total biomass of marsh vegetation of the Gulf Coast, largely due to bushfire. While other studies reveal that the heat from fire rather helps in stimulating the apical and lateral meristems (meristimatic cells) responsible for growth (e.g., Wade et al. as cited in Rohn & Bragg, 1989). Main & Barry (2002) measured the effects of prescribed fire on flowering of three wetland grasses (*Muhlenbergia capillaries, Paspalum monostachyum* and *Schizachyrium rhizomatum*) and found that they all responded positively to fire, through a decrease in flowering. This indicates a strong relationship between fire and aquatic plants. However, the general belief that all plant species will be destroyed by the effect of fire is not always the case, since plant species have varied heat tolerance level. Also, the type of fire, the time of the season, fuel load, frequency and intensity of fire are critical in determining how aquatic plants will be affected and consequently affect their range shift. Collins (1995) observed that that back fires (burning against the wind) tend to have a greater impact on the growing points of plants than head fires (burning with the wind). The author further observed that burning when humidity is high and air temperature low, generally has a lower impact than burning when humidity is low and air temperature high. Huffman and Blanchard (1991) believe that encroachment of shrubs such as coastal plain willow (*Salix* *caroliniana*), common buttonbush (*Cephalanthus occidentalis*) groundsel tree (*Baccharis halimifolia*) and wax myrtle (*Myrica cerifera*) in depression marshes, indicates the lack of fire. The Water and Rivers Commission of Australia (2000) have reported that intense fires rather favour germination of Prickly Moses (*Acacia pulchella*) through the rapid release of burnt seed in the soil, while low intensity fire may not be sufficient to stimulate the release of seeds or expose mineral soil. Fire also has the ability to alter soil nutrient concentration (Kutiel & Shaviv, 1993). This condition could tend to favour some plant species. In ecological context the observed soil transformations may encourage the growth of invasive plant species, such as southern narrow-leaved cattail (*Typha domingensis* Pers.) which exhibits high growth rates in response to increased phosphorus availability, after peat burn by fire (Smith, Newman, Garrett & Leeds, 2001).

Grazing can alter the spatial heterogeneity of vegetation, by influencing ecosystem processes and biodiversity (Adler, Raff & Lauenroth, 2001). Such physical disturbance can affect plant diversity by creating environmental heterogeneity at different spatial scales (McNaughton 1983; Sommer 2000). Milchunas & Lauenroth (1993) found that the resultant grazing intensity led to the conversion of grassland to shrub lands. Mwendera, Mohamed & Dibabe (1997a, b) also observed that significant changes in plant communities' composition were more likely to occur under heavy grazing.

Intensification of agriculture has led to an estimated 50% loss of global wetlands, since 1900s (Millennium Ecosystem Assessment, 2005). A 50 year of floristic dynamics monitoring at different spatio-temporal scales in Rome's archeological sites has shown that over 40% of species disappeared due to environmental disturbances (Ceschin et al. 2009). Vascular flora survey in the Tiber River- Rome has also indicated a decrease in species richness, composition and structure in the last 30 years as a result of human influences (Ceschin et al. 2010). In Africa for instance, Nsor and Gambiza (2013) revealed that impacts of alien invasives, erosion processes and agricultural activities reduced the once pristine Kromme peatland in South Africa, while the presence of water hyacinth in Lake Victoria has also caused a reduction in fish diversity, increased the prevalence of mosquitoes and the breeding of snails (Mailu, 2001).

The observed farming activities in and around wetland zones have the tendency of causing other land disturbances such as erosion, and in the process alter the composition and abundance of sensitive species from their ranges. Wild, Neuha¨uslova´ & Sofron (2004) used a multivariate approach to determine the influence of environmental factors on vegetation. They concluded that factors such as forest fragmentation, soil condition and air pollution, largely explained the cause in the shift in canopy cover (decrease in species diversity to a more species rich community) and frequency of low species turnover in a meadow forest.

Seasonal Variation of Fish Assemblage along an Environmental Gradient

The Millenium Ecosystem Assessment Report (2005) revealed that approximately 20% of the world's 10,000 freshwater fish species have been listed as threatened, endangered, or extinct in the last few decades. Out of this number, 2,000 are known indigenous freshwater fishes in Africa (Kabii, 1997). The threats are largely attributed to both physico-chemicals (Pires, Cowx & Coelho, 1999; Killgore & Hoover, 2001; Ayoola & Kuton, 2009) and anthropogenic factors (Fernandes & Achuthankutty, 2010), although seasonal changes may alter the severity of impacts on fish at different spatio-temporal scales. Fernandes & Achuthankutty (2010) indicated that fish abundance were relatively higher in increased salinity during the post monsoon season than the pre-monsoon in Salcete Taluka wetlands-India, while Ansari et al. (1995) showed that fish species were segregated into seasonal groups, as a result of changes in physico-chemical parameters, such as salinity, temperature and dissolve oxygen concentration.

Fish species are very vulnerable to disturbances in their environment due to the intimate contact of the skin and gills with the surrounding water (Fernandes et al. (as cited in Chezhian, Kabilan, Suresh-Kumar & Senthamil –Selvan, 2011). Fish communities in rivers are structured by habitat complexity, environmental variables and periodic phenomena of low-flows and floods, changes in water quality, agriculture and urban land use (Johnson et al. 2006). Therefore, degradation of water quality through human activities can have adverse effects not only on fish communities, but also on the phytoplankton and zooplankton, which constitute the base of the food chain.

In a comparative study of fish abundance in water systems, Sandström & Karâs (2002) found that a number of young perch were reduced in highly eutrophic areas compared to less eutrophic areas. This condition could be attributed to increased supply of nitrogen and phosphorus through human activities. Pires et al. (1999) reported that an aggregation of fish species and competition for food and space in isolated pools is as a result of increase in drought in the summer season. This weather condition further raised the water temperature and reduced dissolved oxygen, thus imposing adverse physical conditions on fish species in the pools (Pires et al. 1999). Dissolve oxygen concentrations below 0.5 mg/l have been reported to substantially reduce species richness, abundance, and size of fish (Killgore & Hoover, 2001). This hypoxic condition occurs in dense vegetation and affects many physiological, biochemical and behavioural processes in fish species (Kramer as cited in Killgore & Hoover, 2001).

Spatial Variations of Bird Diversity in Different Wetland Types

Bird species play a vital role in enriching the biodiversity of wetlands. Their sensitivity to habitat perturbation makes them suitable to be as bioindicators to wetland health, with respect to their population size and composition. The habitat-specific requirements of birds, probably makes them increasingly intolerant of the slightest wetland disturbance. Over 150 bird species are reportedly lost since the year 1500 AD (Birdlife International, 2011). Today, one in eight bird species is threatened with global extinction, with 190 species critically endangered (Birdlife International, 2011) and the International Union for the Conservation of Nature (IUCN) '*Red List'* shows that things are getting worse. Particularly alarming are sharp declines in a number of formerly common and widespread species, such as cranes and some waders. In recent times, birds have gone extinct at an exceptionally high rate, estimated to be 1,000 to 10,000 times the natural background rate (www.Birdlife.org, 2011). Although most documented evidence on extinctions has been of species confined to small islands, the rate of extinctions has been increasing on a continental scale (www.Birdlife.org, 2011). These trends could be a signal of wider ecological disturbances, largely linked to anthropogenic activities. Habitat fragmentation (Kangah-Kesse, Attuquayefio, Owusu & Gbogbo, 2007), pollution (Gordon et al. 1998), cutting of mangrove vegetation (Attuquayefio & Gbogbo, 2001), and agriculture practices (Fox et al. 2005), are among the notable factors influencing bird diversity and abundance at the regional and local scales.

Ward et al. (2005) argued that in summer, salt marshes, with dominant plant species like Carex and Puccinellia, are key habitats for raising young gooselings, while lake shorelines with fine freshwater grasses and sedges are important for molting birds.

Disturbances like irrigation directly reduce water levels, which is critical to bird survival. For instance Riffell, Keas & Burton (2001) pointed out that annual water depth changes within the Great Lakes coastal wetlands can affect breeding and foraging habitat preference for a variety of wetland-dependent bird species. Timmermans, Badzinski & Ingram (2008) also gave an account of how some marsh-dependent birds in Great Lakes coastal marshes, such as swamp sparrow (*Melospiza georgiana*), American coot (*Fulica americana*), least bittern (*Ixobrychus exilis*), marsh wren (*Cistorthorus palustris*) and pied-billed grebe (*Podilymbus podiceps*) were affected by long-term changes and annual water level fluctuations. Kushlan (1987) and Austin (2002) explained that these wetland-dependent birds used the availability of water in the whole of spring, as proximate cues to assist in their broad scale selection of habitat preference.

Of the 728 bird species recorded in Ghana 37 are restricted to the Sudan-Guinea Savanna biome (Ntiamoa-Baidu et al. 2000a), while the remaining 691 species are from the forest belt (Owusu, 2007, 2008; Demey & Hester, 2008) and coastal wetlands (e.g., Ntiamoa-Baidu, Owusu, Asamoah & Owusu-Boateng, 2000a; Suapim, Attuquayefio, Gbogbo & Owusu, 2007; Gbogbo & Attuquayefio, 2010). Six of these are considered threatened and 12 near threatened (Birdlife International, 2000). The National Biodiversity Strategy for Ghana Report (2002), mentioned hornbill, parrots and birds of prey, as the few keystone species under threat.

Global Overview of Temperature and Precipitation and Projected impacts on Wetland Biodiversity

The Earth's climate has warmed by ~ 0.68C over the past 100 years with two main periods of warming, between 1910 and 1945 and from 1976 onwards (IPCC, 2001; Warren & French, 2001). General circulation models predicts that global mean annual temperature will show an increase in order of 1-5^{o}C during the next century, while in the same period, precipitation will also surge by 25% (Totland & Nylehn, 1998) as a result of doubling atmospheric CO_2 from industries.

The relationship between climate and the biosphere has been argued since ancient Greece (Gates, as cited in Warren & French, 2001). The concept that vegetation reaches equilibrium with climate was used in the 20th century to map and propose management strategies for natural resources (Agnew & Siobhan Fennessy, 2001). These findings suggest a direct relationship between climate change indicators and biodiversity, which are regionally and locally specific. Erwin (2009) stated that wetland habitat responses to climate change and the implications for restoration will be realized differently on a regional and mega-watershed level, making it important to recognize that specific restoration and management plans will require examination by habitat. The effect of climate change is projected to cause significant transformations to aquatic biogeochemical processes, (including carbon dynamics), plant diversity, range distribution and habitat quality/quantity of aquatic mammals and waterfowl (Wrona et al. 2006) giving the current noticeable changes in many ecological communities (Hughes, 2003; Winn, Saynor, Eliot & Elio, 2006). However, there is a probability that future changes in the range shift of wetland plants are likely to be dependent on individual levels of functional diversity instead of the total number of species in a stressed ecosystem. The absence of information on the responses of individual species to with concurrent historical climatic data on the same spatio-temporal scale in the study area makes it difficult to determine the extent of impact on species range shift and to predict future scenarios. This suggests the need to investigate at the local scale the responses of species to climate change.

In spite of these projected impacts of climate change levels on wetland biodiversity, there may be some uncertainties in predicting species range shift responses in different wetlands especially at the local spatial levels. For example, Wrona et al. (2006) explained that locally adapted arctic species are likely to be extinct from certain areas as environmental conditions begin to exceed their physiological tolerances and/or ecological optima. Hence, species with limited climatic ranges (i.e., highly specialized environments) or restricted habitat requirements, with low population numbers are likely at risk to climate change effects. For instance, climate impacts may result in migratory birds arriving and breeding earlier than expected (Dunn & Winkler, 1999; Waite & Strickland, 2006). This phenomenon could lead to a shift in breeding phase and in the end affect reproduction of young once.

Walther et al. (2002) argued that organisms, populations and ecological communities do not respond to approximated global averages, but rather regional changes, which are highly spatially heterogeneous, and are more relevant in the context of ecological response to climatic change. There is evidence of differences in response to climate change between species at particular sites or with time of season (Walther et al. 2002). For plants, strong seasonal variation is reported with the highest advances in early spring (and notable advances of succeeding phenophases) and almost no response in summer and early autumn (Menzel & Estrella, 2001). Walther, Berger & Sykes (2005) reanalysis of both biogeographic and bioclimatic data of equal spatiotemporal resolution, covering a time span of more than 50 years, showed a coherent and synchronous shift in the northern margin of *Ilex aquifolium* alongside a gradually increasing winter temperatures in Europe. There are indications that emergent aquatic plants are also expected to expand their distribution northward, with a possibility of altering the overall levels of primary production in ponds and small lakes in the Arctic (Wrona et al. 2006). For example, Alexander (as cited in Wrona et al. 2006) reported a total primary production of 300 to 400 g C/m^2/yr. in ponds of emergent Carex (covering one-third of the pond), compared to total primary production of 1 g C/m2/yr. for phytoplankton and 10 g C/m2/yr for epilithic algae, after colonization. Traditional ecological observations suggest that muskrat abundance is likely to increase in high-latitude lakes, ponds and wetlands as emergent aquatic vegetation becomes more prominent (Thorpe, 1986).

In North America, for example, the distribution of yellow perch (*Perca flavescens*) is projected to expand northward beyond its current subarctic distribution (Wrona et al. 2006). Oswood et al. (1992) explained the possible reasons why species may shift away from their ranges into new habitat. For example, the many northward-flowing arctic rivers provide pathways for colonization of the mainland by freshwater species that are hitherto restricted to subarctic or temperate portions of the drainage basins due to present climate change limitation. However, as climate change effects become more pronounced (e.g., degree-day boundaries or mean temperature isotherms shift northward), the more ecologically vagile species are likely to shift their geographic ranges northward (Oswood, Milner & Irons, 1992). This is probably a resultant interaction between anthropogenic disturbances and natural climatic factors and not solely the role of climate change. The responses of species to adverse climatic impacts may not entirely cause the range shift of hydrophytes out of their natural habitats, since there is the likelihood of some of the species to exhibit adaptive strategy, in order to survive.

Impacts of Climate Change in Africa

Warming of the continent is very likely to be greater (Christensen et al. 2007) than the global annual mean warming throughout all seasons, with drier subtropical regions warming more than the moister tropics. In spite of the expected increase in warming and its direct influence on rainfall pattern, model simulations of precipitation changes for the Sahelian and Guinea coast regions of Africa are strongly divergent and most models fail to reproduce realistic inter-annual and inter-decadal rainfall variability in the Sahel in 20th century simulations (Christensen et al. 2007). Therefore predicting with certainty of the direction of future change may be daunting, due to the lack of understanding of the complex processes causing tropical rainfall from the two different bioclimatic zones and the absence of consistent historical dataset. This area will therefore require further research to explain how the array of climatic models responds to the region's different ecological zones. Although model simulations show wide disagreements in projected changes in the amplitude of future El Niño events, climate projections for Africa will likely increase to an average of 1.5 to 4° C in this century, which is generally higher than the global average (IPCC, 2007). Annual rainfall is likely to decrease in much of Mediterranean Africa and the northern Sahara, with a greater likelihood of decreasing rainfall as the Mediterranean coast is approached. In southern Africa rainfall is likely to decrease in much of the winter region and western margins, while East Africa may experience an increase in annual mean rainfall in (IPCC, 2007).

In West Africa, precipitation and drought are strongly influenced by El Niño southern oscillations (ENSO), thus contributing to uncertainty in climate projections for the sub-region. Camberlin (1995) showed how rainfalls in north-east Africa correlated well with ENSO, especially droughts in Ethiopia and Uganda. Expected changes in rainfall patterns will be accompanied by an increase in droughts and floods, and sea level rise in most countries in Africa (IPCC, 2007). Devastating floods events have already occurred in Ghana and Mozambique in 2012. Sub-Saharan Africa is home to wetlands of global significance, and hence impacts of climate change will further weaken these ecosystems, already stressed by overfishing, farming and deforestation.

Temperature and Precipitation Threats to Ghana's Wetland Ecosystems

Historical data from 1961 to 2000 show a progressive rise in temperature and decrease in mean annual rainfall in all the six agro-ecological zones in the country (National Strategy for Climate change, 2009). Overall, mean annual temperature has increased by 1.0°C since 1960, with an average rate of 0.21°C per decade (McSweeney, Lizcano, New & Lu, 2009). The rate of increase has been most rapid in the months of April to June (~ 0.27°C per decade) in the three northern regions of the country than in the southern sector. Daily temperature data indicate that the frequency of 'hot' days has increased significantly in all months except December to February, while the frequency of ‘hot’ nights has also increased significantly in all seasons (McSweeney et al. 2009). The average number of ‘hot’ days per year has increased by 48 days (an additional 13.2% of days) and 73 nights (an additional 20% of nights) between 1960 and 2003. The rate of increase by 7.2 days per month (an additional 23.3% of days) and 8.9 nights per month (an additional 28.8% of nights), was observed mostly in the months September to November. The frequency of cold days and nights has decreased significantly since 1960 in some seasons (McSweeney et al. 2009).

According to World Bank Group (2010) climate change is projected to have significant impact on Ghana. The World Bank Group (2010) further observed that although there will be variations in annual temperatures and precipitation, the trend for temperature over the period 2010–2050 indicates warming in all regions. The highest temperature increases will be in the Northern, Upper East, and Upper West Regions, while the lowest will be in the Brong Ahafo Region (McSweeney et al. 2009; World Bank Group, 2010). For example, under one of the climate scenarios (Ghana Dry), temperatures in the three regions of the North will rise by 2.1–2.4°C by 2050. In comparison, the predicted rise in the Ashanti, Western, Eastern, Central, and Volta Regions will be 1.7–2.0°C, and the rise in the Brong Ahafo Region will be 1.3–1.6°C (World Bank Group, 2010). Some other findings indicate that mean annual temperature is projected to increase by 1.0 to 3.0°C by the 2060s, and 1.5 to 5.2°C by the 2090s (McSweeney et al. 2009). The range of projections by the

2090s under any one emission scenario is around 1.5-2.5°C. The projected rate of warming in the three northern regions of Ghana suggests that all other things being equal, future impacts of temperature may lead to a drastic reduction of water table in wetlands, through evapotranspiration. This condition has the potential to modify the current state of flora and fauna composition, in respect of their future state under predicted climate scenarios.

For instance, Armah & Amlalo (1998) showed how the loss of land by shoreline recession and flooding could potentially transform mangrove, strand and salt marsh vegetation such as Silver-leaved Buttonwood (*Conocarpus erectus*), Pacific rosewood (*Thespesia populenea*), Golder leatherfern (*Acrosticum aureum*), Beach bean (*Canavalia rosea*) and Beach morning glory or Goat's foot (*Ipomea pes-caprae*). By far the most vulnerable wetlands are those within the Volta Delta.

Annual rainfall in Ghana is highly variable on inter-annual and inter-decadal timescales (McSweeney et al. 2009). This suggests that long term trends are difficult to predict at regional to local scales. Rainfall over Ghana was particularly high in the 1960s, and decreased to low levels in the late 1970s and early 1980s, which led to an overall decreasing trend in the period 1960 to 2006, of an average 2.3 mm per month (2.4%) per decade (McSweeney et al. 2009). Since farmers in Northern Region rely on erratic rain-fed agriculture, wetlands along the floodplains of the White, Red and Black Volta are used as an alternative source of water agricultural activities.

Hence the increase in the use of water from the few existing wetlands could lead to future transformation of the permanent wetlands to seasonal and subsequently to temporary wetlands. This phenomenon has the potential to degrade the ecological and economic functional state of these ecosystems. The Growing aridity in the northern Savannah belt may cause reductions in groundwater recharge of between 5 and 22 percent by the year 2020 (Gyasi, Karikari, Kranjac-Berisavljevic' & Von Vordzogbe, 2006), with reductions projected to be between 30 and 40 % by 2050. The White Volta River floodplains, where most of the under study wetlands are located, is likely to lose substantially its amount of groundwater. This may consequently impact on the wetlands that are partly sustained by ground water recharge from the White Volta River. For example, the Kukobila permanent natural marshland, had an estimated 97% of its saturated zone completely dried up in this year's dry season (2012); the first of its kind in the historical existence of the wetland. This phenomenon could partly be linked to impacts of climate change, although other human disturbances, such as the intensification of dry season irrigation farming, contributed in exacerbating the problem.

Conservation Measures to Promote Wetlands Functional State

The Wise use Concept: Wise use of wetlands involves maintenance of ecological character, as a basis not only for nature conservation, but for sustainable development that may yield the greatest continuous benefit to present generations while maintaining its potential to meet the needs and aspirations of future generations (Davis, 1993). These wise use guidelines highlighted on the establishment of national wetland policies covering all problems and activities related to wetlands, including institutional and organizational arrangements, legislative and government policies, increasing knowledge and awareness of wetlands and a review of wetland priorities in a national context. Ghana is signatory to the Ramsar Convention since 1988.

Right after ratifying the Convention on wise use, several national policies and legislation such as the Fisheries Decree (1972), the Land Policy, the Water Resources Act, Ghana Vision 2020 and the Decentralization Policy, have been passed into law. But what is most worrying is that, governments over the years have not ensured the strict implementation of these policy guidelines for the sustenance of the functional state of our wetlands. This is probably due to difficulties in overcoming traditional beliefs and attitudes towards wetlands.

In the context of strengthening policy formulation on Northern wetlands, the wise use concept will help promote regional wetland policy on a long-term and through emergency actions targeted at specific wetlands, with the aim of ensuring that they are listed among Wetlands of International Importance. In spite of the setbacks of strict enforcement of Ghana's wetland policies, some conservation activities has taken place on coastal wetlands like Sakumo, Songor and Mukwe lagoons. These wetlands are known habitats for resident and migratory birds (Ntiamoa-Baidu 1991; Ntiamoa-Baidu &

Gordon, 1991). The management of these coastal lagoons has traditionally been vested in the ‘owners’ of the lagoon, made up of local clans, fetishes or stools (Ntiamoa-Baidu & Gordon, 1991).

In the Northern Region, traditional rulers are the sole caretakers of wetlands and sacred grooves in their traditional areas. They control resource exploitation by placing limits on access, through the use of taboos. For many years, traditional approach has been effective in harnessing the ecological integrity of wetlands, especially those closer to secred grooves. Although there are policies governing the protection of wetlands in the country, the conservation status of wetlands in Northern Region is ‘*unprotected*’, thus exposing them to various disturbances. Conservation activities between governments and wetland owners/users are needed to protect and sustain the flow of resources, through wise use.

The hands-off approach between government and wetland owners in the protection and maintenance of wetlands is noted as one of the best way out. Living with Michigan's Wetlands (1996) describes the hands-off approach means as ‘not actively changing the key components of the wetland to modify the functions it naturally provides’. It means that wetlands owners are aware of the potential threats to their wetlands and have resort to the best intervention strategies, to either prevent or minimize the impacts of those threats. A number of conservation activities are often limited within the wetland zone. But it is proper to extend conservation activities beyond the wet zone, where most of the land use activities take place. Catchment land use activities can have far reaching consequences on wetland biodiversity, either directly or indirectly.

Conservation of Wetlands: Integrated Management Approach and Traditional Governance

Integrated management approach of wetlands requires a thorough understanding of relationship between the bio-physical and chemical processes in sustaining wetland functions, before choosing the right conservation method. For instance, disturbance on one component of wetland ecosystem (hydrology), could have direct effect on the fauna and flora species, because of their interdependence. To showcase such an integrated planning procedure, calls for the creation of an integrated management authority at the administrative level, with well-developed manual on integrated management techniques and procedures (Pergantis as cited in Klein, 1988). Davis (1993) added that besides having to deal with the national policy for integrated management, such an authority would have to deal with the different wetlands on a case-by-case basis. It might be useful to regroup smaller wetlands into larger administrative units. Day-to-day management would have to be based on an integrated management plan, with the zonation of wetlands to include, the whole hydrological catchment area.

In Ghana, the modern system for natural resource management follows a three tier approach, involving district, regional and national levels (Government of Ghana 1995 [Vision 2020]). One key institution is the District Environmental Management Committee, which has representation from the decentralized departments, such as Fisheries, Forestry and Wildlife.

However, none of these integrated management structures considered the role of local authorities (i.e., chiefs and clan heads) in wetland governance, since they are the caretakers and major beneficiaries of wetland resources. The lead role of managing wetlands by traditional authorities in their respective communities is vital in the reversal of degraded wetlands, alongside central government and non-governmental organizations. This is possible once chiefs and opinion leaders in the communities are properly made to understand the vital role that wetlands play in their livelihood and the need to conserve this unique ecosystem for future generations. This research work seeks to address this gap, by highlighting the critical role of chiefs or clan heads in the management of wetlands for sustainable use.

CHAPTER THREE

MATERIALS AND METHODS

Description of the Study Area

The study was carried out in six wetlands located in the Northern region of Ghana. The co-ordinates of the six wetlands are as follows: (i) Wuntori (N09º 08.335' W00º1 09º.685'); (ii) Kukobila (N10º 08.723' W000º 48.179'); (iii) Tugu (N09º 22.550' W000º 35.004'); (iv) Bunglung (N09º 35.576' W000º 47.443'); (v) Adayili (N09º 41.391' W000º 41.480') and (vi) Nabogo (N09º 49.941' W000º.51.942') (Fig. 3.1). The climate is dependent on the movement of the south-west moist monsoon winds and the North-east dry Harmattan winds (Slaymaker & Blench 2002). Annual rainfall is in the range of 1000-1,300 mm/p.a and the wet season lasts from June to early October, while the dry season last from November to May (Slaymaker & Blench 2002). About 2000 mm/p.a. of estimated reference evaporation occurs, creating a huge seasonal deficit every dry season. Temperatures are consistently high in most parts of the year, with clear diurnal variations in the dry seasons, which become more pronounced as the latitude increases (Slaymaker & Blench 2002). Average temperature varies between 14°C and 40°C, while relative humidity with maximum night and midday values in the range 69 – 95% and

32 – 69%, respectively, is experienced from the months of April to October (Slaymaker & Blench 2002).

The landscape is gently undulating, with broad and poorly drained valleys and a crest of the scarp forms the northern boundary of the Nasia River. Altitude ranges between 108 – 138 meters above mean sea level. The fine sandy loam soils are from upper Voltaian sandstone, while the iron pan concretion and the yellow sandy loams soils are from the Lower Voltaian shales and alluvial floodplains and slougths. The vegetation cover is a mixture of grassland dominated by *Hyparrhenia rufa* and *Lersia hexandra* and woodland dominated by Mahogany (*Khaya senegalensis*) and shea tree (*Vitellaria paradoxa*) interspersed with shrubby communities of *Mitragyna inermis* and *Ziziphus abissynica*. The trees are relatively short with thick bark and occlusions, signifying their adaptation to the cyclical dry season bush fires.

There is extensive floodplain along the course of the Volta and Nasia rivers, which has overtime become incised and modified through meandering and aligning along various topographic features. This has led to the development of streams that have diverted from the main White Volta (Slaymaker & Blench 2002). The hydrological regimes of the six wetlands under study were typical of permanent wetlands, whose depth at low tide did not exceed 2 m on average. All the wetlands were within the catchment of the main White Volta River or its tributries. Total land areas covered by these wetlands were as follows: (a)

Wuntori = 7.7 ha; (b) Kukobila = 5 ha, Tugu (c) 2.7 ha; (d) Nabogo = 7.9 ha; (e) Adayili = 6.7 ha and (f) Bunglung = 11.5 ha.

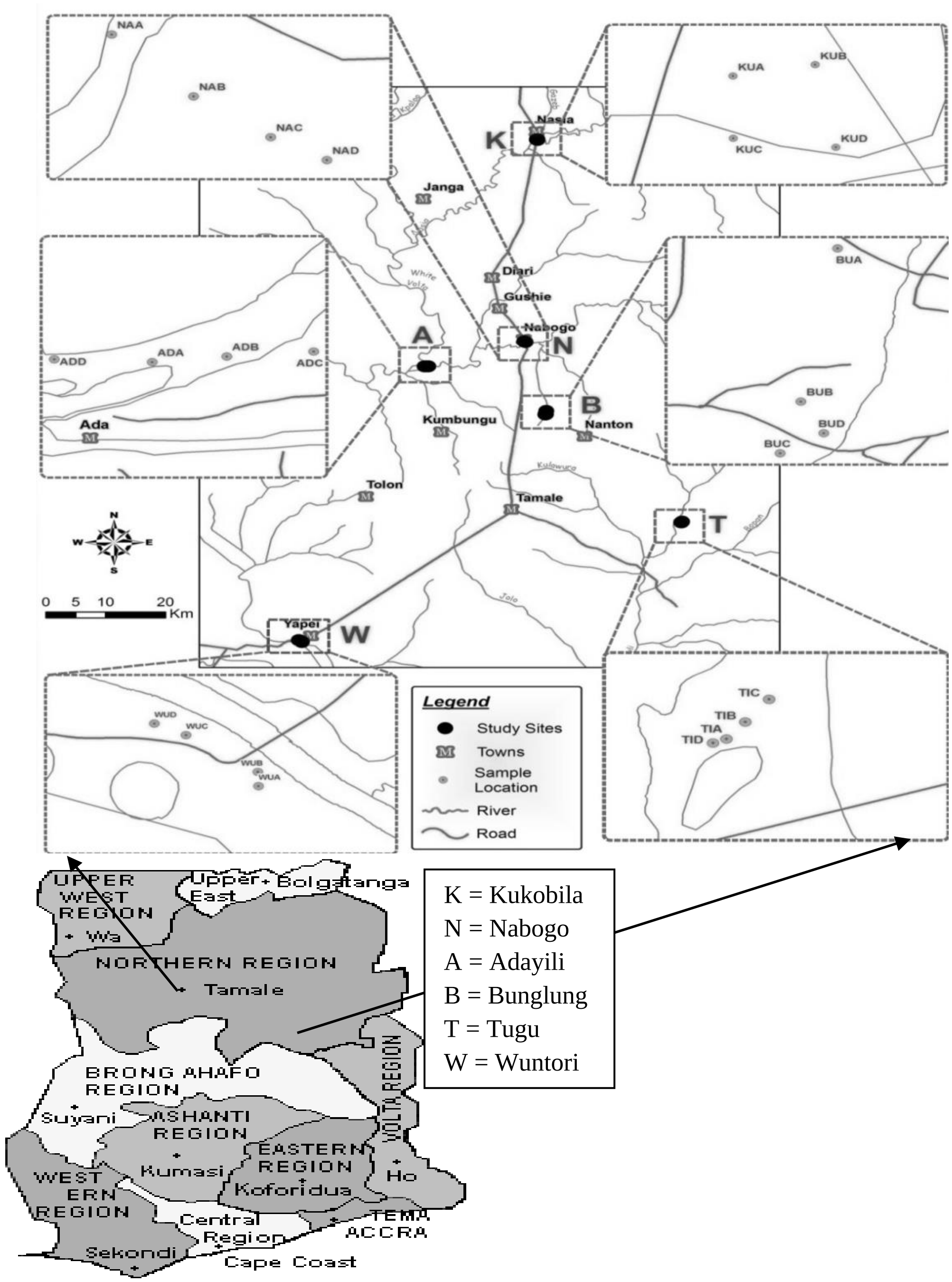


Figure 3.1: Map of the study areas, showing the location of the wetlands in the floodplains of the White Volta River catchment, Northern Region

Selection of Wetlands for indepth Study

After a reconnaissance survey, six wetlands were selected for detail study (see results section; Plates 4.1 – 6.6), following a three point criterion. Firstly, it was ensured that all the wetlands (three marsh standing wetlands, two riparian wetlands and one artificial or man-made wetland), reflected the description by the Ramsar Convention adopted by the International Union for the Conservation of Nature and Natural Resources (IUCN) especially as Waterfowl habitat (Barbier, 1997). Secondly, only permanent wetlands were selected for the purposes of continuous monitoring of the seasonal changes in species range shift, composition and pattern of distribution. Thirdly, they represent the largest wetlands in terms of surface area among all the 12 wetlands surveyed (~7.5 ha) from the geographic North, South, East, West and Central plains of Northern Region. Finally, the distance from one wetland to the other, ranges from 35-80 km. This provides a good gradient assessment of species distribution.

Environmental Assessment

Soil sampling

Random soil samples were taken with soil augur at a depth of 15 cm, using the zigzag sampling method (Pennock, Yates & Braidek, as cited in Carter & Gregorich, 2006) on each Modified-Whittaker plot (Fig. 3.2). The zigzag sampling design ensures greater representation of soil composition across a plot. Three composite samples were taken from three different 10 cores in each plot. Samples were put in transparent polyethylene bags and labeled according to the code assigned to each plot and taken to the laboratory at Savanna Agricultural Research Institute (SARI)-Nyankpala to analyse the presence of Nitrogen, Phosphorus, Potassium, Magnesium, Calcium and soil pH, using atomic absorption spectroscopy (AAS) techniques (Murphy & Riley, 1962; Van der Merwe, Johnson & Ras, 1984). Organic carbon was determined using the Walkley-Black method (Walkley & Black, 1934; Walkley, 1947).

Water sampling and analysis of water quality

A total of 13 physico–chemical parameters of the six wetlands were determined. They included: pH, Turbidity, temperature, Conductivity, TDS, Nitrate-N (NO_3-N), Phosphate (PO_4), Ammonia (NH4- N), Total Alkalinity, Total Hardness, Calcium, Magnesium and Dissolve Oxygen. pH and water temperatures were measured in the field using a portable pH meter and mercury-in-glass thermometer, respectively, while the rest of the parameters were assessed in the laboratory at the Water Research Institute (W.R.I)-Tamale. Samples were collected in dry and wet seasons over a 2-year period, at three stations-upper, mid and downstream in a clean 1-litre polyethylene bottle. All samples were transported on the same day to the W.R.I for analysis. All analyses of physico-chemical parameters of water samples were carried out in accordance with the outlined Standard Methods for the Examination of Water and Wastewater (APHA, 1998).

Determination of land disturbance

A proposed land index score, known as Land disturbance Index score (LDI) was used to estimate the intensity or the extent of impact of these environmental drivers of change on the wetlands (farming activities, grazing intensity, erosion and bush fire). This proposed LDI, followed similar disturbance index used by Huffman & Rohde (2007). Assessment of the area disturbed was carried out within 1.2 km radius starting from the hydric delineated zone of the wetland. This is because all land use activities mentioned were observed within this radius following a preliminary survey of the wetlands. The LDI is computed as Land area of wetland disturbed over the total area of the Whittaker plot (1000 m^2) multiplied by 100% as shown below:

$$LDI = \frac{L_d}{T_w} \times 100$$

Where

LDI is land disturbance index, L_d is land area disturbed by farming activities, grazing intensity, erosion and bush fire T_w = Total area of the Whittaker plot.LDI scores were assigned as follows: 1-20% = 1, 21-40% = 2, 41-60% = 3, 61-80 = 4 and 81-100% = 5. A score of 1 is interpreted as less disturbed, 2-3 as moderately disturbed and 4-5 as highly disturbed.

Biological Data Assessment

Sampling procedure of aquatic plants

Sampling of aquatic plants was carried in each of the 24 Modified-Whittaker plots over a 2-year period (Fig. 3.2). The Modified-Whittaker plot is a vegetation sampling design that is used to assess plant communities at multiple scales (Stohlgren, Falkner & Schell, 1995). Each Modified-Whittaker plot measures 20 m x 50 m (1000 m^2) and contains three different sizes of nested subplots. A 5 m x 20 m (100 m^2) subplot was placed at the centre of the plot, while two 2 m x 5 m (10 m^2) subplots were placed in opposite corners of the plot. The remaining ten of 0.5 m x 2 m (1 m^2) subplots were placed at the edges of the main plot. Four Whittaker plots were randomly laid in each of the six wetlands, bringing the total to 24 plots. Plots were laid along an environmental gradient of the vegetation type being sampled, in order to register majority of species heterogeneity. The Whittaker plot (1) reduces biases and under reporting of species richness due to its spatial autocorrelation and (2) detect more species per plot than the intensive and extensive plot design type (Stohlgren et al. 1999; Barnett & Stohlgren, 2002). Data collected were plant height, ground or foliage cover, plant density, and stem girth. The Domin-Krajina cover abundance scale (see Mueller-Dombois & Ellenberg, 1974) was used to estimate ground cover. Species diversity was only quantified in the 0.5 x 2 m^2, whereas species richness and stem girth were measured in the 5 x 20 m^2 and 2 x 5 m^2, respectively. Wetland hydrophytes were identified up to species level, with the aid of manuals developed by Johnson (1997), Okezie & Agyakwa (1998) and Arbonnier (2004). Plants that were difficult to identify in the field, were taken to the University for Development Studies herbarium for identification. The sites ware located ~ 60 km radius of the Tamale weather Station.

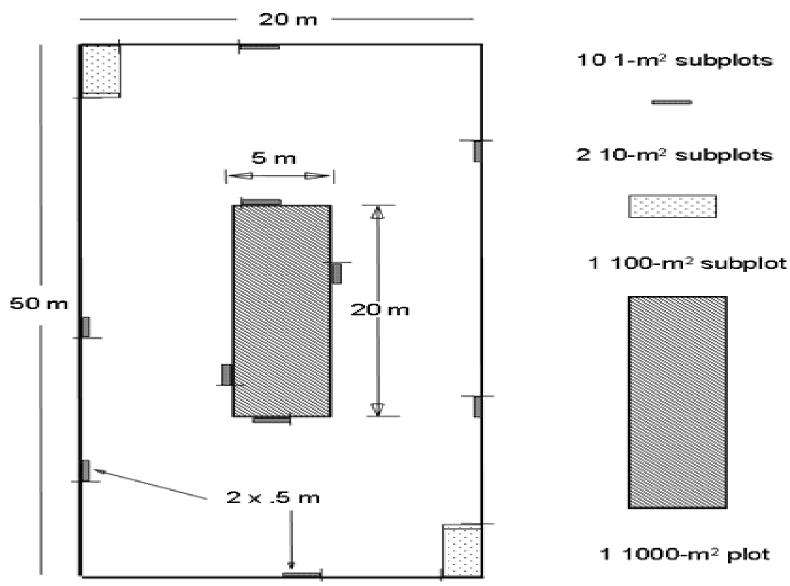


Figure 3.2: A schematic diagram of the Modified-Whittaker nested plot

Assessment of species range shift, using the hydrophyte community as indicators

To determine whether plant species present were typical wetlands plants or from terrestrial systems, the Prevalence Index Method (Cronk & Siobhan-Fennessy, 2001) was employed to classify the weighted average of indicator status of sampled species as follows: obligate plants (OBL) = 1.0;

facultative wetland plants (FACW) = 2.0; facultative plants (FAC) = 3.0; facultative upland plants (FACU) = 4.0 and obligate upland plants (UPL) = 5.0. Obligate wetland plants – (i.e. hydrophytes with >99% probability of occurring in wetlands); facultative wetland plants- (usually found in wetlands with an estimated probability of 67% - 99% occurrence, but occasionally found in uplands); facultative plants- (having 34% - 66% equal chance of occurring in wetlands); facultative upland plants- (usually occur outside wetlands, but occasionally found in wetlands, and obligate upland- (occur only in uplands (Tiner, 1999). In addition to the indicator status categories, positive (+) sign was used to indicate all facultative species categories with a frequency towards wetter ends (more frequently found in wetlands) and the negative (-) sign with a frequency towards drier ends (less frequently found in wetlands) (Tiner, 1999). Plant species on each plot were identified, counted and classified under the different species indicator status, to determine their abundance per plot. Total number of species in each indicator status category was subsequently divided by the total number of plots on which they were sampled, in order to obtain the average for each plot. Plots that score < 3.0 were considered to be obligate wetland plants (OBL) and those that score >3.0 were designated as upland plants (FACW; FAC; FACU and UPL categories), that may have migrated into the wetlands over time. Plant species were further counted from each of the indicator status category and expressed it as a percentage of the total species sampled, in order to determine whether the wetland plant communities are predominantly hydrophytes. The values obtained were used to compare with the standard value of >50% cumulative cover of OBL, FACW or FAC species present in a site (Cronk & Siobhan-Fennessy, 2001). To avoid duplication of species count, species of the same type that were already identified and counted in previous plots, were not recorded in subsequent plots in which they occurred. Classification of all wetlands species under the five categories (known as wetland indicator status) based on their expected frequency of occurrence in wetlands are shown in appendix A.

Assessment of livestock droppings for plant seed presence

To determine one of the modes that accounted for species range shift into wetlands, livestock droppings from the 24 sample plots were collected and sun dried in each sampling season. The droppings were subsequently broken into smaller clumps and placed on 24 soil medium containers each. Watering of the droppings was carried out in the morning at 7 am and in the evening at 5 pm daily, so as to enable plant seeds that may have been embedded in the droppings to germinate. After 5 to 6 days, seeds that germinated into seedlings were identified and categorized as obligates, facultative and upland species. The rationale behind this experiment was to confirm whether grazing activities by livestock could have partly contributed in the range shift of plants in the six wetlands.

Fish sampling procedure

Since one of the objectives of this study was to quantify fish diversity, richness and abundance, fish were sampled using castnets and cross nets (Plates 1a & b) at several locations on each wetland. These two fishing gears were selected in order to: (1) increase the catch per unit effort per net compared to other smaller gears like basket, "*Aha*" and hook and line and (2) a large area is covered at each sampling effort, hence reduce time, energy and resources. The mesh sizes of the nets used ranged between 2 cm and 3 cm (laterally stretched mesh size). The radius of cast net was 5 m while that of the cross net was 31 m and 2.7 m breadth. Cross nets were mostly used in the rainy season. Setting of cross net was done at 5 pm, till the next day, between the hours of 0600-0700 GMT, when the net is lifted from the water body. To increase sampling effort in the rainy season, cast nets were used alongside cross nets. Each of the wetlands (Wuntori, Kukobila, Tugu, Adayili, Nabogo and Bunglung wetlands) was sampled four times in a month (once per week). Dry season sampling commenced from November-February, 2010 while the rainy season sampling was from July to October, with the aid of hired fishermen. Fish were identified with the assistance of keys developed by Dankwa et al. (1999) and Paugy, Leveque & Teugels (2004). The Total length (TL) of each fish was measured to the nearest 0.1 mm and body weight (BW) to the nearest 0.1 g.

Plate 1a: cast net used to sample fish

Plate 1b: crossnet used to sample fish

Sampling of birds

Population monitoring type of survey was used to determine the seasonal variations in bird population, using transects line approach (Buckland, Anderson, Burnham & Laake, 1993). Ten plots in each of the six wetlands of 60 m x 10 m dimension were laid. The distance between one sampling plot and the other was 5 m. Birds were counted each of the ten plots with increasing five class distance scale (1-10, 10–20, 20–40, 40 - 50 and 50 – 60 m) from the base of the transect line, using visual approach and vocally through bird sounding technique developed by the Royal Society for the Protection of Birds (www.RSPB.org.uk, October, 2010). Bird sounding technique is software of recorded sounds of different birds, accompanying their names and photos. This vocal technique was only used to count birds that were hidden in dense vegetation and difficult to visualize. This was made possible after observing and listening to the same bird screech, chirps or tweet in the open vegetation in previous sampling. Repeated and careful listening of the bird sound in the thick vegetation for 5 minutes was followed by playing the composed sound in order to identify the right bird. Also, birds that were hidden in the thicket vegetation were counted through a deliberate agitation of the vegetation. This was done, by carefully throwing a stone inside the dense vegetation, in order to force the hidden bird(s) to fly out. They were counted after settling on the open vegetation. Counting of birds was done from 0700 – 01100 GMT when most of the birds were feeding. Counting was done once a week and hence four times in month. Birds were counted in the dry (absence of rain or harmattan season) and wet seasons (rainy season). The total number of birds recorded was compiled on a monthly basis. Bird nest were not counted, since it was impossible to establish the type and number of birds co-habitating a nest.

A pair of Bushnell Falcon binoculars with a 10 x 50 mm dimension was used to observe birds located beyond 20 m distance for morphological features like colour and structure of the beak, colour of tail feather, colour of feathers around the neck, colour of the head feathers and the presence of comb-like feathers (See Birds of Ghana Galleries, www.pbase.com, October, 2010).

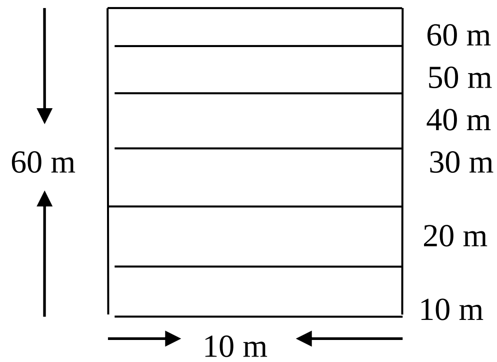


Figure 3.3: **A stratified transect line sampling unit, showing how birds were estimated with increasing distance from the base of the transect walk**

Assessment of Historical Data of Temperature, Precipitation and Evapotranspiration in Relation to Aquatic Plants

Data on temperature, precipitation and evapotranspiration from 1960 to 2010 were obtained from the Ghana Meteorological Service, while the use of historical traditional knowledge or local Observations method on species assemblage was adopted, following similar approach employed by Iversen (1944); Krupnik & Jolly (2002); Huntington et al. (2005) to determine whether plants sampled were present in the last 50, since there were no documented data on aquatic plants. Three indigenes from each of the six wetland areas were interviewed (Appendix E). The criteria considered in selecting these people were:

1. Whether they are herbalist, who frequented in the wetlands under study, to source their herbs in the last 60^{+} years) and

2. Whether they practice farming and fishing activities within the catchment of the wetlands?

Assessment of the Views of Wetlands Users

A community participatory approach involving 10 members each from the six wetlands localities was selected for field discussion on human activities that posed a threat to the ecological integrity of the wetlands. Community members, who were selected, composed of different active users of the wetland namely livestock headsmen, farmers, fishermen, tree hewers, domestic water drawers and herbalists. Initial field discussion was centered on the general support of the wetlands to their livelihood. This was categorized into economic, ecological and cultural benefits. The next discussion was for members to list all possible threats to the wetlands, after which participants ranked the identified threats according to their severity. Threats were scored as follows 1 = less severe, 2 = moderately severe and 3 = highly severe. The final session of the field discussion, was to find out from users of the wetlands the proposed conservation measures to be instituted in order to reverse the identified threats.

Analysis of the Seasonal Variations between Biological and Environmental Data

A Canonical correspondence analysis (CCA) (ter Braak, 1986) was performed to determine the relationship between environmental drivers of change and the biological species data, using two analytical packages- Environmental community analysis version 1.3 (ECOM.exe) and Community analysis package version 1.41 (Henderson & Seaby, 1999). Cluster analysis (Complete-linkage clustering) was applied to aggregate plant species of similar/dis-similar morphological features, based on their spatial distribution and structure (Sneath & Sokal, 1973). The degree of matching between each pair of sub-plots was computed on the basis of similarity of species cover and plant height, using the coefficient of squared Euclidean distance (Noest & Van der Maarel, 1989). A One-way ANOVA was used to determine if environmental variables differed significantly from one wetland to the other, using SPSS version 16.0. Shannon-Weiner index was performed to determine the current status of aquatic plants, fish and bird community composition. Shannon-Weiner index equation expressed as:

$$H' = -\sum_{i=1}^{s} p_i (\ln p_i)$$ (Shannon-Wiener, 1963)

Where s is the number of species and P_i is the proportion of individuals or the abundance of the *ith* species expressed as a proportion of the total cover and *ln* is a natural logarithm (Shannon and Wiener, 1963). Species evenness distribution was evaluated using Pielou evenness index (J) expressed as:

$$J = H'/\ln S$$

Where H´ is the diversity index, S is species number and ln is natural Logarithm (Pielou, 1969). Species richness was quantified using Margalef's index (D) for species richness expressed as:

$D = (S-1)/\ln N$ (Margalef, 1968).

The effect of different sizes of Whittaker sub quadrats on species richness was examined using the simple regression analysis, on SPSS ver 16. Species accumulation was computed in all 24 Whittaker plots to determine species-area relationship. This was calculated using the formula: S= ¼ CAz where S is the number of species, A is the area, C is a parameter that varies widely depending upon the taxa or taxon being considered and the unit of area measurement and z is a constant (Gleason as cited in Ssegawa, Kakudidi, Muasya & Kalema, 2004). A one-way ANOVA test was applied to test for the differences in species diversity/evenness and species richness from one wetland to the other, using SPSS version 16. Kruskal-Wallis test was applied to test the differences in the mean of the diversity index.

Fish data and water physico-chemical parameters were subjected to a Principal Component Analysis (PCA) to determine the variables that influence the spatial distribution of fish species to their preferred wetland type. Fish abundance was determined by monitoring and recording fish catch data. Fish abundance was only log transformed, when initial test showed that their variances were much larger than their means.

Bird density (*D*) was estimated as the number of individuals ($\hat{N}$) per unit area (*A*) (Buckland et al. 2001). A one-way ANOVA was used to test for the significant difference between number of birds in the wetlands. The bird species found were compared with the '*Red List'* of International Union for the Conservation of Nature (IUCN) for birds. A simple linear regression model was used to determine the relationship between physico-chemical parameters from individual wetlands using Minitab version 15 statistical package.

Statistical analysis of temperature, precipitation and evapotranspiration

A time series analysis was performed to deduce the pattern of air temperature and precipitation for the 50-year period (1960 – 2010) and mean evapotranspiration for 48-year period (1961 – 2009). A linear regression analysis was carried out to evaluate the influence of air temperature on rainfall pattern and mean evapotranspiration using Statistica ver 10.0 package. A one-way ANOVA test was employed to test whether all climate parameters showed any significant variation over the 48-and 50-year period, respectively. The available 50-year data on temperature and precipitation and 48-year data on potential evapotranspiration was subjected to an ARIMA Model analysis to project future trends in average temperature, precipitation and mean potential evapotranspiration in the next 20 and 17 years respectively, using past pattern. The assumption for using this model is that the seasonal periods are known (Barnette & Dobson, 2010).

CHAPTER FOUR

RESULTS

The findings presented in this chapter were in line with the five thematic areas of the objective of the research questions. Pictures of wetlands and their georeferenced landsat images (September, 2013), showed were all field observations were carried out. On-screen digitizing of landsat images were performed on Google earth satellite^{+} software.

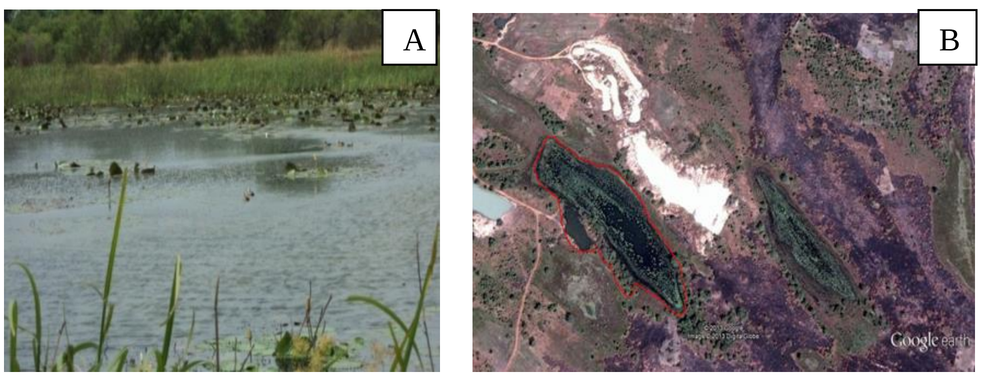


Plate 2: (A) Wuntori shallow marsh standing wetland (October, 2010) and (B) 2013 landsat image at Yapei

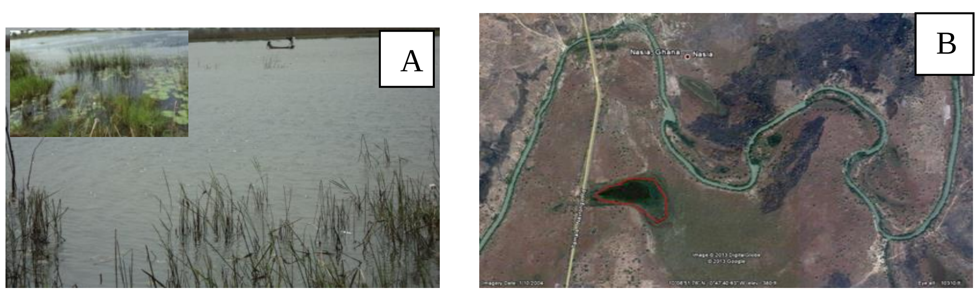


Plate 3: (A) Kukobila deep marsh standing wetland, ~200 m from the White Volta River and its (B) landsat image at Nasia in the Savelugu-Nanton District

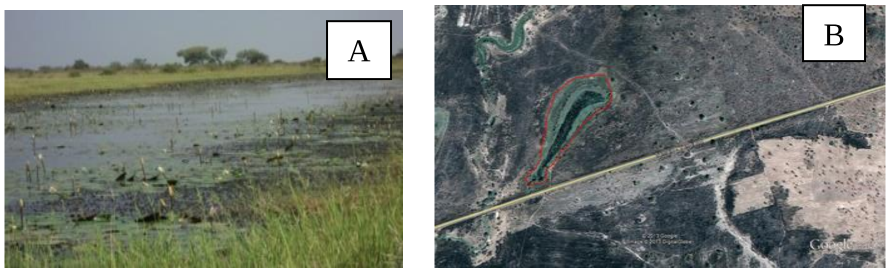


Plate 4: (A) Tugu shallow standing marsh wetland showing water lily *Nymphaea lotus* Linn. and it's (B) 2013 landsat image in the Eastern part of Northern Region

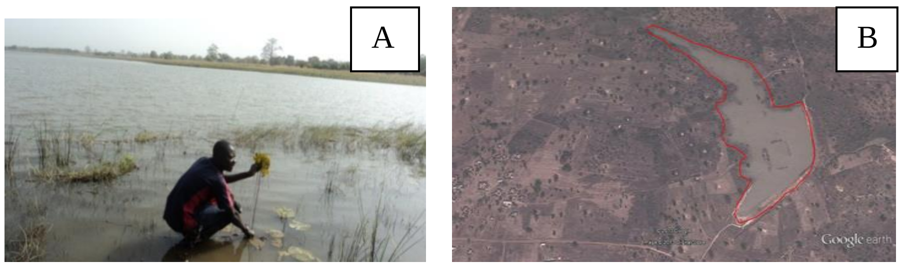


Plate 5: (A) Bunglung man-made flowing wetland in the Savelugu-Nanton District showing the researcher measuring the height of water lily (*Nymphaea micrantha*) and its (B) 2013 landsat image

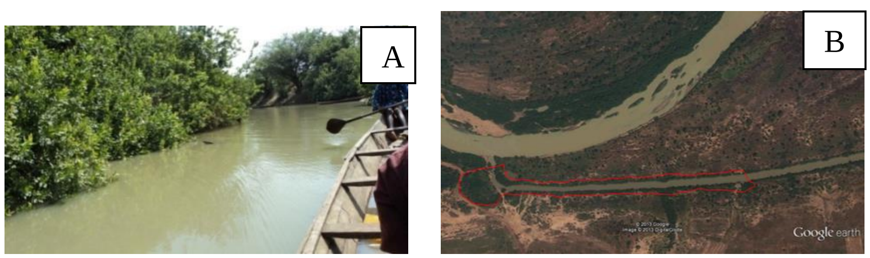


Plate 6: (A) Adayili riparian wetland and its (B) 2013 landsat image in the Western parts of Northern Region

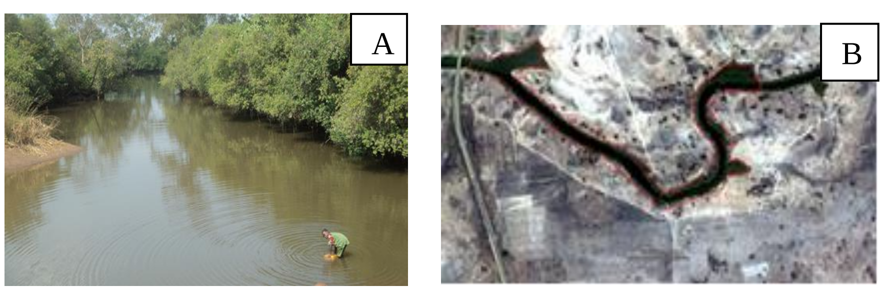


Plate 7: (A) Nabogu riparian wetland and its (B) 2013 georeferenced landsat image in the Savelugu-Nanton District

Plant Richness and Composition among the Six Wetlands

A total of 40 different plant species, belonging to 18 families were registered across the six wetlands (Appendix B). Kukobila wetland recorded the highest mean number of species, predominantly herbs and grasses (29.5±1.9) (Table 4.1). Examples included: *Nymphaea lotus* Linn, *Ipomea aquatica* (Forssk), *Cyperus spacelatus* (Rottb) and *Oryza longistaminata* A. Chev. & Roehr). The least mean number of species (23.5±1.04) was recorded from Bunglung man-made wetland in the Savelugu-Nanton District. The other wetlands that followed Kukobila were Tugu (26.5±1.19), Wuntori (26.0±1.41) and Nabogo (25.0±0.91). The dominant vegetation types were grasses (e.g., *Deplachne fusca* (L.) P. Beauv. Ex Stapf and *Echinochloa pyramidalis* (Retz.) P. Beauv.), with pockets of herbaceous layer in areas of the wetlands that had water present all year round. Woody plant species such as *Syzygium guineense* (Wild) D.C., and *Vitex crysocarpa* (Planch. Ex Benth.) with an average height of 5.6 m, were the predominant species recorded in the forested wetlands of Adayilli and Nabogo, respectively. Grass and herb species were completely canopied and hence were very few in those wetlands. The few grasses sampled, were restricted at the extreme ends of the shores (i.e. away from the shades of the bottomland hardwood). Kruskal-Wallis test showed significant differences ($p<0.05$) in plant species recorded in the four Whittaker plots in each of the six wetlands.

Table 1: Number of plants recorded in the 24 Whittaker plots across the six wetlands (*Number of species* = 40)

Wetlands	Plot A	Plot B	Plot C	Plot D	Mean ± SE
Wuntori	28	26	22	28	26.0±1.41
Bunglung	26	24	23	21	23.5±1.04
Adayilli	28	25	26	22	25.3±1.25
Kukobila	28	32	31	27	29.5±1.19
Tugu	25	30	25	26	26.5±1.19
Nabogo	26	24	23	20	25.0±0.91

Of the 40 species recorded, herbaceous cover constituted 52.5%, thus representing the largest number of species type, followed by species from the graminae family (32.5%) and hardwood (15%). Out of the 24 Whittaker plots laid in the six wetlands, *Deplachne fusca* from the graminae family was the most frequent occurring individual species, as it was registered in 21 plots (87.5%). *Cyperus sphacelatus* (family cyperaceae) was the second most occurring species (16 plots), representing 66.7%. Among the hardwood species, *Mitragyna inermis* (family rubiaceae) was the only species recorded in more than half of the total plots (13 plots) and constituted 54.2%. Unlike the riparian wetlands where *Mitragyna inermis* was found close to the edge of the saturated zone, its distribution was largely confined to the fringes of the shallow and deep marshes of Wuntori, Tugu and Kukobila wetlands. *Cyperus distans, Setaria pumila* (Poir.) Roem & Schult. *Brachiaria mutica, Imperata cylindrical, Fimbristylis ferruginea* (L.) *Vahl., Ludwigia octovalvis* (Jacq.)

Raven. *Ludwigia hyssopifolia* (G. Don) Exell. and *Sacciolepsis africana* C.E. Hubb. & Snowden., were the species that occurred in only one plot. *Ceratophyllum demersum* was the only submerged species and was recorded in 11 plots (45.8%) whereas two emergent plants *Nymphaea lotus* and *Pistia stratiotes*, were registered in 14 (58.3%) and three plots (12.5%), respectively.

Species accumulation curves from the 12 plots each across the six wetlands (72 sub quadrats), revealed a change in species richness in line with increasing numbers of sub quadrats sampled (Figure 4.1). The two natural marsh systems- Wuntori (407 sp.) and Kukobila (363sp.), tended to be species rich, followed by Adayili swamp forest wetland (259 sp.) and Bunglung man-made wetland (241 sp.). Tugu shallow marsh system (236 sp.) and Nabogo riparian wetland (236 sp.) were the least in species richness. Although Wuntori wetland (R^2 = 0.76, $p<0.05$) was the richest in species accumulation, Adayili (R^2 = 0.98, $p<0.05$) and Kukobila wetlands (R^2= 0.931, $p<0.05$), rather showed the strongest plot size-species relationship (Figure 4.1). Even though the shallow marshes of Tugu and the riparian wetland of Nabogo recorded the same number of species accumulation, Tugu wetland exhibited a relatively strong species-area relationship (R^2= 0.555, $p<0.05$) than Nabogo wetland (R^2= 0.398, $p<0.05$).

Generally, mean plant diversity was fairly high across the six wetlands (H′ = 1.86 to 2.66), but differed significantly from their evenness distribution (t = -16.511, $p<0.05$) (Figures 4.2 & 4.3). On average, all the three natural marshlands (Kukobila, Wuntori and Tugu) were reasonably high in species diversity. Although Kukobila (H′ = 2.259±0.096) and Tugu wetlands (H′ = 2.231±0.110) tended to be the most diverse and evenly distributed, Kukobila was the most diverse among the six wetlands (Figures 4.2 & 4.3), while the man-made wetland (H′ = 2.026±0.048) and Wuntori wetland (H′ = 1.979±0.09) closely followed respectively. In spite of the strongest species-plot size relationship observed in the two riparian wetlands (Adayili and Nabogo), they registered the lowest in species composition (H′ = 1.865±0.110 and H′ = 1.895±0.078, respectively) in the dry season.

Comparatively, plant diversity was much higher in the wet season than the dry season (Figure 4.2). Kukobila registered the highest diversity (H′ = 2.656±0.079), closely followed by the shallow marshes of Wuntori (H′ = 2.476±0.132), Nabogo (H′ = 2.342±0.132) and Adayili (2.213±0.215) in the wet season. Bunglung wetland was the least diverse among the six wetlands (H′=1.857±0.260). Diversity in Tugu (H′ = 2.308±0.074) marginally varied ($p=0.563$) from that of Nabogo wetland (H′ = 2.342 ±0.134). Observations of community evenness distribution were generally not evenly distributed (J = 0.862 to 0.96) across the six wetlands in the two seasons despite some variations. Evenness indices of species distribution were high in wetlands that registered high diversity indices, (e.g., Kukobila - J = 0.961±0.003 in the wet season) and low were diversity was low (Wuntori -J = 0.862±0.018 in the dry season). Species distribution in Adayilli (J = 0.900±0.013; J = 0.921±0.013) and Nabogo wetlands (J = 0.885±0.017; 0.915±0.036) for dry season and wet seasons respectively, followed suit in the evenness distribution of plants after Kukobila and Tugu wetlands (Figure 4.3).

One-way ANOVA test did not show any variations in mean plant diversity ($p>0.05$) and evenness distribution ($p>0.05$), in all the 24 Whittaker plots sampled in both seasons. Kruskal-Wallis test showed that, species diversity between Bunglung wetland and Adayilli swamp forest wetland did not differ significantly between dry and wet season ($p>0.05$) although diversity varied between the two wetlands within each season. Plant composition in Bunglung did not differ from that of the deep marshes of Kukobila ($p>0.05$) in the dry season, but was significantly lower in the wet season ($p<0.05$). Nabogo swamp forest were significantly lower in diversity from the marshes of Kukobila in the dry and wet seasons ($p<0.05$). The two natural marshes of Wuntori and Kukobila differed significantly in the dry season ($p<0.05$). However, diversity did not vary in these wetlands in the wet season ($p>0.05$).

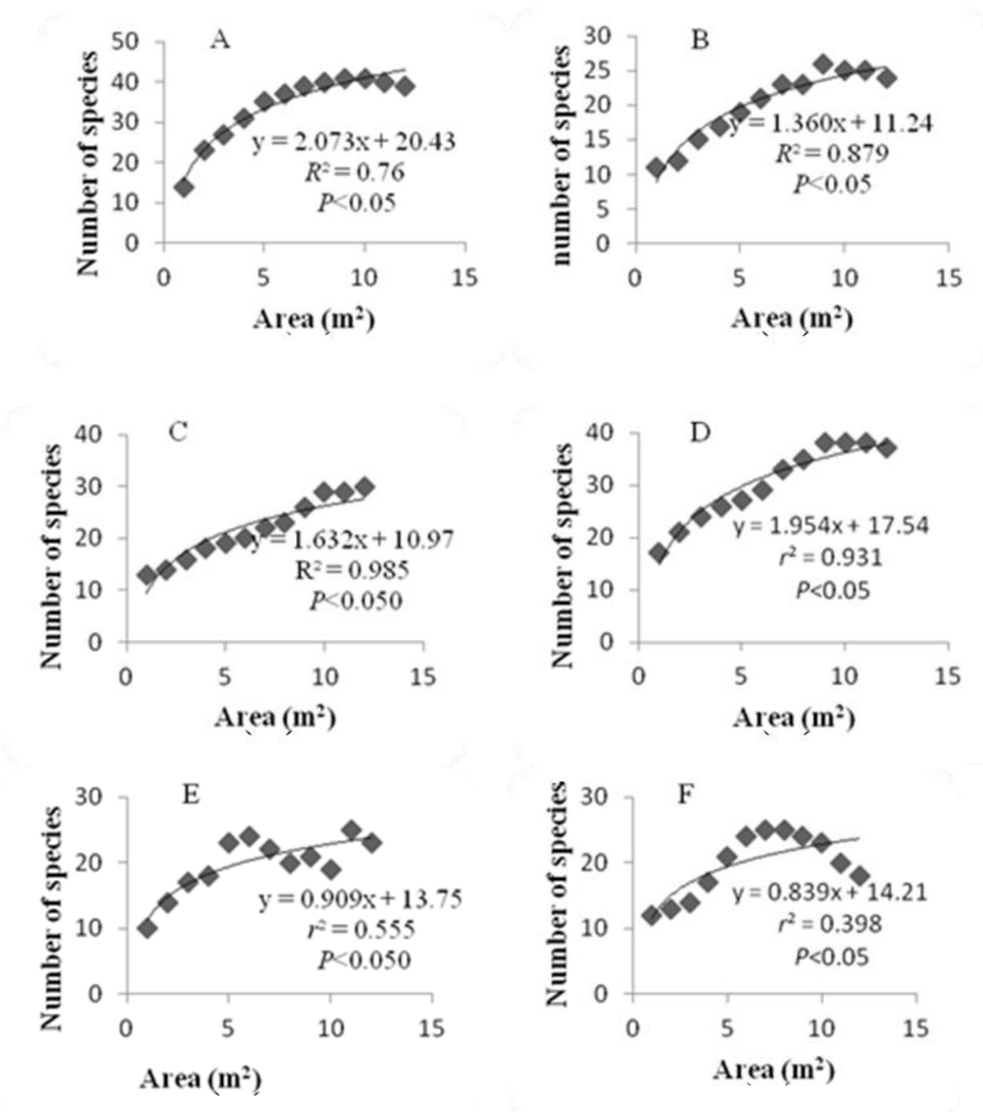


Figure 4.1: Relationship between plot size and species accummulation, among the six wetlands. The alphabets A-F, denotes the following wetlands: A = Wuntori; B = Bunglung; C = Adayili; D = Kukobila; E = Tugu; F = Nabogo. Notice that species accumulation does not generally correspond with increased sample quadrats

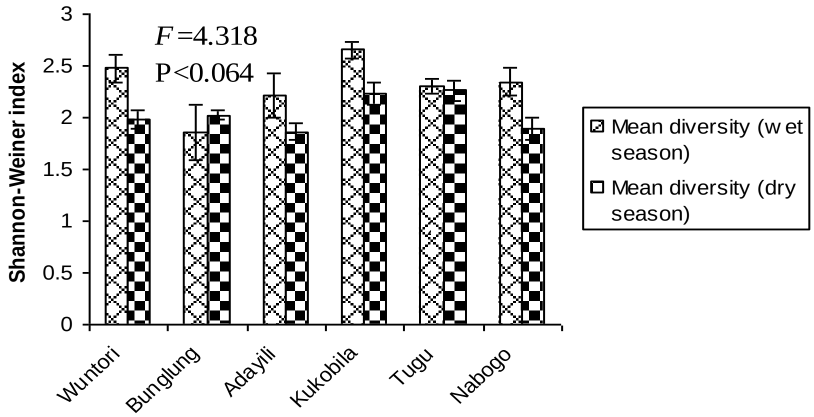


Figure 4.2: Plant community diversity index among the six wetlands in the dry and wet seasons

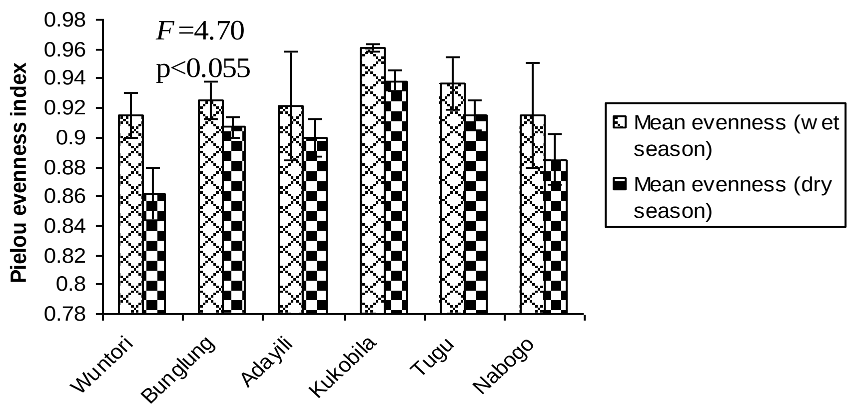


Figure 4.3: Seasonal variations in plant community evenness distribution across the six wetlands in dry wet season

Hydrophytic Plant Communities as Indicators to Range Shift of Species, Using the Dominance Ratio Approach

All 40 species identified and recorded were categorized as either obligate wetland species, facultative wetland (FACW), facultative species (FAC), facultative upland species (FACU) or obligate upland species (UPL) (Tiner, 1999; Cronk & Siobhan-Fennessy, 2001) (Tables 2). The basis of this classification was to determine which species were typical hydrophytes and dry land species and to subsequently quantify their dominance and frequency towards or away from the wetlands. Obligate wetland plants constituted 35%. Facultative wetland species were the most abundant species and represented 40% of the species sampled. Obligate species such as *Cyperus spacelatus* (Rottb.), *Nymphaea lotus*, *Ipomea aquatica* (Forssk) and *Pistia stratiotes* were usually found in the saturated zone of the wetlands. Out of the 16 species classified as facultative wetland plants, 15 species were found on the wetter fringes of the wetlands, while only one species (*Pennisetum polystachion*) was a little far away onto the dryland. Facultative species such as *Schizachyrium sanguineum*, *Cynodon dactylon* (Linn.) Pers. and *Syzygium guineense* (Wild.) D.C., constituted 32.5% (Table 2). Three out of the 13 facultative species (FAC), persisted well on the dry margins of the wetland zone, while eight species (20%) out of the 40 species sampled, constituted facultative upland species. Four out of the eight species thrived well in the wet zone (e.g., *Ludwigia hyssopifolia* (G. Don) Exell., while the remaining four were restricted to the drier areas of the wetland zone. A total of 11(27.5%) obligate upland (UPL) species were registered. All these species were typical of dry land weeds from derived savanna. Examples included: *Ziziphus abyssinica*, *Pennisetum polystachion* and *Helioptropium indicum* Linn.

Majority of species range shift occurred in Nabogo (14 sp.) and Adayili (10 sp.) riparian wetlands, while the Kukobila (6 sp.) and Bunglung (5 sp.) registered the least range shift (Table 3). From the 24 Whittaker plots sampled, 10 plots recorded an average of 1.3 OBL species/plot, 2 plots = 3.2 FACW species/plot, 4 plots = 3.25 FAC species/plot, 2 plots = 4 FACU species/plot and 3 plots = 3.6 UPL species/plot (Tab 4).

Assessment of animal dungs revealed that 14 seedlings (35%) of the 40 species sampled were identified as the same species occurring in the wetlands. Examples were *Pennisetum polystachion*, *Setaria pumila* (Poiret.) Roemer & Schultes, *Schizachyrium sanguineum, Echinochloa pyramidalis* (Retz.) P. Beauv.), *Saciolepsis Africana*, *Brachiaria mutica* and *Imperata cylindrica*. The prevalence index method, showed that the tendency of plant species from the four indicator status categories (FACW; FAC; FACU and UPL) to shift towards wetter areas were greater (+) compared to a shift towards drier areas (-) (F =3.33; p=0.117) (Fig. 4.4). Below were the results of indicator species under the following categories among the six wetlands:

Table 2: Plant species showing the application of Cronk and Siobhan-Fennessy (2001) and Tiner (1999) model to categorize species under different indicator status* = dryland weeds of arable and plantation crops/derived savanna. Indicators of frequency species shifting towards wetter areas is denoted by (+) and towards drier areas by (-) signs

Obligate wetland sp.	Facultative wetland sp.	Facultative sp.	Facultative upland sp.	Obligate Upland sp.
Cyperus difformis	*Cynodon dactylon +*	*Brachiaria mutica +*	*C. retusa* -*	*C. retusa*-*
Cyperus spacelatus	*Deplachne fusca*+*	*Crotalaria retusa*-*	*E. pyramidalis+*	*Deplachne fusca*+*
Cyperus distans	*Echinochloa stagnina +*	*Cynodon dactylon+*	*Imperata cylindrica*-*	*H. indicum *+*
Ceratophyllum demersum	*Echinochloa pyramidalis+*	*Deplachne fusca*+*	*H. indicum*+*	*I. cylindrica*-*
Eleocharis mutata	*Fimbristylis ferruginea*+*	*E. pyramidalis+*	*Ludwigia hyssopifolia*+*	*Khaya senegalensis-*
Ipomea aquatica	*Helioptropium indicum*+*	*H. indicum*+*	*Mormodica chrantia*-*	*L. hyssopifolia*+*
Ludwigia octovalvis	*Leersia hexandra+*	*P. polystachion*-*	*P. polystachion * -*	*M. chrantia* -*
Neptunia oleracea	*Ludwigia hyssopifolia*+*	*Salacia reticulate+*	*S. sanguineum*+*	*P. polystachion *-*
Nymphaea micrantha	*Mitragyna inermis+*	*Scoparia dulcis*+*	*S. sanguineum* +*	
Oryza longistaminata	*Mimosa pigra+*	*Schizachyrium sanguineum*+*	*S. pumila*+*	
Polygonium salicifolium	*Pennisetum polystachion*-*	*Syzygium guineense+*	*Z. abyssinica -*	
Paspalum varginatum	*Phyllanthus amarus +*	*Vitex crysocarpa+*		
Pistia stratiotes	*Scoparia dulcis*+*	*Ziziphus abyssinica -*		
	Setaria pumila+*			
	Saciolepsis Africana +			
	Salacia reticulate +			
32.5%	40%	32.5%	27.5%	20%

Table 3: Number of identified plant species that shifted to and from the six wetlands

Wuntori	Bunglung	Adayili	Kukobila	Tugu	Nabogo
*Deplachne fusca**+	*D. fusca**+	*D. fusca**+	*M. pigra+*	*C. dactylon+*	*D. fusca**+
Echinochloa pyramidalis+	*Cynodon dactylon+*	*L. hexandra+*	*M. chrantia**-	*D. fusca**+	*I. cylindrica**-
*Helioptropium indicum**+	*L. hexandra+*	*M. pigra+*	*D. fusca**+	*E. stagnina+*	*K. senegalensis-*
Leersia hexandra+	*M. chrantia**-	*M. inermis+*	*S. dulcis**+	*H. indicum**+	*L. hexandra+*
Mimosa pigra+	*Scoparia dulcis**+	*S. dulcis**+	*S. sanguineum**+	*M. chrantia**-	*M. chrantia**-
*Mormodica chrantia**-	*Setaria pumila**+	*S. sanguineum**+		*M. pigra+*	*M. pigra+*
Mitragyna inermis+		*Ziziphus abyssinica-*		*M. inermis+*	*M. inermis +*
*Scoparia dulcis**+		*S. guineense+*		*P. amarus+*	*P. polystachion**-
*Schizachyrium sanguineum**+		*Vitex crysocarpa+*		*S. dulcis**+	*P. amarus +*
		Salacia reticulate+		*S. sanguineum**+	*S. sanguineum**+
					S. reticulate+
					S. guineense+
					V. crysocarpa+
					Z. abyssinica -
9	6	10	5	10	14

Table 4: Summary of indicator species categories, showing their relative abundance of dominance among the 24 Whittaker plots

Indicator species status	No. of sp.	No. of plots dominated	Av. Sp./plot	
Obligate wetland species (OBL)	13	10	1.3	< 3.0
Facultative wetland species (FACW)	16	5	3.2	> 3.0
Facultative species (FAC)	13	4	3.25	
Facultative upland species (FACU)	8	2	4.0	
Obligate upland species (UPL)	11	3	3.6	
Number of Whittaker plots		24		

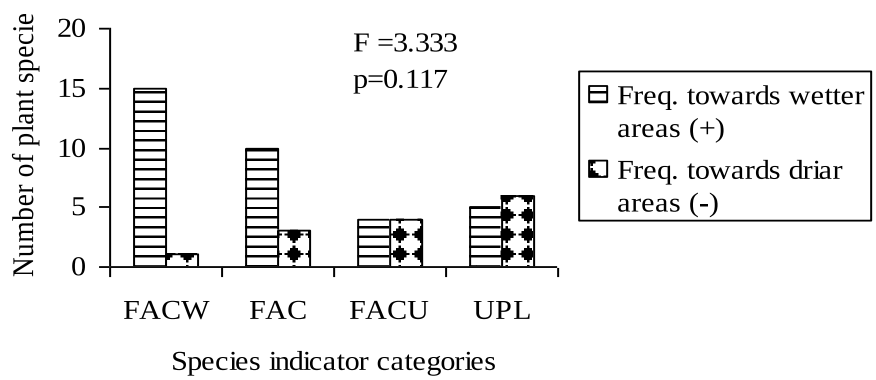


Figure 4.4: **Indicator species status showing the frequency of species shift towards wetter and drier areas. The abbreviations denote the fallowing: Facultative wetland plants (FACW); Facultative plants (FAC); Facultative upland plants (FACU) and Obligate upland plants (UPL)**

Determinants of Aquatic Plants Structure and Pattern of Distribution

Similarity in ground cover composition among wetlands

Four different plant communities were identified as a result of spatio-temporal changes in ecological variables and anthropogenic-led activities, namely hydric soil nutrient status, bushfire, farming activities, erosion and grazing intensity. They included: (a) the forest communities of the riparian zones; (b) the grassland communities of the floodplain marshes; (c) the herbaceous communities of the floodplain marshes and (d) shrub land communities.

Hierarchical cluster analysis and detrended correspondence analysis (DCA) separated aquatic plants into three floristic associations across the six wetlands, based on variations in plant community and wetland types (Figures 4.5 & 4.6). The descriptions of the three floristic associations are as follows:

Cluster 1: Plant species in these sample plots cluster, were predominantly grassy-herbaceous community and characterized by standing floodplain marshes of Wuntori, Kukobila and Tugu. Some of the indigenous plant species common in these wetlands, as shown in DCA ordination were *Ceratophyllum demersum, Cyperus spacelatus* (Rottb), *Eleocharis mutata*, *Glinus oppositifolius*, and *Ludwigia octovalvis* (Jacq.) Raven (Figures 4.6). The pattern of plant community distribution was mostly influenced by the degree of tolerance to continuous inundation. Species like *Cyperus spacelatus* (Rottb), *Eleocharis mutata* and *Oryza longistaminata* were much closer to the permanent wet zone of the wetland, followed by successive species that were less tolerant to permanent wetness (e.g., *Deplachne fusca, Echinochloa pyramidalis* and *Lersia hexandra*). Submerged plants such as *Ceratophyllum demersum*, formed a maze of intertwined below the surface of the water level. This was the only dominant submerged species in all the three marsh wetlands. With exception of Kukobila wetland, the remaining two wetlands were characterized by a maze of emergent or floating aquatic plants (e.g., *Nymphaea lotus* Linn. and *Glinus oppositifolius*, which virtually created a closed water system.

Ground cover in both Wuntori and Kukobila wetlands were denser compared to Tugu wetland. Though the first two wetlands were characteristic of marsh wetlands, there were pockets of shrubs such as *Mitragyna inermis* and *Salacia recticulate* that were sparsely distributed. These shrubs were restricted to the fringes of the wetlands and served as nesting sites for birds, while a portion of their stem bole beneath the water surface also served as breeding grounds for fish. Major environmental drivers of change common among these clustered wetlands were rill erosion, fire, farming activities, grazing intensity and animal trampling.

Clusters 2: Plant communities from these sample plots, were largely from the artificial wetland (Bunlung wetland) with the exception of one Whittaker plot (KUD) from Kukobila wetland that was grouped alongside plots from the said wetland (Figure 4.5). Bunlung wetland was dominated by grassland community alongside a relatively small herbaceous layer. Almost all Whittaker plots sampled had a fair percentage representation of herbaceous cover. The dominant grass species were *Cynodon dactylon* and *Deplachne fusca,* while *Polygonium salicifolium* Brouss. ex. Wiild and *Neptunia oleracea* constituted the herbaceous cover recorded in the Bunglung wetland (Figure 4.6). Both tree species and shrubs were absent. Previous burnt tree stumps and grass tussocks were found in some of the plots. Farming and tree felling were the major anthropogenic activities being carried out all year round. Textural class of the hydric soils in Bunglung wetland was high in sand (57.72%) compared to the ratio of silt: clay% (12.36% silt : 29.92% clay).

Clusters 3: Sample plots in this cluster were from the permanent swamp forest communities of Adayilli and Nabogo wetlands and characterized by dense fringing forest along the banks of the wetlands (Figure 4.5). Grass and herbaceous communities were relatively less and confined to the undergrowth of the dense shrubs, largely dominated by *Syzygium guineense* (Wild) D.C., *Vitex crysocarpa* (Planch. Ex Benth), *Salacia reticulate, Ziziphus abyssinica* and *Mitragyna inermis*. The grass species were represented by *Schizachyrium sanguinum*, *Lersia hexandra* and *Deplachne fusca*. *Scoparia dulci* was the least herbaceous species that was registered under this cluster of plots. Tree species were naturally arranged according to the tolerance level of water saturation. While *Syzygium guineense* (Wild) D.C and *Salacia reticulate* had a quarter of their stems submerged, *Vitex crysocarpa* (Planch. Ex Benth), *Ziziphus abyssinica* and *Mitragyna inermis*, were at a much higher ground along the fringes of the riparian zone. Stream bank erosion and grazing intensity were the main environmental drivers of change observed within the wetland zone. Eigenvalues generated from DCA ordination for ground cover, showed a strong species-site relationship in the first axis (Axis 1 = 0.79) compared to the second axis (Axis 2 = 0.37).

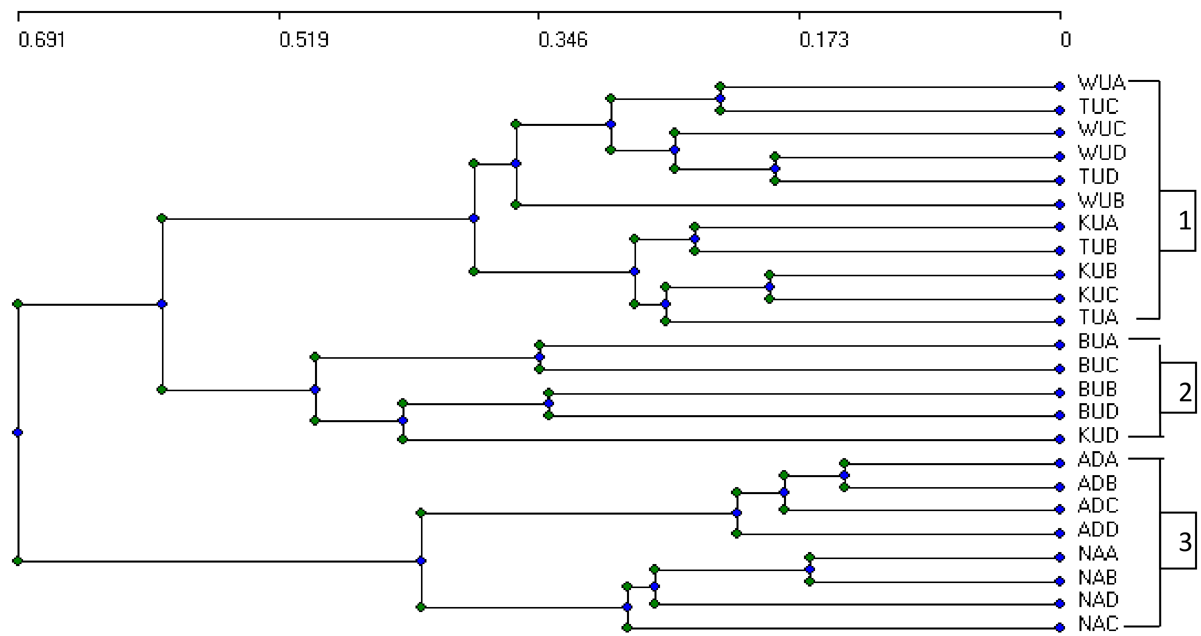


Figure 4.5: Hierarchical Cluster Analysis (HCA) dendrogram showing three clusters of plant communities based on similarity in ground cover. The abbreviations denote different sample plots in the six wetlands. Plot codes WUA-WUD represented sample plots from Wuntori wetland at Yapei; TUA-TUD represents sample plots from Tugu wetland in the Eastern corridors; KUA-KUD in Kukobila wetland; BUA-BUD in Bunglung wetland; ADA-ADD in Adayilli wetland and NAA- NAD in Nabogo wetland

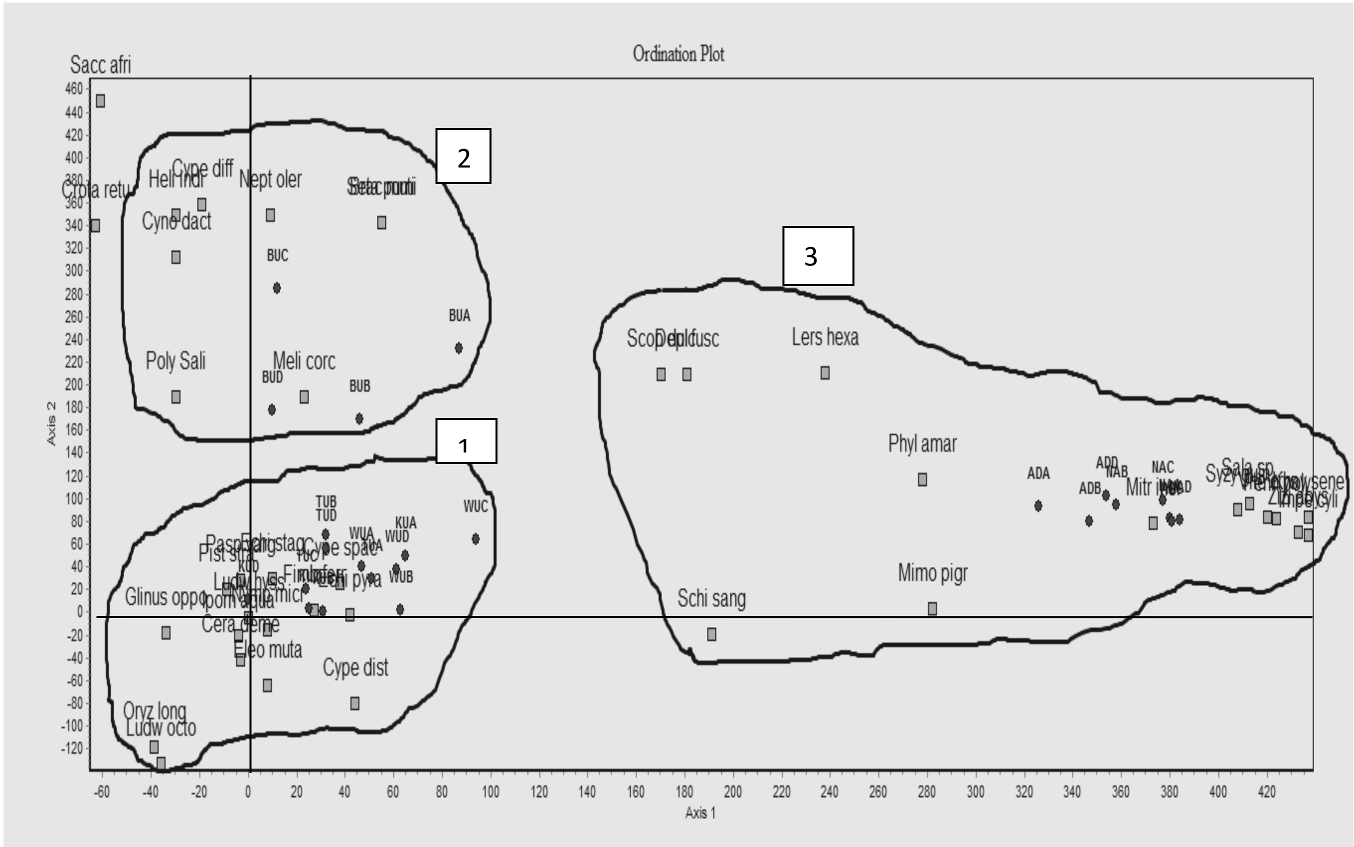


Figure 4.6: A species-site biplot DCA ordination showing similarity in ground cover separated into three groups along axes I & II. The ordination diagram shows the species and sample sites relationship in all six wetlands. The abbreviations represent sample plots and the associated plant species. The squares denote plant species, while the circles denote saple plots

Similarity in the distribution pattern of plant height among wetlands

Hierarchical cluster analysis and DCA ordination separated aquatic plants into four floristic groups across the six wetlands, based on variations in plant community height (Figures 4.7 & 4.8). The descriptions of the four plants associations are as follows:

Cluster 1: Sample plots in this group were from Wuntori (three plots) and Tugu wetlands (two plots) and characterized by trees, shrubs and grass plant communities. Examples included: *Schizachyrium sanguinum* (family graminae), *Mimosa pigra* (family mimosaceae) and *Mitragyna inermis* (family rubiaceae). On average, *Deplachne fusca* and *Schizachyrium sanguinum* grew up to 2.4 m high, *Mimosa pigra* (3.3 m high) and *Mitragyna inermis* (6.2 m high). These plants were rarely found in the high saturated zone of the wetlands, but were rather confined to the edges of the wet zones. *Mimosa pigra* (thorny and sensitive to touch) occupied a larger portion of the Kukobila wetland. Some reptiles (pythons and crocodiles) and birds (e.g., marsh warblers and red-headed quelea) were found sheltering under the dense intertwined branches of the plant.

Cluster 2: Plant community in this group was not different from clusters 1 and 3, except that there were no species represented in the DCA ordination diagram from the graminae family (Figure 4.8). With the exception of one sample plot from Wuntori wetland, the remaining three plots were from Kukobila wetland. Species from the plot in Wuntori wetland shared some height similarities with species in plots from Kukobila wetland. Plant species from these plots were grasses and herbs.

Cluster 3: floristic compositions in plots were from Bunglung, Kukobila and Tugu wetland systems. Herbaceous plant community such as *Pistia stratiotes*, *Nymphaea lotus*, and *Polygonium salicifolium*, largely dominated in these sample plots, with fewer grass species (e.g., *Oryza longistaminata* A. Chev. & Roehr) and sedges (*Cyperus spacelatus* Rottb.) (Figure 4.8). With the exception of the dominant rice plant (*Oryza longistaminata* A. Chev. & Roehr) that was located mid-way in the saturated zone all other species from the graminae family were located a further away from the main saturated zone of the wetland. The distribution of water lettuce (*Pistia stratiotes*) was extremely limited, as they were only present in one out of the ten 1 m^2 sub-quadrats. *Cyperus spacelatus* Rottb. was the most common occurring plant in the sample plots. On average, the height of the sedges was 77 cm, while the grasses were about 1.12 m.

Cluster 4: Plant species in this cluster were predominantly trees and shrubs from the Adayilli and Nabogo riparian wetlands. Tree distribution pattern showed a gradual decrease in height, from the top of the embankment to the bottom of the stream bank close to the water surface. Shrubs like *Syzygium guineense* (Wild) D.C, *Vitex crysocarpa* (Planch. Ex Benth) and *Salacia reticulate* that had a greater part of their stem beneath the water surface, appeared lush green compared to the *Ziziphus abyssinica* that had its stem barely submerged. *Pennisetum polystachion* was the only grass species that clustered among the tree species. Shrubs which were very close to the water level (e.g., *Syzygium guineense* (Wild) D.C.) served as a hiding place for crocodiles and other resptiles. Drooping branches of trees and shrubs (plate 4.7) were used by fishermen to anchor their canoes, when they were not fishing. On average, the maximum height of the tree species was 6.5 m. Eigenvalues from DCA ordination, indicated a strong species-site relationship in the first axis (Axis 1 = 0.66), while the second axis showed a rather weak relationship (Axis 2 = 0.17).

Plate 8: **Adayilli wetland showing some of the drooping branches of the tree species lined up along the banks of the wetland**

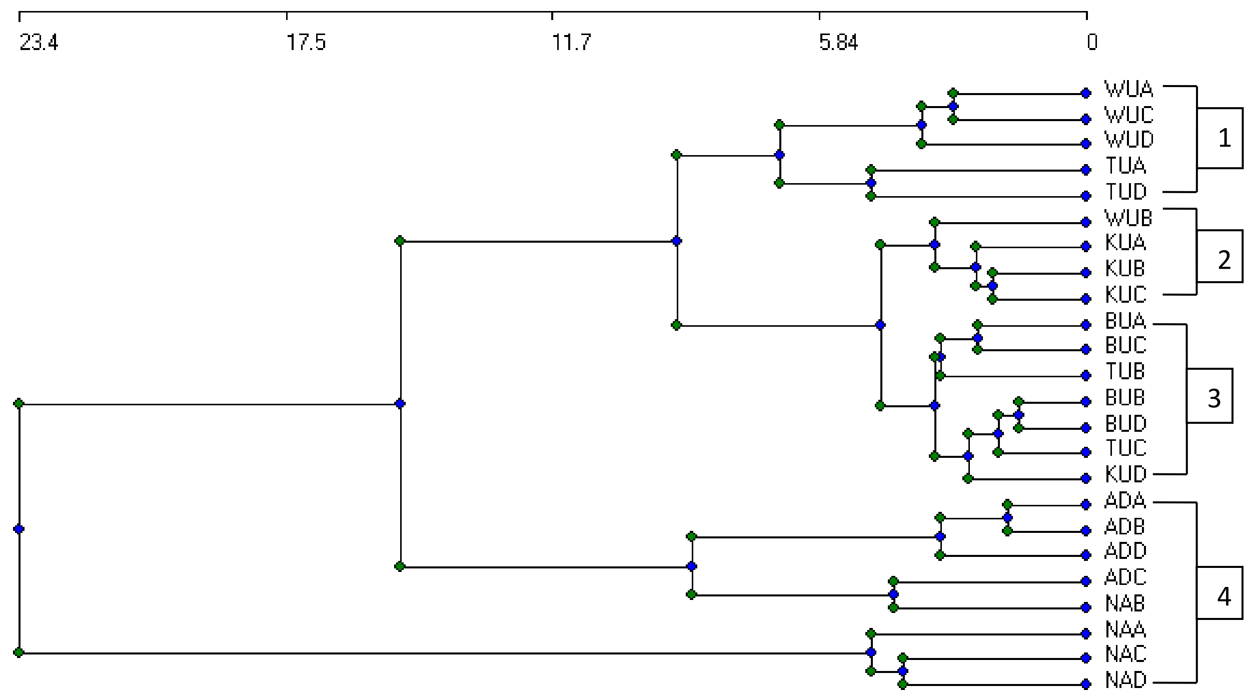


Figure 4.7: Hierarchical Cluster Analysis (HCA) dendrogram showing four clusters of hydrophytes based on plant height. The abbreviations denote different sample plots in the six wetlands clustered on the basis of similarity in plant height as indicated in Figure 4.5

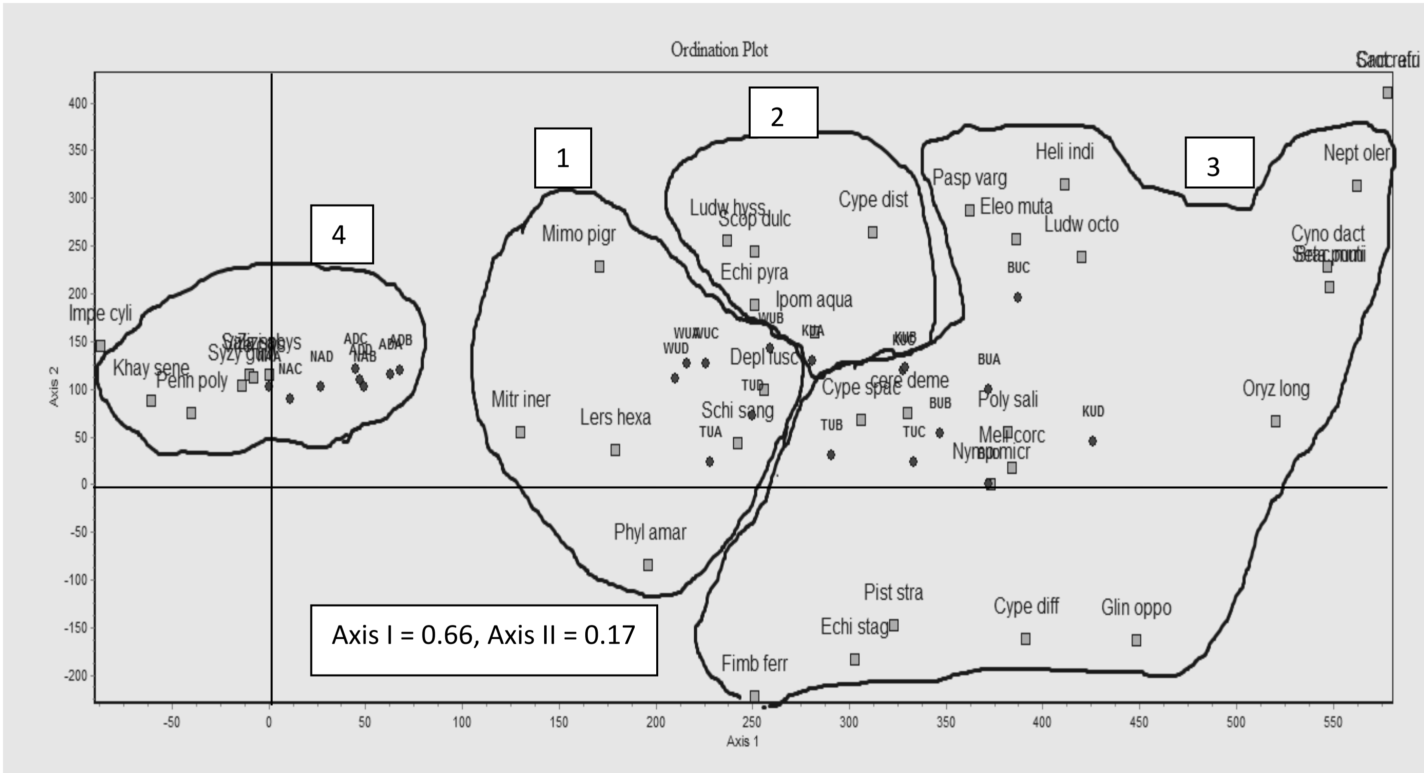


Figure 4.8: **A species-site biplot DCA ordination showing the similarity in plant height, separated into four groups along axes 1 and 2. The ordination diagram shows the species and sample sites relation in all six wetlands. The abbreviations represent sample plots and the associated plants as indicated in Fig. 4.7**

Environmental Drivers of Change as Predictors of Aquatic Plant Assemblage, Composition and Distribution among the Six Wetlands

General observation from canonical correspondence analysis (CCA) ordination diagram revealed farming activities, bushfire, magnesium, soil pH, phosphorus, potassium and nitrogen (Figure 4.9, Table 5) as the major environmental factors that influenced community composition and distribution among the six wetlands. CCA analysis diagram showed the various groups of plant communities' distribution according to the type of environmental mediating factors and the type of wetland sampled. The dominant hardwood communities (e.g., *Vitex crysocarpa* Planch. Ex Benth. and *Salacia reticulate*) from the swamp forest of Adayilli and Nabogo were located on the left half of the ordination diagram, with few grass species (*Pennisetum polystachion* (L.) Schultes and *Imperata cylindrica*).

Both wetlands had significant portions of their stream banks eroded, with scars from current and previous burnt undergrowth. The eroded parts of the stream banks lacked ground cover, and even in areas where some amount of ground cover was recorded, they were mostly invaders. Erosional features such as gullies, rill and channel incision, were prominent in areas that had less ground cover. Incidences of bushfire were common, as farmers in the community periodically used fire to clear the grasses and shrubs along the stretch of the wetlands for farming purposes. The arable farms at Nabogo wetland for instance, were a little over 100 m away from the stream banks, while the dry season vegetable farms were approximately 20 m away from the main wetland zone. It was also noted in the diagram that *Syzygium guineense* (Wild) D.C. *Salacia reticulate* and *Ziziphus abyssinica* strongly correlated with fire and erosion intensity, while *Vitex crysocarpa* Planch. Ex Benth, *Khaya senegalensis, Pennisetum polystachion* (L.) Schultes, *Imperata cylindrica* and *Phyllanthus amarus* Schum. & Thonn were the least influenced by fire and erosion intensity, but rather by soil pH.

The matrices of the species-site biplot generated by the CCA (Table 5) suggested that fire and soil pH for axis I and potassium for axis II, were the most important ecological variables influencing the distribution of plants. Although erosional features were observed in the two riparian wetlands, their severity was not widespread as this was evident in the rather weak correlation on both axes I and II (Table 5). Canonical coefficients of these variables, correlated significantly ($t = -0.6024$; $p<0{\cdot}05$) for axis I and axis II (approximate *t*-test, ter Braak, 1987).

Herbaceous and grassland communities (e.g., *Cynodon dactylon* (Linn.) Pers., *Meliochia corchorifolia* Linn, *Lersia hexandra*, *Cyperus difformis* Linn, *Sacciolepsis Africana* Hubb. & Snowden and *Helioptropium indicum* Linn.) from Bunglung wetland were found on the right half of the diagram. The wetland had high amount of magnesium from the hydric soil and disturbed by farming activities. In Figure 4.9, it was observed that *Sacciolepsis Africana* C.E. Hubb. & Snowden. *Crotolaria retusa*, *Helioptropium indicum* Linn. and *Cynodon* *dactylon* (Linn.) Pers. were strongly correlated with farming activities ($p<0\cdot05$) along axis I, whereas *Polygonium salicifolium* Brouss. ex. Wiild., *Lersia hexandra* and *Neptunia oleracea* Lour were the least influenced by faming activities. However, *Polygonium salicifolium* Brouss. ex. Wiild., *Lersia hexandra* and *Neptunia oleracea* rather showed a strong association with magnesium on axis I ($p<0\cdot05$). *Polygonium salicifolium* Brouss. ex. Wiild. and *Lersia hexandra Neptunia oleracea* were not recorded in plots that were randomly laid in farmed areas. Their distributions were only limited in plots that were close to the saturated zone. With the exception of obligate species like *Cyperus difformis* Linn. and *Polygonium salicifolium* Brouss. ex. Wild, the rest of the species were from derived savanna and mostly associated with disturbed terrestrial areas. The fringes of Bunglung wetland was heavily farmed all year round. There was patchiness in all plots that species were recorded. Tree stumps were visible within a 100 m radius of the wetland, where the land was put under cultivation. Animals from neighbouring communities used the wetland for both grazing and watering point. Soil structures were disturbed by animal tramplings in sample plots that were heavily grazed. Finally, species typical of natural marsh wetlands of Kukobila, Wuntori and Tugu (*Ceratophyllum demersum, Eleocharis mutata*, and *Nymphaea micrantha)* were located at upper centre of the CCA diagram. Majority of species not represented in the ordination diagrams grew in habitats with average conditions of the environmental factors investigated.

Floristic composition from the natural marsh wetlands of Wuntori, Kukobila and Tugu was shown to have reasonably high nitrogen, phosphorus, potassium and calcium. Of the species captured in the ordination diagram, herbaceous layer and grasses constituted 72.72% and 27.27% respectively. Some of the herb species were made up of *Ipomea aquatica* (Forssk), *Pistia stratiotes* and *Polygonium salicifolium* while grasses were *Paspalum varginatum* and *Schizachyrium sanguineum.* Though these wetlands experienced some level of disturbances like bushfire and grazing, they were not severe and widespread. Two plots in Tugu wetland were marginally grazed with some isolated patchy conditions. There were few boulders and animal trampling in some plots at Kukobila wetland, while two plots in Wuntori wetland was characterized with scars of fire on the vegetation. Livestock from neighbouring communities used the wetlands as their grazing and watering points, especially during the dry season.

Cumulative percentage variance of the joint ground cover data and environment relationship was well explained by the first two axes of the CCA ordination (axis I = 24.84 and axis II = 36.45). The two axes accounted for 61.29% of the variation in the weighted averages of the 40 species in relation to 11 environmental factors (Table 6). Since axes I and II accounted for more 50% of the variation in ground cover data, as recommended by ter Braak (1986, *cited in* Kent and Coker, 1992), axes III and IV were not considered. Eigenvalues generated by the first two axes of all 24 plots were 0.733 and 0.342 (Table 6).

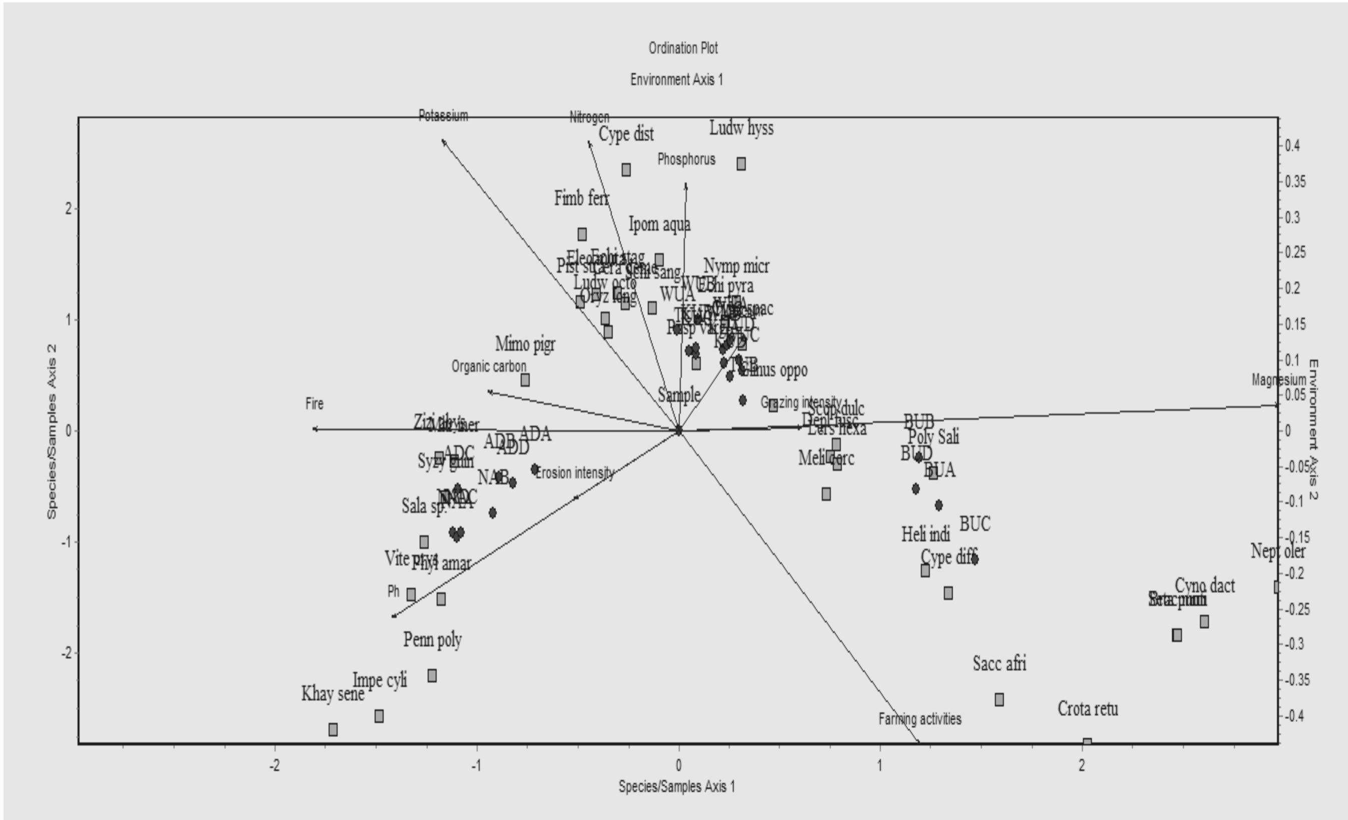


Figure 4.9: Canonical correspondence analysis (CCA) ordination diagram, showing the relationship between environmental factors and ground cover in the six wetlands. The green squares represent plant species, the red circles represent sample sites and the arrows represent each of the environmental variables plotted pointing in the direction of maximum change of explanatory variables across the six wetlands

Table 5: Canonical coefficients and the correlations with the first four axes of the environmental variables of the canonical correspondence analysis (CCA) for the six sites. * Significant p<0.05

	Axis 1	Axis 2	Axis 3	Axis 4
pH	-0.367*	-0.261	0.065	-0.024
Organic carbon	-0.244	0.056	0.153	0.105
Nitrogen	-0.115	0.405*	0.163	0.106
Phosphorus	0.009	0.346*	0.233	0.038
Potassium	-0.303*	0.406*	0.045	0.199
Calcium	0.085	0.132	-0.139	0.005
Magnesium	0.772*	0.035	-0.101	0.123
Fire	-0.469*	0.002	-0.197	-0.079
Grazing intensity	0.157	0.005	0.167	-0.186
Erosion	-0.134	-0.095	0.127	-0.065
Farming activities	0.311*	-0.441*	0.075	0.060

Table 6: Summary of CCA axis lengths for ground cover, showing the levels of correlation between axes and environmental gradients, percentage variance of species and species-environment relationships

	Axis1	Axis2	Axis3	Axis 4
Canonical eigenvalues for cover	0.733	0.342	0.198	0.165
Pearson correlation sp-envtal scores	0.81	0.88	0.84	0.82
Kendall rank correlation sp.-envtal	0.48	0.69	0.48	0.67
Cumulative percentage variance	24.84	36.45	43.16	48.74
% variance explained	24.84	11.6	6.71	5.84
Number of species (response variables)	40			
Number of environmental variables	11			
Total variance in species data	2.951			

Plates 8 – 12 below showed some of the observed anthropogenic disturbances that were across the six wetlands.

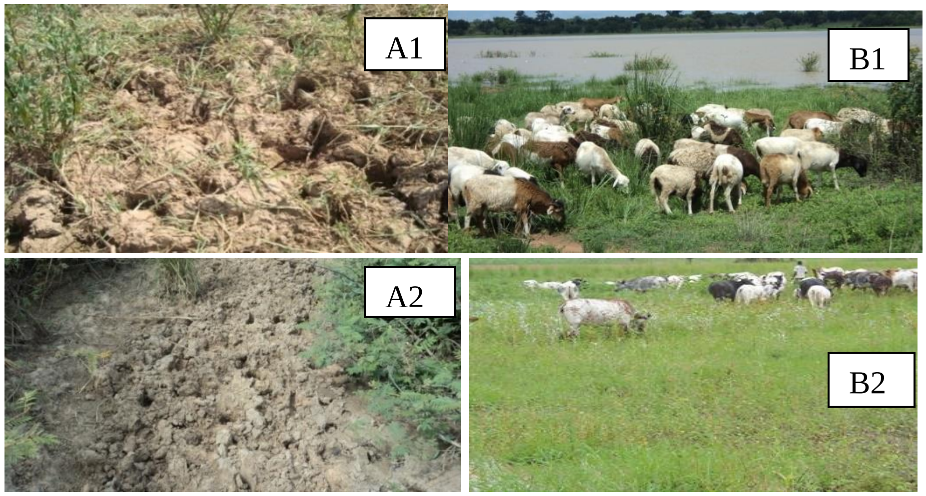


Plate 9: (A1 & A2): Kukobila wetland showing soil disturbance as a result of animal trampling during grazing and (B1 & B2) livestock grazing on the fringes of the wetland in the dry season

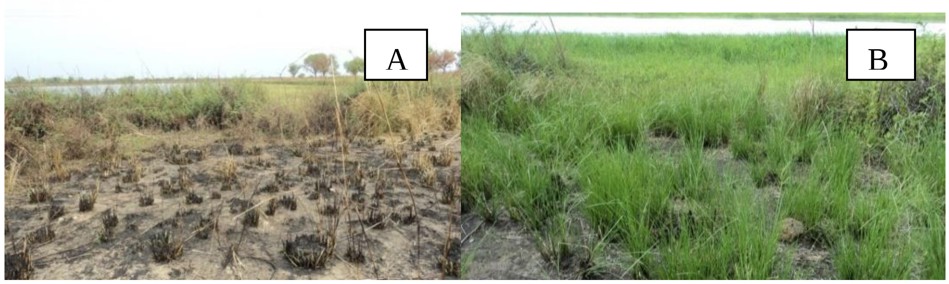


Plate 10: (A): Kukobila wetland showing the burnt portion of the wetland zone in the dry season and (B) the gradual recovery of the burnt portion in the wet season

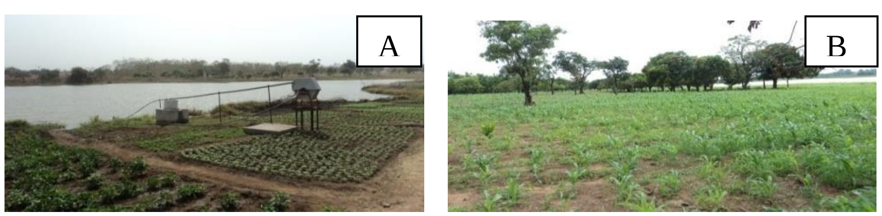


Plate 11: **Bunglung wetland showing (A) dry season irrigation activities and (B) maize farm in the wet season on the periphery of the wetland**

Plate 12: **Kukobila wetland showing (A) water level in the peak of wet season (August-September) in 2011 and (B) draining for dry season irrigation activities, which resulted in the formation of (B1) desiccated hydric soil in April 2012**

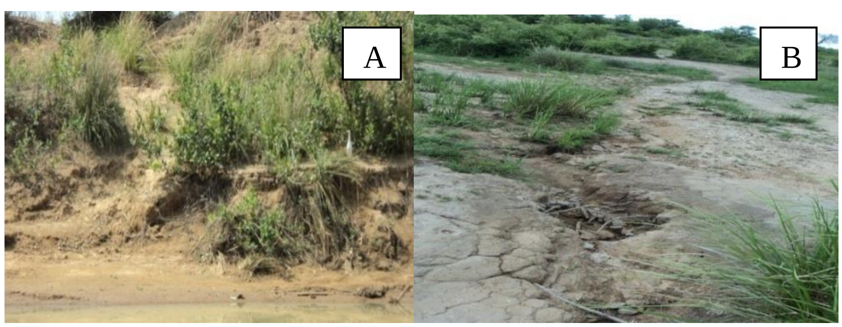


Plate 13: Portions of (A) Adayili and (B) Nabogo wetlands Showing eroded streambanks, less ground cover and bare ground

Seasonal Variations in Fish Composition and Distribution among the Six Wetlands

Fish composition and abundance in the six wetlands were generally high in the dry season compared to the wet season (Figure 10). A total of 2, 239 44 species belonging to 16 families were sampled in the dry season, while 1, 938 individuals belonging to 41 species from 12 families were identified during the wet season (Figure 4.11; Appendix C). A total of 44 species belonging to 16 families were sampled in the dry season, while. The mean number of individuals for the dry season (428±95.74) and wet seasons (323±101.14) were not significantly different (F = 3.411, p>0.05). The highest dominance of fish families were sampled in the riparian wetlands of Adayili (23%) and Nabogo (21%), while Bunglung was the least encountered (10%) (Figure 4.11a) in the dry season. Wuntori, Kukobila and Tugu wetlands, respectively had 19%, 14% and 13% numerical composition of fish families in the same season. Five species from three families (Cichlidae, Cyprinidae and Alestidae) were sampled in more than half of the six wetlands and included: *Brycinus nurse, Sarotherodon galilaeus* and *Labeo coubie*. *Sarotherodon galilaeus* was the only species that was registered in all the six wetlands. A total of 19 individuals (40.91%) out of the 44 fish species were the least sampled in each of the six wetlands. Examples of these species were: *Alestis beremoze, Chromidotilapia guntheri*, *Heterotis niloticus,* and *Polypterus endlicheri.*

For the wet season, Wuntori wetland recorded the highest number of fish families (23%), while Tugu shallow marshland recorded the least (13%) (Figure 4.11b). Nabogo and Adayilli had the same percentage representation (17%), while Bunglung and the natural deep marsh of Kukobila recorded the same numerical composition (15%) of fish families. The dominant species that were encountered in more than half of the wetlands belong to eight families (Cichlidae, Cyprinidae, Alestidae, Clariidae, Claroteidae, Mochokidae, Mormyridae and Schilbeidae) (Figure 4.12a & b). They included: *Oreochromis niloticus, Auchinoglanis occidentalis, Clarias anguillaris, Synodontis schall* and *Schilbe intermedius* (Figure 13a & b). A total of 17 species (42.5%) of the 40 species registered, were the least recorded in each of the six wetlands. Examples were: *Brycinus macrolepidotus, Hippopomyrus paugyi, Mormyrops deliciosus, Raimas nigeriensis* and *Parachanna obscura. Labeo senegalensis* was the only species recorded in all the six wetlands.

In general, species richness provided by Margalef index (D), indicated a higher mean richness in the dry season (2.395±0.366) compared to the wet season (2.354±0.738) (Figure 4.14). The richness index further showed that both Nabogo (D = 2.548) and Adayili (D = 3.755) wetlands were the most rich in species for the dry season, followed by Wuntori wetland (D = 2.245). However, in the wet season, Adayili (D = 3.355) and Wuntori (D = 3.133) wetlands were the richest in species. Among the three natural marsh wetlands, Wuntori consistently recorded the highest species richness, followed by Kukobila and Tugu wetlands, in both dry and wet seasons (Figure 4.14).

Similar trend was also observed in fish diversity. Community composition was relatively higher in the dry season ($H' = 2.395 \pm 0.366$) than in the wet season ($H' = 2.354 \pm 0.738$) ($F = 0.11$, $p < 0.05$) (Figure 4.15). The moderately high diversity in the two seasons was followed by an increase in evenness spatial distribution for the dry season ($J = 0.906 \pm 0.016$) and wet season ($J = 0.933 \pm 0.020$) (Figure 4.16). Though the mean evenness was < 1, the results showed a progressive increase in evenness distribution of fish species from the riparian wetlands to the marshlands and finally to the constructed wetlands.

Fish diversity was much higher in Nabogo ($H' = 2.544$) and Adayili ($H' = 2.851$) wetlands in the dry season. However, in the wet season, Wuntori wetland was the most diverse ($H' = 2.8630$), and closely followed by the two riparian wetlands of Nabogo ($H' = 2.521$) and Adayili ($H' = 2.73$). Bunglung wetland, was the least diverse in the dry ($H' = 1.753$) and wet seasons ($H' = 2.261$).

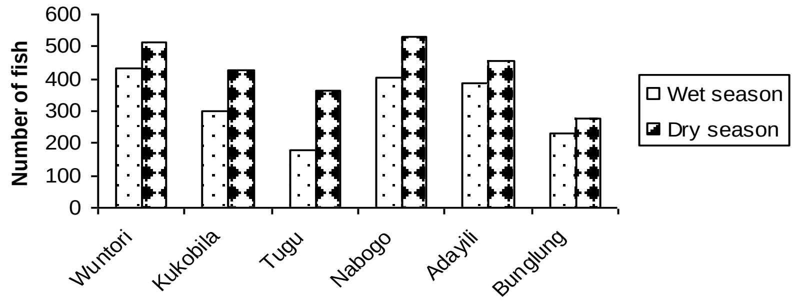


Figure 4.10: Seasonal variations of fish abundance in the six wetlands

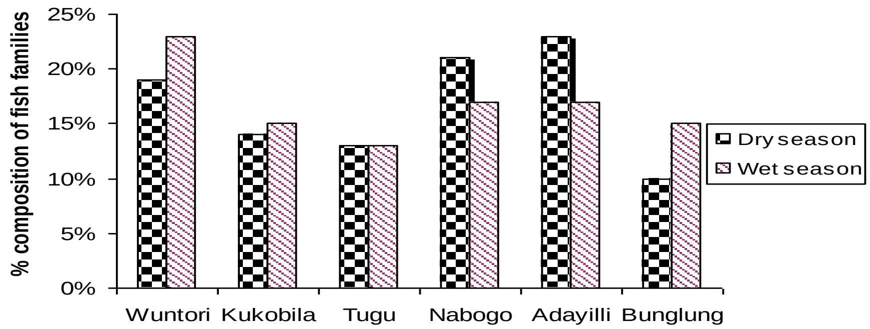


Figure 4.11: Composition of 16 fish families from each wetland in the dry season and 12 fish families in the wet season

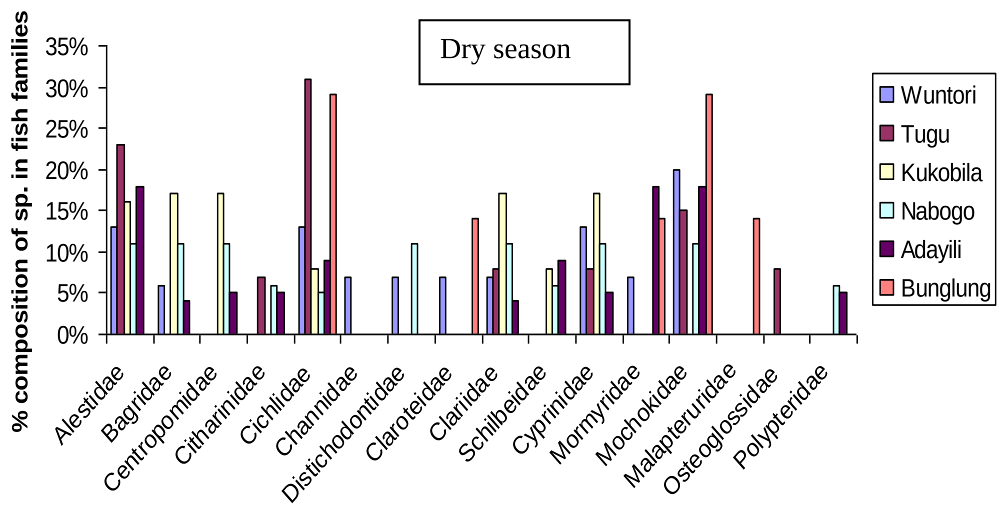


Fig 12a: **Percentage numerical compositions of fish families in each of the six wetlands in the dry season**

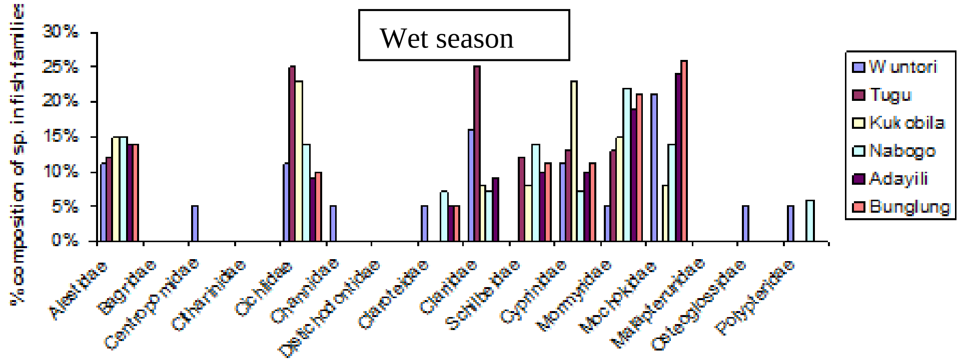


Figure 4.12b: **Percentage numerical compositions of fish families in each of the six wetlands in the wet season**

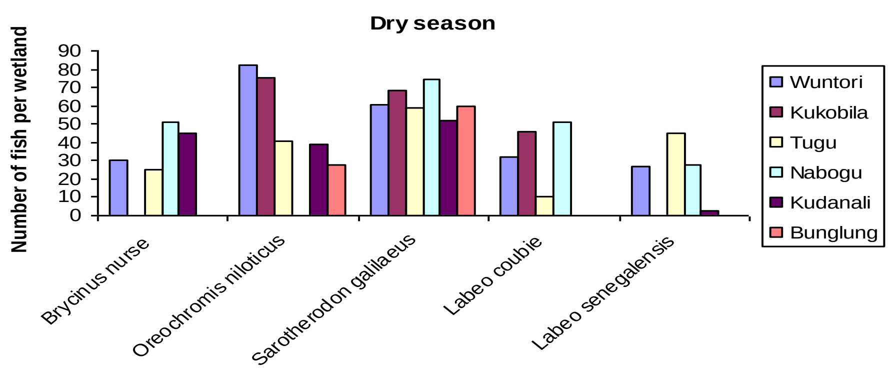


Figure 4.13a: **Frequency of different species recorded in more than half of the six wetlands in the dry season**

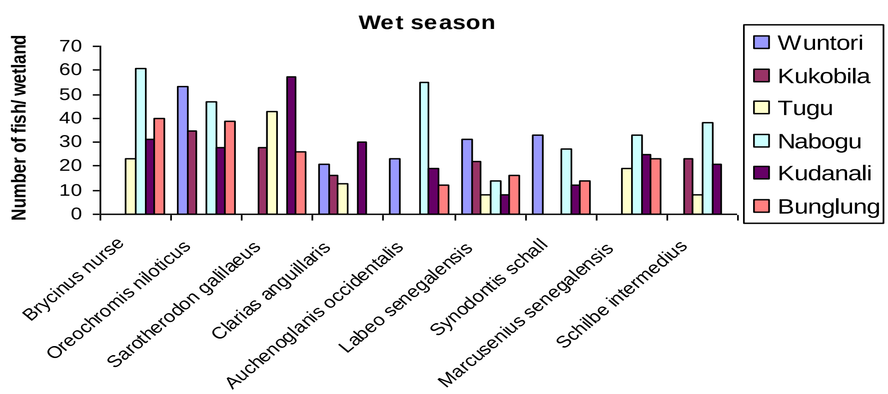


Figure 4.13b: Frequency of different species recorded in more than half of the six wetlands in the wet season

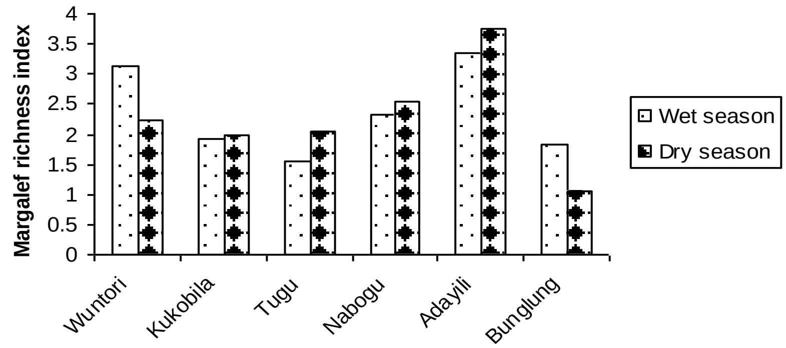


Figure 4.14: Seasonal changes of fish species richness in the six wetlands

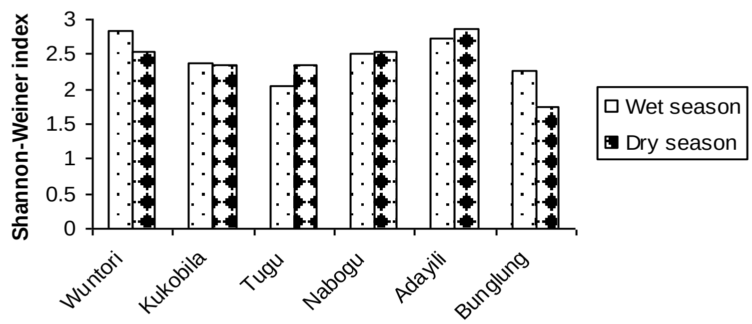


Figure 4.15: Variations in fish species beta diversity in the six wetlands for both dry season and wet season

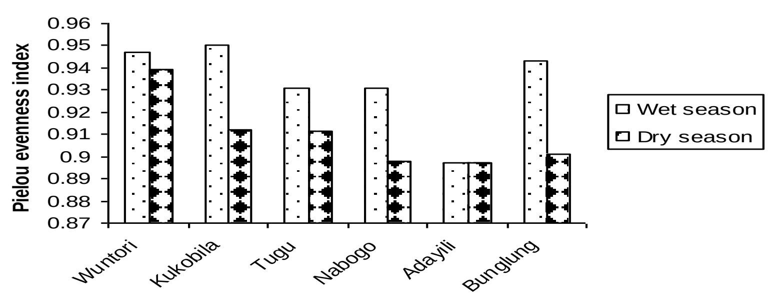


Figure 4.16: Evenness distribution of fish species in the six wetlands for dry season and wet seasons

Chromidotilapia guntheri

Raimas nigeriensis

Hetrotes niloticus

Polypterus endlicheri

Alestes beremose

Mormyrops deliciosus

Plate 14: Representative sample of fish species with the least occurrence among the six wetlands

Similarities in the abundance and distribution pattern of fish species among wetlands

Dry season

Detrended correspondence analysis (DCA) separated all six wetlands into three associations, based on fish community abundance and species-site ecological conditions (Figure 4.17). Rare species were down weighted. The descriptions of the three fish communities associations were as follows:

Group 1: Fish community in Bunglung wetland were the least in species abundance and had about four species from the ordination diagram that were similar in abundance and adapted to the wetland conditions. They were: *Auchinoglanis occidentalis, Malapterurus electricus, Synodontis velifer* and *Marcusenius senegalensis.* This wetland was not close to the catchment of the White Volta floodplains. Farming activities and grazing were commonly practiced all year round. Physical observation of the water appeared muddy or milky, with the Northern ends of the wetland embankment raised to about 5 m high.

Group 2: With the exception of Tugu wetland, fish assemblage in the remaining three wetlands namely Wuntori, Adayilli and Nabogo were the most abundant in species richness and highly diverse. These wetlands were typical of shallow standing marsh and flowing riparian wetlands respectively. Adayilli and Nabogo wetlands drain into the main White Volta to the Western corridors of Northern Region. The volume of water in both wetlands varies markedly from the wet and dry seasons, bringing in its wake diverse fish species. Farming activities, burnt vegetation and erosional features, were more common along the banks of the two riparian wetlands, than in the shallow marshes of Wuntori. The most common feature in Wuntori wetland was traces of previously burnt vegetation that has exposed wetland soils and created gaps within the dense ground cover. Some of the fish sampled were *Alestes dentex*, *Bagrus bajad*, *Distochodus engycephalus*, and *Lates niloticus* (Figures 4.17).

Cluster 3: Kukobila wetland which is characteristically a deep standing marshland constituted the second most abundant in fish species. The fringes of the wetlands were put under cultivation of arable crops, with scars of burnt vegetation and isolated eroded areas.

Fish species identified in this wetland were *Brycinus macrolepidotus, Labeo coubie, Clarias gariepinus, Oreochromis niloticus* and *Sarotherodon galilaeus*. Eigenvalues for the species-site for axes I = 0.42 and II = 0.27, showed a strong correlation between fish assemblage and the wetlands in which they were sampled.

Wet season

Species ordination was slightly different from that of the dry season. Two groups out of the six wetlands were separated, as result of their inherent ecological and anthropogenic variables influencing similarity in fish abundance (Figure 4.18).

Group 1: This cluster was made up of shallow natural marshlands of Wuntori, the two forested wetlands of Nabogo and Adayilli and the Bunglung man-made wetland. With exception of Bunglung wetland, the rest of the three wetlands registered the highest abundance of fish species in the wet season. Fish assemblage in these wetlands were made up of *Alestes dentex, Auchinoglanis occidentalis, Heterobronchus longifilis, Petrocephalus bovei, Mormyrus rume, Synodontis Clarias, Clarias anguillaris, Schilbe intermedius, Oreochromis niloticus, Labeo senegalensis* and *Tilapia zilli*. Farming activities were being practiced along the banks of the two riparian wetlands. Water was highly turbid.

Group 2: Kukobila and Tugu wetlands which are characteristically marshlands varied in water depth and registered the least in fish abundance. Grazing intensity was very common in Tugu, while crop farming was widespread along the fringes of the Kukobila wetlands. Some of the common species were *Alestes beremoze, Labeo coubie, Sarotherodon galilaeus, Macralestes occidentalis,* and *Synodontis batiani*. Eigenvalues for the two axes (Axis I = 0.4525, Axis II = 0.318) indicated a weak correlation between fish assemblage and the wetlands in which they were sampled.

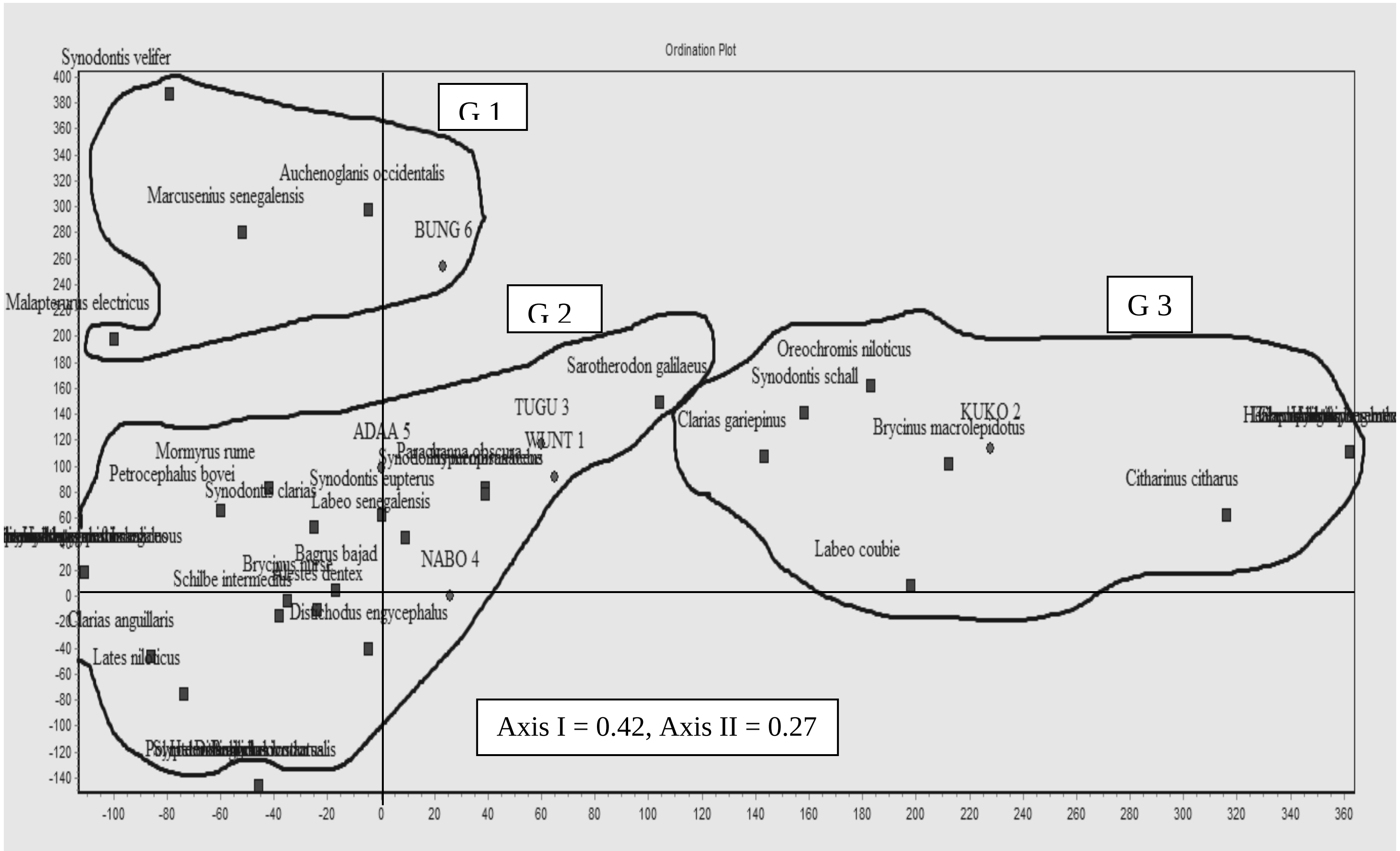


Figure 4.17: A species-site biplot DCA ordination showing similarity in fish distribution in the dry season, being separated into three groups along axes I & II. The ordination diagram shows the species and sample sites relationship in all six wetlands. The abbreviations represent sample plots and the associated fish species. The squares denote plant species, while the circles denote sample plots

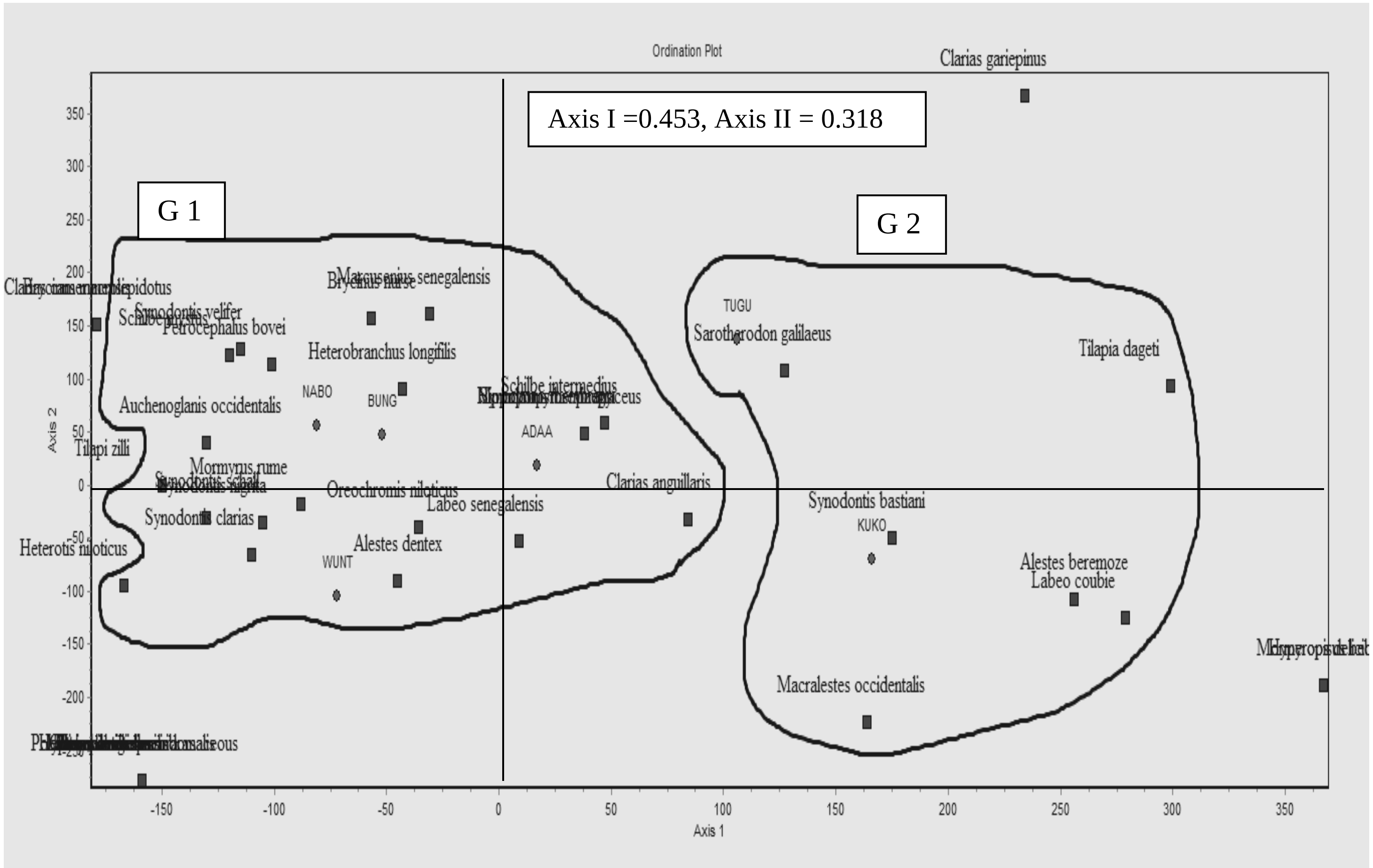


Figure 4.18: A species-site biplot DCA ordination showing similarity in fish distribution in the wet season, being separated into two groups along axes 1 & 2. The ordination diagram shows the species and sample sites relationship in all six wetlands. The abbreviations represent sample plots and the associated fish species, as indicated in Fig. 4.17

Fish community distribution along an environmental gradient

General observation from PCA ordination diagram revealed a number of key physico-chemical and anthropogenic activities influencing the distribution pattern of fish communities for dry and wet seasons and from the type of wetland they were sampled (Figures 4.19 & 4.20; Tables 7 & 8). The physico-chemical variables included: temperature, dissolve oxygen, turbidity, nitrate-nitrogen, ammonia, pH and conductivity while the anthropogenic factors were made up of farming activities, fire and grazing intensity for the dry season. Fish assemblage from Bunglung wetland located in the left hand side of the PCA diagram, was largely influenced by nitrate-nitrogen, dissolved oxygen, erosion, turbidity, temperature, grazing and farming activities in the dry season. The fringes of Bunglung wetland was heavily farmed with vegetables and cereals all year round. Turbidity and temperature levels were more pronounced in the wet season, which coincided with farming activities.

The two riparian wetlands of Nabogo and Adayili were profoundly influenced by temperature and turbidity and in dry and wet seasons (Figures 4.19 & 4.20). Farming activities were carried out along the course of the wetland (~ 100 m away from the main saturated zone) mostly in the wet season. This wetland is typically a valley-bottom wetland and received huge amount of water volumes, especially in the peak of the wet season (August-September) which subsequently drains into the main White Volta River. Fishing activities were intensified in the month of October, which marks the beginning of the dry season. Some of the fish species sampled were *Auchinoglanis occidentalis*, *Brycinus macrolepidotus*, *Oreochromis niloticus*, *Marcusenius senegalensis* and *Synodontis clarias*.

Fish communities from Kukobila, Tugu and Wuntori wetlands, were were mostly influenced by fire, grazing, D.O., phosphorus, magnesium calcium, TDS and conductivity in axes I and II. Wildfires were common in the onset of the wet season, primarily in preparation for farming activities and the peak of the dry season, to hunt for game (e.g., grasscutters and squirrels). These wetlands received a lot of inflows from the overflows of the main White Volta River, during the peak of the wet season and also serve as major grazing area and watering point all year. *Oreochromis noloticus, Tilapia dageti, Labeo coubie, Bagrus bajad, Synodontis eupterus*, and *Alestes beremoze*, were among the common species identified.

The PCA generated matrices of the species-site biplot (Tables 7) suggested that out of the 15 ecological and anthropogenic factors, nitrate-nitrogen, phosphate, magnesium, fire, erosion and grazing pressure for axis I and conductivity, TDS, calcium, dissolved oxygen, turbidity and farming activities for axis II were the most important ecological variables influencing the distribution and abundance of fish in the dry season. Although surface water temperatures were fairly high in the dry season (~ 30º C), their impact was not significant on fish assemblage as this was evident in the rather weak correlation on both axes I and II.

Correlation among the environmental variables was significant ($t = -0.1894$; $p<0\cdot05$) for axis I and axis II (approximate *t*-test, ter Braak, 1987). Cumulative percentage variance of the species–environment relationship was sufficiently explained by the first two axes of the PCA ordination (axis I = 49.06 and axis II = 32.77). The two axes accounted for 81.84% of the variation in the weighted averages of the 45 fish species in relation to 15 environmental factors (Table 8). As recommended by ter Braak (cited in Kent and Coker, 1992), since axes I and II accounted for more than 50% of the variation in fish spatial distribution abundance and diversity, axes 3 and 4 were not considered. Generated eigenvalues for PCA ordination for the first four axes of all six wetlands were 7.36, 4.92, 1.78 and 0.82, respectively.

For the wet season, the generated PCA matrices of the fish species-site biplot showed that phosphate, D.O., fire, grazing and Erosion for axis 1 and conductivity, TDS, turbidity and temperature for axis 2, were the most important variables that determined fish composition and distribution across all wetlands. Canonical correlation of both the ecological and anthropogenic variables, was significant ($t = -3.117$; $p<0\cdot05$) for axis I and axis II (approximate *t*-test, ter Braak, 1987). Cumulative percentage variance of the species–environment relationship was explained by the first two axes of the CCA ordination (axis I = 64.73 and axis II = 18.69). The two axes accounted for 83.41% of the variation in the weighted averages of the 41 fish species in relation to 15 environmental factors (Table 8). Eigenvalues for PCA ordination for the first four axes of all six wetlands were 9.71, 2.80, 1.91 and 0.32, respectively.

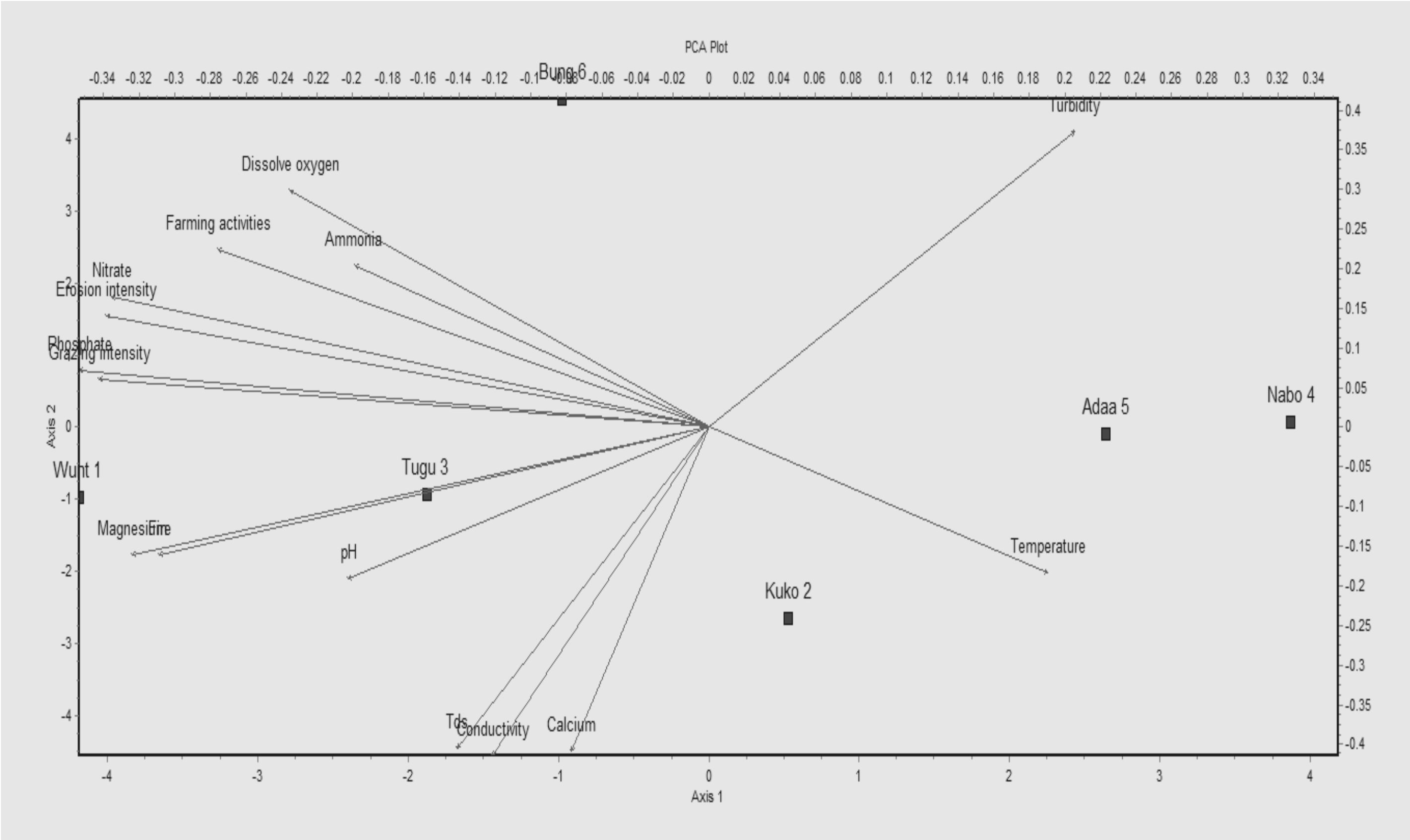


Figure 4.19: Principal component analysis (PCA) ordination diagram, showing the relationship between ecological/anthropogenic factors and fish assemblage in the six wetlands in the dry season. The squares represent the wetlands, while the arrows represent each of the environmental factors plotted pointing in the direction of maximum change of explanatory variables across the six wetlands

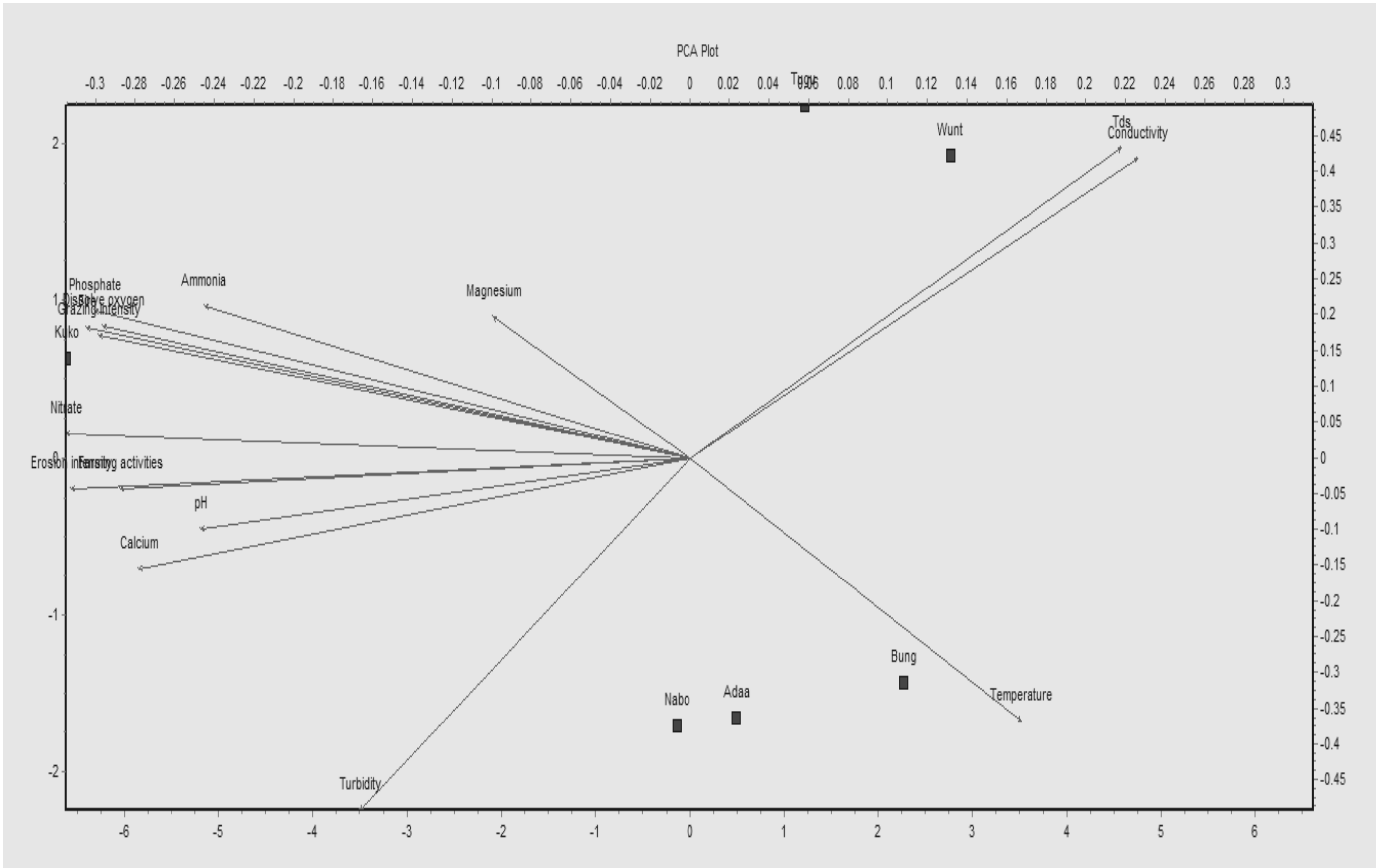


Figure 4.20: Principal component analysis (PCA) ordination diagram, showing the relationship between ecological/anthropogenic factors and fish assemblage in the six wetlands in the wet season, as explained in Fig. 4.19

Table 7: Summary of PCA eigenvectors showing the levels of correlation with the first four axes of the environmental variables of the six sites

Dry season

	Axis1	Axis 2	Axis 3	Axis 4
Conductivity	-0.122	-0.414*	0.152	-0.08
TDS	-0.141	-0.404*	0.156	-0.088
pH	-0.202	-0.192	-0.530	-0.147
Nitrate-nitrogen	-0.335*	0.165	0.080	-0.132
Phosphate	-0.354*	0.072	0.148	-0.044
Ammonia	-0.199	0.205	0.284	0.658
Calcium	-0.077	-0.408*	0.249	0.179
Magnesium	-0.324*	-0.162	-0.194	0.061
Dissolved oxygen	-0.235	0.298*	-0.258	-0.198
Turbidity	0.205	0.374*	0.0004	0.009
Temperature	0.190	-0.183	-0.540	0.216
Fire	-0.308*	-0.160	-0.181	0.376
Grazing intensity	-0.342*	0.060	0.085	-0.329
Erosion	-0.338*	0.141	0.075	-0.169
Farming activities	-0.275	0.225*	-0.241	0.332
Eigenvalues	7.36	4.92	1.78	0.82
% total variance	49.064	32.770	11.855	5.451
Cum % total variance explained	49.06	81.84 (first two axes)		

*Significant ($p<0.05$)

Table 8: Summary of PCA eigenvectors showing the levels of correlation with the first four axes of the environmental variables of the six sites
Wet season

	Axis1	Axis 2	Axis 3	Axis 4
Conductivity	-0.226	0.418*	-0.072	-0.098
TDS	0.218	0.433*	-0.063	-0.098
pH	-0.247	-0.097	-0.442	0.171
Nitrate-nitrogen	-0.316	0.036	0.004	0.246
Phosphate	-0.301*	0.207	0.005	0.033
Ammonia	-0.245	0.211	0.389	-0.027
Calcium	-0.278	-0.15	0.003	-0.4
Magnesium	-0.098	0.199	-0.6	-0.193
Dissolved oxygen	-0.296*	0.183	-0.003	0.118
Turbidity	-0.167	-0.493*	0.146	0.122
Temperature	0.167	-0.366*	-0.429	0.046
Fire	-0.299*	0.169	0.002	0.340
Grazing intensity	-0.297*	0.171	-0.126	-0.015
Erosion	-0.317*	-0.003	-0.099	0.111
Farming activities	-0.286	-0.079	0.058	-0.67
Eigenvalues	9.71	2.80	1.91	0.32
% total variance	64.73	18.69	12.74	2.10
Cum % total variance explained		64.73	83.41 (first two axes)	

*Significant (p<0·05)

Seasonal Variations in Physico-Chemical Parameters in the Six Wetlands

Laboratory results of all 13 physico-chemical parameters for both wet and dry seasons from the six wetlands (Table 9; Figures 4.21 & 4.22), were presented below:

Physico-chemical parameters

Although physical parameters values showed an increase in the wet season compared to the dry season they were not statistically significant ($p > 0.05$) in the wetlands. Turbidity showed higher mean values in Kukobila in the wet season (395.3 NTU) and Bunglung in the dry season (123.3 NTU) (Figure 4.21). Mean pH values for all wetlands showed a rather weak acidic to neutral condition for both the dry (6.4 – 6.9) and wet seasons (6.8 – 7.04). With the exception of Wuntori shallow marshes that had a pH value of 7.04 in the wet season, the rest of the wetlands had their pH values in the range of 6.4 – 6.9. The neutralizing potential or buffering ability of total alkalinity on pH was reflected in their optimum range recorded for both dry (21.7 - 63.00 mg/l) and wet seasons (25.7 and 62.7 mg/l) across all wetlands. Conductivity was consistently high only in the shallow marshes of Wuntori (154-162 µS/cm dry season and 198-204.0 µS/cm wet season) and Tugu (115-119 µS/cm dry season and 146-150 µS/cm wet season) (Figure 4.22).

Total hardness for both seasons did not vary substantially among wetlands except in Bunglung man-made wetland, which recorded the lowest value in the dry season (12.3 mg/l). Mean range values for dissolved oxygen were considerably low across the six wetlands, in both seasons. With the exception of Tugu wetland that recorded dissolved oxygen levels of 3.5 mg/l ±0.2 in the dry season, the remaining wetlands all had dissolved oxygen concentration < 3 mg/l. (e.g., 2.1- 2.8) for the dry season and (1.7 - 2.8) for the wet season. Nabogo riparian wetland had the lowest dissolved oxygen concentration in the wet season (1.7 mg/l). Temperature values ranged between 29.8º C - 31.3º C in the dry season, while in the wet season values were in the range of 29.6º C - 31.4º C (Figures 4.23 & 4.25). The highest mean temperature was recorded in the shallow marshes of Wuntori wetland (31.3) while Tugu wetland recorded the lowest (29.8º C) in the dry season. However, in the wet season, the highest mean temperature was observed in Nabogo riparian wetland (31.4º C) while Kukobila recorded the lowest (29.6 º C). Overall, mean temperature values correlated with dissolved oxygen in dry season (r = -0.917; $p<0.001$) and wet season (r = -0.063; $p<0.05$) (Figures 4.24 & 4.26). Further regression of DO on temperature revealed a greater possibility of predicting levels of DO, using temperature data from the six wetlands in the rectilinear equation: **Y = -0.743x + 25.4 → [DO] = -0.743[temperature] + 25.4** at 95% confidence interval, with **R^2 = 0.841** in the dry season and **Y = -0.036x + 3.372 → [DO] =-0.036[temperature] + 3.372** in the wet season (Figures 4.24 & 4.26).

Ammonia levels were consistently high in both seasons across the six wetlands. Mean values ranged between 0.15 – 1.15 mg/l for the dry season and 0.81 – 1.8 for the wet season (Figure 4.21b). Bunglung man-made wetland had the highest amount of ammonia concentration for dry and wet seasons (1.52 and 1.8 respectively), while Kukobila wetland recorded the lowest ammonia concentration only in the dry season. The concentration of calcium and magnesium (major cations) did not follow any incremental sequence from one season to the other and among wetlands, as their concentrations varied substantially. Both NO_3-N and PO_4 levels were generally low in the dry and wet seasons and did not show any wide variations among wetlands. Bunglung wetland recorded the highest NO_3-N concentration in the dry season (1.9 mg/l) followed by Nabogo (1.2 mg/l). Wuntori wetland had the lowest NO_3-N concentration (0.21 mg/l). However, in the wet season the deep marshes of Kukobila recorded elevated levels of NO_3-N up to 6.2 mg/l followed by Adayili (2.7 mg/l) and Nabogo (2.1 mg/l).

Phosphates levels were highest in Wuntori wetland (0.14 mg/l) in the dry season while Kukobila wetland had the highest in the wet season (0.25 mg/l). Total dissolved solids (TDS) were generally low in both seasons. The two shallow marshes of Wuntori and Tugu consistently recorded relatively high TDS concentration in the dry season (87.7 mg/l and 70.5 mg/l) and the wet season (122.7 mg/l and 88.5 mg/l), respectively. The least TDS concentration for dry season was recorded in the Bunglung (31.8 mg/l), while the wet season was observed in Adayili wetland (30.9 mg/l).

Table 9: Selected physico-chemical parameters of water samples collected from the six wetlands for both dry and wet seasons. Dry season (Dec – April) and wet season (July – October)
[a] = dry season, [b] = wet season

Parameters	Wuntori	Kukobila	Tugu	Nabogo	Adayilli	Bunglung
			Wetlands			
Conductivity	[a] = 154 – 162	[a] = 61.6 - 65.3	[a] = 115 -119	[a] = 60.3 -64.5	[a] = 86.4 -93.6	[a] = 52.1 -55.5
	[b] = 198 - 204	[b] = 59.6 - 64.7	[b] =146 - 150	[b] = 55.4 -58.1	[b] = 51.6 -55.2	[b] = 65.4 - 66.1
TDS	[a] = 85.1- 91.8	[a] = 37.2 - 43.1	[a] = 70.1 -77.4	[a] = 35.6- 40.0	[a] = 51.8 -57.2	[a] = 29.9 -34.2
	[b] = 121 – 124	[b] = 36.9 - 39.5	[b] = 86.9 – 90.0	[b] = 31.7 -34.5	[b] = 29.7-32.4	[b] = 39.4 - 40.3
pH	[a] = 6.08 -7.15	[a] = 6.5 - 7.02	[a] = 5.9 -7.09	[a] = 6.25- 7.1	[a] = 6.7 -7.09	[a] = 6.74 -7.03
	[b] = 6.9 - 7.14	[b] = 6.1 -7.4	[b] = 6.6 - 7.05	[b] = 6.81- 6.87	[b] = 6.56 -7.0	[b] = 6.69 -6.82
Turbidity	[a] = 5.0 -8.0	[a] = 12.0 - 14.8	[a] = 19.0 -22.0	[a] = 69.0 - 75.0	[a] = 76.0 - 82.0	[a] = 121 - 126
	[b] = 72 - 78	[b] = 389 – 402	[b] = 22.0 -26.0	[b] = 146 – 149	[b] = 125 - 128	[b] = 116 - 122
Nitrate-N	[a] = 0.19 -0.23	[a] = 0.46 - 0.57	[a] = 0.66 -0.82	[a] = 0.68 – 0.77	[a] = 1.17 – 1.19	[a] = 1.88 – 1.92
	[b] = 1.29 – 1.36	[b] = 0.69 - 0.78	[b] = 2.2 -2.6	[b] = 1.97 – 2.25	[b] = 2.55 – 2.88	[b] = 1.58 – 1.66
Phosphate	[a] = 0.12 -0.15	[a] = 0.01 - 0.04	[a] = 0.03 -0.06	[a] = 0.02 – 0.05	[a] = 0.06 – 0.0	[a] = 0.06 – 0.08
	[b] = 0.01 -0.04	[b] = 0.2 - 0.3	[b] = -0.15 - -0.2	[b] = -0.03 – -0.1	[b] = -0.05 – -0.9	[b] = -0.10 – -0.13

Ammonia	[a] = 0.13 -0.16	[a] = 0.18 - 0.31	[a] = 0.34 - 0.43	[a] = 1.04 - 3.62	[a] = 0.43 - 0.8	[a] = 1.06 - 1.51
	[b] = 0.64 -2.30	[b] = 1.43 - 1.56	[b] = 0.79 - 0.83	[b] = 0.61 - 2.72	[b] = 0.77 - 1.56	[b] = 1.06 - 3.03
Total Alkalinity	[a] = 59 - 66	[a] = 21.8 - 28.3	[a] = 38.0 – 44.0	[a] = 19.0 - 24.0	[a] = 37.0 - 45.0	[a] = 22.0 - 25.0
	[b] = 60 – 65	[b] = 26 - 30	[b] = 34.0 – 37.0	[b] = 29.0 - 32.0	[b] = 26.0 - 28.0	[b] = 24.0 - 27.0
Total Hardness	[a] = 36 - 44.0	[a] = 30.0 - 41.5	[a] = 32.0 – 37	[a] = 39.4 - 42.6	[a] = 28.7 - 33.2	[a] = 11.0 – 14.0
	[b] = 49 - 55.0	[b] = 38.0 - 45.0	[b] = 45.0 – 50.0	[b] = 48.0 - 53	[b] = 38.0 - 42.0	[b] = 39.0 - 44.0
Calcium	[a] = 6.7 - 8.8	[a] = 5.6 - 7.2	[a] = 5.8 – 8.0	[a] = 5.71 - 7.68	[a] = 6.9 - 8.0	[a] = 1.6 - 1.9
	[b] = 7.5 - 8.8	[b] = 11.0 -14.0	[b] = 5.5 – 5.9	[b] = 9.4 - 9.9	[b] = 5.6 - 6.4	[b] = 5.9 - 6.4
Magnesium	[a] = 4.9 - 5.8	[a] = 2.8 - 4.4	[a] = 2.7 – 3.1	[a] = 2.38 – 2.43	[a] = 2.2 – 2.8	[a] = 2.0 – 2.5
	[b] = 6.9 - 7.8	[b] = 2.0 - 2.4	[b] = 7.6 – 8.3	[b] = 5.8 – 6.3	[b] = 5.8 – 6.3	[b] = 6.0 – 6.5
Dissolve Oxygen	[a] = 1.9 - 2.4	[a] = 2.2 - 2.9	[a] = 3.3 – 3.7	[a] = 2.2 – 2.7	[a] = 2.4 – 3.1	[a] = 2.5 – 3.2
	[b] = 2.3 -2.6	[b] = 2.3 - 2.7	[b] = 1.9 – 2.4	[b] = 1.4 – 2.0	[b] = 1.7 – 2.0	[b] = 2.5 – 3.1
Temperature	[a] = 30.8 - 31.7	[a] = 29.8 - 31.2	[a] = 29 – 30.6	[a] = 30.7 – 31.4	[a] = 29.2 – 31.6	[a] = 29.8 – 30.5
	[b] = 30.4-31.3	[b] = 28.5-30.7	[b] = 29.1-30.9	[b] = 31.2-31.7	[b] = 29.6-30.9	[b] = 30.1-31.6

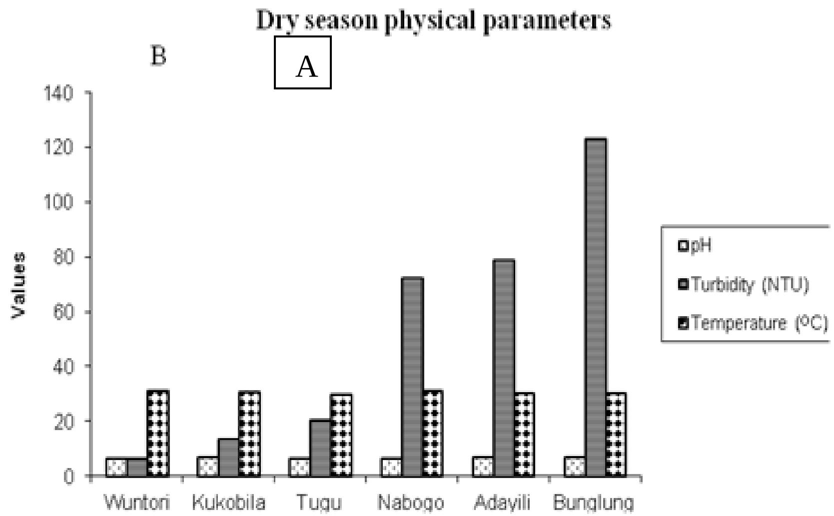


Figure 4.21a: **Seasonal variations of mean physical parameters across the six wetlands in dry season (Dec – March). All axes were re-scaled to log10**

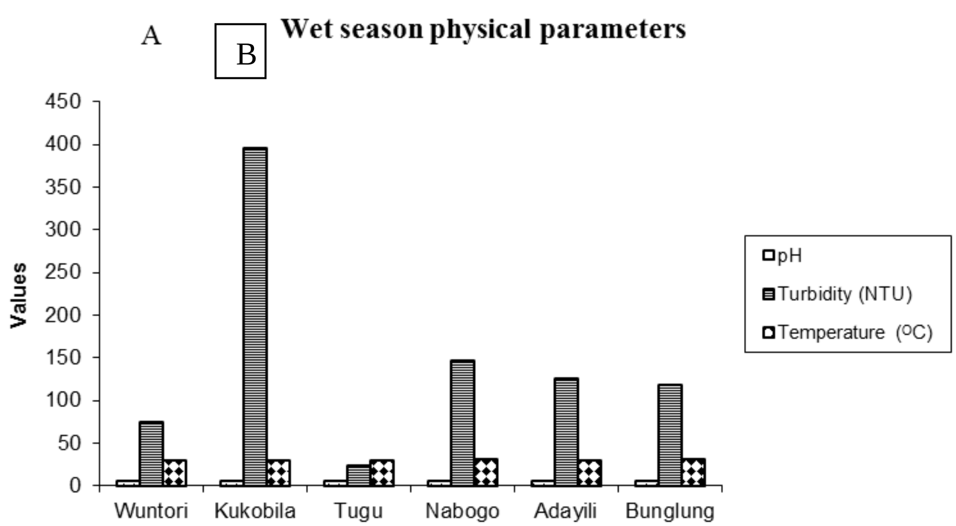


Figure 4.21b: Seasonal variations of mean physical parameters across the six wetlands in the wet season (June –Sept)

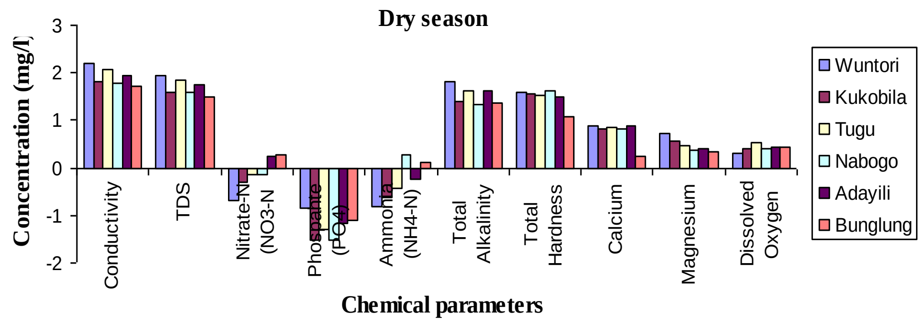


Figure 4.22b: **Seasonal variations of mean hydrochemical parameters across the six wetlands in dry season (Dec – March) and wet seasons (June –Sept). All axes were re-scaled to log10**

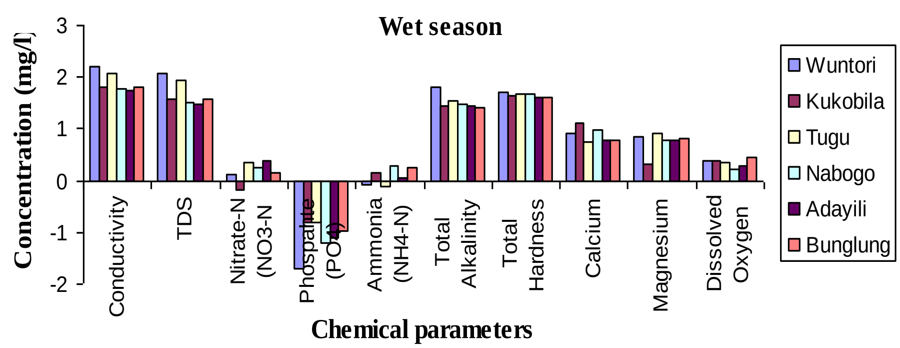


Figure 4.22b: Seasonal variations of mean hydrochemical parameters across the six wetlands in dry season (Dec – March) and wet seasons (June –Sept). All axes were re-scaled to log_{10}

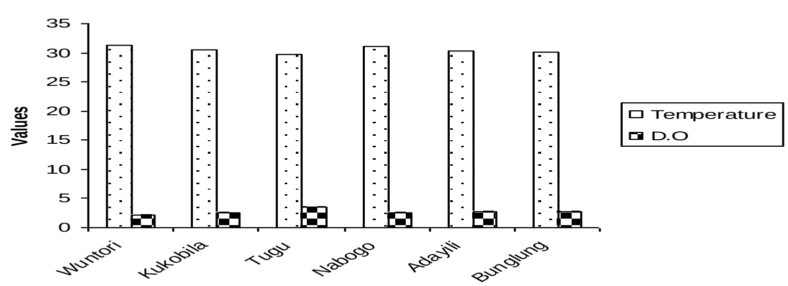


Figure 4.23: Variations in temperature and dissolved oxygen across the six wetlands in the dry season

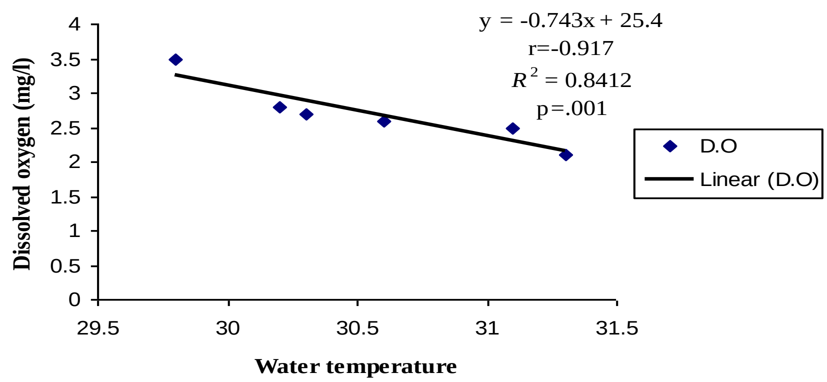


Figure 4.24: Relationship between temperature and dissolved oxygen among the six wetlands in the dry season

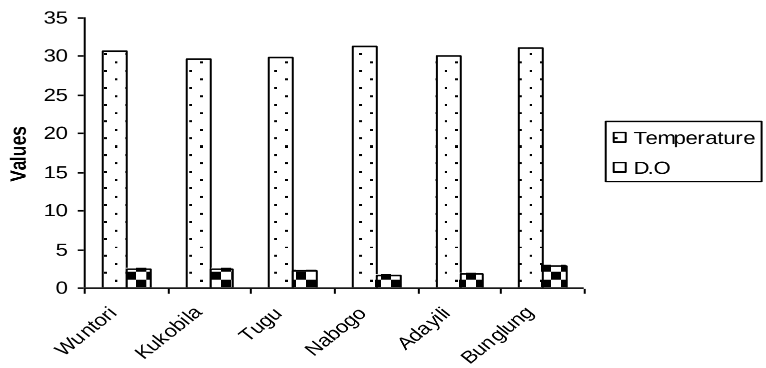


Fig. 4.25: Variations in temperature and dissolved oxygen across the six wetlands in the wet season

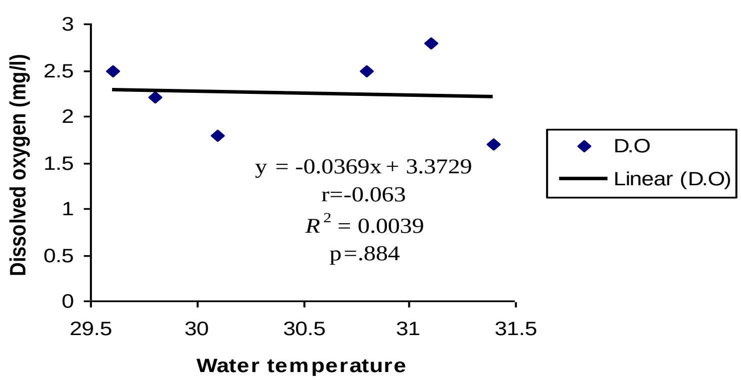


Fig. 4.26: Relationship between surface water temperatures on dissolved oxygen among the six wetlands in the wet season

Spatial Variations of Bird Diversity among Wetlands

Generally, bird abundance was much higher in the wet season than in the dry season across the six wetlands. A total of 1, 169 individual birds from 26 species were identified and counted during the wet season, while 885 individuals from 23 species were observed in the dry season (Tables 10 & 11). The species encountered for the two seasons, were from 21 bird groups. Examples were coots, waders, finches, terns, weavers and hornbills (Table 12). Example Nabogo swamp forest registered the highest abundance of birds (239) while Adayili (152) was the least in bird abundance in the wet season. However, in the dry season, Tugu wetland registered the highest number of bird species (183) while the least of individuals detected were from Wuntori wetland (118) (Tables 10 & 11).

Comparing all the four wetland classes in dry and wet seasons, the shallow close marshes of Wuntori and Tugu supported the greatest number of birds followed by the riparian wetlands (Figure 4.27). Birds in the three marshes (Tugu, Wuntori and Kukobila wetlands) and the two riparian wetlands substantially differed in both seasons ($p<0.05$) whereas species in Bunglung wetland did not vary significantly ($p>0.05$). Mean number of birds in each line transect ranged between 2.0±0.5 and 11.6±2.8 in the wet season and 2.2±0.5 to 9.6±4.4 in the dry season (Figures 4.28a & b). Nabogo wetland registered the highest mean number of birds per plot while

Bunglung artificial wetland was the least recorded in the same season in the wet season. Cattle egret (*Bubulcus ibis*) was the single most abundant species in the wet season while Marsh warbler (*Acrocephalus palustris*) was the single most abundant species in the dry season (Table 10). All bird species censused in the two seasons were from 21 families (Table 13).

Bird densities overall, increased among wetlands in the wet season than in the dry season (Figure 4.29a & b). With the exception of Kukobila wetland, the first 0 – 10 m line transect, consistently recorded the highest density of birds in the five remaining wetlands for the wet season compared to the dry season. Increase in bird density with a corresponding increase in area of lateral distance was only observed in Nabogo wetland in the wet season. This was followed by the Wuntori wetland where five line transects out of six (i.e., with the exception of the 40 – 50 m line transect) registered a consistent increase in birds alongside an increase in the lateral distance (Figure 4.28a & b). A total of 14 species had frequented in more than half the six wetland classes during the wet season (Figure 4.30a). Pied kingfisher (*Ceryle rudis)* (9%) and black headed plover (*Vanellus tectus*) (9%) constituted the highest number of species sampled, while four species (e.g., Bearded barbet-*Lybius dubius*) were the least detected.

In the dry season, 16 species belonging to 13 families were recorded in more than half of the six wetlands surveyed (Figure 4.30b). Four of the species (e.g., Black-crown tchagra-*Tchagra senegalus*) were the highest, while seven species (e.g., Squacco heron- *Areodeola rolloides*) were the least detected. The ploceidae family which represented 15% of the total number of bird families, had the largest number of species namely: Northern red bishop (*Euplectes franciscanus*); Yellow weaver bird (*Ploceous megarhrynchus*) and Red billed quelea (*Quelea quelea*) followed by species from the families Ardeidae (e.g., cattle egret-*Bubulcus ibis*) and Columbidae (e.g., Vineceous dove - *Streptopelia vinacea*) (Table 13).

Of the 26 species counted, 25 species representing 96.2% were classified as List concern (LC), using the IUCN '*Red List'* database guide (Table 12). The Yellow weaver bird (*Ploceous megarhrynchus*) was only the species classified as vulnerable (VU) and represented 3.8%. This species was restricted to tree species that were characteristically thorny (e.g., *Ziziphus abyssinica*) and some tufted and rough edge grasses such as *Deplachne fusca* along the banks of Nabogo forested and the Bunglung man-made wetlands. These birds spend a greater part of the day weaving their nest with leaf blades of grasses.

Plate 15: **Yellow weaver birds on the thorny branches of *Ziziphus abyssinica* tree on the fringes of Bunglung man-made wetland**

Overall, mean diversity index in the dry season (H'= 1.24±0.14 and 1.56±0.07) was relatively lower than that of the wet season (H'= 1.361±0.14 and 1.75±0.13) (*F* = 4.101; $p<0.05$) (Figure 4.31). Bird diversity generally followed their evenness distribution ((Figure 4.32) with some slight variations (Kruskal-Wallis test, p=0.297)**.** Comparatively, Wuntori wetland was most diverse (H'= 1.75±0.13) in the wet season followed by Kukobila wetland (H'= 1.56±0.07) in the dry season. Nabogo wetland closely followed the two wetlands in the wet (H'= 1.67±0.08) and dry (H'= 1.52±0.04) seasons. Bunglung and Tugu wetlands respectively exhibited similar pattern in species diversity in the wet (H'= 1.57±0.09, H'= 1.36±0.14) and dry seasons (H'= 1.32±0.11, H'= 1.24±0.14).

Mean species richness provided by Margalef index differed among wetlands (Kruskal-Wallis test, $p<0.05$) positively correlated with diversity indices in the dry season (r = 0.032, $p<0.05$). Adayili swamp forest was the highest in mean species richness (D= 1.88±0.22) while Tugu was least rich in the wet season (D= 1.44±0.15). Nabogo on the other hand was the highest in the dry season (D= 1.96±0.25) while Bunglung was the least rich in the same season (1.36±0.18) (Figure 4.33). Wuntori wetland was the second most species rich in both wet (D= 1.87±0.29) and dry seasons (D= 1.927±0.20).

Table 10: Seasonal abundance of individual bird species recorded in the six wetlands, from January – April. (--) = not present. ***Dry season*** ***Wetland classes***

	(*Close shallow marshes*)				**(*Open deep marsh*)**		**(*Riparian wetlands*)**				**(*Artificial wetland*)**	
species	*a. Wuntori*	*%*	*b. Tugu*	*%*	*c.Kukobila*	*%*	*d. Adayili*	*%*	*e. Nabogo*	*%*	*f. Bunglung*	*%*
African Jacana	7	5.9	6	3.3	4	2.8	--	--	--	--	19	10.6
Black-billed dove	--	-	3	1.6	3	2.1	--	--	--	--	8	4.5
BlackcrownedTchagra	9	7.6	9	4.9	9	6.4	20	16	4	2.9	7	3.9
Black-headed plover	5	4.2	3	1.6	5	3.5	11	8.7	8	5.8	--	--
African pygme goose	15	13	--	--	17	12	--	--	--	--	--	--
Cattle egret	23	20	58	32	46	33	21	16.7	30	21.7	19	10.6
Collard sunbird	2	1.7	1	0.5	1	0.7	--	--	--	--	6	3.4
Red-headed quelea	--	--	--	--	--	--	--	--	1	0.7	--	--
Gambaga flycatcher	6	5.1	15	8.2	--	--	--	--	--	--	--	--
Kingfisher	1	0.8	4	2.2	2	1.4	6	4.8	2	1.4	7	3.9
Lanner Falcon	3	2.5	4	2.2	--	--	--	--	--	--	--	--
Little bee-eater	--	--	--	--	--	--	4	3.2	13	9.4	--	--

Table 10 continued

Marsh warbler	15	13	29	15.8	36	25.5	--	--	--	--	76	42.5
Northern Hornbill	3	2.5	--	--	1	0.7	5	4.0	2	1.4	--	--
Red-billed quelea	14	11.9	11	6.0	--	--	20	15.9	14	10	17	9.5
Spooted Creeper	--	--	--	--	--	--	3	2.4	5	3.6	1	0.6
Squacco heron	5	4.2	5	2.7	4	2.8	--	--	--	--	3	1.7
Veneceous dove	2	1.7	4	2.2	4	2.8	17	13.5	--	--	2	1.1
Violet backed	1	0.8	2	1.1	3	2.1	5	4.0	1	0.7	--	--
Westerngrayplantaineater	2	2	1	0.5	2	1.4	5	4	3	2.2	--	--
Wooly-necked stock	2	1.7	1	0.5	--	--	2	1.6	4	2.9	--	--
Yellow-billed kite	3	2.5	2	1.1	2	1.4	7	5.6	4	2.9	2	1.1
Yellow weaver bird	--	--	25	13.7	2	1.4	--	--	47	34.1	12	6.7
Total no. of bird sp.	***118***		***183***		***141***		***126***		***138***		***179***	

Table 11: Seasonal abundance of individual bird species recorded in the six wetlands, from June – September. (--) = not present. ***Wet season*** ***Wetland classes***

	(*Close shallow marshes*)				**(*Open deep marsh*)**		**(*Swamp forested wetlands*)**				**(*Artificial wetland*)**	
species	*a. Wuntori*	*%*	*b. Tugu*	*%*	*c.Kukobila*	*%*	*d. Adayili*	*%*	*e. Nabogo*	*%*	*f. Bunglung*	*%*
African Jacana	25	11	9	4.3	17	9.6	--	--	--	--	21	12.9
Bearded barbet	2	0.9	--	--	--	--	--	--	--	--	--	--
Black-billed dove	--	--	--	--	--	--	--	--	--	--	5	3.1
Black crowned tchagra	--	--	--	--	--	--	12	7.9	22	9.2	4	2.5
Black-headed plover	12	5	7	3.4	9	5.1	11	7.2	17	7.1	3	1.8
African pygme goose	31	13	9	4.3	21	11.9	--	--	--	--	--	--
Cattle egret	39	17	62	30	41	23.2	43	28.3	60	25.1	31	19.0
Collard sunbird	3	1.3	--	--	--	--	--	--	--	--	5	3.1
Red-headed quelea	--	--	1	0.5	3	1.7	3	2	2	0.8	--	--
Double spurred francolin	--	--	5	2.4	--	--	--	--	--	--	--	--
Gambaga flycatcher	15	7	--	--	--	--	--	--	--	--	--	--

Table 11 continued

Pied Kingfisher	1	0.4	6	2.9	2	1.1	2	1.3	6	2.5	7	4.3
Little bee-eater	--	--	--	--	--	--	14	9.2	20	8.4	--	--
Marsh warbler	57	24.7	51	24.6	41	23.2	--	--	--	--	29	1 8
Northern Red bishop	10	4.3	--	--	17	9.6	13	8.6	12	5.0	3	1.8
Northern Hornbill	4	1.7	4	1.9	3	1.7	6	3.9	4	1.7	--	--
Red-billed quelea	--	--	22	10.6	5	2.8	20	13.2	27	11	28	17
Spooted Creeper	--	--	--	--	--	--	1	0.7	2	0.8	2	1.2
Squaco heron	7	3.0	6	2.9	5	2.8	--	--	--	--	5	3.1
Veneceous dove	11	4.8	13	6.2	3	1.7	7	4.6	13	5.4	4	2.5
Violet backed	1	0.4	--	--	1	0.6	2	1.3	4	1.7	--	--
Westerngrayplantaineater	5	2.2	9	4.3	7	4.0	5	3.3	6	2.5	--	--
Wooly-necked stock	4	1.7	2	1.0	--	--	5	3.3	3	1.3	--	--
Yellow-billed kite	4	1.7	1	0.5	2	1.1	8	5.3	2	0.8	3	1.8
Yellow weaver bird	--	--	--	--	--	--	--	--	39	16.3	13	8.0
Total no. of bird sp	***231***		***207***		***177***		***152***		***239***		***163***	

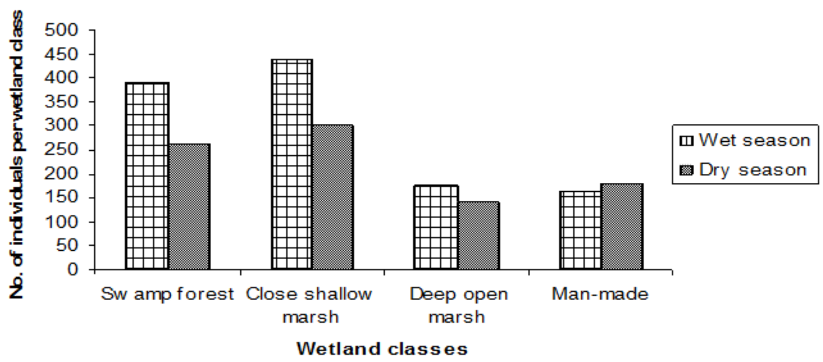


Figure 4.27: Comparison of bird population and distribution pattern Among the differentwetland classes in both wet and dry seasons

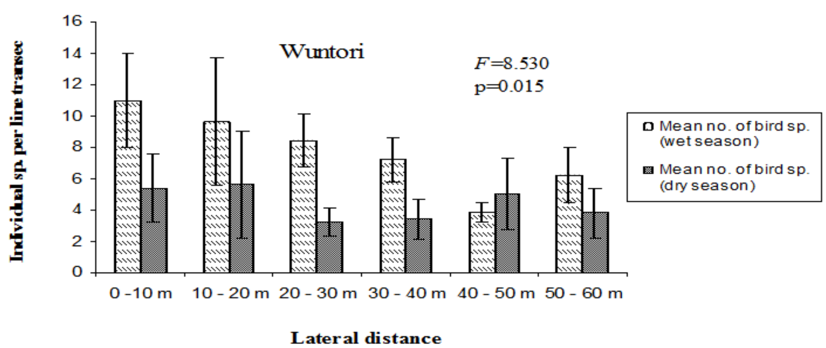


Figure 4.28a: **Mean number ofbirds countedon different Plots for dry andwet seasons in Wuntori**

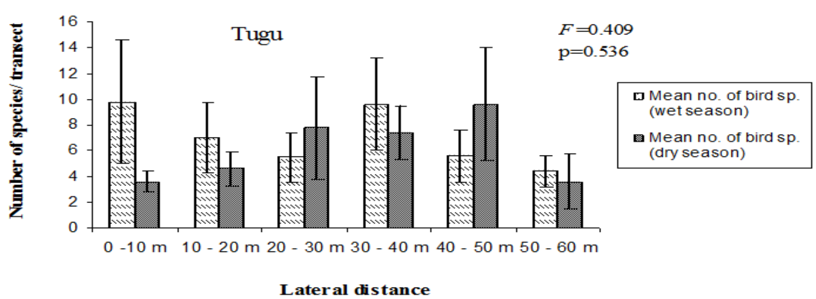


Figure 4.28b: Mean number of birds present on different plots for dry and wet seasons in Tugu

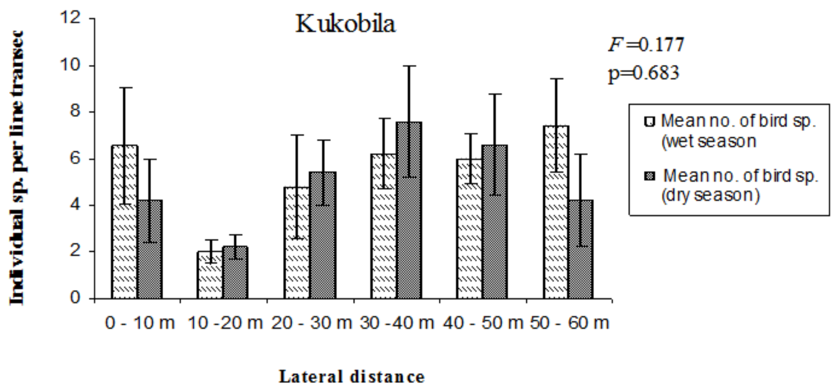


Figure 4.28c: **Mean number of birds identified on different plots for dry and wet seasons in Kukobila**

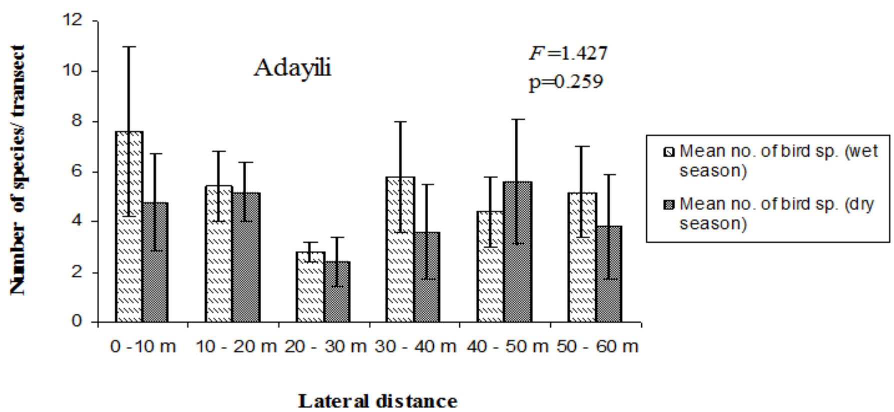


Figure 4.28d: **Mean number of birds identified on different plots for dry and wet seasons in Adayili**

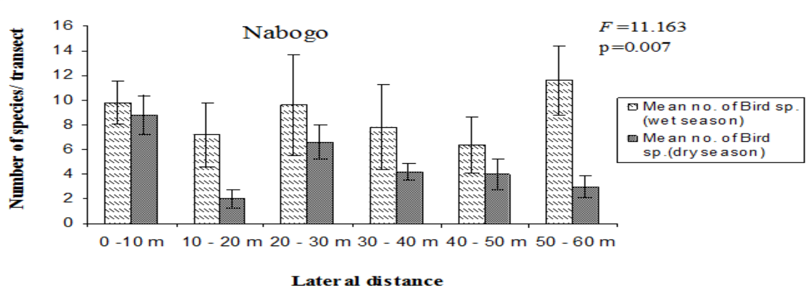


Figure 4.28e: **Mean number of birds identified on different plots for dry and wet seasons in Nabogo**

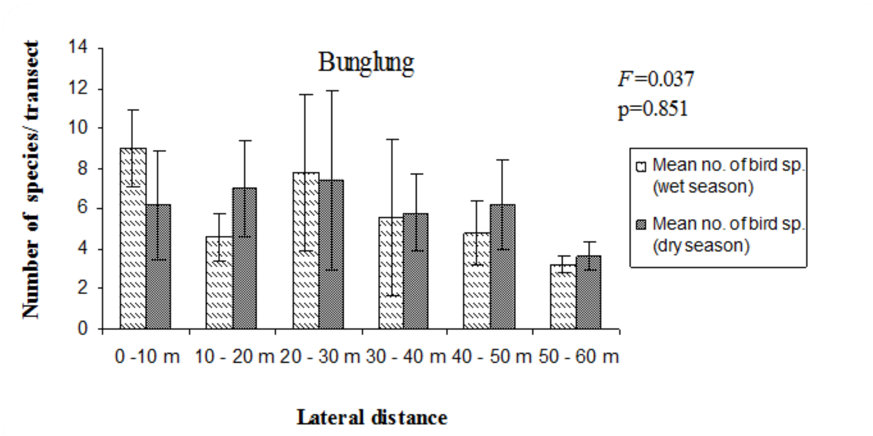


Figure 4.28f: Mean number of birds identified on different plots for dry and wet seasons in Bunglung

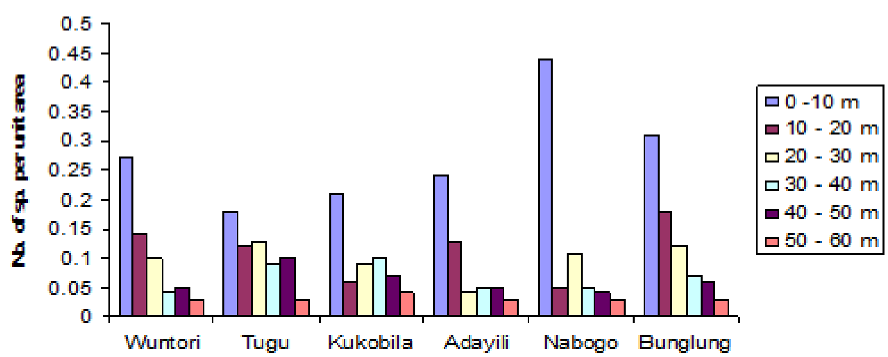


Figure 4.29a: **Bird density counted in different plot sizes in the dry season across the six wetland**

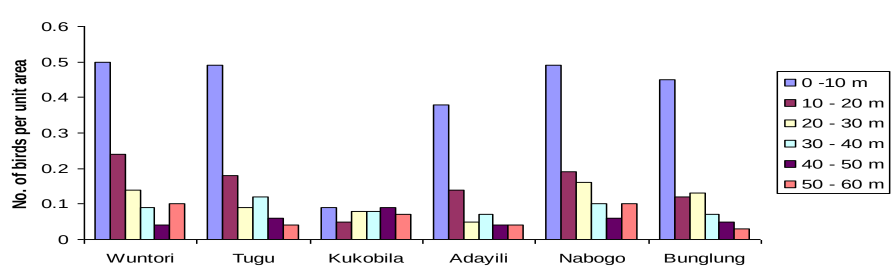


Figure 4.29b: Bird density counted in different plot sizes in the wet season across the six wetland classes

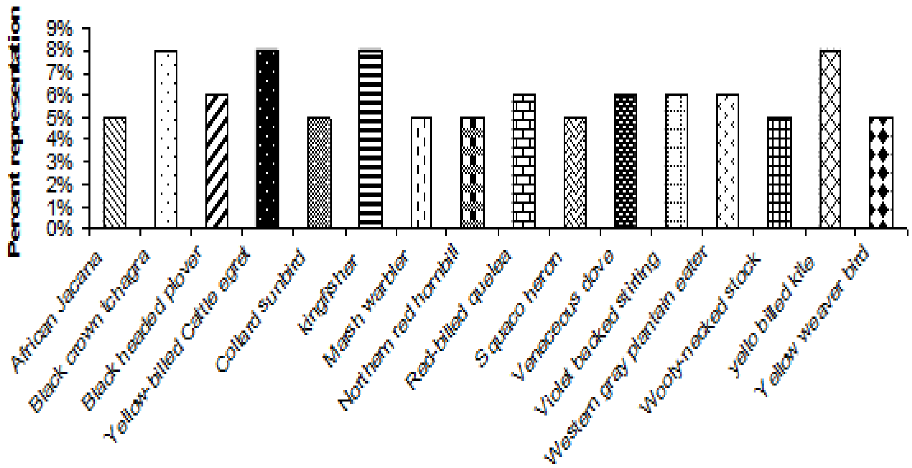


Figure 4.30a: Numerical composition of birds species counted in more than half of the six Wetlands in the dry season

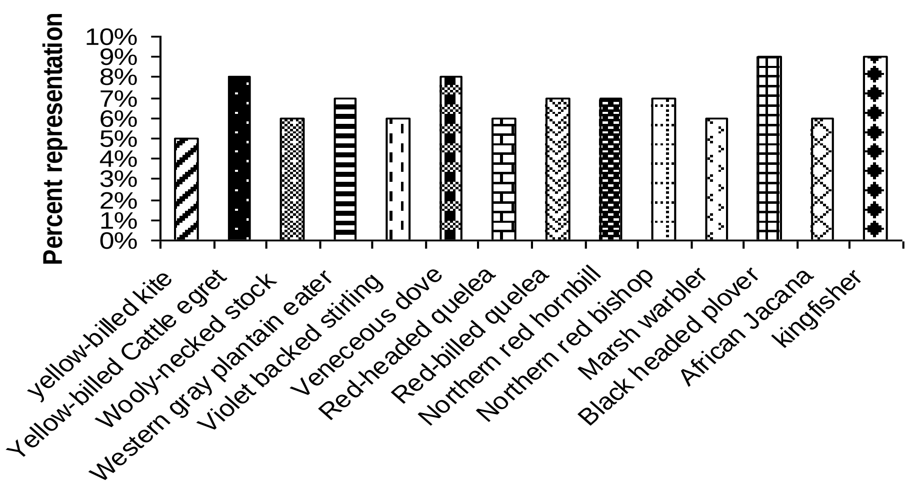


Figure 4.30b: Numerical composition of birds species counted in more than half of the six wetland in the wet season

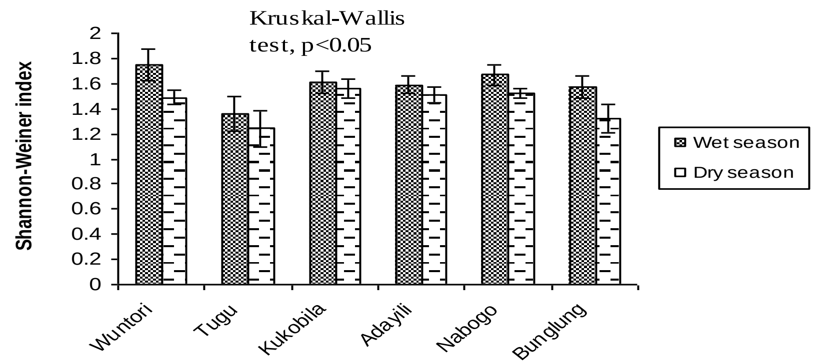


Figure 4.31: **Variations in mean diversity of birds in the wet and dry season**

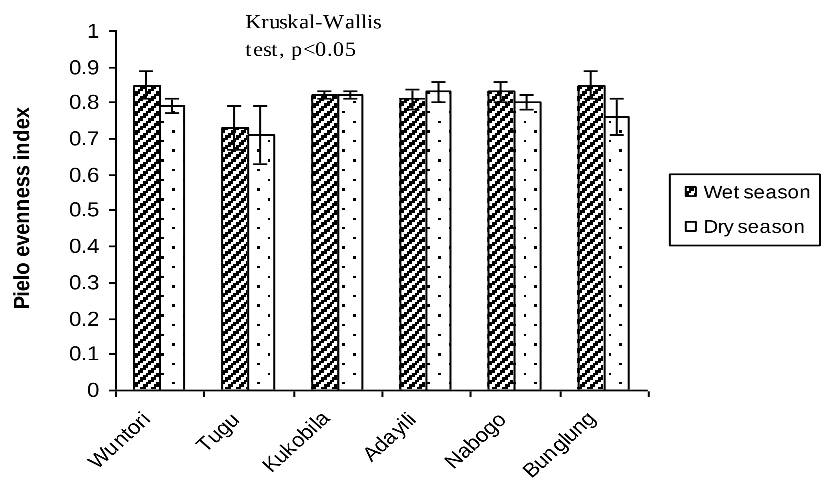


Figure 4.32: Bird evenness distribution in the wet and dry season

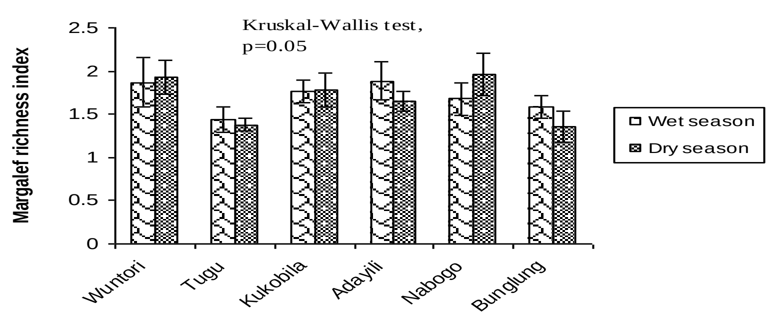


Figure 4.33: Comparison of bird richness in the six wetlands in wet and dry seasons

Table 12: List of sampled birds classified under various bird groupings among the six wetlands

Bird group	Common name
Coots	African jacana
Waders	Wooly necked stock Squacco heron
Terns	Violet backed stirling
Falcons	Lanner falcon
Weavers	Red-billed quelea
Warblers	Marsh warbler
Swans, ducks and geese	African pygme goose
Bitterns and heron	cattle egret
Touracos	Western gray plantain eater
Flycatchers	Gambaga flycatcher
Pheasants and patridges	Double spurred francolin
Kingfishers	Pied kingfisher
Hornbills	Northern red hornbill
Swallows	Yellow-billed kite
Bee eaters	Little bee eater
Plovers and lampings	Black headed plover
Pigeons and doves	Black-billed dove Vineceous dove
Treecreepers	Spooted creeper Collared sunbird
Finches	Yellow weaver bird Northern red bishop
Shricks	Black-crown tchagra
Woodpeckers	Bearded barbet

Table 13: List of birds identified and their IUCN global '*Red list*' database status. The status abbreviations are as follows: Least concern (LC); Vulnerable (VU); Threatened (T); Near threatened (NT); Critical (CR); Extinct (EX)

Family	Genera	Species	Common name	IUCN Status
Jacanidae	*Actophilornis*	*africanus*	African jacana	LC
Anatidae	*Nettapus*	*auritus*	African pygme-goose	LC
Lybiidae	*Lybius*	*dubius*	Bearded barbet	LC
Columbidae	*Turtur*	*abyssinicus*	Black-billed dove	LC
Malaconotidae	*Tchagra*	*australis*	Black-crown tchagra	LC
Charadriidae	*Vanellus*	*tectus*	Black headed plover	LC
Ardeidae	*Bubulcus*	*ibis*	Cattle egret	LC
Nectariniidae	*Anthreptes*	*collaris*	Collared sunbird	LC
Phasianidae	*Pternistis*	*bicalcaratus*	Double spurred francolin	LC
Muscicapidae	*Musicapa*	*gambagae*	Gambaga flycatcher	LC
Falconidae	*Falco*	*biarmicus*	Lanner falcon	LC
Meropidae	*Merops*	*pusillus*	Little bee eater	LC
Acrocephalidae	*Acrocephalus*	*palustris*	Marsh warbler	LC
Ploceidae	*Euplectes*	*franciscanus*	Northern red bishop	LC
Bucerotidae	*Tockus*	*erythrorhynchus*	Northern red hornbill	LC

Alcedinidae	*Ceryle*	*rudis*	Pied kingfisher	LC
Ploceidae	*Quelea*	*quelea*	Red-billed quelea	LC
Certhiidae	*Salpornis*	*spilonotus*	Spotted creeper	LC
Ardeidae	*Areodeola*	*rolloides*	Squacco heron	LC
Columbidae	*Streptopelia*	*vinacea*	Vineceous dove	LC
Sturnidae	*Cinnyricinclus*	*leucogaster*	Violet backed stirling	LC
Musophagidae	*Crinifer*	*piscator*	Western gray plantain eater	LC
Ciconiidae	*Ciconia*	*episcopus*	Wooly necked stock	LC
Accipitridae	*Milvus*	*aegyptius*	Yellow-billed kite	LC
Ploceidae	*Ploceous*	*megarhrynchus*	Yellow weaver bird	**VU**

Relationship between Environmental Factors and Bird Assemblage

Canonical correspondence analysis (CCA) diagram showed that bird diversity and abundance were generally influenced by farming practices, bushfires and grazing intensity although the level of impact varied between the wet and dry seasons (Figures 4.34 & 4.35). Although farming practices was a common activity within the catchment of the wetlands in the wet season, the situation was more severe and widespread within 100 m radius in the artificial wetland, with almost 90% of the fertile lands cultivated. Birds that were identified in these farmed plots were less diverse, low in abundance and sensitive to disturbances. Examples included: black-billed dove (*Turtur abyssinicus*), marsh warbler (*Acrocephalus palustris*) and the yellow weaver bird (*Ploceous megarhrynchus*) compared with birds found in the remaining five wetlands. Heavily grazed plots in Wuntori and Tugu shallow marshes, with severe animal tramplings, supported high abundance of birds like the African pygme-goose (*Nettapus auritus*), collard sunbird (*Anthreptes collaris*), African jacana (*Actophilornis africanus*), Pied kingfisher (*Ceryle rudis*) and the Squacco heron (*Areodeola rolloides*) (Figure. 4.34).

Bushfire was the key human-led factor that consistently influenced bird population and diversity in the two riparian wetlands in the dry and wet seasons, and a few plots in the Tugu shallow marsh. Observed patchy conditions brought about by previously and recent burnt areas (for the purposes of farm clearing and charcoal production) were more extensive in Adayili and Nabogo forested wetlands than tin Tugu wetland. This disturbance scenario rather attracted diverse birds such as Little bee eater (*Merops pusillus*), Yellow weaver bird (*Ploceous megarhrynchus*), Spooted creeper (*Salpornis spilonotus*), Northern red hornbill (*Tockus erythrorhynchus*) and Western gray plantain eater (*Crinifer piscator*) to these wetlands, in spite of the narrow ranges that were created (Figure.4. 34). Majority of species not captured in the ordination diagrams, were detected in habitats with average conditions of the environmental factors evaluated. Cumulative percentage variance of the species–environment relationship (axis I = 5.54 and axis II = 10.39) explained 15.93% of the variation in the weighted averages of the 25 species in relation to three environmental variables in the wet season (Table 14). Kendall rank correlation showed a strong relationship between species-environmental variables, by the first three axes (r = 0.430, r = 0.523 and r = 0.320) (Table 14).

The dry season saw water from the three marshes (Kukobila, Wuntori and Tugu) and Bunglung were drained to irrigate nearby farms. Consequently, birds such as African jacana (*Actophilornis africanus*), Lanner falcon (*Falco biarmicus*), Marsh warbler (*Acrocephalus palustris*) and black billed dove (*Turtur abyssinicus*), were confined to the central part of the wetlands that had isolated pools of water and vegetation (Figure. 4.35). Although birds were spatially diverse in these wetlands, they were less abundant. However, the population of Yellow billed kite increased in the first 0 – 10 m and 10 – 20 m transect lines, where incidences of bushfire was observed. All the three wetlands with inherent human-led disturbances (grazing intensity and farming activities) were spatially autocorrelated in the dry season (Figure.4.35).

Cumulative percentage variance was explained by the first two axes (axis I = 8.963 and axis II = 5.092) and accounted for 14.06% of the variation in the weighted averages of the 23 species diversity and abundance (Table 15). Kendall rank correlation further indicated a strong influence of environmental factors bird abundance and diversity (r = 0.581, r = 0.644 and r = 0.629)

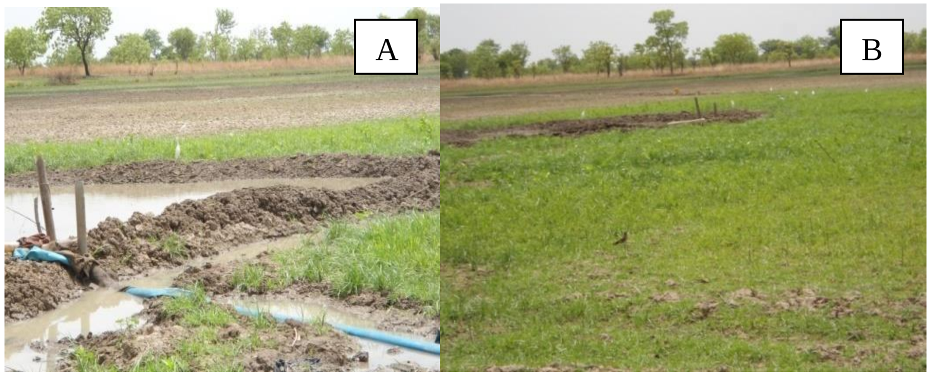


Plate 16: Desicated hydric soil of Kukobila wetland, showing (A) water hose used to drain water for irrigation purposes of nearby farms in the dry season and (B) fewer birds nesting on a small portion of the remaining vegetation in the middle of the wetland, following draining for irrigation activities

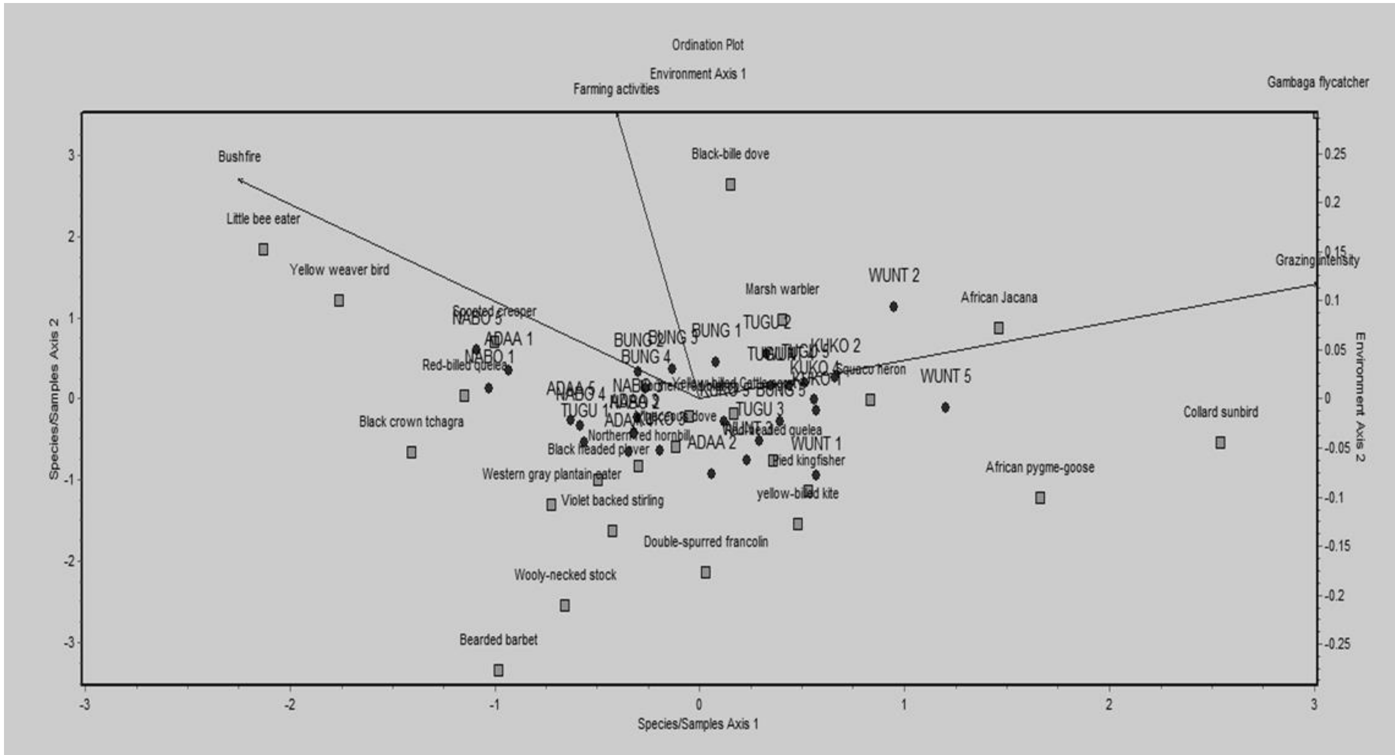


Figure 4.34: Canonical correspondence analysis (CCA) ordination diagram, showing the relationship between environmental factors and bird species in the six wetlands in the wet season. The red circles represent sample plots, the green squares represent bird species and the arrows represent each of the environmental variables plotted pointing in the direction of maximum change of explanatory variables across the six wetland

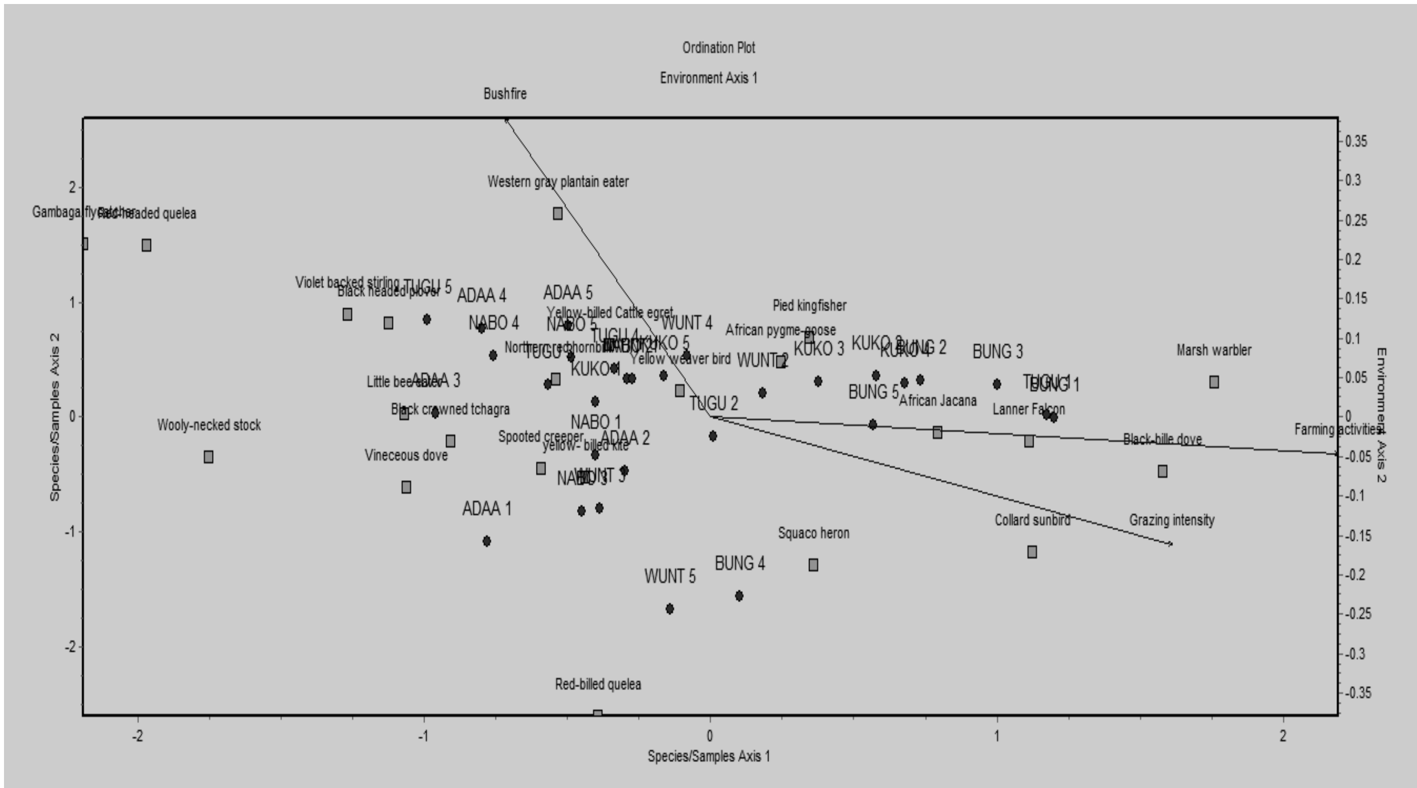


Figure 4.35: Canonical correspondence analysis (CCA) ordination diagram showing the relationship between environmental factors and bird assemblage in the six wetlands in the dry season. Diagram description is the same as in Figure 4.3

Table 14: Summary of CCA axis lengths for birds, showing the levels of correlation between axes and environmental gradients, percentage variance of species and species-environment relationships
Wet season

	Axis1	Axis 2	Axis 3
Canonical eigenvalues for bird sp.	0.163	0.143	0.078
Pearson correlation sp.-env'tal scores	0.722	0.795	0.558
Kendall rank correlation sp-envtal scores	0.430	0.523	0.320
Cumulative percentage variance	5.54	10.39	13.05
% variance explained	5.54	4.85	2.66
Number of sites	30		
Number of species (response variables)	26		
Number of environmental variables	3		
Total variance in species data	2.94		

Table 15: Summary of CCA axis lengths for birds, showing the levels of correlation between axes and environmental gradients, percentage variance of species and species-environment relationships
Dry season

	Axis1	Axis2	Axis 3
Canonical eigenvalues for bird species	0.287	0.163	0.100
Pearson correlation sp-env'tal scores	0.858	0.645	0.606
Kendall rank correlation sp-env'tal	0.581	0.644	0.629
Cumulative percentage variance	8.969	14.06	17.2
% variance explained	8.963	5.092	3.136
Number of sites	30		
Number of species (response variables)	23		
Number of environmental variables	3		
Total variance in species data	3.2		

Associated similarities between bird species and habitat type

Dry season

Sample plot clusters in the dry season, were different from that of the wet season, since ecological conditions in the wetlands varied in line with the season (Figure 4.36). The various clusters are explained below:

Clusters 1 & 4: Sample plots in this group were from Wuntori, Adayili and Nabogo and Bunglung wetlands. Common birds such as cattle egret and the pied Kingfisher were observed from the farmed edges of the wetland and on short trees and stumps (Figure 4.36). Gambaga flycatcher and Spooted creeper were more habitats-specific. The Spooted creeper had a narrow habitat, as it was usually spotted on tree trunks and occasionally pecking on insects on the bark of trees lined up along the banks of the swamp forest wetland, while Gambaga flycatcher preferred nesting on shrubs like *Mitragyna inermis* and *Mimosa pigra*) with profuse branches in marshlands (Plate 4.16).

Plates 17: Spooted creeper (www.pbase.com) Gambaga flycatcher

Cluster 2: Sample plots in this group were from Adayili, Tugu and Kukobila. Adayili wetland was characterized by tall dense trees, which served as shelter, resting and breeding place for most of the birds. Birds such as the little bee eater, Northern red hornbill and the Spooted creeper fed on the ripe fruits of *Syzygium guineense* (Wild) D.C. The Lanner falcon, Northern red hornbill and the Wooly necked stock prefered tree summit along the banks while the smaller birds such as the Vineceous dove usually hunged on the lower branches (Plate 4.16). Birds such as African pygme goose, Squacco heron and the Black headed plover were associated with the marshlands. The Black headed plover birds were sensitive to human movement or disturbances on the wetland vegetation.

Plates 18: Lanner falcon (www.pbase.com)   Laughing dove

Cluster 3: All the three plots from this group were from the Nabogo swamp forest, where the preferred habitat of all the birds observed was that of dense riparian vegetation. Birds such as pied Kingfisher and the Northern red hornbill were seen either standing on the extrusive rocks in the middle of flowing water (when levels dropped to ~1m) while occasionally fed on smaller fishes.

Clusters 5 & 6: this group comprised of the three marshlands and Bunglung man-made wetland. Common bird species that shared these preferred habitats where the water depth were lower with fewer floating and emergent aquatic plants, were African jacana, cattle egret and squacco heron. Collard sunbird and Violet backed Stirling were associated with plots in Kukobila, Tugu and Bunglung that had fewer and scarted shrubs and trees, interspersed with grasses.

Plates 19: Collared sunbird   Violet backed Stirling (www.pbase.com)

Wet Season

Hierarchical cluster analysis (HCA) separated the 30 sample plots in the six wetlands into five groups, on the basis of bird species and habitat use, habitat characteristics and their relative abundance in wet and dry season. The various clusters in the wet season were explained below:

Cluster 1: The shallow close marsh of Wuntori was inhabited by 15 species, while 14 species occupied the deep open Kukobila marshes. These wetlands were predominantly covered by herbaceous and grasses with fewer shrubs along the fringes (Figure 4.37). Water depth in the two wetlands was approximately 1 and 1.5 m, respectively. Some of the bird species that were censused were African pygme goose, pied kingfisher, Marsh warbler and Cattle egret. These species were mostly associated with marsh standing waters, where they spent a significant amount of time walking or resting on the maze of floating herbaceous plants and grass cover, while feeding on leaves, insects and fish. The pied kingfisher was mostly found on the shrubs and trees along the fringes of the marshes while waiting to prey on fish. Different species were seen clustered together, although there were isolated cases where some of the birds from different species such as the Squacco heron and the African pygme goose were spotted feeding together. During mid-day when air temperatures were high, hordes of cattle egrets were found resting along the shores of the wetlands or on the trees and shrubs while the African pygme goose, preferred nestling on the saturated zone. The presence of cattle during grazing period more often led to a corresponding increase in the number of cattle egrets in the wetlands, either walking alongside the animals or riding on their backs while feeding on insects and seeds that are hooked on their skin.

Squacco heron (www.pbase.com)

Cattle egret

African pygme-goose

Plates 20 A-C: Pictures of some birds with high abundance in Wuntori and Kukobila wetlands

Cluster 2: This group was made up of the forested, deep open marsh and the man-made wetlands of Nabogo, Adayili, Kukobila and Bunglung (Figure 4.37). A total of 16 species were recorded in Nabogo wetland and constituted the highest number of species representation among all the wetlands. This was followed by 15 species from Adayili and 12 species in Bunglung wetland. With the exception of Bunglung man-made wetland, the remaining three wetlands lie within the catchment of the White Volta River. Water depth during the peak of the wet season, was on average 2.84 m. Grazing activities and farming practices were a common sight among these four wetlands. However, channelization was only limited to the two riparian wetlands. Species such as Western gray plantain eater, wooly necked stock and little bee eater, were mostly spotted on the dense trees along the banks of the forested wetlands, while the Yellow weaver bird was predominant in both Nabogo and Bunglung wetlands. The Northern red bishop, though common in Kukobila and Adayili wetlands, was only confined to the fewer tufted grasses (e.g., *Deplachne fusca*) located behind the tall canopied trees at Adayili forested wetland. The Northern red bishop- *Euplectes franciscanus*, bird was only common during the wet season and associated with marshlands more than forested wetlands.

Northern red bishop **Wooly necked stock (www.pbase.com)**

Plates 21: (A) is a seasonal bird that migrates from the Coastal zone to the Northern Region during the wet season and mostly found on marsh wetlands. (B) Usually found along the stream banks of riparian wetlands, but occasionally spotted on marshes

Cluster 3: Bird species from sample plots in this group were mostly from the two forested wetlands. Only one plot from the close shallow marshes of

Tugu and the Bunglung man-made wetlands were clustered among this group. The Northern red hornbill, Yellow-billed kite and Black crowned Tchagra, were common in all the wetland classes. But the African Jacana species, was only restricted to the shallow marshes of Tugu wetland, as well as Bunglung man-made wetland, where the water is characteristically standing. Most of these birds congregated on the edges of the wetlands, where there were tall grasses such as *Scyzachiarium sanguineum* and *Deplachne fusca*, as their preferred habitats.

Plates 22: Africn jacana **Northern red hornbill**

(www.pbase.com)

Cluster 4: This group was made up of Nabogo and Tugu. A total of 16 and 14 bird species were counted in Nabogo and Tugu wetlands, respectively. These plots were slightly patchy as a result of previous bush burn and some erosional features. Grazing intensity was not too widespread. Common species in these wetlands were Black headed plover and the cattle egret. The Black headed plovers mostly nest on the fringes of the wetlands, where the ground cover was slightly bare. They were always in groups of 5-6 individuals.

Plate 23: Black headed plover (www.kenyabirds.org.uk)

Cluster 5: Wetlands in this group, constituted all three marshlands and the man-made wetland. Bird composition in these systems were only associated with marshy conditions dominated by herbaceous and grassland communities and characteristically open or close standing waters. Birds found in these habitats were rarely detected in flowing forested wetlands and spend most of their life cycles only in these systems. Examples included: African jacana, Marsh warblers, African pygme-goose, Squacco heron and double –spurred francolin.

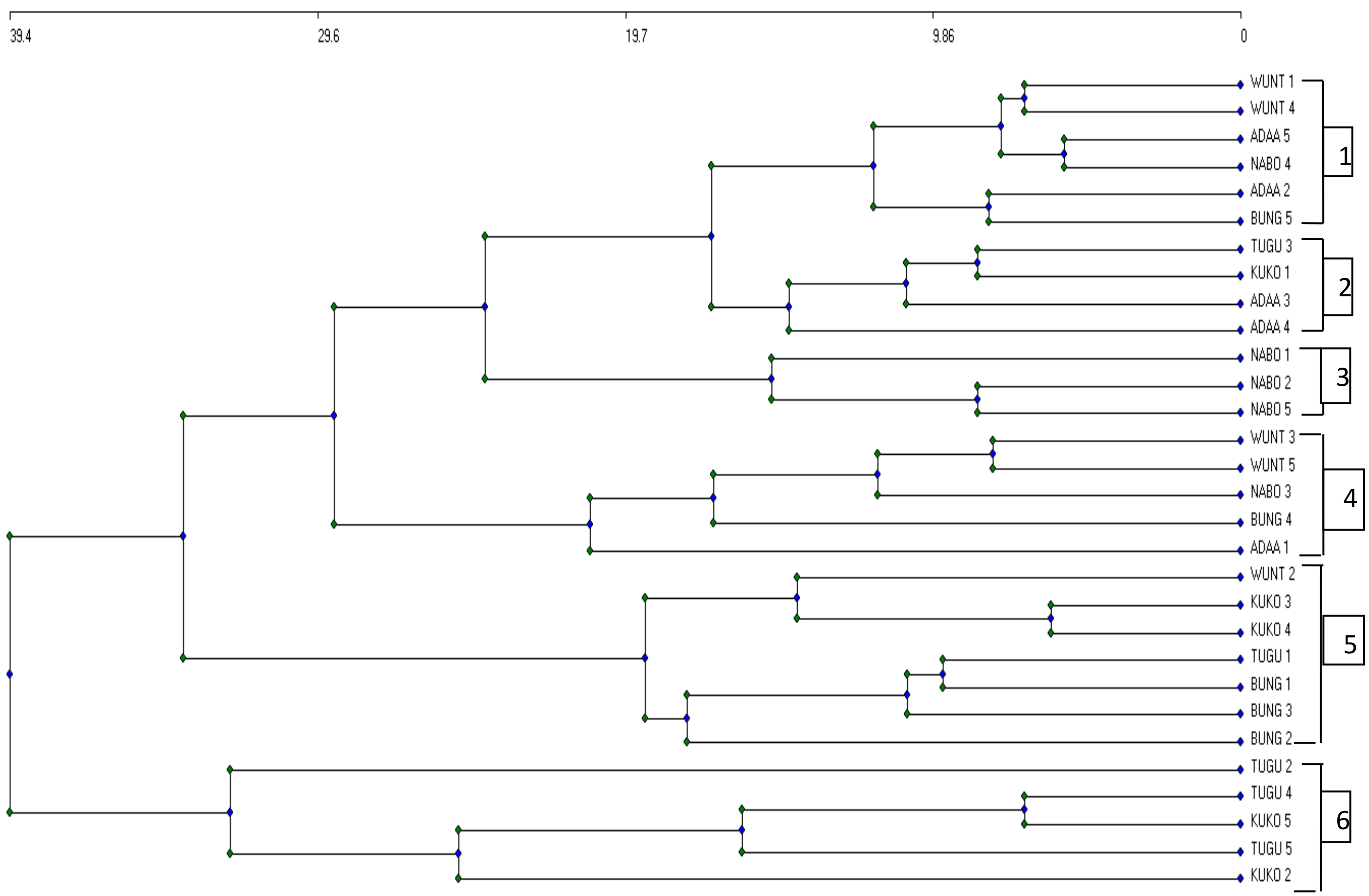


Figure 4.36: Dendrogram showing three clusters of bird communities based on their presence similar wetland classes in the dry season. The abbreviations denote sample plots in the six wetlands. Plot codes WUNT1-WUNT5= Wuntori; TUGU1-TUGU5= Tugu; KUKO1-KUKO5=Kukobila; BUNG1-BUNG5= Bunglung; ADAA1-ADAA5= Adayilli and NABO1- NABO5 = Nabogo

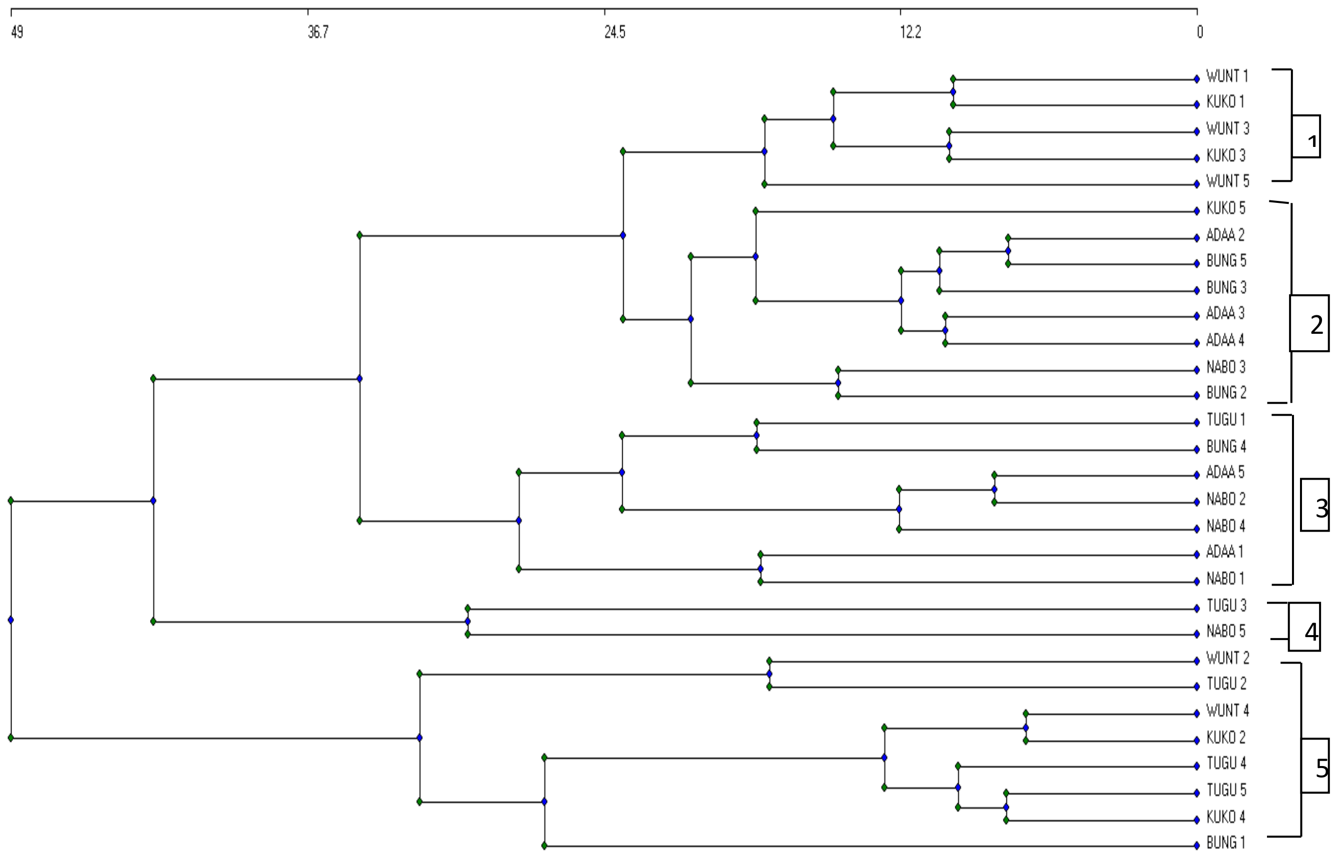


Figure 4.37: Dendrogram showing three clusters of bird communities based on their presence similar wetland classes in the wet season. The coefficient of squared Euclidean distances was employed to compute for similarity under complete linkage model. The abbreviations denote sample plots as described in Fig. 4.36

Historical Trend in Air Temperature, Precipitation and Potential Evapotranspiration Over the Last 50-years in Northern Region

Overall assessment of the historical trend on weather elements suggests a gradual increase in air temperature over the last 50-years (1960-2010). This was observed in both minimum and maximum air temperatures (Figures 4.38 & 4.39). Annual least mean minimum temperature was recorded in 1986 (21.8ºC) and highest maximum temperature in 1998 (35.8ºC). Both minimum (R^2 = 0.526) and maximum air temperature (R^2 = 0.596) showed a significant ($p<0.05$) variation over the 50 year period (Figures 4.38 & 4.39), with a decadal rate of change of +0.1ºC-Tmin and +0.2ºC-Tmax (Table 16). It was observed that annual mean minimum air temperature had increased from 21.8ºC in 1986 to 23.3ºC in 2010 while mean maximum air temperature on the other hand, dipped marginally from a high of 35.8ºC in 1998 to 34.9ºC in 2010. Monthly average temperatures showed that February and March still remained the hottest months throughout the 50-year period; with the highest monthly maximum average recorded in March, 1998 (39.9ºC) and closely followed in 2002 (39.6ºC) (Figure 4.40). The three hot months (February-April) also appear to show a decrease by the close of 2010 (38.6, 38.6 and 36.5°C, respectively, from a peak of 39.9, 38.9 and 39.2°C in 1998 and 2003.

Projected future trends in the next 20 years indicate that Tmin (ºC) will slightly increase by 0.72 ºC (from 23.3ºC in 2010 to an average of 22.58ºC)

(Figure 4.41) while Tmax (ºC) will also decrease by 0.83 ºC (from 34.9ºC in 2010 to an estimated 34.07ºC) (Figure 4.42).

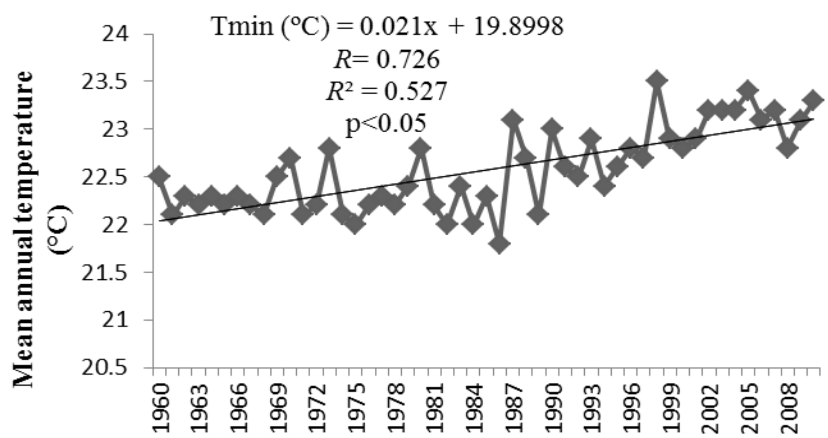


Figure 4.38: **Trends in minimum temperatures over the last 50 years**

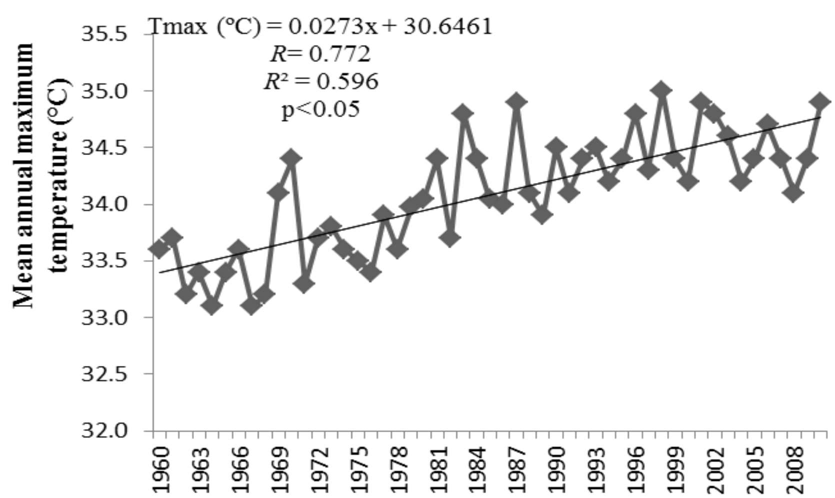


Figure 4.39: **Trends in maximum temperature variations Over the last 50 years**

Table 16: **Decadal change of mean annual temperature over 50-year period**

Year	Air temperature (ºC)	
	Max	Min
1960	33.6	22.5
1970	34.4	22.7
1980	34.1	22.8
1990	34.5	23
2000	34.2	22.8
2010	34.9	23.3
Decadal change over the 50-year period	+0.2ºC	+0.1ºC

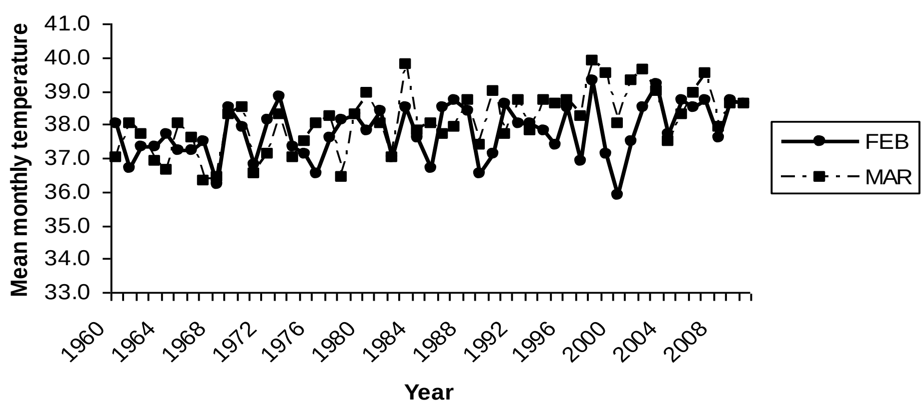


Figure 4.40: **Trends in the hottest months (February-March) over the last 50 years showing day temperatures generally in an increasing pattern with a slight dip beyond 2008**

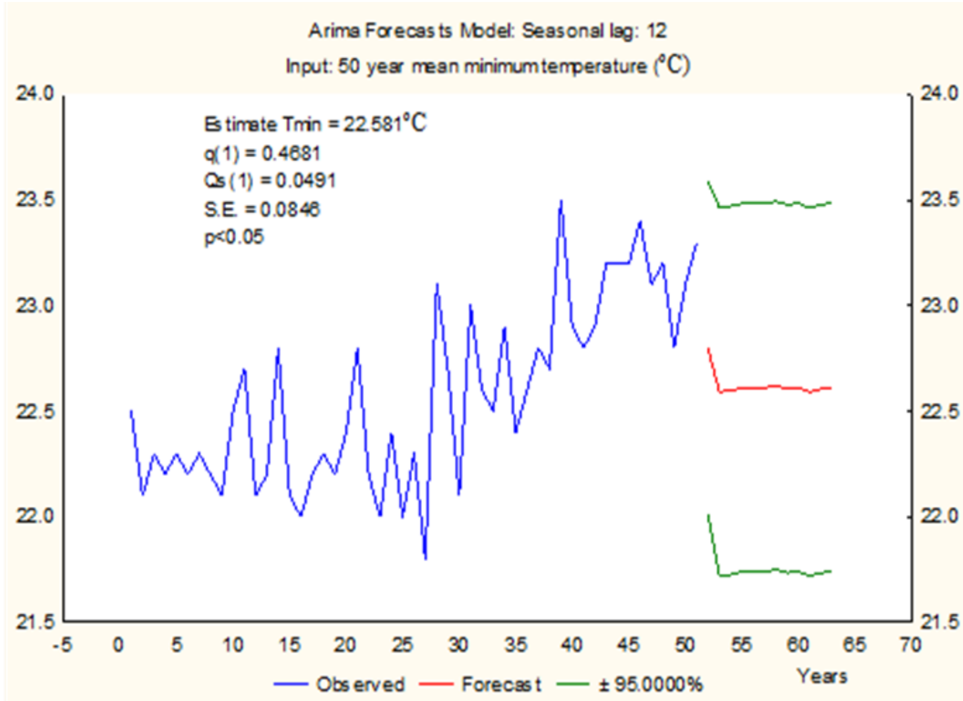


Figure 4.41: **Projected increase in minimum temperatures over the next 20 years**

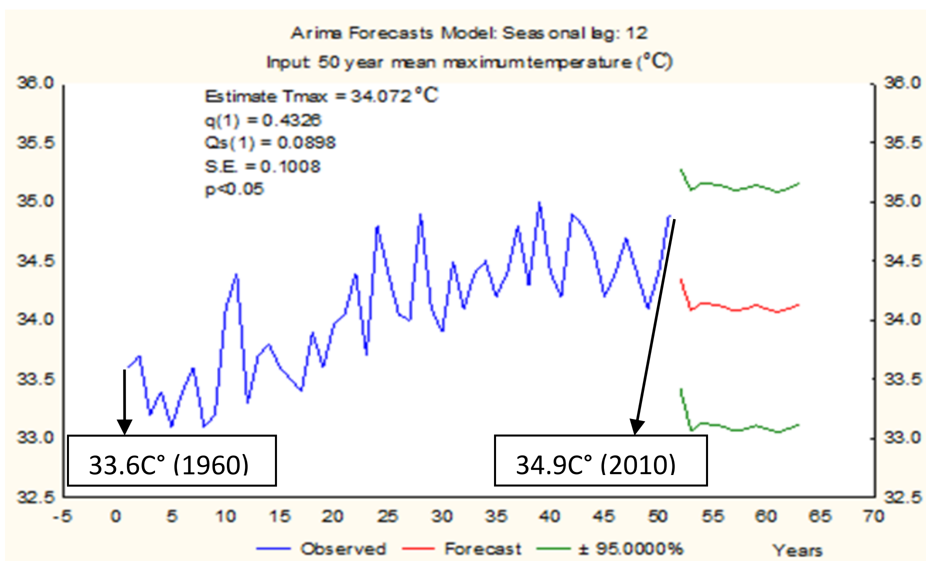


Figure 4.42: **Projected rise in maximum temperatures over the next 20 years**

Precipitation over the last 50 years showed a general significant ($p<0.05$) decrease from a mean annual high of 2, 311.4 mm in 1964 to 695.3 mm in 1992 (R = -0.237), although there were some relatively higher rainfall recorded in between these two periods and beyond 1992 (Figure 4.43). By 2010, mean annual rainfall had marginally increased to 987.4 mm from the lowest of 695.3 mm in 1992 and projected to increase to an annual average of 1126.4 mm in the next 20 years (Figure 4.44). It was also evident that the coolest and peak rainy month which used to be August, had gradually shifted to September, although the shift was significant ($p>0.05$) (Figure 4.45 a&b). The highest average monthly rainfall in September was recorded in 1989 (495.8 mm) while the least was recorded in August, 1992 (45.2 mm). The second least precipitation was recorded in the same month of August, in 1983 (81.3 mm) when the entire country was hit by the worst draught in history. Estimated shift in peak monthly rainfall from August to September will be 204.4 mm and 221 mm, respectively in the next 20 years (Figure 4.45 a & b).

Although precipitation negatively correlated with air temperature (r = -0.599, *Tukey HSD test*, $p<0.05$), the extent of influence by temperature was not substantial enough (R^2 = 0.359) as 65% of the variation in precipitation over the last 50 years was accounted for by other environmental and natural factors (Figure 4.46).

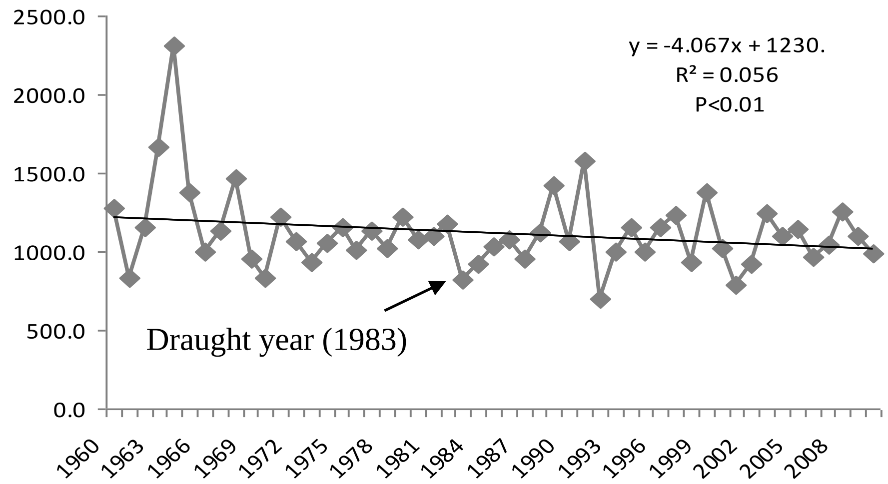


Figure 4.43: Precipitation trends over the last 50 years showing a general decreasing pattern

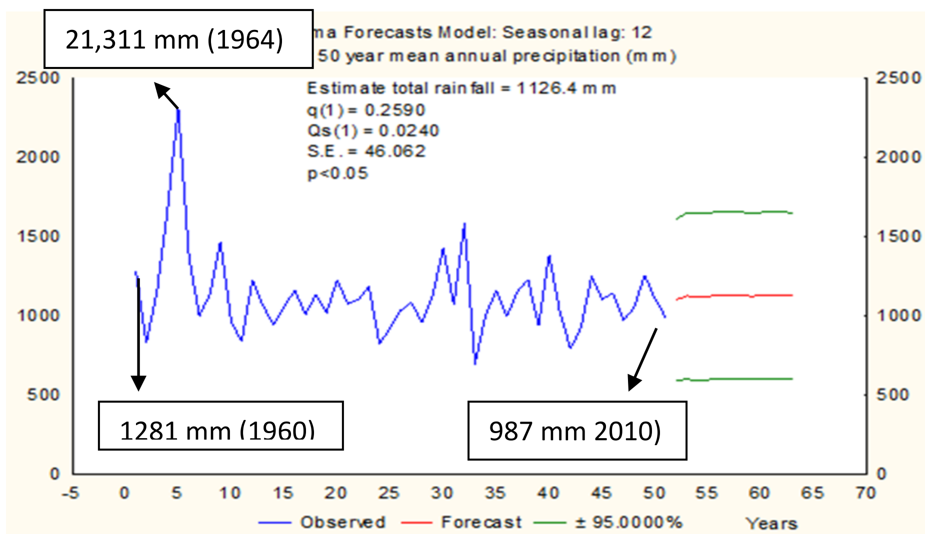
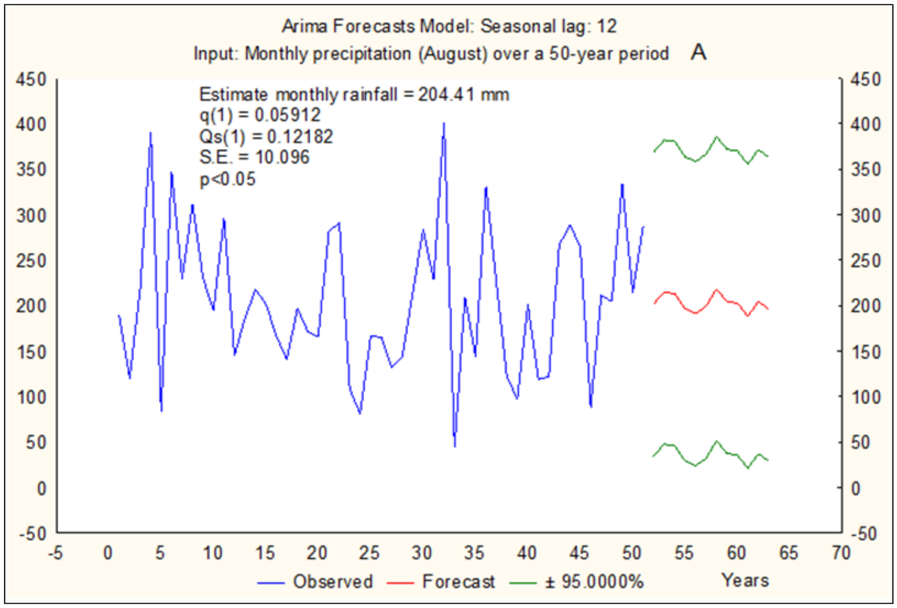


Figure 4.44: Projected precipitation trends in the next 20 years



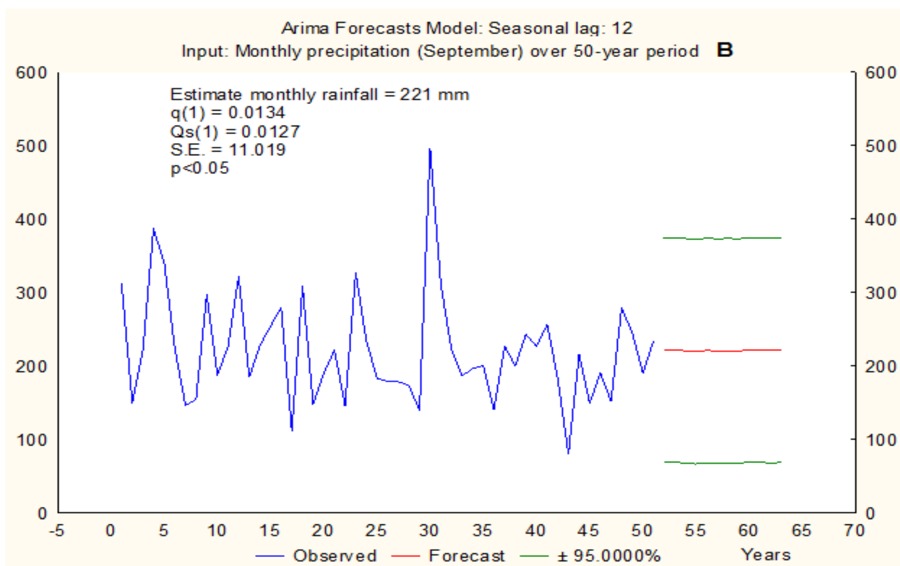
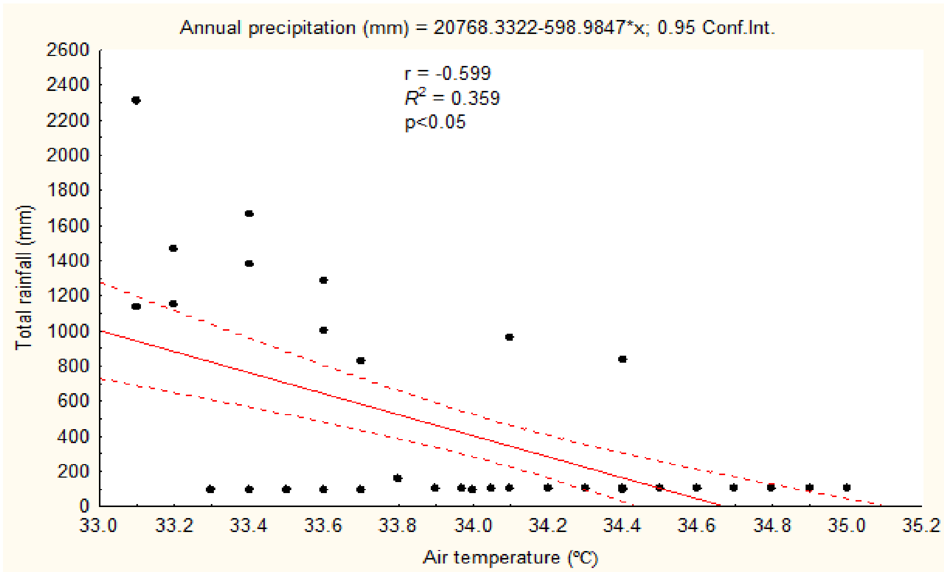


Figure 4.45 a & b: A shift in the peak monthly rainfall pattern from August to September over the period 1960 to 2010



Figures 4.46: Relationship between air temperature and rainfall showing a decreasing trend as temperature increases over the period 1960 to 2010

Mean potential evapotranspiration (PET) generally increased in the last 48 years and showed a marked correlation between the period 1961 and 2009 ($p<0.05$) (Figure 4.47). Mean minimum PET (1833.4 mm) was recorded in 1965 and the maximum (2329.3 mm) in 1998. The highest PET (2329.3 mm) recorded in 1998, correlated with similar highest mean temperature (35.8ºC) recorded in the same year as shown in Figure 4.41. Mean PET was strongly influenced by increasing air temperature (R^2 = 0.61630, $p<0.05$) over 48 year period (1961 – 2009) (Figure 4.48). Projected future average evapotranspiration in the next 17 years show that PET will increase from 2094 mm in 2009 to 2117.9 mm by 2026. Even though PET will increase in future projections, the increase will fall below the highest maximum of 2329.3 mm that was recorded in 1998 (Figure 4.49).

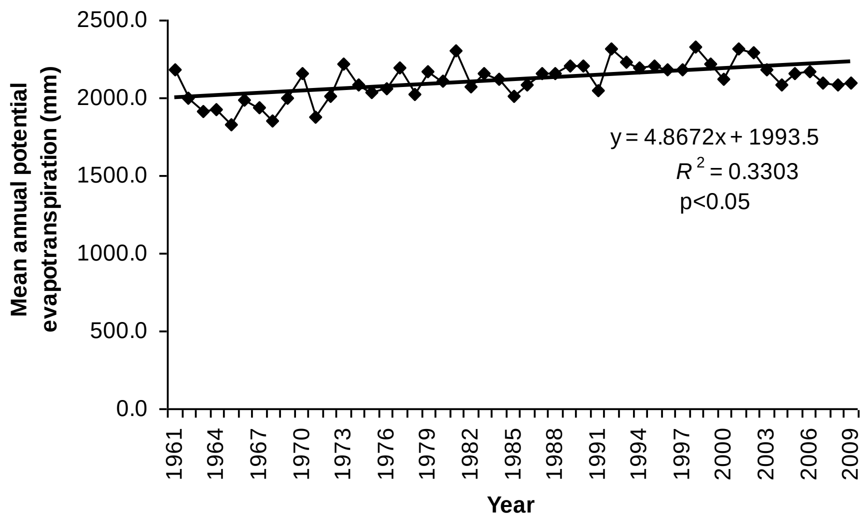


Figure 4.47: **Variations in mean potential evapotranspiration over 48-year period**

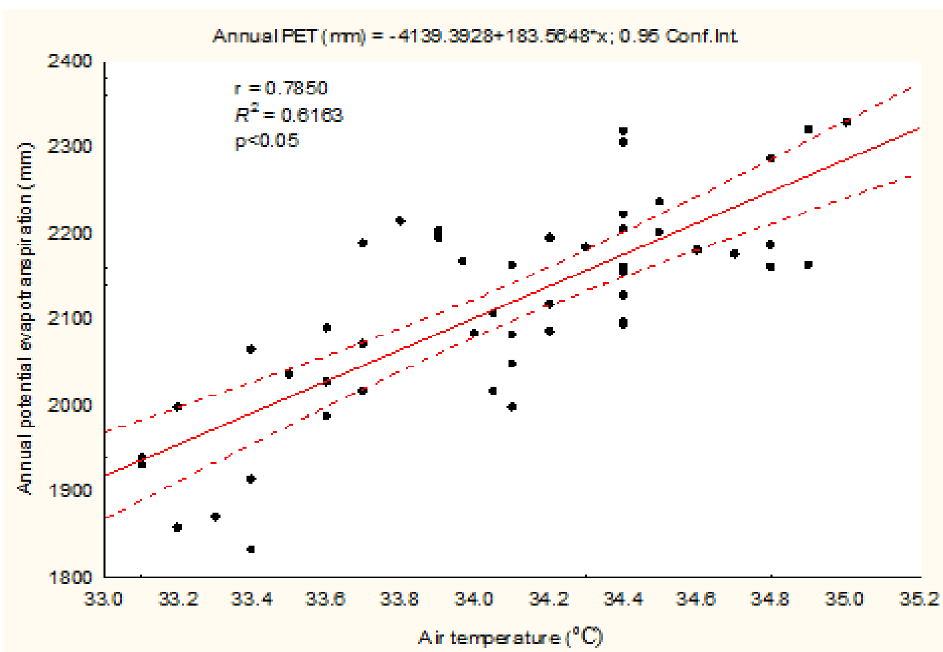


Figure 4.48: **Relationship between air temperature and annual potential evapotranspiration between 1961 and 2009**

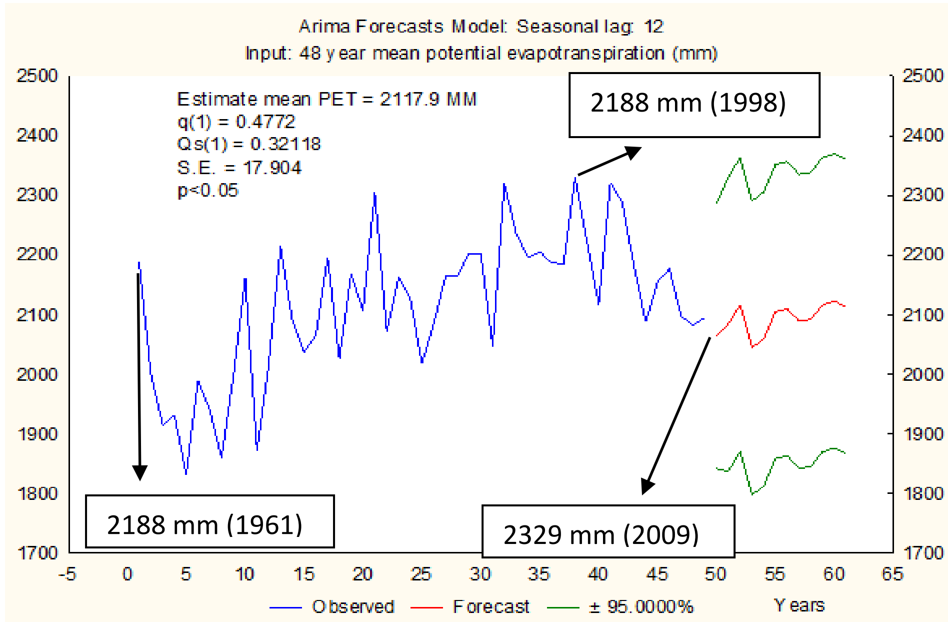


Figure 4.49: Future trends in potential evapotranspiration in the next 17 years

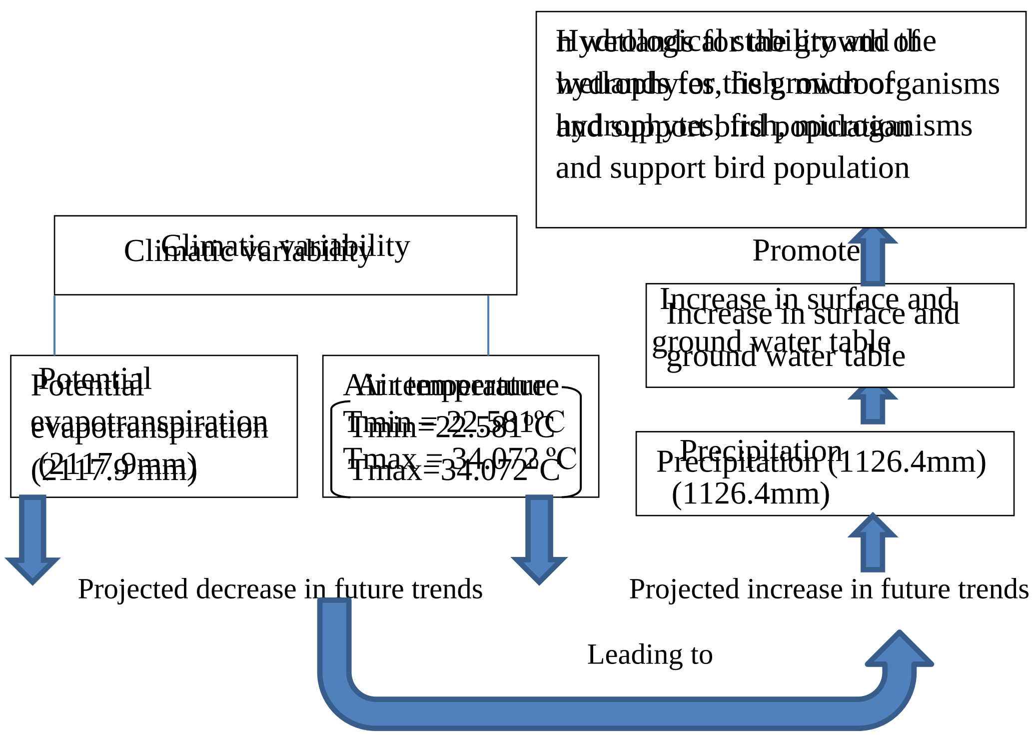


Figure 4.50: **A conceptual model showing the relationship between projected future trends in climatic variability and wetland hydrological stability in the next 20 years**

Identified Threats to the Wetlands and Proposed Conservation Measures

Identification of major threats was assessed beyond 2 km of the wet zone. With the exception of bushfires and water withdrawal for irrigation that occurred in the dry season, the rest occurred in the wet season. Wetland users, ranked farming practices, bushfires, grass harvesting and tree felling, as the most severe threats to the wetland health (Table 17).

From the assessment of all the studied wetlands, eight major threats were identified. They included: i) farming practices; ii) animal grazing; iii) animal trampling; iv) over fishing; v) tree felling; vi) grass harvesting; vii) bushfires and viii) water withdrawal for dry season irrigation (Table 17).

These direct threats put the wetlands under severe stress all-year-round. The surge in these anthropogenic activities was the resultant effect of population increase (indirect threat), coupled with low levels of rainfall in recent times and the general impoverished nature of terrestrial soils. Wetlands served as the alternative source of livelihood sustenance for rural communities, since they are by far the most fertile areas with a reasonable level of moist surface within the catchment throughout the year. These threats leave in their wake severe erosion and species range shift (i.e. loss/reduction of typical keystone species and the increase terrestrial and invasive species into wetlands), reduction in species diversity and the inability of the wetlands to control flooding. The results of threat assessment prompted the need to propose practical conservation measures to forestall the functional state of the wetlands under study, using traditional approach.

Table 17: Ranking of human-led threats across the six wetlands under study

Major threats	***Level of threats***
Farming practices	•••
Animal grazing	•
Animal trampling	•
Over harvesting of fishery resources	••
Tree felling	•••
Grass harvesting	•••
Water withdrawal for irrigation	••
Bushfires	•••

• = less severe; •• = moderately severe; ••• = highly severe

CHAPTER FIVE

DISCUSSION

Plant Richness among the Six Wetlands

While altitude has been noted to positively associate with plant richness (Rolon & Maltchik, 2006), other studies have rather found a positive relationship between area and plant richness in aquatic systems (Allen & White, 2003; Jones, Li & Maberly, 2003). In this study, plant richness was not directly proportional to increase in plot size from one wetland to the other. Although the three marsh wetlands (Kukobila, Tugu and Wuntori), all tended to be rich in species accumulation, the two forested wetlands at Adayili and Nabogo, showed the strongest plot size-species relationship (R^2 = 0.946 and R^2= 0.905) respectively, while Tugu wetland showed the weakest plot-size relationship (R^2 = 0.011). This observation could mean that the amount of species accumulated in a given wetland, was not directly proportional to plot size, since there were differences in tolerance level to inherent ecological conditions largely driven by ecological or anthropogenic factors. Similar findings by Linton & Goulder (2000) negate the attempt to consider generalizing a positive species-area relationship to aquatic plants, as documented in some studies. While Rolon & Maltchik (2002) argued that the lack of prediction between area and plant richness in the lacustrine subsystem may be related to the fact that most plant species grow mostly in the shores of the subsystems, thus weakening the species–area relationship. Veestgaard & Sand-Jensen (2000) suggest that the plant richness may be more related to the colonization area than the total wetland surface. In the present study, the lack of consistency in positive species-area relationship in sample plots, suggests that some other human-induced or environmental factors, could have accounted for this trend. Thus response to disturbances by aquatic plants could be used as a measure of wetland functional status at different spatio-temporal scales.

The reduction in plant biomass principally through grazing pressure at Tugu wetland, could have explained the weakest relationship between species accumulation and plot size encountered. Robertson & Rowling (2000) have demonstrated that livestock grazing has had substantial impacts on riparian vegetation of the Murrumbidgee River, southern New South Wales. The location of the wetlands within intensive crop farming areas along the floodplains, may contribute in explaining why many livestock use the wetlands as their watering points and grazing zones, which in the end altered plant structure and composition as well as soil structure. Jansen & Robertson (2001) indicated that in agricultural landscapes, the stress posed by grazing pressure on wetlands, is of particular concern as domestic stock and feral grazing herds usually congregate in and around water areas. The impacts from grazing activity can potentially alter the spatial heterogeneity of vegetation, by influencing ecosystem processes and biodiversity (Taddese et al. 2002;

Hopfensperger, Wu & Gill, 2006). This is done through a decrease of plant biomass by destroying their growth and reproductive parts (Brock, 2003).

Such physical disturbance from grazing activities has the potential of reducing endemic species, while encouraging the invasion of dryland species in many marshlands, as was observed especially in the Nabogo riparian wetland. Furthermore, the least mean number of species recorded in the Bunglung constructed wetland, could be attributed to the inability of the plants to withstand extensive human-led activities carried out within the wetland catchment, leading to resource depletion.

Other studies however, have shown that grazing have contributed in increasing species richness at large spatial scales, by intensifying intra- and intercommunity seed flow (Malo & Suárez 1995a; Traba, Levassor & Peco, 2003). Species that are adapted to resource-abundant habitats with disturbances, such as grazing, are displaced by competitive species that tolerate decreased amounts of disturbance (Grime, as cited in Hopfensperger, et al. 2006). The author further pointed out that competitive ability of a plant may be altered when leaf area is subject to grazing and some species respond with renewed growth when defoliation occurs. Though grazing intensity has the ability to transform the natural vegetation of wetlands, the impact may depend on how palatable the species is (i.e., whether they are decreasers, increasers or invaders), the grazing regime, the period of grazing and the number of livestock occupying a unit space at a given time. This is because the extent of damage to soil structure by livestock trampling will be directly related to these factors mentioned above. In some cases grazing *per se* may not lead to a range shift in species, but the indirect effect on soil structural transformation (soil compaction) could lead to the creation of patchiness, soil erosion and runoffs. The aggregation of these disturbances could result in a shift in species from their natural habitats or a complete reduction of endemic species. Molles (1999) observed that heavy human impacts generally reduce the number of native species in a community while encouraging the presence of alien species.

Influence of Environmental Factors on Community Composition and distribution of Plants among the Six Wetlands

A number of studies on wetland systems have shown that farming activities (Millenium Ecosystem Assessment, 2005; Mironga, 2005; Kopec et al. 2008 & Kath et al. 2010), fire (Kutiel & Shaviv, 1993; Wuver et al. 2003), Grazing (Taddese et al. 2002) and soil condition (wild et al. 2004) are among the factors that account for the global loss of plant diversity and shift in species range. In this study, farming activities, fire, grazing and soil nutrient status, were the predictors of species heterogeneity and pattern of distribution, although, some minor factors such as erosion and grazing disturbances were seen in some wetlands. Although the findings by Taddese et al. (2002); Wuver et al. (2003); wild et al. (2004) and Kath et al. (2010), agree with the findings in this study, other research have shown that the diversity, composition, condition and recruitment of wetland fringing vegetation are directly linked to the water regime of a wetland (Leck & Brock, 2000; Warwick & Brock, 2003; Siebentritt et al. 2004). The fairly high species diversity indices in some wetlands, fell within the Shannon-Weiner index of 1.5-3.5 (and 4.5 in exceptional cases), provided by Kent & Coker (1992). However, indices recorded, fell short of the maximum 3.5 Shannon-Weiner index, thus indicating that plant diversity was probably under threat from both ecological and human-led disturbances. The fairly high diversity reflected in the average evenness distribution of species. This was partly attributed to the location of the wetlands in the floodplain catchment of the White Volta River and the land disturbances that are seasonally driven. The seasonal flooding that had occurred over the last 10-20 years, alongside catchment activities, could have transported and deposited different plant propagules from other surrounding landscape into the wetlands. Salo et al. (1986) reported that the high species diversity in parts of the Amazon basin rainforest was the result of long-term history of flood disturbances and channel migration. Brock, Smith & Jarman (1999) confirmed that wetlands are reliant on the dynamic and fluctuating water regimes to maintain habitat diversity in the New England Tablelands of New South Wales. For instance, in the Great Lakes of Michigan, Wilcox & Nichols (2008) found that alterations between wet and dry periods were an important condition for generating diversity in the plant community. From a seasonally driven land use disturbances, Kath et al. (2010) found that wet and dry periods were an important factor in determining diversity in the plant community. Consequently, variations in frequency and duration of land use activities from one season to the other, could lead to a long term effect on floristic composition and structure. Disturbances that alter vegetation structure and organic inputs to streams can significantly impair stream habitats, which are a major concern in watersheds and wetlands in the Pacific Northwest (Hopfensperger, et al. 2006).

The unevenness in species distribution probably indicates the varied impacts of both anthropogenic and ecological drivers of change from one wetland to the other, which are largely determined by seasonal changes. The Millenium Ecosystem Assessment Report (2005) indicated that many wetland-dependent species in most parts of the world are in decline; of which the status of species dependent on inland wetlands is of particular concern. The fairly high species diversity, in the three natural marsh wetlands (Kukobila, Wuntori and Tugu) were strongly associated with low nutrient load (nitrogen, phosphorus and potassium), with isolated grazing and erosion disturbances. While Murphy (2002) reported similar highest plant diversity relationship with observed mesotrophic or slightly eutrophic condition in lakes, Jones et al. (2003) did not find any relationships between nitrate and phosphorus concentrations and the diversity of aquatic plants in ponds. Other authors (e.g., Verhoeven, Kemmers & Koerselman, 1993) have also reported that nutrient enrichment, such as phosphorus and nitrogen in several wetlands, led to the overall loss in plant diversity, changes in species composition, replacement of native species to exotics and the conversion of a unique flora by a few common species in some wetlands. Moore & Keddy (1989) concluded that for relatively undisturbed wetlands, high species diversity is frequently associated with low nutrient status, and that species rich wetlands usually have average productivity and standing crop. It can be concluded that the contrasting findings by these authors, relative to the findings in this study, could be linked to the mediating effect of some other soil nutrient elements on the plants present on these wetlands.

The high soil nutrient load from the standing marsh wetlands could be due to the cyclical deposits of decomposed plants and other organisms, as well as the transport of point source nutrients from nearby farmlands. Dung deposits from livestock, which constantly use these wetlands as grazing and watering points, may also explain for the high soil nutrient status. Finally, the pockets of bushfires that occurred in some parts of the three wetlands could contribute in increasing the soil nutrient level high, through the ash deposits. Kutiel & Shaviv (1993) observed that soil nutrients levels increase after fire in wetlands. The abundance of species from the cyperaceae family (*Cyperus difformis* Linn. and *Cyperus spacelatus* (Rottb.) in all the three marshlands probably showed their positive responses to high amount of phosphorus, potassium and nitrogen availability. While Nalubega & Nakawunde (1995) point out the importance of phosphorus in sustaining the growth of *Cyperus papyrus* dominated vegetation community, Ssegawa et al. (2004) rather showed the positive relationship between potassium and *Cyperus papyrus* growth performance. The abundance of the only submerged plant (*ceratophyllum demersum*), particularly in the open system of Kukobila wetland, may relate to the availability of nutrients as well as the ease of light penetration, into the bottom of the wetland for photosynthetic activity. Cronk & Siobhan-Fennessy (2001) pointed out that light availability is probably the most important regulator of the distribution of submerged plants, though the availability of light to these plants depends on numerous factors, e.g. the depth of water column and the turbidity.

Plants responses to farming activities and fire disturbances from the Bunglung man-made wetland and the two riparian wetlands, showed a slight variation in species diversity. For instance, Bunglung wetland which strongly correlated with farming activities was relatively high in species diversity, thus suggesting the need for some level of deliberate disturbances in order to promote species heterogeneity, while the two riparian wetlands which strongly correlated with bushfire, had low species diversity. These two varying scenarios probably indicate the tolerance level of disturbances among the different wetlands from either anthropogenic or natural drivers. The intensity of crop farming around wetlands was partly due to the erratic rainfall pattern commonly experienced in the Northern Region and the high water table level all year round. Ssegawa et al. (2004) also found cultivation as one of the determinants that contributed in explaining species assemblage and composition in wetlands areas of Uganda.

The low species diversity that was reported in the two forested wetlands of Adayili and Nabogo was largely caused by wild fire. Wetland fires do not only destroy plants, but also kill soil macrobes and ‘bake’ the hydric soil into had pan concretion. Main & Barry (2002) also measured the effects of prescribed fire on flowering of three wetland grasses (*Muhlenbergia capillaries, Paspalum monostachyum* and *Schizachyrium rhizomatum*) and found out that they all responded positively to fire, through a decrease in flowering. Such disturbances suggest a strong relationship between fire and plant species and could be used as a measure of the functional state of the wetlands.

From the assessment of plant-environmental relationship, it was clear that the first two axes of the CCA ordination accounted for 61.29% of the explained variance in species richness, diversity and distribution, while the remaining 38.71% unaccounted for in explainable variance, could be attributed to other natural drivers of change such as climatic variability. Richardson & Bond (1991) and Hulme (2003) suggest that the interaction between disturbance regime and biotic may possibly override climatic variables in explaining species distribution. Ceschin et al. (2009) attributed the disappearance of over 40% of plant species at Rome's archeological sites over the last 50 years to environmental disturbances. A survey carried out by Ceschin et al. (2010) further revealed that vascular flora richness, composition and structure in the Tiber River- Rome has decreased in in the last 30 years as a result of human- led influences. It can be argued that the magnitude of current and future impacts on species range shift may be linked more to human-led disturbances rather than climatic scenarios.

Hydrophytic Plant Communities as Indicators to Range Shift of Species, using the Dominance Ratio Approach

A number of studies in recent times have indicated a shift in species range, in direct responses to climate change and other experimental warming simulations (Parmesan & Yohe, 2003; Colwell et al. 2008). Although the evidence has geographical limitations and is chiefly from species already globally threatened with extinction, this pattern is consistent for different groups of species (Millennium Ecosystem Assessment Report, 2005). However, the present study showed that a shift in wetland plants from their range was largely linked to the combined effects of human-led and ecological variables. This was evident from outcome of CCA analysis. From the application of the dominance ratio method Cronk and Siobhan Fennessy (2001), it was clear that 13 (35%) out of the 40 species identified as typical hydrophytes (obligates species), fell short of the > 50% score. This observation is indicative of their lack of resilience to increasing disturbance. Therefore the predominance of the rest of the 27 plants from dryland arable crop fields and derived Savannah was likely due to the observed disturbance scenario among the wetlands. It was noted that, plant propagules of derived savanna origin, were found in animal dungs on the wetlands during grazing and watering. These introduced facultative wetland species (FACW), in the presence of growth medium condition (oxygen, moisture and temperature), exhibited high adaptive means, through a rapid reproductive and dispersal ability in their new wet environment. This process described as endozoochory (a dispersal processes in which livestock grazing essentially transports many seeds to points at varying distances from the parent plant and leaves them in safe sites for germination) is one of the noted mechanism for plant propagule dispersal (Traba et al. 2003). Ungulates such as dear and cattle are noted to be effective seed dispersers of grasses, herbs and trees, colonizing a wide array of new sites (Myers, Vellend, Gardescu & Marks, 2004; Cosyns, Claerbout, Lamoot & Hoffmann, 2005).

Though, not scientifically established, field discussion among indigenous community leaders, through the use of local knowledge or local observation indicated that hydrophyte like *Pistia stratiotes* that were hitherto abundant in the last decade, were very rare in recent times. For instance, *Pistia stratiotes* was visibly present at the start of the study in 2010 in Tugu marsh wetland. And by the close of 2012, the species was completely extinct. The extinction of these species could be linked to their sensitivity to disturbances such as draining of wetlands for farming purposes. Also, the location of the wetlands in the floodplains of White Volta River at Nasia, were the flooding is a regular phenomenon since 1974, may have contributed in explaining the higher number of facultative species recorded. The plant propagules of herbs, grasses, shrubs and trees, could have been transported with sediment from distance and nearby terrestrial systems and deposited in the wetlands, during flooding. The mixture of plant progagules with sediment and in the presence of moisture and other growth factors, could potentially lead to the survival of these species, especially those with shorter dormancy. Hughes and Rood

(2001) argued that though flooding creates a temporal disturbance of sediment through erosion, transport and deposition within the ecosystem, it simultaneously provides new sites conducive for regeneration of vegetation. Lowering of water levels as a result of draining for dry season irrigation activities (as was observed in Kukobila wetland), could potentially lead to the recruitment of nearby dryland species that perform well in less saturated conditions. Hudon (2011) argued that low water levels markedly altered wetland vegetation in the St. Lawrence River in Canada, leading to the invasion by *Phalaris arundinacea* and *Phragmites australis* and facultative annual species. While submerged species previously found in shallow waters were replaced on dry ground by annual terrestrial plants, *Alisma gramineum* colonized emergent waterlogged mudflats (Hudon, 2011). Wilcox et al. (2002) reported that *Percent of Taxa as Obligate Wetland Plants* is a measure of tolerance that should decrease with disturbance.

Comparatively, facultative wetlands were more than the obligate wetland plants (hydrophytes), suggesting a gradual shift of obligate plants away from their natural habitats and the establishment of facultative wetland plants. Tiner (1999) reported that Facultative wetlands species had an estimated probability of 67% - 99% to occur in wetlands, but occasionally grow on uplands or terrestrial systems. The ability of some of the facultative plants to either grows towards wetter areas or away from wet zones could be due to the fact that over time, a good number of the dryland plant species became physiologically and morphologically adapted to the wetter conditions. Thus the sensitive nature of hydrophytes to environmental changes such as hydrological regimes from dry to the wet season, changes in nutrient load and human-led activities, could have given a competitive urge to the facultative species dominance in colonizing the wetlands. Cronk & Siobhan Fennessy (2001) showed how this adaptive strategy may be possible physiologically through: germination flexibility; oxidized rhizosphere; accelerated stem growth; C4 photosynthesis and alternate metabolic pathways. Cronk & Siobhan Fennessy (2001) also showed how morphologically plant species can adapt to wet conditions through: the development of shallow rooting system for gas exchange with the atmosphere; development of hollow stems to improve root aeration and the accumulation of CO_2 and development of air spaces in the roots and stems which allow diffusion of oxygen from the aerial portions of the plant into the roots. The U.S. Army Corps of Engineers (as cited in Collins, 2005) illustrated a diagram, depicting how anaerobic pathways permit metabolism to continue in the absence of oxygen, but at reduced energy efficiency and with the potential for buildup of toxic by-products, such as ethanol (Figure 4.10).

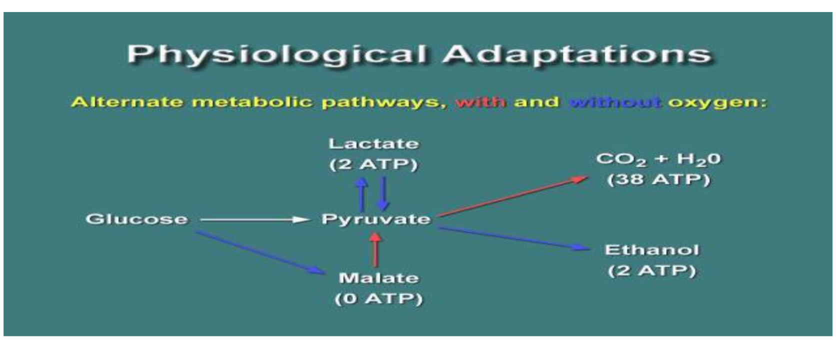


Figure 5.1: An illustration of alternative metabolic pathways as a physiological adaptation to anaerobic soil conditions (Source: U.S. Army Corps of Engineers, 2004)

The evidence provided from literature, therefore suggests a strong relationship between multiple environmental drivers and the species range shift.

Seasonal Variations of Fish Composition and Distribution along an Environmental Gradient among the Six Wetlands

Spatial variation among fish assemblages has been found in this study to correlate well with temperature, dissolved oxygen, turbidity, nitrate-nitrogen, ammonia, pH and conductivity, farming activities, fire, grazing intensity and farming activities, as was observed in PCA ordination diagram. Using canonical correlation analysis approach, Alen (1982) observed that temperature and salinity as key determinants that influenced littoral fish abundance. Pires et al. (1999) also found temperature among other factors, as the most important ecological variable that mediated fish structure along the streams of Guadiana basin in Portugal while Argent and Carline (2004) mentioned increased in agricultural activities in major factor influencing fish structure sub-watersheds in Pennsylvania.

Generally, fish abundance and spatial distribution were slightly higher in the dry season than the wet season, with variations from one wetland to the other. These observed variations were largely influenced by anthropogenic and physico-chemical factors that consequently affected the water quality in the wetlands on a seasonal basis. In their study in Lagos lagoon, Ayoola and Kuton (2009) observed that the abundance and biomass composition of fish species were much higher in the dry season relative to the wet season, while Allen (1982) observed increase in fish abundance in spring and summer. Abban, Casel, Dugan & Falk (2004) suggested that the lower fish abundance encountered in the wet season, could be linked to the physical expansions of the wetlands. The fairly high fish diversity and abundance especially from the riparian wetlands of Nabogo and Adayilli was probably due to their direct drain into the main White Volta River course and thus get stocked with fish from the wet season heavy flows. The dense vegetation along the banks of the wetlands may serve as good breeding grounds for fish and as well as a filter to sediment transport, which are vital to fish growth. Similarly, Alen (1982) indicated that the high abundance of individual fish in the Newport Bay was due to the rapid growth of large numbers of juveniles that utilized the littoral zone as nursery ground. Wetland plants are critical to maintaining productive fish habitats because they stabilize stream banks (Kauffman & Kruegar, 1984) and reduce erosion and sedimentation through the vegetative filtering of sediments (Davis as cited in Hopfensperger, et al. 2006). A similar high diversity was observed by Quarcoopome, Amevenku & Ansa-Asare (2007), in some two reservoirs located within the floodplains of the White Volta. The range of diversity indices in this study, agree with similar diversity indices range observed by Fernandes & Achuthankutty (2010) in the Salcete Taluka wetlands at Goa – India. The increase in species evenness distribution in the wet season may be attributed to fish movement to all wetlands during floods, since these wetlands are located in the floodplains of the White Volta River.

The generally low fish abundance in the Tugu natural marhes and Bunglung man-made wetland in the dry season could be due to over exploitation by the indigenes and the high intensity of disturbances through farming activities all year round and grazing around the immediate fringes of the wetland. This phenomenon could potentially shift bird population to over depend on fish for their survival, since seeds and leaves (one of their feed source from the fringing vegetation) will be destroyed during tilling.

The dominance of five species in the dry season and nine species in wet season in more than half of the six wetlands, probably indicate the ability of these species to adapt to different ecological conditions in their habitat complexity, brought about by cyclical flood events and other disturbances. Fausch & Bramblett (1999) reported that flooding is one of the most important natural drivers of change that structure the biotic assemblages in streams. In addition, changes in water quality, agriculture and urban land use (Johnson et al. 2006) have been cited as partly playing a role in structuring fish assemblage in most wetlands. The near 100% dominance of the cichlide family (e.g., *Sarotherodon galilaeus*), probably suggest their endemic nature in Northern wetlands, as a result of their widespread tolerance to changes in ecological conditions. Ayoola & Kuton (2009) also observed that fish species from the cichlide family dominated in abundance in both seasons in the Lagos lagoon. It is therefore possible to consider the presence of these species in all the six wetlands, as indicator species, that should be consistently monitored, to determine their abundance and widespread distribution against changing weather elements and environmental disturbances.

Though ammonium levels in Nabogo, Adayilli, Bunglung, Wuntori and Kukobila wetlands were high (0.6 – 1.9 mg/l) and largely due to fertilizer application on farmed crops along the fringes of the wetlands, they did not adversely affect fish abundance. Knepp & Arkin (1973) observed that when ammonia levels reach 0.06 mg/L some fish species can suffer gill damage and at 0.2 mg/L levels, sensitive fish like trout and salmon begin to die. Knepp & Arkin (1973) concluded that ammonia levels greater than approximately 0.1 mg/L usually indicate polluted waters. But in this study, the high abundance of fish species registered was probably due to the low surface water temperature and pH recorded that neutralize the lethal effects of high ammonia concentration on fish composition and abundance. The toxic effect of high ammonia concentration on fish occurs when higher pH values and warmer temperatures (36^{o}C) have occurred in aquatic system (HACH, 2011). Therefore, fish population was not affected by surface water temperature that is directly influenced by air temperature, but rather other physico-chemical and anthropogenic factors. This was shown in the significant correlation of canonical coefficients between other physico-chemical and anthropogenic activities for dry and wet seasons. Thus, the confirmation of ecological and anthropogenic determinants on fish abundance and composition was reflected in the high cumulative percentage variance of the total fish species sampled. Similar findings by Allen (1982) showed that about 83% of the variation in the abundance of individual species was accounted for by two abiotic factors in the Newport Bay. The observed mean surface water temperature values in this study were similar to the findings by Ayoola & Kuton (2009) in the Lagos lagoon (21º C - 31º C). The generally low levels of nutrient loads such as orthophosphates and nitrate-nitrogen suggest that the wetlands were not polluted and this probably reflected in the high abundance of fish recorded in all the wetlands. In a comparative study of fish abundance in water systems, Sandström & Karâs (2002) found that the number of young perch was reduced in highly eutrophic areas compared to less eutrophic areas. Moss et al. (1996a) states that the abundance of slender knotweed (*Polygonium salicifolium*) is indicative of low ortho-phosphate concentrations (<0.025 mg/l). The predominance of *Polygonium salcifolium* in the three marshes may have partly explained the low ortho-phosphate recorded and hence could be used as an indicator to wetland nutrient load.

The low dissolved oxygen concentration recorded in dry and wet seasons could be attributed to the seasonal burning of aquatic plants that hitherto serve as a source of oxygen in water bodies and the application of chemical fertilizer by farmers. The low range of dissolved oxygen values of across in the wetlands indicates a hypoxic condition brought about by the presence of dense emergent (e.g., *Eleocharis mutata*), submergent (e.g., *Ceratophyllum mutata*) and floating aquatic plants (e.g., *Nymphaea lotus*). Kramer (1987) have shown that hypoxia, usually occurs when dissolved oxygen concentrations were less than 5 mg/l, especially in dense vegetation. The author further stated that this phenomenon may affect many physiological, biochemical and behavioural processes in fish species. The Water quality guidelines for dissolved oxygen concentration levels of 5.5- 6 in warm water and 6.5 – 9.5 in cold water, are necessary for the protection of freshwater aquatic life (Canadian Council of Resources and Environment, 1987) and Truelson (1997), further confirmed the dissolved oxygen values recorded in this study were significantly below the standard required to support fish life. However, the abundance of fish recorded in the wetlands may be linked to the low surface water temperature recorded throughout the study period or a possible physiological adaptation, that enable fish species to tolerate less dissolved oxygen levels. In contrast to the findings in this study, Killgore & Hoover (2001) reported that dissolved oxygen concentrations below 0.5 mg/l have substantially reduced species richness, abundance and size of fish, thus suggesting a threshold response level of fish assemblage beyond which they may not survive except to move to highly oxygenated areas. From the observations made by Killgore & Hoover (2001) it can be concluded in this study that future mortality threats to fish assemblage may be widespread if temperatures increase to about 1.5º C - 2º C.

The seasonal spatial distribution, composition and abundance of fish observed in the field, indicate that environmental drivers of change were largely responsible in altering the structural assemblages of fish in the wetlands. The findings in this study agree with the observations by Pires et al.

(1999), Marsh-Matthews & Matthews (2000) and Humpl & Pivnicˇka (2006) that used similar multivariate approach (DCA and CCA) to determine the structural assemblage of fish species along an environmental gradient.

Similarity Trends on Fish Community Distribution Pattern along an Environmental Gradient, among the Six Wetlands

The structural assemblages of fish species among wetlands, as shown in DCA, were largely due to the influence of different physico-chemical variables and anthropogenic factors. For example, Wuntori shallow marshes and Nabogo flowing forested wetland, which registered the highest species richness and diversity, had species such as *Alestes dentex* and *Distochodus engycephalus*) that were probably tolerant to low dissolved oxygen levels and high ammonia concentration and plant cover. *Lates niloticus*, for instance were mostly common in marshy wetlands, with some level of plant cover, suggesting their abundance in wetlands with close water systems. The deep marshes of Kukobila and the Adayili swamp forest wetland, shared some similarity in community composition (e.g., *Brycinus macrolepidotus* and *Sarotherodon galilaeus*), that probably preferred wetlands with optimal pH and temperatures. Ansari et al. (1995) employed cluster analysis to indicate how fish species were segregated into seasonal groups and intense association among different species groups, brought about by changes in physico-chemical parameters, such as salinity, temperature and dissolved oxygen concentration. Pires et al. (1999) mentioned water depth, isolated pools and cover, as the factors that segregated the preferred habitats for fish species in the streams of the Guadiana basin in Portugal. The factors highlighted in this study, could be used to predict habitat preference of some fish species, in spite of their tendency to adapt to changes in habitat conditions, caused by human activities and natural climatic impacts.

Influence of Environmental on Bird Species Composition, Abundance and Pattern of Distribution among the Wetlands

There have been reported declines in the global diversity of habitat-specific birds and shorebird populations, since 1980 – 2007 (Butchart et al. 2010). The decline in bird population worldwide has been linked to a number of anthropogenic factors, including pollution (Gordon et al. 1998), cutting of mangrove vegetation (Attuquayefio & Gbogbo, 2001) and water fluctuations (Riffell et al. 2001; Timmermans et al. 2008). In this study, however, bird population was influenced by farming practices, grazing intensity and bushfires. Although farming activities had intensified especially in the wet season, bird diversity was fairly high in the wet season than in the dry season, thus suggesting the presence of food availability, stable hydrological regime, dense vegetation (serving as secured nesting sites against hunting) and the near absence of inflammable litter that could cause bushfire. In their study on the seasonal changes and the influence of land cover on breeding birds, Malavasi, Battisti & Carpaneto (2009) revealed that mean values of Margalef richness, Shannon diversity, and β-diversity of birds were higher in winter than summer periods. The authors concluded that the high mean values of richness and diversity could be due to 'intermediate disturbance hypothesis' leading to seasonal changes in habitat heterogeneity. Vâlcu (2006) also observed that resident bird species diversity was higher during winter, both in terms of species richness and evenness in their distribution number than in summer, in the Comana Lake - Romanian Plains. The patchy condition created during farming activities could have contributed in the surge in bird numbers in the wet season, since the presence of African Jacana (*Actophilornis africanus*) and Cattle egrets (*Bubulcus ibis*) had increase on freshly tilled farmlands, feeding on grains and soil organisms.

Gaston, Blackburn & Goldewijk (2003) observed a loss of pre-agricultural bird numbers, as against an increase in global bird populations, in the advent of agricultural activities. The authors concluded that poor agricultural practices rather than destroy bird habitats, contributed in increased bird population. Norriss & Wilson (1993) cited an example of the Greenland white-fronted goose (*A. albifrons flavirostris*) increased preference for more intensive agricultural land than in natural and semi natural habitats.

Bird diversity indices across the six wetlands were fairly high ($H' = 1.24 – 1.75$), compared to similar findings in the Abiriw sacred grove in the Eastern Region of Ghana ($H'= 0.011- 0.012$) (Kangah-Kesse et al. 2007). These observations suggest that bird species may appear to be on a steady decline. Euler (2001), revealed that between 1600 and present, bird species evolutionary history has been lost at similar rates and concluded that the relative rate of history loss in the future may continue at a rate not less than 80%. Bushfires were a common phenomenon in Northern Region and mostly occur as a result of land clearing, hunting and charcoal processing. Bushfire affected the population of some birds detected in the dry season, such as bearded barbet - *Lybius dubius* and Spooted creeper (*Salpornis spilonotus*). The presence of fewer Bearded barbet in Wuntori wetland in the wet season, probably showed their sensitivity to dry season disturbances and habitat preference for marshy conditions. The abundance of the Spooted creeper in the two riparian wetlands during the dry season, where bushfires were more widespread and severe, suggests their gradual shift from food scarce areas to places where there is readily availability of carcass from burnt rodents and insectivores, by the use of their proximate cues. Allen (2000) indicated the population decline of honeyeaters, through post mortality of bushfires, predation and food scarcity in Australian wetlands; agree with similar findings in this study on the low number of Bearded barbet (*Lybius dubius*) and Northern Red hornbill (*Tockus erythrorhynchus*) recorded in severely burnt wetlands.

However, the numbers of some birds such as Yellow-billed cattle egret (*Bubulcus ibis*) had increased in the burnt wetlands, as they were attracted to sites that were burnt. The surge in their abundance was probably due to the development of response cues to the availability of burnt and decomposed carcass after bush burn. Vogl (1973) found out that only five out of 35 species observed, were seen in unburned sites in a Florida wetland and concluded that the bird species encountered, showed no fear of fire and were rather attracted to the smoking landscape. Powell (2006) also detected an increase in the abundance of Upland Sandpipers (*Bartramia longicauda*) following burning and grazing activities. Mean bird richness were higher in Wuntori and Kukobila wetlands as a result of less disturbance, whereas Tugu was least rich in wet and dry seasons because of severe impacts of grazing pressure. Grazing pressure and animal trampling has the tendency of destroying bird nest through vegetation removal.

The increase in bird density in the wet season, with a corresponding increase in area of lateral distance, in Nabogo and Wuntori wetlands could be due to the adaptation of most birds to the inherent spatial habitat heterogeneity conditions brought about by human-led activities. Furthermore, the corresponding increase in birds per unit area, suggests the importance of plot size effect on bird abundance. The findings in this study, agree with similar observation documented by Kantrud & Stewart (1984). The authors reported that higher densities of bird species were recorded in semi-permanent wetlands in North Dakota, which they believe was partly due to the effects of wetland size in the respective study areas.

With reference to the IUCN '*Red List'* database (2011), it was observed that the Yellow weaver bird was considered vulnerable (VU), thus indicating that a large number of birds in Northern Savannah wetlands may not be under threat. This may be attributed to the fact that about 96% of the birds encountered, were well adapted to the patchy habitat conditions due to disturbances as was observed during the study. The VU status of the Yellow weaver bird was confirmed by their presence on the narrow range habitat especially along the banks of Nabogo and Bunglung wetlands, where *Deplachne fusca* and *ziziphus abysinica* plants were predominant. It is thought that the habitation of the Yellow weaver bird on the rough serrated surface of *Deplachne fusca* and thorny nature of *Ziziphus abysinica* plants (which are unpleasant when in contact with the human body), served as the only source of safe haven for the birds against hunting.

In order to confirm the general habitat range size of the Yellow weaver bird from the rest of the ecological zones of Ghana, an extensive survey was conducted along the forest and coastal zones where the birds were found nesting on similar narrow range habitat, predominated by fewer economic tree species like Bamboo plant (*Bambusa vulgaris*), Kassod tree (*casia siamea*), coconut tree (*Cocos nucifera* L.) and Oil palm tree (*Elaeis guineensis*). Some identified birds like Wooly-necked stork, African pygme-goose and squacco heron, indicates the importance of Northern wetlands as possible waterfowl habitats. But there is the likelihood giving the current trends of human-led activities, that future scenarios could see some of the birds categorized as LC, becoming vulnerable and the Yellow weaver bird, completely extinct. Other evidence of possible risk in the future of birds reaching the critical level of vulnerability, is the relatively low number of species (26 species) encountered in this study, compared to 48 species of water birds detected in four Coastal wetlands of Ghana (Gbogbo & Attuquayefio, 2010).

Classified Bird Similarities in the different Wetland types

While Kantrud and Stewart (1984) reported that Seasonal and semi permanent wetlands provided habitat for the largest proportion of the population of all species, the current study however, found that the close shallow marshes supported the highest number of resident birds like African Jacana and Squacco heron in both seasons. Whereas the Spooted creeper and the Northern hornbill for instance, were confined to the swamp forested wetlands. The pied Kingfisher and Cattle egret were found in all the wetland classes, suggesting the tolerance to a wide range of habitats. Bird-habitat association may in part explain habitat preferences on the basis of the type of food they feed and the ease with which they can have access to food resources and the hydrological regime of wetlands. The marsh warbler preferred areas with grasses and herbaceous cover intersperse with shrubs, which are suitable nesting sites compared to riparian wetlands.

The Northern Red bishop (*Euplectes franciscanus*) was not only associated marshy habitats but was only common during wet season. This probably indicates that environmental conditions in the wet season were favourable for their survival than the dry season. The Black headed plover

(*Vanellus tectus*) a typical wader, was among the largest number of species that was found in more than half of the six wetland classes. Ntiamoa-Baidu (1991) reported that 85% of waders were being supported in majority of Ghana's Coast wetlands. Thus the findings in this study showed that the Black headed plover were adapted to a broad range of habitats; from the Savannah to Coastal ecosystems. Tolerance to habitat alteration is species-specific and varies in line with the resilience level of wetlands to disturbances. Different wetland types such as permanent seasonal and temporal marshes exhibit varied stress tolerance to disturbed scenarios in different seasons. Thus the long term transformation of permanent wetland to a semi-permanent or seasonal wetland, could potentially affect the abundance of both resident and migratory birds. This phenomenon may be linked to simultaneous changes in hydrological regime, reduction in food availability and destruction of nesting sites.

Historical Trends in Climate Change Indicators of the last 50 years in Northern Region

Limitations of the study

Since there are no historical data of aquatic plants distribution in the study area with a concurrent data on climate at the same spatio-temporal scale, it may be difficult to accurately draw a conclusion of shift range of macrophytes, using only local knowledge or local observation approach, to correlate with available climate change data over the last 50 years. Since variations on climate data and impacts of anthropogenic activities in the southern sector sligthly varies from that of the Nothern sector, it is possible that the findings in this study may be local-specific.

Historical record for Ghana from the year 1961 to 2000 showed a progressive rise in temperature and decrease in mean annual rainfall in all the six agro-ecological zones in the country (National Strategy for Climate change, 2009). The results in this in this study agree with the findings by the National Strategy for Climate change (2009), since it was evident that historical temperature trend had generally increased from 1960 to 2010, with an average rate of increase of +0.2°C (Tmax) and +0.1°C (Tmin) per decade. From a simulated analysis of temperature record in Ghana, McSweeney et al. (2009) similarly found that overall mean annual temperature has increased by 1.0°C since 1960, with an average rate of 0.21°C per decade. The rate of increase as indicated by the authors has been most rapid in the months of April to June; approximately 0.27°C per decade. The Inter-governmental Panel on Climate Change (2001) and Warren & French (2001) have also shown that the Earth's climate has warmed by approximately 0.68°C over the past 100 years with two main periods of warming between 1910 and 1945 and from 1976 onwards. Even though air temperature generally increased over the 50-year period, there were marked fluctuations and this was evident from a slight decrease from the mean peak 35.8ºC in 1998 to 34.9ºC in 2010.

General circulation models predict that global mean annual temperature will show an increase in order of 1-5°C during the next century (Totland & Nylehn, 1998) as a result of doubling of atmospheric CO_2. At the regional level, Burundi and Rwanda will show future increases in temperature by 1.6 – 2.8% in 2060 (McSweeney et al. 2008). But in this study, projected temperature changes will decrease by 0.72°C (Tmin) and 0.83°C (Tmax) in the next 20 years (2030) in Northern Region. Totland & Nylehn (1998) also predicted a surge in precipitation by 25% in the next century. This future prediction agrees with similar projections in this study, which show that precipitation will increase from 987 mm in 2010 to 1126.4 mm by 2030. Future predictions in Burundi and Rwanda also reveal an increase in precipitation (5-15%) by 2060 (McSweeney et al. 2008). The authors concluded that despite the future predictions in increase precipitation in Burundi and Rwanda, there is a possibility of year-in-year variability which could lead to drought conditions. However, other studies conducted in Southern Africa (Christensen et al. 2007; Meehl et al. 2007) concluded that annual rainfall will decrease in the next decade, with implications on water availability and distributions. For instance, rainfall pattern in Tanzania has shown a decreasing trend over the years, with an average rate of 2.8 mm per month per decade (equivalent to -3%).

From the observations over Northern Region of Ghana, it can be stated that future predictions of increase in precipitation and temperature may not be applicable globally because of differences in regional to local bioclimatic envelopes that are largely influenced by local conditions. The uncertainty in predicting future rainfall and temperature patterns in higher altitudes in the tropics, suggest the lack of complete understanding of the interactions among natural and environmental variables. The IPCC has identified this knowledge gap, as an area requiring further research to understand the variety of model responses in this region (Christensen et al. 2007).

The shift in the peak and coolest month of rainfall from August to September probably indicates some historical interference in the movement of the Inter-tropical Convergence Zone (ITCZ) over the Atlantic Ocean, brought about by variations in sea- surface and air temperatures, humidity and wind. The movements of the ITCZ According to McSweeney et al. (2008) are sensitive to variations in Indian Ocean sea-surface temperatures and vary from year to year; hence the onset, duration and intensity of rainfalls vary substantially each year. The authors concluded by stating that El Niño Southern Oscillation (ENSO) is one of the most well documented ocean influences on rainfall in Tanzania.

Even though there was a positive relationship between air temperature and precipitation, the influence was not strong thus suggesting that some ecological disturbances might have accounted for the sharp decrease in precipitation. This claim was evident from Kukobila wetland where water from the wetland was drained for dry season irrigation activities within the catchment. The general increase in mean evapotranspiration in respect of increasing air temperature suggests that PET may have contributed to the drop in water level among wetlands. Therefore, the continuous rise in temperature as has been predicted with the needed energy for evaporation, may lead to an increase in atmospheric demand for water from wetland surfaces. But from a climate model simulation carried out by Regab & Prudhomme (2002) suggest that an increase of 3-15% in the evaporation will only be possible if the CO_2 concentration is doubled. Hence air temperature is not likely to be the only key driving factor to cause increases in future evapotranspiration.

Contribution of Temperature, Precipitation and Mean Evapotranspiration in the Range Shift of Aquatic Plants

It appears that some natural climatic factors have contributed in the shift range of aquatic plants, either directly or indirectly, although its significant contribution is less compared to human-led disturbances. For example, the contribution of nearly 36% of air temperature influence (R^2 = 0.359) in the reduction of rainfall has to some extent reduced the quantity of water in Kukobila wetlands in two different years, from an average depth of 2.3 m in 2004 (Obodai & Nsor, 2010) to an average of 1.1 m in 2011/2012. Therefore, farmers who hitherto relied on rain-fed agriculture would have to resort to either draining the wetlands to irrigate distant and nearby farms or till their lands close to the wetlands, where the water table is relatively high. These human activities may have contributed in the range shift of aquatic plants, through competing demands for water and nutrient availability. Recent researches have shown that the diversity, condition and recruitment of Wetland fringing vegetation is intrinsically linked to the water regime of a wetland (Leck & Brock, 2000; Warwick & Brock, 2003; Capon & Brock, (as cited in Kath et al. 2010). The historical range of night temperatures recorded (21.8-23.3^{o}C), may have contributed in the abundance of water lily (*Nymphaea micrantha*). This is confirmed by Bryson, Fox & Byrd Jr. (2006) who noted similar increase in heights, nodes and leaves of wetland nightshade plants (*Solanum tampicense* Dunal.) at temperatures of 26/36, 20/30, 14/24, and 8/18 (±0.5) ^{o}C at the 14/10 day/night length. Wrona et al. (2006) pointed out that a combination of environmental stressors and climatic variability, may synergistically contribute to the degradation of biodiversity at the species, genetic and habitat ecosystem levels.

A reanalysis of both biogeographic and bioclimatic data of equal spatiotemporal resolution, covering a time span of more than 50 years have revealed a coherent and synchronous shift in both species' distribution (*Illex aquifolium*) and climate in northern Germany, Denmark, southern Norway and Sweden (Walther et al. 2005). These ecological offsets brought about by climatic factors may eventually impinge on the long term functional status of species, with less chances of recovery. From the observation of temperature influence on precipitation and evapotranspiration, some researchers (Prentice et al. 1992; Sykes, Prentice & Cramer 1996; Woodward, Lomas & Kelly, 2004) have argued that mean temperatures are not themselves considered to be physiologically effective on species, as they correlate with absolute minimum, and therefore are used as a surrogate for the frequency of lethal extreme events that impact on vegetation. "*Temperature used as a surrogate for the absolute minimum, means that if the minimum mean coldest month temperature in a grid cell falls below the species limit, the species is excluded*" (Walther et al. 2005). For instance, the influence of air temperature on potential evapotranspiration, probably contributed in the low abundance of plants encountered (40 species), since most plants will lose water into atmosphere through stomatal conductance and consequently suffer from wilting. But Regab & Prudhomme (2002) think that plant loss will vary from evapotranspiration, since several factors such as plant type, plant cover, root depth, stomata behaviour and CO_2 concentration will have to be taken into account.

Assessment of the role between weather elements and environmental drivers in the range shift of aquatic plants

From the assessment of air temperature, precipitation and potential evapotranspiration which directly or indirectly influences wetland conditions, it was evident that these weather elements have contributed little in the transformation of the six wetlands under study. For instance in Figure 4.46, it was observed that air temperature marginally influenced the general decreasing trend in precipitation (R^2 = 0.359) in the last 50 years, while 61.29% cumulative percentage variance accounted for the variation in the range shift of 40 aquatic plants across the six wetlands. This was confirmed through the use of indigenous observation or local knowledge, which showed that all 14 obligate plants registered were endemic in the six wetlands under study when decadal change in air temperature in the last 50 years was +0.02ºC (Tmax) and +0.01ºC (Tmin). Further field monitoring revealed that water lettuce (*Pistia stratiotes*) were growing profusely and well distributed, until 2011 when they were completely extinct in the three marshlands. This phenomenon was largely due to the clearing of these plants by the rural fisher folks, since the species were obstructing the free movement of nets, traps and free navigation of their canoes. The herbalists contended that out of the 16 facultative wetland plants identified, nine of them (e.g., *Helioptropium indicum* Linn., *Lersia hexandra* and *Phyllanthus amarus* Schum & Thonn.) were observed within the fringes of the wetlands in the last 10-15 years. The herbalists and other users of the wetlands linked the presence of this species to the surge in farming practices, animal grazing and the cyclical flooding.

The drying up of Kukobila wetland in 2011 (the first time in the history of the wetlands existence) was largely due to draining to irrigate the expansion of agricultural lands within the catchment of the wetland rather than low rainfall. Kath et al. (2010) reported that wetland losses in agricultural landscapes have been driven by land use and coinciding hydrological changes, which together led to clearing of vegetation, increased pressure from grazing and alterations to wetland hydrology. For example, agricultural landscapes of Australia have led up to 98% loss of wetlands (Jensen, 2002).

Identified Threats to Wetlands and Proposed Conservation Measures

The identified threats put the wetlands under severe stress all-year-round. The surge in these anthropogenic activities was the resultant effect of population increase, coupled with low levels of rainfall in recent times and the general impoverished nature of terrestrial soils. Wetlands served as the alternative source of livelihood sustenance for rural communities, since they are by far the most fertile areas with a reasonable level of moist surface within the catchment throughout the year. These threats leave in its wake severe erosion; species range shift reduction in species diversity and the inability of the wetlands to control flooding. From the outcome of field discussion on possible threats to the wetlands coupled with detailed assessment of environmental disturbances and climatic variability in this study, the following practical conservation measures were proposed, to forestall the functional state of the wetlands under study, using traditional approach.

Indigenous approach to wetland management, using local by-laws

From the outcome of field discussion among chiefs and other community members on how to conserve the wetlands from further degradation, the following approaches were considered:

Cutting of grass/herbs and trees

It was observed that harvesting of grass/herbs and cutting of trees for thatch materials, fish traps, herbal treatment and domestic fuel load, was on the increase. These activities were carried out in both seasons and exposed the wetlands to various forms of erosion. The proposed by-laws to regulate the cutting of grass/herbs and trees were as follows:

i) All trees and shrubs found within 1 kilometre radius of the wetlands should not be cut. Instead, planting of fast growing trees that are adapted to infertile soils, erratic rainfall and prolong dryness conditions, should be encouraged. Example of these multipurpose trees are Kassod tree (*Cassia siamea*), White Lead tree (*Leucaena lecocephala*), and moringa tree (*Moringa oleifera*);

ii) One type of grass species such as *Schyzachyrium sanguinum* should be harvested at a time as thatch material. This is to ensure that other grass species are allowed to grow and replace those harvested. Harvesting of grass should be rotated from one section of the community to another. This is to ensure recovery by other grass species especially, those that were accidentally trampled upon during the harvesting period. Grasses that grow on surrounding terrestrial systems should be harvested as alternative source of thatch materials, so as to lessen the heavy dependence on the wetland grasses.

Animal grazing/trampling

Although animal grazing was categorized as least severe, it was still regarded as an 'emergent threat', which should be tackled before it becomes severe and widespread. It was proposed that:

i) Grazing be regulated especially in the dry season, where grazing pressure increases. Owners of livestock in and outside the communities, who frequently use the wetlands as grazing grounds, will be registered, to determine how many animals each person or family owns. An agreed number of 30 cattle/herd and 50 sheep/head, will be allowed to graze on a rotational basis, by partitioning the wetland into paddocks;

ii) A three-year fallow period will be instituted to allow the vegetation to recover and regenerate;

iii) Headsmen should ensure that animals are evenly distributed in each paddock, so as to avoid too much pressure on soil structure and ground cover, at one location through trampling;

iv) Fencing of the wetland, using barbed wire, to prevent livestock and wild animals from gaining access into the wetland and

v) Herdsmen from other communities should be made to pay a fee for using wetlands outside their jurisdiction (payment for ecosystem service). The generated funds will be used to motivate indigenes who monitor the users of the wetland resources, to ensure that the proposed by-laws are adhered to.

Farming practices

Farming was scored high in terms of its severity and threat to the functional status of the wetlands. Arable crops such as maize, millet, rice and sorghum, were commonly cultivated in the wet season and are located within 50-100 m radius of the saturated zone. It was proposed that:

i) Farmers should re-locate about a kilometer away from the wetlands. This is to prevent the continuous clearing of vegetation to expand farmlands that in the end, makes it easier for applied chemical fertilizers to be washed back into the wetlands, during heavy rains. This phenomenon could lead to an increase in nutrient load in wetlands, as well as create a turbid condition.

Water abstraction for dry season irrigation

Dry season irrigation close to the wetlands, has been on the increase in recent times and farmers are heavily engaged in as an alternative source of food and income supplement. The Kukobila wetland for instance, was completely drained for irrigation purposes in the whole of dry season (2011). A few of the crops cultivated were water melon (*Citrullus lanatus* Thunb.), tomatoes (*Solanum lycopersicum*), Alefu (*Amaranthus spinosus*), pepper

(*Capsicum annuum*) and cabbage (*Brassica oleracea*). The proposed conservation measures included the following:

i) A total ban of water withdrawal from the wetlands should be effected;

ii) Government should assist communities in the construction of mini dams and dug-outs, as an alternative source of water for their irrigation activities.

Over harvesting of fish

To ensure sustainable supply of fish stocks, it was proposed that:

i) Strict enforcement of the close season should be observed by everyone in the communities, through monitoring by community leaders;

ii) Anyone caught fishing during the close season, should be surcharged by the chief, with an amount of GH¢ 200.00;

iii) Members must endeavour to use the recommended net size approved by the Fisheries division of the Ministry of Food and Agriculture;

iv) All crude methods of fishing such as draining water from wetlands and use of mercury must be discouraged;

v) The construction and placement of baskets and hexagonal cage-like structures (locally called *Aha*) in the shallow parts of the wetlands and all channels must be encouraged in the wet season;

vi) Construction of dikes (2 x 2 m dimension) along the banks of the White Volta River (about 30 m away from the fringes of the River), could serve as points of water pools during flood events. Fish species are likely to migrate into these sites during peak flows from the main River. They are trapped in the dikes as the water retreats during dry season. This will serve as an additional source of fish stock to augment allowable catch in wetlands.


(A) Basket


(B) A hexagonal cage-like structure locally known as *Aha*


(C) Wooden poles, arranged in a circular form and stuck the wetland bed in

Plates 24: Different types of local fishing gears used to catch fish in the wetlands

Bushfires

To reduce the impact of cyclical bushfires on wetland biodiversity, the following proposed conservation measures were considered:

i) All herdsmen and hunters within and without the communities must uphold the ban on indiscriminate bush burning;

ii) For any form of burning to take place, it must be under the principle of selective or control burning. This involves burning of vegetation, with the intention of creating some level of disturbance, to increase diversity (species heterogeneity). This type of burning is done by considering the amount of fuel load, the direction of wind speed, day temperature and section of the wetland to be burnt and the time of the season.

Plate 25: **Exposed tussocks and hydric soil surface following bush burn in some sections of Kukobila wetland in the dry season**

Erosion

For the restoration of damaged wetlands as a result of erosion, the application of the following indigenous technology was proposed:

i) Stone bunding technique: This entails the use of stones arranged in a contour form or horizontal (terracing) parallel to the wetland and against the flow of water during rainstorm. The stones are interspersed with plant residue. This method is particularly effective for wetlands with geomorphic setting typical of valley-bottom or hill slopes, thus help in mitigating gully erosion and channelization. The distance from one terrace stone bund to the other is approximately 1-5 m;

ii) Construction of gabions across the riparian wetlands, in order to correct channel incision. The construction entails casting a concrete slab, with stones packed in a metallic wire mesh, as reinforcement. The stones are mostly conglomerates or igneous rocks.

Plate 26: A gabion constructed at Nabogo wetland to correct an incised channel along the course of the flowing water

Conservation and micro-credit trade-off approach

This involves the provision of micro-credit facility as a trade-off to conservation and preservation of wetlands. This approach is geared towards reducing poverty of the indigenes, by advancing credit facilities to them and they in turn completely abstain from exploiting wetland resources or are actively involved in restoration of degraded wetlands caused by natural or human-led factors. Credit facilities will be given to community members upon satisfactory execution of conservation activities as highlighted above. The loan earmarked for members will be dependent on the type and extent of conservation activities to be undertaken. Members will be required to only pay the principal, while the interest on the loan is negated to balance the conservation activity rendered. This loan is to be used as alternative livelihood support programmes to be determined by individuals in the communities. Some of the livelihood programmes such as dry season irrigation in faraway terrestrial lands, aquaculture, petty trading and honey production, can be considered. This innovative approach of addressing conservation issues will involve Central Government, para-statal organizations and Non-governmental organizations (N.G.Os.), who are interested in environmental related activities.

On preservation of wetlands, with rare keystone species, community members including chiefs' will agree on a consensus not to have access to such wetlands and in return 50% of the working or principal capital shall be written off. If assessment of the wetland health after 5 to 10-year period indicates an increase in the gene pool, the remaining principal capital will also be written off. A new revolving credit facility will then be set up in the community to further enhance their alternative livelihood activities. The long term objective is to ensure that some wetlands in the study area are declared as Ramsar sites, by meeting the criteria set aside by Ramsar International in declaring a wetland as Ramsar site.

A similar innovative approach known as the Bio-rights revolving fund has been adopted in the Central Java Province and Pemalang District in

Indonesia in 2011 (Living With Michigan's Wetlands, 1996). For instance, in Thailand, the restoration of mangroves and degraded fish ponds using Bio-rights revolving fund in Ban Don Bay has lifted more than 100 fishermen families out of poverty. While in Mali's Inner Niger Delta Bio-rights micro-credit have enabled local communities to restore flood forests and fish ponds, promote bourgou cultivation and kitchen gardens with women's groups and introduced water management into development plans for 9 municipalities (Living With Michigan's Wetlands, 1996).

The bio-rights field story

Living with Michigan's Wetlands, (1996) reported that "In the village of Severy in the Inner Niger Delta, Bio-rights microcredit provided a women's group with a rice husker alleviating the daily stress of pounding rice the traditional way by manual force. For a little pay, the village members can use the husker while the women managing it make some money from it. In return for the credit, the women planted acacia trees in the degraded floodplain forest. When flooded, fish will lay their eggs on the roots of the trees, which will also provide shelter during heavy weather.

The women took great care of the trees so that after one year 75% of them were still intact. This turned the credit - which they refunded 100% - into a gift. The women decided to invest the money into a revolving fund for the whole village to benefit. Moreover, a neighbouring village started to plant

Acacias as well, even without the incentive. Furthermore, Bio rights are now effectively included into the Malian national micro-credit system"

CHAPTER SIX

CONCLUSIONS AND RECOMMENDATIONS

Conclusions

Generally, plant diversity was fairly high. Although species richness was high, it generally did not follow increase in plot size. The unevenness in species distribution probably indicated the varied impacts of anthropogenic drivers of change, which were seasonally oriented. Farming activities, fire, grazing, erosion and soil nutrient status, were the predictors of species range shift, diversity and spatial distribution of plants. Comparatively, Facultative wetlands were more than the obligate wetland plants (hydrophytes) suggesting a gradual range shift of obligate plants out of their natural habitats and the replacement of derived savanna plant species.

The high abundance with moderately high fish diversity especially in wetlands with high ammonium concentration (which hitherto could have caused high fish mortality), indicated that surface water temperature impact and pH were rather low. Finally, the identified species that occurred in more than half of the wetlands could be used as indicator species, to monitor their resilience to climate stress factors and human-led activities.

Overall observation of bird assemblage showed that their diversity, abundance and associated habitat preference, were in part, influenced by some anthropogenic factors. The low species detected probably reflected the level of disturbances that directly impacted on the hydrological regime and the vegetation, serving as their nesting and breeding sites. The Yellow weaver bird that was identified to be vulnerable in accordance to IUCN '*Red List'* database could be used as key indicator species to evaluate the functional status of wetlands, by monitoring their presence and abundance in both seasons. The Northern red bishop which appears only in the wet season could also be considered as an indicator species, by monitoring their presence in the wet season. Future disturbances in wetlands are more likely to cause the remaining 25 species categorized as least concern to become vulnerable and this could have profound consequence of creating an imbalance in the wetlands ecosystem.

Ecological changes as a result of changes in temperature, precipitation and evapotranspiration influence, caused species to suffer severely beyond their morphological threshold tolerance, leaving species-specific with adaptive capacity in narrow range habitats to survive. However, projected future decreases in air temperature and increase in precipitation, could lead to the lowering of surface water temperatures and the maintenance of a stable hydrological regime among the six wetlands. This condition could contribute in increasing the biodiversity status of the wetlands; a vital resource needed to sustain the livelihood of rural folks.

The quest to double conservation effort in the face of increasing human-led activities and other natural causes on wetlands biodiversity was long overdue. The bottom up approach where chiefs and people play a pivotal role in conserving wetlands had to be considered. Indigenes have come to appreciate the vital role that wetlands play in their livelihood and hence owe it a duty to manage the resources. Deepening awareness of wetlands economic and ecological importance was critical in the conservation effort and sustenance of their livelihood.

Recommendation

From the results and discussion of the investigation, the following recommendations are proposed:

(i) Further studies should be carried out, using field experimental simulation, to determine how one of the keystone hydrophyte (e.g., water lily-*Nymphaea micrantha*), will respond to increase in air temperature to approximately 2°C;

(ii) Detailed studies should be conducted to determine the impact of flood dynamics on species range shift and biodiversity and

(iii) Government and N.G.Os should commit more resources in the implementation of the proposed conservation and micro-credit trade-offs approach, if wetlands in the study area are to be protected from further degradation.

REFERENCES

Abban, E. K., Casel, C. M. V., Dugan, P. & Falk, T. (Eds.) (2004). Biodiversity, Management and Utilization of West African Fishes. *WorldFish Center Conference Proceedings*. Penang, Malaysia. 63pp.

Adler, P. B., Raff, D. A. and Lauenroth, W. K. (2001). The effect of grazing on the spatial heterogeneity of vegetation. *Journal of Oecologia*, ***128***:465–479.

Akpene, P. (2001). Bushfire, an annual ritual? The Ghanaian Times. 10th December. 14pp.

Alberta Environmental Protection (AEP). (1997). Alberta water quality guideline for the protection of freshwater aquatic life: Dissolved oxygen. Policy document. Alberta Environmental Protection, Standards and Guidelines Branch, Edmonton.

Allen, L. G. (1982). Seasonal abundance, composition and productivity of the littoral fish assemblage in upper Newport Bay, California. *Journal of Fisheries Bulletin*, ***80*** (4).

Allen, M. (2000). Wetlands and Fire. Water and Rivers Commission. *Water Notes for Wetlands Managers.* WNS2. Natural Heritage Trust, Australia.

Allen, C. D. (2007). Interactions across spatial scales among forest dieback, fire, and erosion in Northern New Mexico Landscapes. *Journal of Ecosystems*, ***10***: 797–808.

Anene, A. **(**2005). Condition Factor of Four Cichlid Species of a Man-made Lake in Imo State, Southeastern Nigeria. *Turkish Journal of Fisheries and Aquatic Sciences* ***5***: 43-47.

Ansari, Z. A., Chatterji, A., Ingole, B. S., Sreepada, R. A., Rivonkar, C. U. &Parulekar, A. H. (1995). Community Structure and Seasonal Variation of an Inshore Demers'al Fish. Community at Goa, West Coast of India. *Journal of Estuarine, Coastal land Shelf Science,* ***41***: 593-610.

APHA. (1998). S*tandard Methods for the Examination of Water and Wastewater*, 20th edn. APHA, Washington, D.C.

Argent, D. G. and Carline, R. F. (2004). Fish assemblages in relation to watershed land use disturbance. *Journal of Aquatic Ecosystem Health & Management*, ***7***(1):101-114.

Arbonnier, M**.** (2004). Trees, shrubs and liannes of West African dry zones. CIRAD, MAGRAF MNHN. CTA-The Netherlands. 228pp.

Armah, A. K. & Amlalo, D. S. (1998) "*Coastal profile of Ghana." Gulf of Guinea Large Marine Ecosystem Project*. Ministry of Environment Science and Technology, Accra, Ghana. 111pp.

Armah, A. K., Wiafe, G. & Kpelle, D. G. (2005). Sea-level rise and coastal biodiversity in West Africa: a case study from Ghana. *Climate Change and Africa*, Pak Sum Low (Ed.). Cambridge University Press. Pp. 204-217.

Ashton, A. (2009). Africa Partnership Station: *Coastal Geomorphology and Hazards Planning*. Woods Hole Oceanographic Institution (WHOI). MS #22, 360 Woods Hole Rd. Woods Hole, MA 02543

Attuqueyefio, D. K. & Gbogbo, F. (2001). Prospects of conserving wetlands along the Mukwe Lagoon at Nungua in the Greater Accra Region of Ghana. *West African Journal of Applied Ecology*, ***2***: 65-75.

Austin, J. E. (2002). Responses of dabbling ducks to wetland conditions in the Prairie Pothole Region. *Journal of Waterbirds*, ***25***:465–473.

Avisar D, Fox D, (2012). Chemical evolution and vegetation response in an altered wetland ecosystem, Hula Valley, Israel (1988-2004). *Journal of Environmental Science and Health, Part A*, ***47***: 1096-1103.

Ayoola, S. O. & Kuton, M. P. (2009). Seasonal variation in fish abundance and physicochemical parameters of Lagos lagoon, Nigeria. *African Journal of Environmental Science and Technology*, ***3***(5): 149-156.

Barnett, D. T. and Stohlgren, T.J. (2002). A nested-intensity surveying plant diversity. *Journal of Biodiversity and Conservation*, ***12***(2):255-278.

Barnett, A. G. and Dobson, A. J. (2010). *Analysing Seasonal Health Data*. Springer. 164pp.

BirdLife International (2000). *Threatened birds of the world*. Barcelona/ Cambridge: Lynx Edicions/BirdLife International.

Brawn, J. D., Robinson, S. K. & Thompson, F. R. (2001). The role of disturbance in the ecology and conservation of birds. *Journal of Annual. Review of Ecological. Systems*, ***32***: 251–276.

Brock, M. A. (2003). Australian Wetland Plants and Wetlands in the Landscape: Conservation of diversity and future management. *Journal of Aquatic Ecosystem Health & Management*, ***6***: 29-40.

Brock, M. A, Smith, R. & Jarman, P. (1999). Drain it, dam it: alteration of water regime in shallow wetlands on the New England Tableland of New South Wales, Australia. *Journal of Wetland Ecology and Management*, ***7***:37-46.

Bryson, C. T., Fox, A. M. & Byrd, Jr. J. D. (2006). Wetland Nightshade (*Solanum tampicense*) Growth Response to Temperature, and Winter Survival, in Relation to Potential Spread. *Journal of Weed Technology*, ***20***:778–783.

Buckland, S. T., Anderson, D. R., Burnham, K. P. & Laake, J. L. (1993). *Distance Sampling: Estimating Abundance of Biological Populations*. Chapman and Hall, New York. 6pp.

Butchart, S. H., Walpole, M., Collen, B. & Strien. A. V. (2010). Global Biodiversity: Indicators of Recent Declines. *Journal of Science*, ***328***: 1164-1168.

Camberlin, P. (1995). June-Sptember rainfall in north-east Africa and atmospheric signals over the tropics. *International Journal of Climatology*, ***15***:773-83.

Canadian Council of Resource and Environment Ministers (CCREM). (1987). Canadian water quality guidelines. Prepared by the Task Force on Water Quality Guidelines. No. 1299.

Carter, M. R & Gregorich, E.G. (Eds.). 2006. *Soil Sampling and Methods of Analysis Second Edition*. Taylor & Francis Group 6000, Broken Sound Parkway NW, Suite 300 Boca Raton, FL 33487-2742. 11pp.

Ceschin S, Salerno G, Caneva G, 2009. Multitemporal floristic analysis of a humid area in Rome's archaeological site as indicator for environmental change. *Journal of Environmental Monitoring and Assessment*, ***149***: 29-42.

Ceschin S, Salerno G, Bisceglie S, Kumbaric A, 2010. Temporal floristic variations as indicator of environmental changes in the Tiber River in Rome. *Journal of Aquatic Ecology*, ***44***: 93-100.

Chambers, R. M., Meyerson. L. A. and Saltonstall, K. (1999). Expansion of *Phragmites australis* into tidal wetlands of North America. *Journal of Aquatic Botany*, ***64***:261-273.

Chapin, F. S. III, Zavaleta, E. S., Eviner, V. T., Naylor, R. L., Vitousek, P. M., Reynolds, H. L., Hooper, D. U. & Lavorel, S. (2000). Consequences of changing biodiversity. *Journal of Nature*, ***405***: 234–242.

Chezhian, A., Kabilan, N., Suresh Kumar, T. & Senthamil Selvan, D. (2011). Influence of different calcium levels and low pH of water on the plasma electrolyte regulation of a fresh water teleost fish *Cyprinus carpio* Var. *communies*, (Linnaeus, 1958). *Current Research Journal of Biological Sciences*, ***3***(2): 147-154.

Christensen, J. H., Hewitson, B., Busuioc, A., Chen, A., Gao, X., Held, I., Jones, R., Kolli, R. K., Kwon, W-T., Laprise, R., Magaña Rueda, V., Mearns, L., Menéndez, C. G., Räisänen, J., Rinke, A., Sarr, A. & Whetton, P. (2007): Regional Climate Projections. In: *Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change* [Solomon, S., Qin, D., Manning, M., Chen, Z., Marquis, M., Averyt, K.B., Tignor, M. and Miller, H.L. (Eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA. Regional Climate Projections. 11pp.

Climate Change 2001. *Third Assessment Report of the Intergovernmental Panel on Climate Change IPCC (WG I & II)* (Cambridge Univ. Press, Cambridge, 2001).

Collins, N. B. 2005. *Wetlands: The basics and some more*. Free State Department of Tourism, Environmental and Economic Affairs. Pp. 30-40.

Colwell, R. K., Brehm, G., Cardelús, C. L., Gilman, A. C. & Longino, J. T. (2008). Global Warming, Elevational Range Shifts, andLowland Biotic Attrition in the Wet Tropics. *Journal of Science*, ***322***: 258-261.

Cosyns, E., Claerbout, S., Lamoot, I. & Hoffmann, M. (2005). Endozoochorous seed dispersal by cattle and horse in a spatially heterogenous landscape. *Journal of Plant Ecology*, ***178***(2):149-162.

Craft, C. B., Vymazal, J. & Richardson, C. J. (1995). Response of Everglades plant communities to nitrogen and phosphorus additions. *Journal of Wetlands*, **15**:258-271.

Cronk, J. K. & Fennessy, M. S. (2001). *Wetland Plants: Biology and Ecology*. Lewis publishers. CRC Press. Boca Raton, Florida, USA. 440pp.

Dankwa, H. R., Abban, E. K. & Teugels, G. G. (1999). *Freshwater Fishes of Ghana. Identification, Distribution, Ecological and Economic Importance*. Annales Science Zoologiques. **283**. 53pp.

Davis, G. A. (1977). *Management alternatives for the riparian habitat in the Southwest*. General Technical Report RM-43, USDA Forest Service, Rocky Mountain and Range Experiment Station, Fort Collins, Colorado. 217 pp.

Davis, T. J. (Ed.). (1993). *Towards the Wise Use of Wetlands*. Wise Use Project, Ramsar Convention Bureau, Gland, Switzerland. Pp. 32-38.

Davis, T. J. (Ed.). (1994). The Ramsar Convention Manual: A Guide to the Convention on Wetlands of International Importance especially as Waterfowl Habitat. 6th edition. Ramsar Convention Bureau, Gland, Switzerland. 207pp.

Demey, R. & Hester, A. (2008). First records of Nimba Flycatcher *Melaenornis annamarulae* for Ghana. *Bulletin of the African Bird Club*, ***15***(1): 95-96

Dugan, P. J. (Ed). (1990). *Wetland Conservation: a Review of Current Issues and Required Action*. IUCN, Gland, Switzerland. 94pp.

Dugan, P. (Ed.). (1993). *Wetlands in Danger – A World Conservation Atlas.* Oxford University Press, New York, United States of America.

Dunn, P. O. & Winkler, D. W. (1999). Climate change has affected the breeding date of tree swallows throughout North America. Proceedings of the Royal Society of London. *Journal of Biological Science,* ***266***: 2487-2490.

Dunne, J. A., Harte, J. & Taylor, K. J. (2003). Subalpine meadow flowering phenology responses to climate change: Integrating experimental and gradient. *Journal of Ecological Monographs*, ***73***(1), 69–86. Ecological Society of America.

Erwin, K. L. (2009). Wetlands and global climate change: the role of wetland restoration in a changing world. *Journal of Wetlands Ecological Management*, ***17***:71–84.

Euler, F. V. (2001). Selective extinction and rapid loss of evolutionary history in the bird fauna. Proceedings of the Royal Society of London. *Bulletin of biological science*, ***268***:127-130.

Fausch, K. D. & Bramblett, R. G. (1991). Disturbance and fish communities in intermittent tributaries of a Western Great Plains river. *Journal of Copeia* ***3,*** 659–674.

Fernandes, B. & Achuthankutty, C. T. (2010). Seasonal variation in fiheriy diversity of some wetlands of the Salcete Taluka, Goa India. *Indian Journal of Marine Science*s, ***39***(2): 238-247.

Ferrati, R., Canziani, G. A. & Moreno, D. R. (2005). Estero del Ibera: hydrometeorological and hydrological characterization. *Journal of Ecological Modelingl*, ***186***:3–15.

Finlayson, C.M. and Moser, M.E. (Eds.). (1991). *Wetlands*. International Waterfowl and Wetlands Research Bureau, Slimbridge, UK.

Florida Natural Areas Inventory (FNAI). (2010). *Depression Marshes. Guide to the Natural Communities of Florida*: 2010 edition.

Fox, A. D., Madsen, j., Boyd, H., Kuijken§, E., Norrissk, D.W., Tombre, I.M. & Stroud, D.O. (2005). Effects of agricultural change on abundance, fitness components and distribution of two arctic-nesting goose populations. *Journal of Global Change Biology*, ***11***: 881-893.

Furness, R. W**.** and Greenwood J. J. D. (Eds.). **(**1993). *Birds as a Monitor of Environmental Change.* Chapman and Hall, London. 356pp.

Gaston, K. J., Blackburn, T. M. & Goldewijk, K. K. (2003). Habitat conversion and global avian biodiversity loss. Proceedings of the Royal Society of London. *Bulletin of Biological Science*, ***270***:1293-1300.

Gbogbo, F. & Attuquayefio, D. K. (2010). Issues arising from changes in waterbird population estimates in coastal Ghana. *Journal of Bird Populations*, ***10***:79-87.

Gboloo, A. T. (1998). *Bushfires: A Ghanaian Approach*. Sedco Publishing, Accra, Ghana. 21pp.

Gordon, C., Yankson, K., Biney, C. A., Tumbolto, J. W., Amlalo, D. S. & Kpelle, D. 1998. Report of the Working Group on Wetland Typology. Report to Ghana Coastal Wetlands Management Project, Accra: Ghana Wildlife Department. 54pp.

Gyasi, E. A., Karikari, O., Kranjac-Berisavljevic', G. & Von Vordzogbe, V. (2006). *Report on Climate Change Vulnerability and Adaptation Assessment Relative to Land Management in Ghana*. 12pp.

Hackney, C. T. & A. A. de la Cruz (1981). Effects of fire on brackish marsh communities: management implications. *Journal of Wetlands, **1***:75-86.

Hall, J. B. & Swaine, M. D. (1981). Geobotany. *Distribution and ecology of vascular plants in a tropical rain forest: Forest vegetation in Ghana*. W. Junk, The Hague, Netherlands. 383pp.

Helfgott, T., Lefor, M.W. and Kennard, W.C. "Proceedings: First Wetlands Conference" 1973. Special Reports, Paper No. 19.

Henderson, P. A. & Seaby, R. M. (1999). *Community analysis package 1.14*. Pisces Conservation Ltd. IRC House, Pennington, Lymington, S041 8GN, UK.

Henderson, P. A. & Seaby, R. M. (2000). *Environmental community analysis 1.3*. Pisces Conservation Ltd. IRC House, Pennington, Lymington, S041 8GN, UK.

Hopfensperger, K. N., Wu, J. Q. & Gill, R. A. (2006). Plant composition and erosion potential of a grazed wetland in the Salmon River subbasin, Idaho. *Journal of Western North American Naturalist*, ***66***(3):354–364.

Hudon, C. (2011). Shift in wetland plant composition and biomass following low-level episodes in the St. Lawrence River: looking into the future. *Canadian Journal of Fisheries and Aquatic Sciences*, ***61***(4): 603-617.

Huffman, M. T & Rohde, R. F. (2007). From pastoralism to tourism: The historical impact of changing landuse practices in Nemaqualand. *Journal of Arid Environments*, ***70***(4): 641-658.

Hughes, F. M. R. & Rood, S. B. Floodplains. In: Warren, A and French, J. R. (Eds.). (2001). *Habitat Conservation: Managing the physical environment*. John Wiley and Sons. Ltd, Baffins Lane, Chichester, West Sussex, England. Pp. 105–121.

Hughes, L. (2003). Climate change and Australia: Trends, projections and impacts. *Austral Journal of Ecology*, ***28***: 423-443.

Hulme, P. E. (2003). Winning the science battles but losing the conservation war? *Journal of Oryx*, ***37***, 178-193.

Humpl, M. & Pivnicˇka, K. (2006). Fish assemblages as influenced by environmental factors in streams in protected areas of the Czech Republic. *Ecology Journal of Freshwater Fish*, ***15***: 96–103.

Huntington, H. H., Fox, S., Berkes, F., Krupnic, I., Whiting, A., Zacharof, M., McGlashan, G. & Brubaker, M. (2005). The changing Arctic: indigenous perspectives. ACIA. In: *Arctic Climate Impact assessment*. Cambridge Univ. Press, UK. Pp. 61-98.

Huntley, B. (1991). How plants respond to climate change: Migration rates, individualism and the consequencies for plant communities. *Journal of Annals of Botany*, ***67***, 15-22.

IPCC (International Panel on Climate Change). (2001). Climate change: impacts, adaptation, and vulnerability. Technical summary, and summary for policymakers. Third assessment report of working group I of the intergovernmental panel on climate change. Cambridge University Press, Cambridge. 3pp.

IPCC (2007) Climate Change 2007: Synthesis report. *Contribution of Working Groups I, II and III to the French Assessment Report of the intergovernmental panel on climate change* (eds Core Writing Team, P. Pachauri & R.K. Reisinger. Cambridge University Press, Cambridge, UK. 104pp.

Iversen, J. (1944). Viscum, Hedera and Ilex as climatic indicators. A contribution to the study of past-glacial temperature climate. *Geol. Fören. Stockholm Förhandl*, ***66***: 463-483.

Jansen, A., Robertson, A.I. (2001), 'Relationships between livestock management and the ecological condition of riparian habitats along an Australian floodplain river', *Journal of Applied Ecology*, ***38***: 63-75.

Jensen, A. (2002). Repairing wetlands of the Lower Murray: Learning from restoration practice. *Journal of Ecological Management & Restoration*, ***3***: 5-14.

Johnson, D. E. (Ed.). (1997). *Weeds of Rice in West Africa*. ADRAO/WARDA. CTA, DFID. Imprint Design, UK. Pp. 5-102.

Johnson, L. B., Olker, J., Ciborowski, J. J. H., Host, G. E., Breneman, D., Brady, V., Brazner, J., & Danz, N. (2006). Identifying Response of Fish Communities in Great Lakes Coastal Regions to Land Use and Local Scale Impacts. *Journal of Great Lakes Research*, ***254***: 399-9636.

Jones, J.I., Li, W. & Maberly, S.C. 2003. Area, altitude and aquatic plant diversity. *Journal of Ecography*, ***26**:* 411–420.

Kabii, T. (1997). Overview of African wetlands. Technical officer for Africa, Ramsar Bureau Switzerland. In: *Wetlands, biodiversity, and the Ramsar Convention: the role of the Convention on wetlands and the conservation and wise use of biodiversity*. Ramsar Bureau. Ministry of Environment and Forest. India. 1pp.

Kantrud, H. A. & Stewart, R. E. (1984). Ecological distribution and crude density of breeding birds on Praire wetlands. *Journal of Wildlife Management*, ***48***(2):426-437.

Kangah-Kesse, L., Attuquayefio, D., Owusu, E. & Gbogbo, F. (2007). Bird Species Diversity and Abundance in the Abiriw Sacred Grove in the Eastern Region of Ghana. *West African Journal of Applied Ecology*, ***11***: 41-50.

Kath, J., Brocque, A. L. & Craig Miller, C. (2010). Eco-Hydrology of Dynamic Wetlands in an Australian Agricultural Landscape: a Whole of System Approach for Understanding Climate Change Impacts. In: BALWOIS. Water Observation and Information System for Decision Support, 25-29 May. Ohrid, Macedonia.

Kauffman, J. B. & Krueger, W.C. (1984). Livestock impacts on riparian ecosystems and streamside management implications . . . a review. *Journal of Range Management*, ***37***:430–437.

Kent, M. & Coker, P. (1992). (Eds.). *Vegetation description and analysis. A practical approach*. John Wiley and Sons Ltd, West Sussex- England. 162pp.

Killgore, K. J. & Hoover, J. J. (2001). Effects of hypoxia on fish assemblages in a vegetated waterbody. *Journal of Aquatic Plant Management*, ***39***: 40-44.

Klanderud, K. & Totland, Ø. (2005). Simulated climate change altered dominance hierarchies and diversity of an Alpine Biodiversity Hotspot. *Journal of Ecology*, ***86***(8), 2047–2054. Ecological Society of America.

Klein, R. 1988. Explanatory note: Preparatory action concerning integrated management of coastal wetlands of Mediterranean type (environmentally sensitive areas in the sense of budget line 6611). Commission of the European Communities DG XI B-3. 7pp.

Knepp and Arkin, 1973. Ammonia Toxicity Levels and Nitrate Tolerance of Channel Catfish, *The Progressive Fish-Culturist*, ***35***: 221-224.

Kopec, D., Halladin-Dąbrowska, A., Chmielecki, B. and Kucharski, L. 2008. Human impact on wetland flora of the Warsaw-Berlin proglacial valley. *Journal of Biodiversity Reources Conservation*, ***9***(10): 57-62.

Krupnik, I. and Jolly, D. (Eds.). (2002). The Earth is Faster Now: Indigenous Observations of Arctic Environmental Change. Arctic Research Consortium of the United States, Fairbanks, Alaska. 384pp.

Kushland, J. A. (1976). Environmental stability and fish community diversity. *Journal of Ecology*, ***57***: 821- 825.

Kushland, J. A. (1987). Responses of wading birds to seasonally fluctuating water levels strategies and their limits. *Journal of Colonial Waterbirds*, ***9***:155–162.

Kutiel, P. & Shaviv, A. (1993). Effects of soil type, plant composition and leaching on soil nutrients, following a simulated forest fire. *Journal of Forest Ecology and Management*, ***53***:329–343.

Leck, M. A. & Brock, M. A. (2000). Ecological and evolutionary trends in wetlands: Evidence from seeds and seed banks in New South Wales, Australia and New Jersey, USA. *Journal of Plant Species Biology*, ***15***: 97-112.

Lévêque, C., Bruton M. N, & Ssentongo, G. W (Eds.). (1988). Biology and Ecology of African Freshwater Fishes. L'ORSTOM, Travaux et Documents No.216, Paris. 508pp.

Linton, S. & Goulder, R. (2000). Botanical conservation value related to origin and management of ponds. Aquatic Conservation: *Journal of Marine and Freshwater Ecosystem*, ***10***: 77–91.

Living With Michigan's Wetlands: A Landowner's Guide, (1996). 6pp.

MacArthur, R.M. (1972a). Will large complex systems be stable? *Journal of Nature*, ***238***: 412-4.

MacArthur, R.M. (1972b). "Limit cycles in predator-prey communities"? *Journal of Science*, ***117***: 900-2

Main, M. B. and Barry, M. J. (2002). Influence of fire flowering of wet prairie grasses in South Florida, USA. Journal of *Wetlands*, ***22***(2): 430-434.

Malo, J. E. & Suárez, F. (1995a). Establishment of pasture species on cattle dung: the role of endozoochorous seeds. *Journal of Vegetation Science*, ***6***:169–174.

Malo, J. E. & Suárez, F. (1995b). Herbivorous mammals as seed dispersers in a Mediterranean dehesa. *Journal of Oecologia*, ***104*:**246–255.

Mailu, A. M. 2001. "*Preliminary Assessment of the Social, Economic, and Environmental Impacts of Water Hyacinth in the Lake Victoria Basin and the Status of Control." In Biological and Integrated Control of Water Hyacinth, Eichhornia crassipes, proceedings of the second meeting of the Global Working Group for the Biological and Integrated Control of Water Hyacinth*. Beijing, China, 9–12 October 2000. Australian Centre for International Agricultural Research (ACIAR) Proceedings, No. 102. Pp. 130–139.

Malavasi, R., Battisti, C. & Carpaneto, G. M. (2009). Seaonal bird assemblages in a Mediterranean patchy wetland: Corroborating the intermediate disturbance hypothesis. *Polish Journal of Ecology*, ***57***(1): 171-179.

Margalef, R. (1968). *Perspective in Ecological Theory*. University of Chicago Press, Chicago. 111pp.

McNaughton, S. J. (1983). Serengeti grassland ecology: the role of composite environmental factors and contingency in community organization. *Journal of Ecolological Monographs*, ***53***:291–320.

McCune, B. & Mefford, M. J. (1999). *PC-ORD. Multivariate Analysis of Ecological Data, Version 4*. MJM Software Design, Gleneden Beach, Oregon, USA. 237pp.

McSweeney, C., Lizcano, G, New, M. & Lu, X. (2010). The UNDP Climate Change Country Profile. Tanzania: Improving the accessibility of observed and projected climate information for studies of climate change in developing countries, *Bulletin of the American Meteorological Society*, ***91***(2): 157-166.

McSweeney, C., New, M. & Lizcano, G. 2009. UNDP Climate Change Country Profiles. Ghana. *University of Oxford, School of Geography and the Environment.* Retrieved from: http://country-profiles.geog.ox.ac.uk.

Meehl, G. A., Stocker, T. F., Collins, W. D., Friedlingstein, P., Gaye, A. T., Gregory, J. M., Kitoh, A., Knutti, R., Murphy, J. M., Noda, A., Raper, S.

C. B., Watterson, I. G., Weaver, A. J., Zhao, Z.-C. (2007). Global climate projections. In: Solomon, S., Qin, D., Manning, M., Chen, Z., Marquis, M., Averyt, K.B., Tignor, M., Miller, H. L. (Eds.), *Climate Change* (2007): *The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change*. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

Menzel, A. & Estrella, N. In: *``Fingerprints'' of Climate Change Adapted Behaviour and Shifting Species Ranges*. Walther, G.-R., Burga, C. A. & Edwards, P. J. (Eds.). (2001). (Kluwer Academic, NewYork. Pp. 123-137.

Millennium Ecosystem Assessment (2005). *Ecosystems and Human well-being: Wetlands and Water Synthesis*. World Resources Institute, Washington, DC. 6pp.

Milchunas, D. G. & Lauenroth, W. K. (1993). Quantitative effects of grazing on vegetation and soils over a global range of environments. *Journal of Ecological Monograph*, ***63***:327–366.

Ministry of Lands & Forestry (1999). *Managing Ghana's Wetlands*: A National Wetlands Conservation Strategy. GERMP-Coastal Wetland Management Project. Closing Report. 15pp.

Mironga, J. M. (2005). Effect of farming practices on wetlands of Kisii District, Kenya. *Journal of Applied Ecology and Environmental Research*, ***3***(2): 81-91.

Moore, D. R. J. & Keddy, P. A. (1989). The relationship between species richness and standing crop in wetlands: the importance of scale. *Journal of Vegetatio*, ***79***: 99–106.

Moss, B., Phillips, G. L. & Madgwick, J. (1996a). A guide to the Restoration of Nutrient Enriched Shallow Lakes. *Journal of Hydrobiologia*, ***342***(343): 241-255.

Moss, B., Johnes, P. & Phillips, G.L. (1996b). The monitoring of ecological quality and the classification of standing waters in temperate regions: a review and proposal based on a worked scheme for British water. *Journal of Biological Reviews*, ***71***: 301-339.

Molles, M.C. (1999). *Ecology: Concepts and applications*. WCB/McGraw-Hill, Boston. 45pp.

Mottle, B. J. (2007). *Selected Methods of Soil Analysis*. University of Calgary, unpublished lab manual. 25pp.

Mueller-Dombois, D. and Ellenberg, H. 1974. *Aims and methods of vegetation ecology*. Wiley New York. 62 p.

Murphy, J. and Riley, J.P. (1962). A modified single solution method for the determination of phosphate in natural waters. *Journal of Analytica. Chimica Acta*, ***27***: 31-36.

Murphy, K. J. (2002). Plant communities and plant diversity in softwater lakes of northern Europe. *Journal of Aquatic Botany*, ***73***: 287– 324.

Mwendera, E. J., Mohamed, S. M. A. & Dibabe, A. (1997a). Effects of livestock grazing on surface run-off and soil erosion from sloping pasture lands in the Ethiopian highlands. *Australian Journal of Experimental Agriculture,* ***37***: 420-421.

Mwendera, E. J., Mohamed, S. M. A. & Zurihun, W. (1997b). Vegetation response to cattle grazing in the Ethiopian highlands. *Journal of Agriculture, Ecosystems and Environment*, ***64***: 43-51.

Myers, S. J. A., Vellend, M., Gardescu, S. & Marks, P. L. (2004). Sedd dispersal by white-tailed deer: implications for long-distance dispersal, invasion and migration of plants in the eastern North America. *Journal of Oecologia*, ***139***(1): 35-44.

Nalubega, M. and Nakawunde, R. (1995). Phosphorus removal in macrophyte based treatment. 21st WEDC Conference: Sustainability of water and sanitation systems. Kampala, Uganda. Pp. 235-237.

Netherlands Climate Change Assistance Programme (NCAP). (2007). Ghana Phase II-Output 3 NCAP Project: *Scenario Development & MCA Workshop Report. Environmental Protection Agency Accra, Ghana*.

Noest, V. & van der Maarel, E. (1989). *A new dissimilarity measure and a new optimality criterion in phytosociological classification. Vegetatio*. In: Kent, M and Coker, P. 1992. *Vegetation description and analysis. A practical approach*. 281pp.

Ntiamoa-Baidu, Y. (1991). Seasonal changes in the importance of coastal wetlands in Ghana for wading birds. *Journal of Biological Conservation*, ***57***:139-158.

Ntiamoa-Baidu, Y. (1991). Species protection as a strategy for conservation action in Africa: The case of the Roseate Tern in Ghana. *ICBP Technical Publication* No.12., Cambridge, U.K.: International Council for Bird Preservation.

Ntiamoa-Baidu, Y., Nyame, S. K. & Nuoh, A. A. (2000). Trends in the use of a small coastal lagoon by waterbirds: Muni Lagoon, Ghana. *Journal of Biodiversity and Conservation*, ***9***(4): 527-539.

Ntiamoa-Baidu, Y., Owusu, E. H. & Daramani, T. (2000). Terrestrial Birds of Muni-Pomazde Ramsar Site. *Journal of Biodiversity and Conservation*, ***9***: 511-525.

Ntiamoa-Baidu, Y., Owusu, E. H., Asamoah, S. A. & Owusu-Boateng, K. (2000a). Distribution and abundance of forest birds in Ghana. *Journal of Ostrich*, ***71***: 262-268.

Ntiamoa-Baidu, Y., Owusu, E. H., Asamaoh, S. A. & Owusu-Boateng, K. (2000b). Avifauna of two upland evergreen forest reserves, the Atewa Range and Tano-Offin in Ghana. *Journal of Ostrich*, ***71***: 277-281.

Nsor, C.A. and Gambiza, J. (2013). Land use changes and their impacts on the vegetation Kromme River peat basin, South Africa. *Science Journal of Environmental Engineering Research.* ***2013***(116): 12.

Okezie, I. A. & Agwakwa, C. W. (Eds.). (1998). *A Handbook of West African weeds. International Institute of Tropical Agriculture (IITA) Nigeria*. African Book Builders Ltd. Pp. 13-120.

Ontoyin, Y. (1993). *A comparative study of temperature as a climate indicator for the periods* of 1931-1960 & 1961-1990. WRRI, CSIR, Accra, Ghana.

Oswood, M. W., Milner, A. M. and Irons, J. G. III. (1992). *Climate change and Alaskan Rivers and Streams*. In: *Global Climate Change and Freshwater Ecosystems*. Firth, P. and Fisher, S. G. (Eds.). Springer-Verlag, London, Pp. 192–210.

Owusu, E .H. (2007). The ornithological importance of the Amansuri Community Nature Reserve in the Western Region of Ghana. *Journal of Science and Technology*, ***27***(3):72-85.

Owusu, E. H. (2008). The perceptions of local communities towards the conservation of birds in an Important Bird Area in Ghana. *West African Journal of Applied Ecology*. ***13***:111-116

Obodai, E.A and Nsor, C.A. (2009): Aspects of biodiversity and fish production in the Kukobila wetland in the Savelugu-Nanton District of the Northern Region of Ghana. *Ethiopian Journal of Environmental Studies and Management*, ***2***(3):27-35.

Parmesan, C. (2006). Ecological and evolutionary responses to recent climate change. *Annual Review of Ecological and Evoutionary Systematics,* ***37***:637–69.

Paugy, D., Leveque, C. & Teugels, G. G (Eds.). (2004). *The Fresh and Brackish water fishes of West Africa*. Publications Scientifiques du Museum, MRAC. IRD Editions. Africa. Tervuren.

Pielou, E. C. (1969). *An introduction to Mathematical Ecology*. John Wiley and Sons, New York. 294pp.

Pires, A. M., Cowx, I. G. & Coelho, M. M. (1999). Seasonal changes in fish community structure of intermittent streams in the middle reaches of the Guadiana basin, Portugal. *Journal of Fish Biology, **54***: 235–249.

Powell, A. F. L. A. (2006). Effects of prescribed burns and Bison (Bos Bison) grazing on breeding bird abundance in tallgrass Prairie. *Auk, **123***(1):183-197.

Prentice, I. C., Cramer, W., Harrison, S., Leemans, R., Monserud, R. A. & Solomon, A. M. (1992). A global biome model based on plant physiology and dominance, soil properties and climate. *Journal Biogeography*, ***19***: 117–134.

Quality Criteria for Water, (1986). U.S. Environmental Protection Agency, EPA Report No. 440/5-86-001.

Quarcoopome, T., Amevenku, F. Y. K. and Ansa-Asare, O. D. (2007). Fisheries and Limnology of two reservoirs in Northern Ghana. *West African Journal of Applied Ecology*, ***12***: 61-80.

Ragab, R. & Prudhomme, C. (2002). Climate Change and Water Resources Management in Arid and Semi-arid Regions: Prospective and Challenges for the 21st Century. *Journal of Biosystems Engineering,* ***81***(1): 3-34.

Ramsar Convention. (2002). Resolution VII.10 *Wetland Risk Assessment Framework*. Retrieved from http://www.ramsar.org.

Richardson, D. M. & Bond, W. J. (1991). Determinants of plant distribution: Evidence from pine invasions. *Journal of American Naturalist,* ***137***: 639–668.

Riffell, S. K., Keas, B. E., & Burton, T. M. (2001). Area and habitat relationships of birds in Great Lakes coastal wet meadows. *Journal of Wetlands,* ***21***:492–507.

Robertson, A.I. and Rowling, R.W. (2000), Effects of livestock on riparian zone vegetation in an Australian dryland river. *Regulated Rivers: Research and. Management*, ***16***: 527–541. doi: 10.1002/1099-1646(200009/10)16:5<527::AID-RRR602>3.0.CO;2-W

Rohn, S. R. & Bragg. T. B. (1989). Effect of Burning on Germination of Tallgrass Prairie Plant Species. *Proceedings of the Eleventh North American Prairie Conference*, University of Nebraska, Lincoln, Nebraska. Pp. 169-171.

Rolon, A. S. & Leonardo Maltchik, L. (2006). Environmental factors as predictors of aquatic macrophyte richness and composition in wetlands of southern Brazil. *Journal of Hydrobiologia*, ***556***:221–231.

Royal Society for the Protection of birds (RSPB). (2010). Retrieved from http://www. RSPB. com.

Rutherford, M. C., Midgley. G. F., Bond. W. J., Powrie. L. W., Roberts. R. & Allsopp. J. (1999). South African Country study on climate change plant biodiversity: Vulnerability and adaptation assessment.

Salo, J., Kalliola, R., Hakkinen, I.,Makinen, Y., Niemala, P., Puhakka, M. & Coley, P. (1986). River dynamics and the diversity of Amazon lowland forest. *Journal of Nature*, ***322***: 254 – 8.

Sandström, A. & Karâs, P. (2002). Effects of eutrophication on young-of-the-year freshwater fish communities in coastal areas of the Baltic. *Journal of Environmental Biology of Fishes*, ***63***:89-101.

Schindler, D. W. (2001). The cumulative effects of climate warming and other human stresses on Canadian freshwaters in the new millennium1. *Canadian Journal of Fish Aquatic Science*, ***58***: 18–2.

Shannon, C.E. and Wiener, W. 1963. *The mathematical theory of communication*. Illinois: Urbana Univ. Illinois Press. 117pp.

Slaymaker, T. & Blench, R.M. (Eds). (2002). Rethinking Natural Resource Degradation in Sub-Saharan Africa: policies to support sustainable soil fertility management, soil and water conservation among resource poor farmers in semi-arid areas: country studies. I. Tamale: University of Development Studies.

Smith, S. M., Newman, S., Garrett, P. B. & Leeds, J. A. (2001**)**. Differential Effects of Surface and Peat Fire on Soil Constituents in a Degraded

Wetland of the Northern Florida Everglades**.** *Journal of Environmental. Quality*, ***30***(6)**:** 1998-2005.

Sneath, P. H. A. & Sokal, R. R. (1973). *Numerical taxonomy*. Freeman, San Francisco. In: Kent, M and Coker, P. *Vegetation Description and Analysis. A practical approach*. John Wiley and Sons Ltd. West Sussex-England, 282pp.

Sommer, U. (2000). Benthic microalgal diversity enhanced by spatial heterogeneity of grazing. *Journal of Oecologia,* ***122***:284–287.

Ssegawa, P., Kakudidi, E., Muasya, M. & Kalema, J. (2004). Diversity and distribution of sedges on multivariate environmental gradients. *African Journal of Ecology,* ***42***(1): 21- 33.

Stohlgren, T. J., Falkner, M.B., and Schell, L. D., 1995. A Modified-Whittaker nested vegetation sampling method. *Journal of Plant Ecology,* **117**(2): 113-121. Kluwer Academic publishers, Belgium.

Stohlgren, T.J., Binkley, D., Chong, D. W., Kalkhan, M., Schell, L. D., Bull, K. A., Otsuki, Y., Newman, G., Bashkin, M. and Son, Y. (1999). Exotic plant species invaded hotspots of native plant diversity. *Journal of Ecological Monographs*, ***69***(1): 25-46.

Suapim, R. H., Attuquayefio, D. K., Gbogbo, F. & Owusu, E. H. (2007). Aspects of the feeding ecology of wintering waterbirds in the Densu Delta Ramsar Site, Ghana. *Ghana Journal of Science*, ***47***: 17-34.

Sykes, M. T., Prentice, I. C. & Cramer, W. (1996). A bioclimatic model for the potential distributions of north European tree species under present and future climates. *Journal of Biogeography*, ***23***: 203–233.

Taddese, G., Mohamed, M. A., Abyie, A. S & Wagnew, A. 2002. Impact of Grazing on Plant Species Richness, Plant Biomass, Plant Attribute, and Soil Physical and Hydrological Properties of Vertisol in East African Highlands. *Journal of Environmental Management*, ***29***(2): 279–289.

terBraak, C. J. F. (1986). Canonical correspondence analysis: a new eigenvector method for multivariate direct gradient analysis. *Journal of Ecology*, ***67***: 1167–1179.

terBraak, C. J. F. (1986). *Canonical correspondence analysis*: *A new eigenvector technique for multivariate Multivariate Statistics for Wildlife and Ecology Research*. Springer-Verlag, New York Inc. USA. *Direct gradient analysi*s. Ecology. In: McGarigal, K., Cushman, S. and Stafford, S. 2000. 70pp.

terBraak, C. J. F. (1987). The analysis of vegetation–environment relationships by canonical correspondence analysis. *Journal of Vegetatio,* ***69***: 69–77.

Timmermans, S. T. A., Badzinski, S. S. & Ingram, J.W. (2008). Associations between breeding marsh bird abundances and Great Lakes hydrology. *Journal of. Great Lakes Research*, **34**:351–364.

Tiner, R. W. (1999). *Wetland Indicators. A Guide to Wetland Identification, Delineation, Classification, and Mapping.* Lewis publishers.

The World Bank Group. (2010). Economics of Adaptation to Climate Change in Ghana. 1818 H Street, NW. 15 pp.

Thomas, C. D., Cameron, A., Green, R. E., Bakkenes, M., Beaumont, L. J., Collingham, Y. C. (2004) Extinction risk from climate change. *Journal of Nature*, ***427***, 145–148.

Thorpe, W. (1986). *A review of the literature and miscellaneous other parameters relating to water levels in the Peace-Athabasca Delta: effect on muskrat numbers*. Environment Canada Gatineau, Quebec.

Totland, Ø. & Nyléhn, J. 1998. Assessment of the effects of environmental change on the performance and density of *Bistorta vivapara*: the use of multivariate analysis and experimental manipulation. *Journal of Ecology*, ***86***: 989-998.

Traba, J., Levassor, C. & Peco.B. (2003). Restoration of Species Richness in Abandoned Mediterranean Grasslands: Seeds in Cattle Dung. *Journal of Restoration Ecology, 11*(3): 378–384.

Truelson, R. L. (1997). Water quality criteria for dissolved oxygen. Prepared for British Columbia's Ministry of Environment, Lands and Parks, Water Management Branch, Victoria. Framework Convention on Climate Change and Its Kyoto Protocol. UNEP/CBD/SBSTTA/91/11.

Vâlcu, M. (2006). Seasonal changes in bird species diversity at the interface between forest and reed-bed. *Journal of Biodiversity and Conservation*, ***15***: 3459–3467.

van der Merwe A. J, Johnson J. C, Ras, L. S. K. (1984). An NH_4CO_3-NH_4F-$(NH_4)_2$ EDTA method for the determination of extractable P, K, Ca, Mg, Cu, Fe, Mn and Zn in soils. SIRI Information Bullettin B2/2.

Van Grunsven, R. H. A., Van der Putten, W. H., Bezemer, T. M., Tamis, W .L. M., Berendse, F., & Veenendal, E. M., (2007). Reduced plant–soil feedback of plant species expanding their range as compared to natives. *Journal of Ecology, **95***: 1050–1057.

Verhoeven, J. T. A., Kemmers, R. H. & Koerselman, W. (1993). *Nutrient enrichment in freshwater wetlands.* In: Vos, C.C. and Opdam, P (Eds.). *Landscape ecology*. Chapman and Hall. London, UK. Pp. 79-99.

Vestergaard, O. & Sand-Jensen, K. (2000). Aquatic macrophyte richness in Danish lakes in relation to alkalinity, transparency and lake area. *Canadian Journal of Fisheries and Aquatic Sciences*, 57: 2022–2031.

Vogl, R. J. (1973). Effects of fire on the plants and animals of a Florida Wetland. *Journal of American Midland Naturalist, **89***(2):334-347.

Waite, T. A. & Stickland, D. (2006). Climate change and the demographic demise of a hoarding bird living on the edge. Proceeding of Royal Society of London. *Journal Biological Science, **273***: 2809-2813.

Walkley, A. (1947). A critical examination of a rapid method for determining organic carbon m soils: Effect of variations in digestion conditions and of inorganic soil constituents. *Journal of Soil Science*, ***63***:251-263.

Walkley, A. & Black. I. A. (1934). An examination of the Degtjareff method for determining organic carbon in soils: Effect of variations in digestion conditions and of inorganic soil constituents. *Journal of Soil Science.* ***63***:251-263.

Walther, G-R., Berger, S. & Sykes, M. T. (2005). An ecological 'footprint' of climate change. Proceeding of Royal Society of London. *Journal of Biological Science,* ***272***(1571):1427-32.

Walther, G-R., Post, E., Convey, P., Menzel, A., Parmesank, C., Beebee, T.J.C., Fromentin, J.M., Guldberg, O.H. and Bairlein, F. 2002**.** Ecological responses to recent climate change. *Journal of Nature,* ***416***:389-395.

Waltert, M. Serge-Bobo, K. S., Sainge, N. M., Fermon, H. & Muhlenberg, M. (2005). From Forest to farmlands: Habitat effects on Afrotropical Forest bird diversity. *Journal of Ecological Applications,* ***15***(4):1351–1366.

Ward, D. H., Reed, A., Sedinger, J. S, Black§, J. M., Derksen, D. V. & Castelli, P. M. (2005). North American Brant: effects of changes in habitat and climate on population dynamics*. Journal of Global Change Biology*, ***11***: 869–880.

Warwick, N. W. M**.** & Brock, M. A. (2003). Plant reproduction in temporary wetlands: the effects of seasonal timing, depth, and duration of flooding. *Journal of Aquatic Botany,* ***77***: 153-167.

Water & Rivers Commission, (2000). *Water Notes for Wetlands Management. Advisory notes on wetland managers on Rivers and Wetlands restoration*. Natural Heritage Trust. Government of Western Australia, WN2.

Wilcox, D. A., Meeker, J. E., Hudson, P. L., Armitage, B. J., Black, M. G. & Uzarski, D. G. (2002). Hydrologic variability and the application of index of biotic integrity metrics to wetlands: A Great Lakes Evaluation. *Journal of Wetlands*, ***22***(3):588–615.

Wilcox, D. & Nichols, J. (2008). The effects of water-level fluctuations on vegetation in a lake huron wetland. *Journal of Wetlands*, ***28***: 487-501.

Wild, J., Neuha¨uslova´, Z. & Sofron, J. (2004). Changes of plant species composition in the S ˇ umava spruce forests, SW Bohemia, since the 1970s. *Journal of Forest Ecology and Management*, ***187***: 117–132.

Winn, K. O., Saynor, M. J., Eliot, M. J. & Elio, I. (2006). Saltwater Intrusion and Morphological Change at the Mouth of the East Alligator River, Northern Territory. *Journal of Coastal Research*, ***22***: 137-149.

Woodward, F. I., Lomas, M. R. & Kelly, C. K. (2004). Global climate and the distribution of plant biomes. Philosophical Transactions of the Royal Society of London. *Journal of Biological Reviews*, ***359***(1450): 1465–1476.

Wrona, F. J., Prowse, T. D., Reist, J. D., Hobbie, J. E., Le´vesque, L. M. J. & Vincent, W. F. (2006). Climate Change Effects on Aquatic Biota, Ecosystem Structure and Function. Royal Swedish Academy of Sciences. *Ambio*, ***35***(7): 359–369.

Wuver, A. M., Attuqueyefio, D. K., & Enu-Kwesi, L. (2003). A study of bushfires in a Ghanaian Coastal wetland. II. Impact on floral diversity and soil seed bank. *West African Journal of Applied Ecology*, ***4***: 11-141.

Yeboah, O. (1999). Biodiversity studies in three coastal wetlands in Ghana. *Journal of the Ghana Science Association*, ***1***(3): 147–149.

APPENDIX A

Classification of all wetlands species into five categories (called wetland indicator status) based on their expected frequency of occurrence in wetlands as developed by Tiner (1999)

No.	Category	Description	Estimated probability
1	Obligate Wetland (OBL)	Almost always occurs in wetlands under natural conditions.	>99%)
2	Facultative Wetland (FACW)	Usually occurs in wetlands, but occasionally found in uplands.	67% - 99%
3	Facultative (FAC)	Equally likely to occur in wetlands, or uplands	34% - 66%
4	Facultative Upland (FACU)	Usually occur → outside wetlands, but occasionally found in wetlands →	61% - 33% 7% - 99%
5	Obligate Upland (UPL)	Occur almost always outside wetlands under natural conditions	>99%

APPENDIX B

List of aquatic plants sampled in the 1m2 quadrat, among the six wetlands

Family	Genera	Species	Common name
Nymphaeaceae	*Nymphaea*	*lotus* Linn.	Water lily
Araceae	*Pistia*	*stratiotes* Linn.	Water lettuce
Graminae	*Paspalum*	*scrobiculatum* L.	Koda millet
Polygonacea	*Polygonium*	*salicifolium* Brouss. Ex.Wiild	Slender knotweed
Convulvulaceae	*Ipomea*	*aquatica* (Forssk)	Water spinach
Graminae	*Brachiaria*	*mutica* (Forsk.) Stapf.	Buffalo grass/Dutch grass
Cyperaceae	*Cyperus*	*sphacelatus* (Rottb)	Roadside flatsedge
Cyperaceae	*Cyperus*	*difformis* Linn	Smallflower umbrella-sedge
Cyperaceae	*Cyperus*	*distans* L.F.	Slender Cyperus
Ceratophyllaceae	*Ceratophyllum*	*demersum* L.	Hornwort/coon's tail
Mimosaceae	*Neptunia*	*oleracea* Lour	Water-mimosa

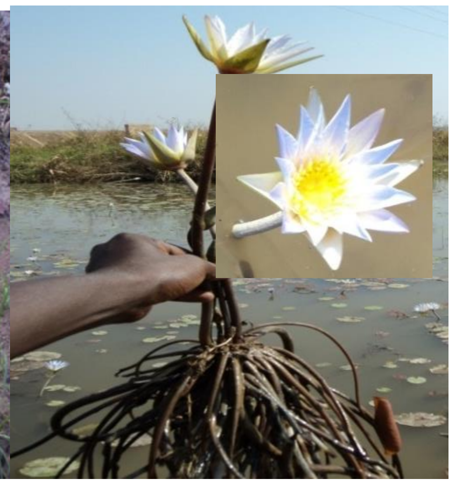
Molluginaceae	*Glinus*	*oppositifolius* (L.)	Bitter leaf
Graminae	*Imperata*	*cylindrica* (L.) P. Beauv.	Blady grass/cogon grass
Graminae	*Oryza*	*longistaminata* A. Chev.&Roehr	Wild rice plant
Graminae	*Cynodon*	*dactylon* (Linn.) Pers.	Bermuda Grass
Fabaceae	*Crotalaria*	*retusa* L.	Wedge-leaf Rattlepod
Graminae	*Deplachne*	*fusca* (L.) P.Beauv.ex Roem.	Brown BeetleGrass
Graminae	*Echinochloa*	*stagnina* (Retz.) P. Beauv.	Hippo grass
Graminae	*Echinochloa*	*pyramidalis* (Lam.) Hitchc. & Chase.	Antelope grass
Cyperaceae	*Fimbristylis*	*ferruginea* (L.) Vahl.	Rusty sedge
Boraginaceae	*Helioptropium*	*indicum* Linn,	Indian heliotrope
Graminae	*Leersia*	*hexandra* Sw.	Swamp rice grass
Onagraceae	*Ludwigia*	*hyssopifolia* (G. Don) Exell.	Linear-leaf water primrose
Onagraceae	*Ludwigia*	*octavalis* (Jacq.) Raven	Mexican primrose-willow
Rubiaceae	*Mitragyna*	*inermis* (Willd.) Kuntze	False abura

Mimosaceae	*Mimosa*	*pigra* L.	Giant sensitive plant
Cucurbitaceae	*Mormodica*	*chrantia* Linn.	Bitter Melon/Bitter Gourd
Poaceae	*Pennisetum*	*polystachion* (L.) Schult	Mission Grass
Euphorbiaceae	*Phyllanthus*	*amarus* Schum.&Thonn.	Gulf leafflower
Scrophulariaceae	*Scoparia*	*dulcis* L.	Broomweed/ bitterbroom
Poaceae	*Setaria*	*pumila* (Poir.) Roem & Schult	Yellow foxtail/ cattail grass
Poaceae	*Saciolepsis*	*Africana* C.E. Hubb. & Snowden	-----
Calastraceae	*Salacia*	*reticulate* L.	Marking Nut Tree
Cyperaceae	*Scirpus*	*grossus* Linn. F.	Coarse bullrush
Myrtaceae	*Syzygium*	*guineense* (Wild) D.C.	Bicoloured waterberry
Meliaceae	*Khaya*	*senegalensis* (Desr.) A. Juss	Senegal mahogany
Graminae	*Schizachyrium*	*sanguineum* (Retz.) Alston.	Crimson bluestem
Verbanaceae	*Vitex*	*crysocarpa* (Planch. Ex Benth.)	Hemp tree
Rhamnaceae	*Ziziphus*	*abyssinica* Hochst. ex A. Rich	Catch thorn

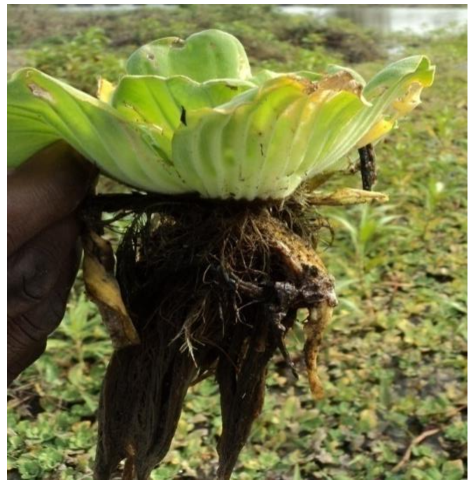
Ceratophyllum demersum

Polygonium salicifolium

Cyperus sphacelatus



Nymphaea latus/micrantha



Neptunia oleracea

Pistia stratiotes

Glinus oppositifolius

Heliotropicum indicum

Eleocharis mutata

Fimbristylis ferruginea

Ipomea aquatic

Ludwigia hyssopifolia

Echinochloa stagnina

Thalia wilwatchii

Ludwigia erecta

Oryza longistaminata

Echinochloa pyramidalis

Setaria pulmila

Scoparia dulcis

Ludwigia octovalis

Crotolaria retusa

Scirpus grossus

Mimosa pigra

Schizachyrium sanguinum

Mitragyna inermis

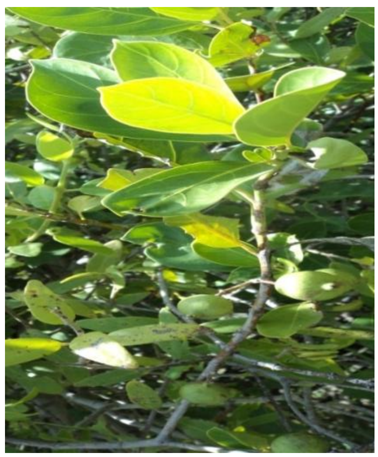
Sacciolepsis africana

Salacia reticulate

Vitex crysocarpa

Phyllanthus amarus

Paspalum scobiculatum



Syzygium guineense

Ziziphus abyssinica

Cyperus difformis

Deplachne fusca

APPENDIX C

DRY SEASON DATA 1

Fish composition, abundance and length-weight characteristics of fish species among six wetlands (November-February, 2010/2011)

1. ***Wuntori wetland in Yapei-Central Gonja District* (*Marsh permanent wetland*)**

Family/Species	*Common name*	*Abundance*	*% Abundance*	*length (mm)*		*Weight (g)*	
				Max	*Min*	*Max*	*Min*
Alestidae							
Alestes dentex	Characins	57	11.15	55	17.9	2567	244.6
Brycinus nurse	Characins	30	5.9	48	18.6	1560	246
Bagridae							
Bagrus bajad	Bagrids	24	4.7	40	29	1285	571
Cichlidae							
Oreochromis niloticus	Nile tilapia	82	16	19.9	15.5	320.7	145.5
Sarotherodon galilaeus	White tilapia	61	11.9	29.5	18	579.8	169.8
Clariidae							
Clarias gariepinus	Mudfish	53	10.4	38.5	20.8	278.5	149
Claroteidae							
Auchenoglanis occidentalis	Claroteids	41	8.0	22.9	18.4	365	177

Channidae							
Parachanna obscura	Snakehead	20	3.9	55	26.5	2841	1242
Cyprinidae							
Labeo coubie	African carp	32	6.3	29	16.2	487.6	169.1
Labeo senegalensis	African carp	27	5.3	26.8	15.5	349.3	162
Distichodontidae							
Distichodus engycephalus	Distichodonts	12	2.3	14.5	11	127.6	85.4
Mochokidae							
Synodontis clarias	Lizardfish	24	4.7	16.7	13	135.9	82
Synodontis membranaceus	Lizardfish	9	1.8	17	13.8	151.8	85.4
Synodontis eupterus	Lizardfish	26	5.1	28	12	357.9	75.3
Mormyridae							
Hyperopisus bebe	Elephant fishes	13	2.5	25	22	354	286.3
Total		**511**					

2. ***Kukobila wetland in Savelugu-Nanton District*** **(*Marsh permanent wetland*)**

Family/Species	*Common name*	*Abundance*	*% abundance*	*length (mm)*		*Weight (g)*	
				Max	*Min*	*Max*	*Min*
Alestidae							
Alestes beremoze	Silversides	64	15	36	19.4	915	258.6
Brycinus macrolepidotus	Characins	41	9.6	19.3	17.5	252.3	241.1
Hydrocynus brevis	Tigerfish	17	3.9	42	27.5	1450	762.6
Cichlidae							
Chromidotilapia guntheri	Cichlids	10	2.3	15.2	13.7	143.7	128.2
Oreochromis niloticus	Nile tilapia	75	17.6	23.9	9.9	364.4	79
Sarotherodon galilaeus	White tilapia	68	15.9	25	12.8	411.6	121.4
Tilapia dageti	Bream fish	19	4.5	16	14.2	158.3	139.6
Citharinidae							
Citharinus citharus	Moonfish	23	5.4	22	17.6	154.6	132.9
Clariidae							
Clarias gariepinus	Mudfish	15	3.5	24.3	19.4	166	151

Cyprinidae							
Labeo coubie	African carp	46	8.8	28	17.5	486.3	182.6
Labeo parvus	African carp	9	2.1	23.3	18	330.5	184.4
Mochokidae							
Synodontis schall	Squeaker Catfish	25	5.9	18.9	17.8	169.2	151.4
Osteoglossidae							
Heterotis niloticus	Bony tongue	14	3.3	66	38	2637	1425
Total		**426**					

3**. *Tugu wetland in Yendi District* (*Marsh permanent wetland*)**

Family/Species	*Common name*	*Abundance*	*% abundance*	*length (mm)*		*Weight (g)*	
				Max	*Min*	*Max*	*Min*
Alestidae							
Brycinus macrolepidotus	Characins	25	6.8	24.3	15.7	523	183.6
Brycinus nurse	Characins	34	9.3	26.4	14	756	169.4
Clariidae							
Clarias gariepinus	Mudfish	31	8.5	30	17.6	168	129.2
Claroteidae							
Auchenoglanis occidentalis	Claroteids	16	4.4	24.5	18.5	351.3	170
Cyprinidae							
Labeo senegalensis	African carp	45	12.3	23.6	16.9	341	181
Labeo coubie	African carp	10	2.7	30	17	501.2	182.3
Cichlidae							
Sarotherodon galilaeus	White tilapia	59	16.2	21.2	13.6	334.8	124.5
Oreochromis niloticus	Nile tilapia	41	11.2	25.5	13.1	418.6	119.5

Mormyridae							
Marcusernius senegalensis	Elephant nose fishes	47	12.9	19.5	12.2	291	126
Mormyrops rume	Elephant nose fishes	9	2.5	28	14.6	406.4	178.7
Petrocephalus bovei	Elephant nose fishes	7	1.9	8.4	6.3	2.9	2.3
Schilbeidae							
Schilbe intermedius	Butter fish	40	10.9	18.5	13	7	2.2
Total			**365**				

4**. *Nabogu wetland in Savelugu-Nanton District* (*Riparian permanent wetland*)**

Family/Species	*Common name*	*Abundance*	*% abundance*	*length (mm)*		*Weight (g)*	
				Max	*Min*	*Max*	*Min*
Alestidae							
Brycinus nurse	Characins	51	9.6	13.5	11	169.4	61.8
Alestes dentex	Characins	44	8.3	36	27.4	915.7	758.5
Bagridae							
Bagrus bajad	Bagrid	12	2.3	45.3	23.5	1782	815
Bagrus docmac	Bagrids	3	0.6	60	52.3	2733	2462

Cichlidae							
Sarotherodon galilaeus	White tilapia	74	13.9	12.7	11.5	119.9	113.8
Centropomidae							
Lates niloticus	Nile perch	16	3.0	19	14.8	195.4	156.2
Clariidae							
Clarias anguillaris	Mudfish	15	2.8	28	26.4	167.8	163
Heterobranchus bidorsalis	Mudfish	77	14.4	35	24.1	182.6	157.4
Citharinidae							
Citharinus citharus	Moonfish	5	0.9	17.9	15	135	119.7
Cyprinidae							
Labeo senegalensis	African carp	28	5.3	16.3	15.4	115.6	156.9
Labeo coubie	African carp	51	9.6	28	16.2	486.4	168.1
Distichodontidae							
Distichodus engycephalus	Distichodonts	13	2.4	17	15.9	128.7	108.6
Distichodus rostratus	Distichodonts	7	1.3	24.8	18.5	178.7	130.1
Mochokidae							
Synodontis schall	Squeaker catfish	43	8.1	16.5	12	136	78

Synodontis nigrita	Squeaker catfish	12	2.3	8	7.3	9.1	6.5
Polypteridae							
Polypterus endlicheri	Bichirs	24	4.5	50	33.5	536	375.2
Schilbeidae							
Schilbe intermedius	Butter fish	58	10.9	14.3	12.6	4.2	3
Total		**533**					

5**. *Adayili wetland in Savelugu-Nanton District* (*Riparian permanent wetland*)**

Family/Species	*Common name*	*Abundance*	*% abundance*	*length (mm)*		*Weight (g)*	
				Max	*Min*	*Max*	*Min*
Alestidae							
Alestes dentex	Characins	31	6.8	23	18.2	519.8	244.5
Brycinus macrolepidotus	Characins	26	5.7	35	16.1	913.5	187
Brycinus nurse	Characins	45	9.8	15.9	13.7	187.5	149.8
Hydrocynus forskali	Characins	4	0.9	55	38.4	2569	1217
Bagridae							
Bagrus bajad	Bagrids	11	2.4	36	29.5	1326	1024

Cichlidae							
Sarotherodon galilaeus	White tilapia	52	11.4	22.9	13.6	346.3	147.9
Oreochromis niloticus	Nile tilapia	39	8.5	25	13.2	412	142.2
Citharinidae							
Citharinus latus	Moonfish	5	1.1	19.5	17.1	154	132.3
Centropomidae							
Lates niloticus	Nile perch	12	2.6	17	15.7	173.5	148.6
Clariidae							
Clarias anguillaris	Mudfish	23	5.0	27	20.3	217.9	132.4
Claroteidae							
Chrysichthys auratus	Claroteids	6	1.3	17.3	15.1	87.5	61
Cyprinidae							
Labeo senegalensis	African carp	3	0.7	22.5	16.9	366.7	172
Malapteruridae							
Malapterurus electricus	Electric fish	6	1.3	41	38.7	1795	1436.4
Mochokidae							
H. membranaceous	Squeaker catfish	7	1.5	13	12.2	82.5	78.5

Synodontis clarias	Squeaker catfish	18	3.9	15.9	12.9	135	80
Synodontis eupterus	Squeaker catfish	9	1.9	14	12.8	121	79
Synodontis velifer	Squeaker catfish	26	5.7	15	13.7	132.7	83
Mormyridae							
M. senegalensis	Elephant nose fish	55	12.0	13	11.9	129	118.5
Mormyrus hasselquistii	Elephant nose fish	1	0.2	17.1	12	277	124.2
Mormyrus rume	Elephant nose fish	10	2.2	19.5	16.5	292	274.8
Petrocephalus bovei	Elephant nose fishes	13	2.8	8.1	5	3.3	1.2
Polypteridae							
P. senegalus senegalus	Bichirs	5	1.1	40	35	430. 4	374.7
Schilbeidae							
Schilbe mystus	Butter fish	17	3.7	12.9	10	3.6	2
Schilbe intermedius	Butter fish	33	7.2	16.1	11.5	6.5	2.4
Total			**457**				

6. ***Bunglung wetland in Savelugu-Nanton District*** **(*Constructed/man-made wetland*)**

Family/Species	*Common name*	*Abundance*	*% Abundance*	*length (mm)*		*Weight (g)*	
				Max	*Min*	*Max*	*Min*
Cichlidae							
Sarotherodon galilaeus	White tilapia	28	10.1	24	10	408	87.8
Oreochromis niloticus	Nile	60	21.7	20	18	248.6	182.9
Claroteidae							
Auchenoglanis occidentalis	Claroteids	41	14.9	36.1	24.3	183.2	127.6
Mochokidae							
Synodontis schall	Squeaker catfish	22	7.9	16.5	13	137	82.1
Synodontis velifer	Squeaker catfish	59	21.4	15.3	9.9	132.4	30
Malapteruridae							
Malapterurus electricus	Electric fish	2	0.7	28.6	27	1125	984.3
Mormyridae							
Marcusenius senegalensis	Elephant nose fishes	64	23.2	20.6	15.6	296	261.4
Total			**276**				

<u>WET SEASON DATA 1</u>

Fish composition, abundance and length-weight characteristics of fish species among six wetlands (June-Sept, 2010/2011)

1. ***Wuntori wetland in Yapei-Central Gonja District* (*Marsh permanent wetland*)**

Family/Species	*Common name*	*Abundance*	*% Abundance*	*length (mm)*		*Weight (g)*	
				Max	*Min*	*Max*	*Min*
Alestidae							
Alestes dentex	Characins	46	10.7	27.8	19	772	245
Macralestes occidentalis	Characins	32	7.4	27.3	18.2	769	236
Cichlidae							
Oreochromis niloticus	Nile tilapia	53	12.3	24	16.8	356	146
Tilapi zilli	bream fish	31	7.2	30	18	479.8	241
Clariidae							
Clarias anguillaris	Mudfish	21	4.9	70	24	821	154
Clarias laeviceps	Mudfish	19	4.4	28.6	20	223	136
Heterobranchus bidorsalis	Mudfish	15	3.5	59	26.2	586	183
Claroteidae							
Auchenoglanis occidentalis	Claroteids	23	5.3	28	19	545	187.4

Channidae							
Parachanna obscura	Snakehead	6	1.4	27.8	26.5	872	855.7
Centropomidae							
Lates niloticus	Nile perch	8	1.9	26.3	18	817	213
Cyprinidae							
Labeo parvus	African carp	15	3.5	25.4	16	347.6	169
Labeo senegalensis	African carp	31	7.2	27	19.4	352	185
Mochokidae							
H. membranaceus	Lizard fish	11	2.6	25	16	300	136
Synodontis clarias	Lizardfish	17	3.9	25.2	13	301	82
Synodontis nigrita	Lizardfish	13	3.0	18.6	14	168	86
Synodontis schall	Lizardfish	33	7.7	19	14	178	85
Mormyridae							
Mormyrus rume	Elephant fishes	25	5.8	22.9	19	294	290
Osteoglossidae							

Heterotis niloticus	Bony tongue	12	2.8	73	44	2767	2263
Polypteridae							
Polypterus endlicheri	Bichirs	7	1.6	40	27.3	432	237
Total			**430**				

2**.** ***Kukobila wetland in Savelugu-Nanton District*** **(*Marsh permanent wetland*)**

Family/Species	*Common name*	*Abundance*	*% Abundance*	*length (mm)*		*Weight (g)*	
				Max	*Min*	*Max*	*Min*
Alestidae							
Alestes berecmoze	Silversides	39	13	18	11.4	247	134.6
Macralestes occidentalis	Characins	51	16.9	14.3	8.5	162.3	41.1
Cichlidae							
Oreochromis niloticus	Nile tilapia	35	11.6	16.4	12.2	146	123.7
Sarotherodon galilaeus	White tilapia	28	9.3	12	11.8	120.6	112.4
Tilapia dageti	Bream fish	24	7.9	14	10.9	139	106.2
Clariidae							
Clarias anguillaris	Mudfish	16	5.3	27.5	19.8	466	253.1
Cyprinidae							
Raimas nigeriensis	African carp	12	3.9	38	18	574.3	192.8

Labeo senegalensis	African carp	22	7.3	19.7	11	218	121
Labeo coubie	African carp	30	9.9	24.3	13	254	130
Mochokidae							
Synodontis bastiani	Squeaker Catfish	5	1.7	12.9	5.5	69.2	15
Mormyridae							
Hyperopisus bebe	Elephant nose fish	18	5.9	23.8	15	348	263
Mormyrops deliciosus	Elephant nose fish	10	3.3	29	21	414	294
Schilbeidae							
Schilbe intermedius	Butter fish	23	7.6	15.2	11.3	5.5	2.4
Total			**301**				

3***. Tugu wetland in Yendi District* (*Marsh permanent wetland*)**

Family/Species	*Common name*	*Abundance*	*% Abundance*	*length (mm)*		*Weight (g)*	
				Max	*Min*	*Max*	*Min*
Alestidae							
Brycinus nurse	Characins	23	12.7	21	16	451	195.4
Clariidae							
Clarias gariepinus	Mudfish	32	17.7	25	17.6	289	149.8
Clarias anguillaris	Mudfish	13	7.2	25	17	461	245.6

Cyprinidae							
Labeo senegalensis	African carp	8	4.4	20	14	335	140.3
Cichlidae							
S. galilaeus	White tilapia	43	23.8	13	10	125	86
Tilapia dageti	Bream fish	25	13.8	14	11	120	95
Mormyridae							
M. senegalensis	Elephant nose fish	19	10.5	17	13	215	52
Mormyrops rume	Elephant nose fish	10	5.5	28	14.6	406.4	116.7
Schilbeidae							
Schilbe intermedius	Butter fish	8	4.4	16	11	6	1.2
Total			**181**				

4**. *Nabogu wetland in Savelugu-Nanton District* (*Riparian permanent wetland*)**

Family/Species	*Common name*	*Abundance*	*% Abundance*	*length (mm)*		*Weight (g)*	
				Max	*Min*	*Max*	*Min*
Alestidae							
Brycinus nurse	Characins	61	15.0	12	9	65	40
Brycinus macrolepidotus	Characins	24	5.9	11	9	62.6	36.1

Cichlidae							
Oreochromis niloticus	Nile tilapia	47	11.6	14.6	12	130	118
Tilapi zilli	bream fish	30	7.4	13	11	124	111
Clariidae							
*Clarias camerunensi*s	Mudfish	6	1.5	30	20.3	397	199
Claroteidae							
A. occidentalis *B.*	Claroteids	55	13.6	17.1	14.9	166	148
Cyprinidae							
Labeo senegalensis	African carp	14	10.1	16.3	14	185.6	154.2
Mochokidae							
Synodontis schall	Squeaker catfish	27	6.7	13	11	46.4	26.2
Synodontis nigrita	Squeaker catfish	12	2.9	8.8	8	17.3	15.8
Mormyridae							
M. senegalensis	Elephant nose fish	33	8.1	13	11.8	229.5	186.3
Mormyrus rume	Elephant nose fish	16	3.9	17	12.7	274	226.7
Petrocephalus bovei	Elephant nose fish	9	2.2	9	7.3	14.2	10.9

Schilbeidae							
Schilbe intermedius	Butter fish	38	9.3	11.3	8.6	5.3	4.1
Schilbe mystus	Butter fish	24	5.9	12	10	8	5
Total			**405**				

5. ***Adayili wetland in Savelugu-Nanton District*** **(*Riparian permanent wetland*)**

Family/Species	*Common name*	*Abundance*	*% Abundance*	*length (mm)*		*Weight (g)*	
				Max	*Min*	*Max*	*Min*
Alestidae							
Alestes dentex	Characins	62	15.9	40	18	829	244
Alestes beremoze	Characins	20	5.2	18.1	15	244	221
Brycinus nurse	Characins	31	7.9	11.6	8.4	142.8	85
Cichlidae							
Sarotherodon galilaeus	White tilapia	57	14.7	17	12	212	137.5
Oreochromis niloticus	Nile tilapia	28	7.2	17.1	13	214	143.2
Clariidae							
Clarias anguillaris	Mudfish	30	7.7	120	27.3	1979	189
Heterobranchus longifilis	Mudfish	7	1.8	40	24.8	457	278
Claroteidae							
A. occidentalis	Claroteids	19	4.9	32	17	583	165

Cyprinidae							
Labeo coubie	African carp	11	2.8	61	23.9	923.7	285
Labeo senegalensis	African carp	8	2.1	14.2	12	144.1	126
Mochokidae							
Synodontis nigrita	Squeaker catfish	11	2.8	14.7	11	97.1	71.3
Synodontis schall	Squeaker catfish	12	3.1	16	13	136	82
Synodontis membranaceous	Squeaker catfish	13	3.4	12.6	10	78.4	65
Synodontis clarias	Squeaker catfish	6	1.5	19.3	12.2	171	77
Synodontis bastiani	Squeaker catfish	7	1.8	13	9	81.9	57
Mormyridae							
Marcusenius senegalensis	Elephant nose fishes	25	6.4	15	13	125.1	65.9
Hippopomyrus paugyi	Elephant nose fishes	2	0.5	14.8	12.3	147.2	62.5
Mormyrops breviceps	Elephant nose fishes	4	1.0	19.4	13	186.4	66
Petrocephalus bovei	Elephant nose fishes	5	1.3	10	8.1	5	3.3
Schilbeidae							
Schilbe mystus	Butter fish	9	2.3	11.1	9	4	2
Schilbe intermedius	Butter fish	21	5.4	10	8	3.2	2
Total		**388**					

6. ***Bunglung wetland in Savelugu-Nanton District*** **(*Constructed/man-made wetland*)**

Family/Species	*Common name*	*Abundance*	*% Abundance*	*length (mm)*		*Weight (g)*	
				Max	*Min*	*Max*	*Min*
Alestidae							
Brycinus nurse	Characins	40	17.2	17.3	14	202.6	175.4
Cichlidae							
Tilapia	bream fish	32	13.7	15.4	12.5	165.1	125
S. galilaeus	White tilapia	26	11.2	23	14.7	400	148.3
O. niloticus	Nile tilapia	39	16.7	18.7	14	184.5	146.2
Claroteidae							
A. occidentalis	Claroteids	12	5.2	23.3	17.8	206.4	88
Clariidae							
H. longifilis	Mudfish	8	3.4	18.9	15	234.3	218
Cyprinidae							
Labeo senegalensis	African carp	16	6.9	23.2	18	251.5	226
Mochokidae							
Synodontis schall	Squeaker catfish	14	6.0	17.5	13	148	82
Synodontis velifer	Squeaker catfish	8	3.4	11.2	9	98.4	29

Synodontis clarias	Squeaker catfish	15	6.4	15.4	12.7	127	78.4
Mormyridae							
M. senegalensis	Elephant nose fishes	23	9.9	17	15	79	132
Total			**233**				

APPENDIX D

Northern Region Climate Dataset from 1960-2010

Maximum Temperature

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
1960	35.3	38.0	37.0	35.6	33.8	30.6	30.2	29.8	30.6	32.8	35.6	34.2
1961	35.7	36.7	38.0	34.9	33.5	30.9	29.4	29.6	30.3	33.6	36.0	35.5
1962	35.8	37.3	37.7	35.8	34.2	29.8	29.4	28.8	29.7	32.1	33.9	34.4
1963	36.0	37.3	36.9	34.5	33.1	31.8	30.4	29.8	30.5	31.7	33.9	35.1
1964	35.0	37.7	36.6	34.4	33.6	31.3	29.6	29.1	29.2	32.3	34.5	34.3
1965	35.1	37.2	38.0	35.7	32.3	30.1	30.6	29.6	29.9	32.6	35.3	34.7
1966	36.4	37.2	37.6	35.6	34.2	30.7	30.6	29.7	30.0	32.1	34.7	34.9
1967	35.0	37.5	36.3	34.0	33.2	30.6	29.9	29.0	29.7	32.5	35.3	34.5
1968	34.8	36.2	36.4	33.5	33.7	30.9	30.1	30.3	30.3	32.8	34.6	35.8
1969	36.4	38.5	38.3	35.1	34.4	33.3	31.1	29.3	30.4	32.5	33.8	36.1
1970	36.2	37.9	38.5	37.9	34.4	34.2	30.5	28.7	29.5	33.8	35.8	35.4
1971	35.7	36.8	36.5	34.9	33.1	31.2	29.7	29.5	30.0	32.7	35.4	34.6
1972	36.2	38.1	37.1	34.4	32.7	31.1	31.0	30.2	30.5	32.5	35.2	35.2
1973	36.4	38.8	38.3	37.5	35.4	31.9	30.7	8.6	30.1	33.8	36.3	36.3
1974	34.5	37.3	37.0	36.4	34.8	31.9	29.5	29.6	29.9	33.0	35.0	34.3
1975	34.4	37.1	37.5	34.5	33.3	31.3	29.4	30.2	30.3	32.6	35.6	35.6
1976	35.4	36.5	38.0	36.2	33.4	30.0	29.6	30.0	31.2	31.3	33.7	35.1
1977	36.1	37.6	38.2	37.4	33.8	31.4	30.8	29.4	30.2	32.5	35.4	34.0
1978	36.2	38.1	36.4	34.2	32.9	31.9	29.7	30.3	30.6	32.6	34.8	35.5
1979	36.3	38.3	38.3	37.2	33.6	30.6	29.9	30.3	30.6	32.7	35.3	34.6
1980	36.6	37.8	38.9	37.6	33.5	31.7	30.9	29.7	31.2	33.0	34.3	33.4
1981	35.6	38.4	38.0	36.7	33.5	32.5	29.9	29.7	31.1	34.8	35.8	36.8

1982	35.6	37.0	37.0	35.0	33.2	31.1	30.7	30.0	31.1	33.1	35.1	35.0
1983	33.2	38.5	39.8	38.1	34.2	32.6	30.8	30.9	31.2	35.1	36.6	36.7
1984	35.8	37.6	37.8	37.7	34.6	32.1	31.2	30.8	31.3	33.9	36.2	34.2
1985	36.2	36.7	38.0	36.2	34.1	32.0	29.5	29.7	30.7	34.1	36.3	35.1
1986	35.5	38.5	37.7	36.4	34.9	31.5	30.2	30.0	30.7	33.8	34.8	34.1
1987	36.6	38.7	37.9	38.8	35.9	32.1	30.9	30.6	31.6	33.6	36.9	35.4
1988	35.3	38.4	38.7	36.4	35.7	30.8	29.7	29.3	30.9	34.2	36.2	33.6
1989	34.2	36.5	37.4	37.4	36.0	31.1	29.9	29.6	30.9	33.0	36.7	35.2
1990	35.9	37.1	39.0	37.1	34.4	32.9	30.3	30.6	31.3	33.5	36.2	35.6
1991	36.2	38.6	37.7	35.8	32.1	32.1	30.3	30.1	32.1	33.7	35.8	34.9
1992	34.2	38.0	38.7	37.3	34.5	31.9	29.8	30.4	31.4	34.7	35.3	36.4
1993	34.7	38.0	37.8	38.2	34.8	33.0	30.2	30.2	30.9	34.5	36.7	35.1
1994	35.4	37.8	38.7	37.4	34.6	31.4	30.4	30.5	31.3	32.7	35.5	34.7
1995	34.9	37.4	38.6	37.5	34.9	32.3	31.1	29.8	31.4	33.1	35.6	35.7
1996	37.4	38.5	38.7	38.1	34.7	32.4	31.2	30.5	31.0	33.3	35.8	36.3
1997	36.8	36.9	38.2	35.5	32.8	31.2	30.1	31.2	32.1	33.8	36.2	36.4
1998	36.3	39.3	39.9	38.9	35.1	32.0	31.1	30.1	30.8	33.6	36.9	35.6
1999	36.6	37.1	39.5	36.5	35.3	33.0	30.6	29.8	30.4	32.0	36.3	35.6
2000	35.7	35.9	38.0	37.3	35.0	31.0	30.5	30.4	30.6	33.1	36.6	36.1
2001	36.5	37.5	39.3	36.4	34.1	32.5	30.7	29.8	30.8	35.2	37.2	37.4
2002	35.3	38.5	39.6	37.3	35.6	32.8	31.0	29.8	31.3	33.6	36.7	36.3
2003	36.9	39.2	39.0	35.3	34.5	30.6	30.8	30.4	31.6	34.2	36.4	36.1
2004	36.3	37.7	37.5	36.4	33.4	30.7	29.5	29.9	30.7	34.9	36.8	36.8
2005	34.8	38.7	38.3	36.4	34.4	32.0	30.3	30.2	31.4	33.6	36.7	34.4
2006	37.0	38.5	38.9	38.2	33.8	32.3	31.2	30.4	30.7	33.2	36.3	36.0
2007	34.9	38.7	39.5	36.2	33.6	32.6	31.8	29.7	30.8	33.2	35.9	35.9
2008	34.0	37.6	37.9	37.0	33.9	31.2	30.5	29.7	30.9	33.2	36.5	36.4
2009	35.5	38.7	38.6	35.7	34.9	32.8	30.3	30.0	31.4	32.9	35.4	36.9

2010	37.9	38.6	38.6	36.5	35.3	33.1	30.4	30.2	31.6	33.7	36.5	36.9

Minimum Temperature

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
1960	21.2	22.3	24.4	24.9	23.9	22.5	21.8	22.3	22.2	22.2	21	21.3
1961	20.4	22.1	24.3	24.6	23.6	22.4	22	21.7	21.5	21.7	21.4	19.2
1962	20.1	23	24.8	24.8	23.5	22	22.4	22	21.7	22	22.2	19.5
1963	20.4	23.9	24.2	23.9	23.4	22.6	22	22.4	22.5	22.2	20.3	18.7
1964	21	22.1	24.4	24.5	23.3	22.1	22	21.9	21.4	21.8	21.6	21.5
1965	21.2	23.4	24.7	24.5	22.9	21.9	22.5	22	22.1	22	20.7	18.5
1966	19.5	22.4	24.6	24.6	24.1	22.3	22.3	22.5	22	22	21.6	19.8
1967	19.5	23	24.5	24	23.3	22.2	22	21.7	21.7	22	20.9	21
1968	19.6	23.1	24.3	23.6	23.2	22.1	21.9	21.9	21.2	21.9	21.4	21.3
1969	19	24.1	25.6	24.7	24.3	23.5	22.5	22.4	21.6	22	20.3	19.8
1970	21	23.4	25.7	26	23.9	22.8	22.3	21.8	21.2	22.4	21.8	19.9
1971	19.1	23.1	24.6	24.1	23.5	22.2	21.9	21.9	21.3	21.9	20.9	20.6
1972	19.3	23.3	24.3	24.4	23.5	22.7	22.6	21.9	22.2	22	19.8	20.8
1973	21.5	23.7	25.4	25.6	24.5	22.9	22.9	22.1	21.8	22.5	20.3	19.8
1974	20.5	22.6	25.2	25.1	23.8	23	22	22.8	21.4	22.1	20	17.2
1975	17.6	22.4	24.5	24.3	24.1	22.7	22.2	22.3	21.9	22.1	21.1	19.3
1976	19.6	23.5	24.7	24.4	23.8	22.2	22.6	22.1	22.4	22.1	21.5	17.6
1977	20.4	21.7	25	26.4	24.4	23	23.1	22.4	22.2	22	19.1	17.6
1978	18.9	23.4	25.2	24.3	23.6	22.8	22.3	22.2	21.8	22.2	20.1	19.4
1979	20.8	21.1	25.6	26.1	24.1	22.7	22.3	23.1	21.9	22.4	22	16.6
1980	20.8	23.6	26.5	26.2	23.8	23.4	22.9	22.6	22.5	22.5	21.4	17.6
1981	16.5	23.8	25.6	25.5	24.2	22.8	22.6	22.5	22	22.8	20.1	17.5
1982	17.7	23.2	24.9	24.8	24.4	22.9	22.7	22.2	21.9	22	19.9	17.8
1983	17.5	23.3	24.8	26.6	25.2	23.2	21.8	22.4	22.7	22.9	21.3	17.6

1984	18.8	21.6	25.9	26.4	23.7	21.3	21.7	22.3	21.5	22	22.2	16.7
1985	19.7	21.6	26.1	25.6	24.3	23.5	22	22.2	21.7	22.6	21.7	16.5
1986	16.9	23.5	25.5	25.6	24.5	22.6	22.4	22.1	22.1	22.1	19.3	15.4
1987	19.8	23.8	25.3	27	25.6	23.6	23.5	23	23	22.6	21	18.6
1988	19.3	22.2	26.9	26	25.5	23.1	22.6	22.4	22.6	22.5	21.2	18.2
1989	16.9	21.5	24.3	26.1	24.8	22.4	23	22.7	22.1	22.3	21	18.2
1990	20.7	21.3	24.4	26.3	24.9	23.2	22.9	22.5	22.4	22.9	23.3	21.6
1991	19.6	23.9	25.9	25.1	23.7	23.9	22.9	22.5	22.6	22.1	20.9	18.2
1992	19.1	22.4	25.8	25.9	24.7	23	22.5	22.5	22.1	22.6	20.9	18.8
1993	18.3	22.8	24.9	26.4	25.2	23.6	22.5	22.8	22.1	22.8	23.6	19.4
1994	19.6	22.6	26.2	25.9	24.4	23.1	22.9	22.8	23	22.4	18.7	16.7
1995	16.5	20	25.6	26.2	24.8	23.9	23.4	22.9	22.8	23	21.1	21.2
1996	20.1	25	27.1	25.5	25.2	23.2	22.7	22.2	21.9	22.1	18.6	19.4
1997	21.1	21.5	24.9	25.1	23.7	23	22.5	23	22.9	23	22.1	19.8
1998	19.5	24.1	26	27.6	25.7	24.1	23.6	23.3	22.7	23.1	21.9	20.3
1999	20.2	22.2	26.7	25.6	25	23.6	22.8	23	22.2	22.3	22.7	18.6
2000	22.4	19.8	24.5	26.2	25.1	23	23.1	22.8	22.5	22.9	22.6	18.6
2001	18	20.8	26.2	26.1	25	23.9	23.4	23	22.5	23.4	22.9	20
2002	19.8	21.5	27.3	26.8	25.6	24	23.6	22.7	22.7	22.9	21.8	19.3
2003	19.5	24.3	25.8	25.6	24.9	23.3	23.2	23.1	22.9	23.6	22.3	19.8
2004	20.5	23.7	25.7	26	25.1	22.7	22.8	22.5	22	23	22.4	21.7
2005	19.6	25.4	26.7	26.4	24.9	23.9	23.1	23.1	22.9	22.6	21.6	20.1
2006	21.8	24.2	27.1	27.6	24.8	23.7	23.6	23.2	22.6	23	18.8	16.8
2007	18.4	23.3	25.9	25.9	24.8	24.1	23.8	23	22.5	22.9	23.5	20.2
2008	17.6	23	26.1	25.9	24.5	23.3	23.2	22.7	22.7	22.9	21.1	21
2009	19.1	25.5	27.1	25.3	24.7	23.9	22.7	22.9	22.6	23.1	21.8	19
2010	18.4	23.9	26.3	24.6	25.8	24.7	23.5	22.8	22.7	23.5	21.9	21.3

Climate dataset from 1960-2010 from Northern Region. Mean Monthly Rainfall

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
1960	0.3	1.3	34.1	129.9	136.1	126.3	243.6	189.1	312.1	100.4	0.0	8.2
1961	0.0	0.0	53.4	70.5	103.3	160.9	144.2	120.2	149.4	29.5	0.0	0.0
1962	0.0	7.4	26.7	62.1	86.0	256.7	115.1	218.9	221.3	58.0	90.8	8.9
1963	0.0	27.7	15.0	133.7	98.2	163.6	207.8	390.1	386.6	243.4	0.3	0.0
1964	0.0	0.0	139.7	36.8	139.3	161.3	108.0	84.2	340.4	35.9	4.3	4.4
1965	18.1	1.1	14.7	132.1	126.3	314.5	126.2	347.2	223.7	74.5	0.0	0.0
1966	0.0	0.0	62.1	89.5	99.4	128.2	103.2	229.7	146.4	139.6	0.5	0.0
1967	0.0	22.1	62.5	98.4	127.9	178.6	130.6	311.3	154.0	38.3	4.6	5.6
1968	0.0	32.8	121.2	133.6	95.3	228.6	246.2	229.8	296.8	82.6	0.0	0.0
1969	0.0	5.6	36.8	105.3	62.2	69.1	154.2	194.7	187.5	72.5	71.9	0.0
1970	27.7	0.0	10.4	3.1	49.5	67.6	124.8	296.6	225.8	19.2	13.5	0.0
1971	0.0	14.5	145.4	85.6	184.4	76.2	174.6	145.4	321.5	75.5	0.0	1.5
1972	0.0	0.0	80.8	82.0	165.6	109.4	171.6	186.2	184.3	85.0	0.0	0.0
1973	0.0	0.8	27.2	14.8	148.1	127.9	143.5	217.9	227.6	31.0	0.0	0.0
1974	0.0	0.0	80.9	13.0	78.8	127.0	210.1	201.7	254.2	90.9	0.0	0.0
1975	0.0	14.2	70.9	145.9	104.3	172.3	166.0	166.4	279.0	40.8	0.0	0.0
1976	0.0	19.8	0.0	89.9	149.6	148.7	109.1	140.8	111.3	207.0	31.8	0.0
1977	11.4	0.0	55.9	55.9	90.6	136.1	120.0	197.1	308.5	146.0	0.0	10.5
1978	0.0	11.4	73.7	181.1	105.4	74.9	146.6	171.2	147.4	88.7	0.0	17.5
1979	0.0	0.0	84.6	93.8	162.7	308.5	157.3	165.7	189.4	64.1	0.0	0.0
1980	6.5	0.0	0.3	95.9	99.1	89.9	141.2	281.2	221.4	100.8	12.8	23.9
1981	0.0	0.0	23.9	66.8	150.5	154.9	226.7	291.6	145.6	41.1	0.0	0.0
1982	0.0	10.7	67.6	239.8	134.8	147.8	78.8	107.9	327.0	46.4	20.6	0.0
1983	0.0	0.0	82.2	47.8	174.7	65.2	129.9	81.3	234.6	4.6	0.0	0.0
1984	0.0	0.0	27.4	66.5	74.0	194.7	165.7	166.6	183.2	23.8	24.0	0.0
1985	0.0	0.0	34.7	63.3	73.8	193.4	273.0	165.1	178.8	52.2	0.0	0.0
1986	0.0	0.0	43.2	80.0	149.8	172.6	168.1	131.8	178.5	126.0	32.3	0.0

1987	0.0	0.0	28.0	14.3	128.0	188.5	173.4	143.8	173.0	107.9	0.0	0.0
1988	0.0	0.0	43.5	88.1	72.7	183.5	329.3	213.1	139.3	23.5	27.4	0.0
1989	0.0	0.0	60.1	41.2	80.3	289.1	102.4	283.8	495.8	71.1	0.0	3.5
1990	0.0	91.2	0.0	45.9	130.0	67.6	97.9	228.6	311.0	55.7	8.9	33.0
1991	0.0	38.0	49.2	92.3	351.8	79.0	190.0	401.3	222.4	155.8	0.0	0.0
1992	0.0	0.0	35.0	44.4	68.4	141.9	116.7	45.2	186.1	34.7	22.9	0.0
1993	0.0	22.4	22.6	55.9	30.1	112.8	272.3	209.5	196.4	48.2	30.2	0.0
1994	0.0	0.0	73.1	43.3	201.6	148.8	191.6	143.7	200.4	156.0	0.0	0.0
1995	0.0	1.8	2.9	30.2	121.8	107.2	83.8	331.6	140.1	172.1	3.2	1.4
1996	0.0	22.5	7.0	111.5	101.5	220.0	86.1	224.5	226.7	139.6	0.0	11.3
1997	0.0	0.0	62.0	226.5	147.6	203.0	148.6	122.3	199.6	119.3	0.0	0.0
1998	0.0	3.1	0.0	34.2	144.6	86.0	123.6	96.6	242.7	187.3	2.7	16.2
1999	4.2	12.2	20.7	81.3	136.8	146.0	365.5	200.4	226.5	187.0	1.7	0.0
2000	60.0	0.0	38.5	46.0	147.4	238.3	54.1	119.1	256.2	64.3	0.0	0.0
2001	0.0	0.0	0.0	131.4	78.0	95.9	167.0	121.5	182.0	15.5	0.0	0.0
2002	0.0	0.0	2.0	92.5	122.6	122.3	104.5	266.6	79.8	131.3	0.9	0.0
2003	17.5	10.4	40.6	123.5	151.0	206.7	109.7	289.0	215.3	69.8	15.5	0.0
2004	14.5	0.8	34.1	67.2	133.2	147.0	209.3	264.8	149.1	33.9	48.1	0.0
2005	0.2	14.2	69.9	138.5	81.2	109.1	340.2	88.1	190.7	69.5	0.0	40.9
2006	0.0	22.9	19.1	58.5	138.0	87.9	156.1	211.2	151.2	124.3	1.5	0.0
2007	0.0	0.0	29.1	82.8	137.4	85.0	160.3	204.6	278.9	68.5	0.0	0.0
2008	0.0	0.0	30.5	94.5	176.9	140.8	148.8	334.6	245.0	82.8	1.8	0.0
2009	0.0	3.1	21.3	122.6	105.7	97.3	240.7	214.3	189.7	108.6	0.0	0.0
2010	0.0	58.8	26.8	0.0	10.3	162.9	108.2	287.2	234.5	98.7	0.0	0.0

Mean monthly Potential Evapotranspiration (MET) (mm)
Station 07006TLE Tamale

Year	Jan	Feb	March	April	May	June	July	Aug	Sept	Oct	Nov	Dec
1961	285.1	306.6	294.8	167.1	135.6	93.9	79.9	90.0	95.6	147.4	217.1	275.1
1962	289.7	288.0	259.9	194.6	158.1	111.4	78.2	73.1	43.8	117.0	151.9	234.0
1963	250.9	235.1	247.5	161.4	126.0	111.4	90.0	79.3	88.3	107.4	184.5	233.4
1964	266.1	297.6	212.1	168.2	142.9	107.4	90.0	85.5	82.1	128.3	152.5	198.6
1965	235.1	259.9	264.4	205.3	120.4	84.9	92.3	85.5	84.9	122.6	21.0	257.1
1966	276.9	284.5	233.7	172.7	144.8	96.5	96.5	81.3	83.8	114.3	165.1	238.8
1967	279.4	289.6	218.4	147.3	132.1	96.5	91.4	78.7	83.8	124.5	193.0	205.7
1968	264.2	228.6	208.3	142.2	139.7	96.5	86.4	88.9	91.4	129.5	170.2	213.4
1969	276.9	261.6	236.2	170.2	152.4	134.6	101.6	76.2	91.4	121.9	165.1	210.8
1970	241.3	289.6	238.8	226.1	160.0	154.9	96.5	73.7	83.8	147.3	200.7	248.9
1971	281.9	238.8	198.1	160.0	127.0	101.6	83.8	78.7	83.8	121.9	180.3	215.9
1972	284.5	261.6	236.2	160.0	119.4	99.1	96.5	88.9	88.9	121.9	213.4	246.4
1973	297.2	307.3	276.9	215.9	132.1	111.8	91.4	81.3	86.4	137.2	221.0	256.5
1974	261.6	297.2	213.4	193.0	160.0	114.3	83.8	86.4	88.9	129.5	205.7	256.5
1975	259.1	274.3	251.5	157.5	132.1	104.1	81.3	96.5	91.4	129.5	203.2	256.5
1976	272.2	263.8	284.6	213.8	139.5	88.3	84.9	92.8	104.1	101.3	167.6	253.1
1977	270.7	277.2	311.6	235.1	143.4	106.8	101.8	81.5	83.8	126.0	223.3	235.1
1978	288.5	279.0	207.5	154.1	127.1	117.0	91.6	95.6	96.2	123.7	208.1	239.0
1979	284.6	329.6	275.6	215.4	166.5	88.3	82.1	83.2	89.4	116.4	185.6	250.9
1980	255.9	335.8	235.7	217.7	138.9	108.5	131.0	81.5	95.6	112.5	173.2	220.5
1981	288.6	302.6	312.5	199.1	133.3	119.3	84.4	79.3	97.3	158.1	240.2	290.8
1982	284.6	273.9	245.3	166.9	127.7	96.8	94.5	88.3	96.2	131.1	212.1	253.7
1983	255.4	310.5	340.3	227.3	130.6	119.0	83.4	79.4	88.7	123.7	176.2	228.0
1984	261.3	282.1	277.7	212.4	157.1	127.6	101.8	75.3	95.6	132.3	169.8	234.7
1985	244.8	265.9	235.0	160.0	145.3	114.3	90.5	81.7	81.3	120.4	223.1	255.5

1986	257.8	304.6	258.4	211.7	104.6	119.8	88.3	94.5	83.9	127.0	186.0	247.6
1987	269.0	299.3	263.3	254.8	183.4	110.3	101.9	72.2	94.6	117.5	168.0	229.8
1988	272.8	321.2	259.9	192.9	175.5	90.0	81.0	74.8	91.7	152.4	221.1	231.2
1989	262.7	302.6	250.3	225.0	190.7	101.3	81.0	79.3	92.3	131.1	235.1	251.4
1990	270.0	291.9	331.9	208.1	147.9	127.7	88.3	88.9	96.8	141.2	190.7	218.3
1991	289.1	284.1	244.7	180.0	104.6	101.8	84.4	79.3	102.4	133.9	203.1	241.3
1992	260.4	322.9	297.0	219.4	159.8	114.8	83.8	99.0	105.2	155.8	218.8	282.4
1993	276.8	300.9	263.3	243.6	158.1	131.6	88.3	82.7	92.8	142.9	203.6	252.0
1994	278.4	309.4	276.8	218.8	153.6	101.3	86.1	88.9	91.1	112.5	214.3	264.9
1995	280.7	324.6	265.5	222.2	163.7	117.6	97.9	73.1	95.6	123.2	207.6	234.0
1996	268.9	290.8	273.9	243.6	155.8	105.8	95.1	82.7	91.1	131.6	189.0	258.8
1997	281.8	320.1	296.4	178.9	119.3	97.3	84.4	93.4	101.8	132.2	208.1	270.6
1998	291.9	325.1	347.6	243.6	155.8	105.8	95.1	82.7	88.9	127.1	226.1	239.6
1999	289.7	290.3	280.1	201.9	167.6	128.3	91.1	78.8	88.0	114.5	216.0	276.2
2000	240.8	225.0	291.4	211.5	163.7	93.9	90.6	89.4	87.2	126.0	213.2	284.6
2001	311.6	320.1	284.9	194.6	145.1	117.0	93.4	77.1	89.4	169.3	232.3	286.3
2002	284.6	327.4	279.6	213.2	170.4	122.1	92.3	74.8	93.9	132.8	225.0	272.3
2003	306.6	299.8	300.4	164.3	147.4	83.3	91.1	80.4	97.9	133.9	209.8	265.5
2004	289.1	295.9	226.1	189.6	127.7	91.7	74.3	75.9	88.3	156.4	236.3	236.3
2005	262.1	295.3	237.9	184.5	141.8	107.4	83.8	85.5	91.7	185.1	221.6	258.2
2006	279.6	294.8	261.0	227.8	132.8	110.8	90.6	83.8	86.1	118.1	228.9	262.1
2007	254.3	300.9	299.3	183.4	127.1	118.7	108.0	73.7	85.5	122.6	185.6	237.9
2008	247.5	288.0	245.3	208.1	140.6	96.8	86.1	75.4	88.3	124.9	229.5	252.0
2009	274.5	271.1	252.0	174.9	155.8	122.1	86.1	73.7	91.7	115.3	204.8	272.8

APPENDIX E

Sample of semi -structure of questionnaire administered among wetland users

Questionaire No:……………………

Name of community where wetland is located: ……………………

Name of community member/participant:…………………………..

Type of activity involved in:…………………………………………

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1. What are some of the benefits you derive from the wetland in your community?

a) Economic	b) Ecological	c) Cultural
1.	1.	1.
2.	2.	2.
3.	3.	3.

2. What human-led activities pose as a threat to the wetland in

your community?

3. Which of the threats that you have identified do you think is severe?
4. How will you rank them according to severity it poses on the wetland, using pebbles?

Identified threats	Level of threat
1.	
2.	
3.	

• = Less severe; •• = moderately severe; ••• = highly severe

5. In your opinion, what proposed conservation measures do you think it can be implemented in order to mitigate these identified threats?