SOCIO-ECONOMIC STATUS AND BIOASSESSMENT OF THE ECOLOGICAL INTEGRITY OF KING’WAL WETLAND, NANDI COUNTY, KENYA

BY

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DECLARATION

Declaration by the student

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Declaration by the supervisors

This thesis has been presented for examination with our approval as the University supervisors.

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DEDICATION

To my parents the late Jairo Wamalwa and the late Grace Were, for the love, education and training opportunities they offered me.

ABSTRACT

Wetlands play a vital role in maintaining ecological balance, providing valuable ecosystem services, and supporting socio-economic activities for local communities. However, wetlands worldwide, including the King'wal wetland under current study, are under threat from anthropogenic activities. Understanding the extent and implications of these changes forms the backdrop of this study. This study aimed to assess the impacts of anthropogenic activities on the King'wal wetland by assessing the water quality variation, macrophytes and macroinvertebrate assemblages, indices of monitoring ecological integrity and examining the socio-economic status, wetland utilization and management, of King'wal wetland. The research was conducted from January to December 2011, with data collected monthly from four sites each having three subsites. Dissolved oxygen (DO), conductivity and pH were measured in situ using a yellow spring instrument (YSI) multiprobe meter, and aliquots of 500ml each were collected in acid washed high density poly ethylene (HDPE) bottles at each site for laboratory analysis. Macroinvertebrate metrics for the Index of Biological Integrity and Human Disturbance Score (HDS) were also assessed. The plant species diversity was determined by conducting random belt transects across the area, while macroinvertebrates were collected using a semi-quantitative kick-net sampling method. There were significant differences in the biodiversity of wetland flora in the study area ($\chi 2 = 65.121$, df = 8, p = < 0.001). Significant spatial variations were observed in all physico-chemical water quality variables (pH, dissolved oxygen, conductivity, total nitrogen, and total phosphorus) ($p < 0.05$). Water pH was highest at Kingwal Bridge, followed by Kiptenden, and lowest at Kesses. The concentration of dissolved oxygen (DO) decreased downstream from Kesses (the upstream site) to Kimondi (the downstream site) (F = 7.9732, p = 0.0002). Conductivity (EC) was highest at Kingwal Bridge, while total nitrogen (TN) and total phosphorus (TP) were highest at Kesses, followed by the Kiptenden sampling site. Total Nitrogen (TN) in water was significantly different (F = 34.5343, P = < 0.001) between the sites and Total Phosphorus (TP) in water differed significantly (F = 11.2321, p = 0.0001) during the sampling periods. The study identified a low macrophyte diversity of approximately 20 species, with 10 species occurring across all sites. The macroinvertebrate species diversity index (Shannon) was higher (2.84) at Kesses, while Kiptenden recorded the lowest diversity (2.65). % oligochaetes /chironomids (OC) relative to the total macroinvertebrate; Kesses had the highest value (6.1%), followed by Kingwal (4.5%), and Kiptenden had the lowest (1.9%). Kruskall-wallis test revealed significant differences in the abundance of the macroinvertebrate assemblages among the sampling sites (H = 7.987, df = 3, p = 0.0193). The percentage of EPT (*Ephemeroptera, Plecoptera*, and *Trichoptera*) taxa, an indicator of stream health, was highest at Kesses and lowest at Kingwal Bridge. These abundances were significantly different across the study sites (H = 5.1322, df = 3, p = 0.002). The upstream Kesses site had the highest Index of Biological Integrity (IBI) score and the lowest Human Disturbance Index (HDI) score. The analysis revealed a significant negative relationship ($p < 0.05$) between the Macroinvertebrate Index of Biotic Integrity (M-IBI) and Human Disturbance Index (HDI, indicating that anthropogenic activities degraded water quality, macrophytes, and macroinvertebrates diversity among the sites. Socio-economic data was collected using a household survey. The findings revealed a ranking order of decreasing importance: grains (98.4%), vegetables (88.9%), papyrus (85.7%), grass (82.7%), water (77.8%), and fodder (77.8%). Social services provided by the wetland included water recharge (75.3%), cultural practices (54.6%), flood control (53.5%), and erosion protection (43.4%). The dominant plant species were *Aeschynomene abyssinica* (48.8%), *Carex pendula* (45.8%), *Cyperus papyrus* (44.5%), and *Lemna minor* (32.3. The most commonly reported animal species by the majority of respondents were sitatunga (*Tragelaphus spekei*) (80.2%), and cranes (65.3%). Management and conservation strategies, implemented in time, should be embraced.

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LIST OF ABREVIATIONS AND ACRONYMS

ANOVA	Analysis of variance
CPOM	Course particulate organic matter
DO	Dissolved Oxygen
EC	Electrical conductivity
EPT	Ephemeroptera, Plecoptera and Trichoptera
FAO	Food and Agriculture Organization
FFGs	Functional Feeding Groups
FPOM	Fine particulate organic matter
GoK	Government of Kenya
GPS	Global positioning system
HDI	Human Disturbance Index
IBI	Index of Biotic Integrity
KWS	Kenya Wildlife Service
LVEMP	Lake Victoria Environmental Management Project
NACOSTI	National Council of Science Technology and Innovation
NMK	National Museums of Kenya
NWCM	National Wetlands Conservation and Management
NWSC	National Wetlands Standing Committee
SD	Standard deviation
TN	Total nitrogen
TP	Total phosphorous
USEPA	United States Environmental Protection Agency
YSI	Yellow Spring Instruments

OPERATIONAL DEFINITION OF TERMS

Benthic macroinvertebrates: Water-inhabiting creatures that lack backbones; are large enough to be seen with the naked eye (larger than 0.05 mm) and spend at least part of their life cycle in or on aquatic ecosystem bottoms.

Biomonitoring: Evaluation of the condition of a waterbody, using biological surveys and other direct measures of the resident biota in surface waters.

Indicators: Any measurement, directly measured or inferred, used to point out changes or status of something such as water quality.

Indices: A numerical score usually derived from a series of indicators used to rate quality. A higher index score, such as in the evaluation of water quality, generally denotes higher quality.

Net primary production: is the amount of Carbon incorporated by a plant or an area of vegetation over a given period of time.

Plant biomass: The total dry weight of living plant material contained above and below a unit of surface area at a given point in time

Primary production: is the production of organic matter from atmospheric or aquatic carbon dioxide, principally through the process of photosynthesis, with chemosynthesis being much less important.

Production: Is the weight or biomass of organic matter assimilated by an organism or community over a given period of time.

Richness: The total number of different taxa of aquatic organisms such as fish or benthic macroinvertebrates in a water sample.

Taxa:	A group of organisms such as macroinvertebrates, which is used to represent the diversity within a sample. Taxa are used as a key metric in some biotic condition indices, for example, the Index of Biotic Integrity.
Trophic (group):	A stratum in the hierarchy of the food web.
Wetland:	**A**reas of marsh, fen, peat land or water, whether natural or artificial, permanent or temporary, with water that is static or flowing, fresh, brackish or salt, including areas of marine water the depth of which at low tide does not exceed six meters

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CHAPTER ONE

INTRODUCTION

1.1 Background

Wetlands are defined as "areas of marsh, fen, peat land or water, whether natural or artificial, permanent or temporary, with water that is static or flowing, fresh, brackish or salt, including areas of marine water the depth of which at low tide does not exceed six meters" (Ramsar convention, 1971). According to USEPA (2004), wetlands are described as areas inundated or saturated by surface or ground water at a frequency and duration sufficient to support, aquatic vegetation and where depth of water does not exceed six meters. A summary of these definition indicate that wetlands comprise both land ecosystems that are strongly influenced by water, and aquatic ecosystems with special characteristics due to shallowness and proximity to land (Roggeri, 2016). In Kenya, wetlands are defined as "Areas of land that are permanently or occasionally waterlogged with fresh, saline, brackish or marine waters at a depth not exceeding six meters, including both natural and man-made areas that support characteristic biota" (National Wetland Standing Committee [NWSC], 1995). Swamps, marshes, bogs, oxbow lakes, river meanders, and floodplains, as well as riverbanks, lakeshores, and seashores where wetland plants flourish, are all included in this definition. It also includes marine and intertidal wetlands such as deltas, estuaries, mud flats, mangroves, salt marshes, sea grass beds and shallow reefs.

Wetlands are estimated to cover about 6% - 9% of the Earth's surface (Lehner and Doll, 2004; Dudgeon *et al.*, 2006; Barbier, 2010; Dugan, 2011; Schuijt, 2012; Duveiller *et al.*, 2018; Jensen *et al.*, 2018). The total area calculated by the Africa dataset amounted to some 121,322,000 - 124,686,000 ha covering 4% of the land surface, with more than 85% of these being inland wetlands (Stevenson and Frazier, 2016). Some of the largest wetlands are located in Central, Southern Africa, and Sudan including; The Okavango Delta of Botswana, Sudd Wetland in Sudan, wetlands of Zaire and the Kafue/Bangweulu floodplains of Zambia (Mfundisi, 2005; McCartney, 2010).

In Kenya, wetlands cover approximately 14,000 km^2 or (4.6%) of the surface area of the country (RoK, 2013). Kenya is home to several iconic wetlands. Examples include Lake Victoria Wetlands, which is the largest freshwater lake in Africa, and its wetlands are crucial for the livelihoods of local communities, providing resources like fish and papyrus. It's also an important habitat for various species of birds and fish. Lake Nakuru wetland located in the Great Rift Valley; Lake Nakuru is renowned for its huge flocks of flamingos that give the lake a pink hue when viewed from a distance. It's a critical habitat for numerous bird species and has been declared a Ramsar site due to its international significance. Tana River Delta is one of the largest and most significant wetland systems in Kenya, hosting a rich variety of bird and fish species. It's an essential water source for local communities and supports agriculture, fishing, and livestock rearing. Another Ramsar site, Lake Bogoria is a saline, alkaline lake famous for its geysers and hot springs, as well as its large flamingo population. And finally, Lake Naivasha wetland which is a freshwater lake is a critical bird habitat, hosting over 400 bird species. It's also an important source of flowers for the international flower market.

Nandi County has some of the largest wetlands in Kenya, including the King’wal Wetland. Previous reports indicate a coverage of 100,000 km^2 in 1960 but due to destruction of the wetlands for human settlement and agricultural purposes, it has shrunk to less than 5,000 km^2 by the year 2000 and by 2010, the area covered by wetlands was 1,400 km^2, of the land surface (GoK, 2013). It is worth noting that the specific wetland studied in this research is located in Nandi. Wetlands play a crucial role in providing ecosystem services that contribute to the achievement of several Sustainable Development Goals (SDGs). They are among the most productive in the world and are critical for supporting human livelihoods in Africa (Chapman *et al*., 1986; Rebelo *et al*., 2009; Wondie, 2018). They provide several goods and services which includes; provisioning ecosystem services which include products obtained from the wetland such as food, agricultural production, fisheries, and water. Regulating services such as air quality regulation, climate regulation, water purification, disease regulation, pest regulation, pollination, and natural hazard regulation (Mitsch *et al.,* 2015; Wondie, 2018). Supporting services which include basic ecosystem processes such as nutrient cycling and primary productivity (Hammer and Bastian, 2020) and serve as habitats for diverse species (Cooper *et al*., 2006; Xu *et al*., 2019). Cultural services such as recreation, ecotourism, aesthetics, formal and informal education, and cultural heritage (Mitsch *et al.,* 2015; Wondie, 2018). In some communities, selected wetland sites are used to perform cultural and spiritual rituals such as circumcision and prayers (Terer *et al.*, 2004). Additionally, wetlands have been recognized as important carbon sinks, playing a significant role in ameliorating climate change by sequestering and storing carbon (IPCC, 2019). Being areas of continued inundation, they reduce the severity of droughts and also play important role in flood regulation by regulating stream flow and can provide vital water resources to support agricultural production (McCartney and Houghton-Carr, 2009; Loucks and Beeks, 2017). Wetlands serve ecological functions such as groundwater recharge and discharge (Burt *et al*., 2002; Neff *et al*., 2020), nutrient retention (Janse *et al*., 2019), sediment/toxicant retention (Cole and Brooks, 2000;

Thorslund *et al.,* 2017), micro-climate stabilization (Bullock and Acreman, 2003; Kelvin *et al*., 2017) and flood control (Costanza *et al*., 2005; Acreman, 2011; Evenson *et al*., 2018).

In eutrophic waterbodies, wetlands are significantly responsible for nutrient reuse and removal (Zedler and Kercher, 2005, Daniels and Cumming 2008; Kamilya *et al.,* 2022). In Kenya, wetlands do serve a range of diverse ecological and socio-economic functions (Gichuki, 2003; Kairu, 2001; Jones and Muthuri, 2005; Abila, 2005; Mironga, 2005a; Abila *et al*., 2008; Mulei *et al.*, 2015; Nyandika, 2019). The presence of unique animals and plants such as water birds, reptiles, amphibians, and fish make them popular tourist attractions (Jones and Muthuri, 2005; Oduor *et al.,* 2015; Makopondo *et al.,* 2020). King'wal wetland in the catchments of the Yala River is popular as a habitat for the rare Sitatunga (*Tragelaphus spekei*), crested cranes (*Balearica regulorum*) and wetland forest of *Syzygium* species (Raburu, 2005). Increased cultivation in King'wal wetland has resulted into destruction of natural wetland flora and fauna for example the rare Sitatunga, crane birds and *Syzygium* trees; degradation of vulnerable soil organic matter which is stored under waterlogged conditions; reduction of the water holding and filtration functions and hence reduction of available drinking water among others (Ashley *et al*., 2004; Kirui, 2010; Momanyi and Ariya, 2015).

Most wetlands in Kenya face growing anthropogenic pressure and are mostly affected by overexploitation, changes in water quality, eutrophication, organic loading, invasive species, and hydrographic changes in aquatic systems (Kansiime *et al*., 2003; Kansiime *et al*., 2007; Farber and Costanza, 2007; Jones *et al.,* 2018). Continued increase in human activities and expansion of settlements (Eliśka *et al*., 2008; Korir and Mulongo, 2010; Mulei, 2018) may further modify the habitat quality of the wetlands thereby affecting the wetland’s ecosystem integrity. Changes in water quality due to addition of nutrients such as nitrogen and phosphorus from the catchment are some of the major contributors to deterioration of the integrity of the wetlands that are contributed by anthropogenic activities (Cole *et al*., 2010; Jones *et al.,* 2018).

Limiting human access to wetlands in order to minimize these destructive activities is one of the most popular strategies of managing designated wetlands. Unfortunately, this is difficult to implement for wetlands that are found on community-owned land. It is also unrealistic to limit a poor community from utilizing a wetland that provides to them with food (agricultural produce and fish) and income (from brick making, art craft) without giving them an alternative means of livelihood. Therefore, environmental pressures in the wetlands will likely continue, hence there is need to develop a criterion for monitoring ecological integrity of these wetlands which can be used to support wise use principle advocated by the Ramsar Convention. Comprehensive knowledge is required at all times to ensure that any water quality and quantity changes, biodiversity alteration and threats to the wetlands are discerned early enough to avert any serious ecological damages to these fragile valuable ecosystems.

Monitoring the ecological integrity of most aquatic ecosystems is usually performed using physical, chemical and biological means (Forio and Goethals, 2020). Recent advances in the monitoring of aquatic ecosystems have shifted from measurement of physico-chemical parameters to the use of biological indicators as early warning signals of ecosystem degradation (McCallie, 2000; MCain and Douglas, 2010). The biological method of monitoring provides more long-term approach than the physico-chemical means. The use of biological monitoring including aquatic organisms in the wetlands has received considerable attention (Mangadze *et al.,* 2019). The use of aquatic macroinvertebrate assemblages for example, provide a comprehensive measure of water chemistry and physical stream conditions (Wrona, 2010) determining the overall health of the system (O'Brien *et al*., 2016).

The index of biotic integrity (IBI) framework uses biota to provide scientifically defensible evidence of environmental condition (Adamus, 1996; Hlass *et al*., 1998; Gernes and Helgen, 2002; King and Richardson, 2008). In turn, IBIs can be used to develop biological criteria for aquatic environmental protection (Simon and Lyons, 2008; Raburu, 2003; Masese *et al*., 2009). Several quantifiable attributes of the biotic assemblage (termed ''metrics'') that assess macroinvertebrate assemblage structure, composition, and function comprise the IBI (Klemm *et al*., 2003). IBI has witnessed wide adoption and application with acceptable results (Ganasan and Hughes, 1998; Simon and Sanders, 1999; Lyons *et al*., 1999; Kesminas and Virbickas, 2000; Lyons, 2000; Kuehne *et al.,* 2017).

In Kenya, IBI has been developed to monitor water quality status of riverine ecosystems including Rivers Sosiani and Kipkaren in Nzoia Basin (Aura, 2010), River Nyando (Raburu *et al*., 2009), rivers in the upper catchment of Lake Victoria Basin (Raburu *et al*., 2009), Moiben River (Masese *et al*., 2009) as well as River Tana (Aura *et al*., 2016). However, there is still paucity of information on the development of IBI in monitoring wetlands in Kenya, with few studies available for Nyando wetlands (Orwa *et al*., 2013) hence this study.

1.2 Statement of the problem

Nandi County has many wetlands including King’wal wetland which has unique habitats for several flora and fauna, some of which are endangered species, (like sitatunga and the crested cranes). Due to rapid population growth, there have been considerable expansion of human settlements in recent years, which have not spared the riparian ecotones as well as the other types of wetlands (Momanyi and Ariya, 2015). Intensification of human activities in these wetlands will continue to threaten the species of flora and fauna in these unique habitats. The utilization of wetland plants and animals without proper management regimen poses a risk to the ecological and functional integrity of the wetland manifested through effects on the organisms. Management of Wetland ecosystems like the King’wal wetland requires adequate data to base management decisions. Inadequacy of such data has continued to hamper the formulation of policies on sustainable utilization and management of wetlands. Secondly, occurrence of unregulated human activities in wetland ecotones continues to pose threats like habitat degradation, which may potentially affect the biotic assemblage and the overall ecological integrity of the wetland. More data on utilization and management of wetlands in Kenya will enable the government to formulate better policies on their protection (Anthonj *et al.*, 2019).

In addition, there is lack of early warning mechanisms to warn if the wetlands are being degraded. Degradation of wetlands can be observed through the changes in the quality of water and biotic assemblage that impacts the overall ecological integrity of the wetlands. Monitoring of these ecosystems is required to provide early warning signals of continued human interference with the ecosystem functioning and integrity.

Aquatic macroinvertebrates have gained prominence as bioindicators of environmental quality in lotic systems (Adams *et al*., 2006; Kennedy *et al*., 2009; Raburu *et al.,* 2009; Masese *et al.,* 2014; Lubanga *et al.,* 2021; Sitati *et al.,* 2021; Yegon *et al.,* 2021). However, there are very minimal studies and published work on monitoring of riverine or palustrine wetlands (i.e., Orwa *et al.,* 2013) using macroinvertebrates. Similarly, there are no protocols for monitoring riverine / palustrine wetland ecosystems in the country.

1.3 Justification of the study

Wetland policies ought to focus on factors that undermine wetland integrity (Magut, 2014; Chepkwony, 2019). Wetland conversion and over exploitation of wetland resources is the main threat to wetlands in Nandi County. Wetland destruction is undertaken at the household levels because of lack of understanding of basic ecology and biodiversity.

Information on wetland biotic assemblage is important for understanding the wetland biodiversity, which is useful in educating the local community on the need for wetland conservation and management. Quantitative inventory of biodiversity is significant in identification of species, their uses, habitats and conservation value of candidate sites. Therefore, to promote effective conservation and optimize the benefits from the wetland, ecological and taxonomic studies are required to provide adequate information about wetland components and processes.

Assessing anthropogenic disturbances on aquatic ecosystems relies mostly on monitoring metrics of aquatic communities and water physico-chemistry (Barbour *et al.,* 1999). Assessment of water quality is important as to help understand the impacts of anthropogenic activities on the wetland biota. Aquatic biota responds to changes in water quality with the sensitive taxa reducing along the degradation/pollution gradient while the tolerant taxa being able to survive and increase along the degradation gradient. So as to incorporate the integrative capacity to inform about the effects of pollutants on biodiversity and the ecological integrity of aquatic resources, benthic macroinvertebrates were used. Biological monitoring using organisms such as macroinvertebrates is reliable, effective and economical (both in terms of money and time).

There is paucity of studies utilizing macroinvertebrates on riverine / palustrine wetlands with most studies that utilize macroinvertebrate IBIs focusing on streams and rivers. This study is important as it developed M-IBI for monitoring riverine / palustrine wetlands that may be undergoing human encroachment in Kenya as is the case with King'wal wetland. The findings of this study are important for the comprehension of systems of King'wal wetland and can be used to determine the extent to which the wetland has been impacted by human activities. These findings can also be used to monitor changes in wetland trends.

1.4 Objectives of the study

1.4.1 Broad objective

To assess the socio-economic status, resource utilization and the ecological integrity of King'wal wetland in Nandi County, Kenya.

1.4.2 Specific objectives

i. To evaluate the spatio-temporal variations in water physico-chemical variables and nutrient levels in King'wal Wetland.

ii. To assess the changes in species distribution and diversity of wetland macrophytes in King'wal Wetland over time.

iii. To Investigate the use of macroinvertebrate assemblages as indicators of the ecological integrity of King'wal Wetland.

iv. To determine the socio-economic status and utilization regimes of wetland resources in King'wal Wetland by the local community members.

1.5 Hypotheses

To realize the aforementioned objectives, the following null hypotheses were formulated:

Ho1: There are no significant spatial variations in the water physico-chemical variables (pH, dissolved oxygen, biological oxygen demand, and electrical conductivity) and nutrients (total phosphorous and total nitrogen) in King’wal wetland.

Ho2: There is no significant change in the species distribution and diversity of wetland macrophyte species in King’wal Wetland

Ho3: Changes in macroinvertebrate assemblages are rather diverse to be used as indicators of the ecological integrity of King’wal Wetland.

Ho4: The wetland resources are not properly utilized and managed by the local community riparian to King’wal Wetland.

1.6 Research Questions

Based on the objectives stated, the study seeks to answer the following research questions:

1. What are the spatial-temporal variations in water physico-chemical variables and nutrient levels in King'wal Wetland?
2. How has the species distribution and diversity of wetland macrophytes in King'wal Wetland changed over time?

3. Can macroinvertebrate assemblages be utilized as effective indicators of the ecological integrity of King'wal Wetland?
4. What is the socio-economic status of local community members within King'wal Wetland, and how are they utilizing the wetland's resources?

1.7 Delimitation of the Study

This study was confined to the King'wal wetland located in Nandi County, Kenya. The research was focus on assessing the spatio-temporal variations in water physico-chemical variables, species distribution and diversity of macrophytes, the potential use of macroinvertebrates as ecological integrity indicators, and socio-economic aspects pertaining to the use of wetland resources by the local community. The study period was limited to one year to understand temporal variations, although it's acknowledged that longer-term trends may not be fully captured within this period.

1.8 Limitations of the Study

The limitations of this study may include potential inaccuracies in the collection and analysis of water physico-chemical variables and nutrient levels due to technical limitations or environmental conditions during sampling. Seasonal fluctuations could affect the representativeness of macrophyte and macroinvertebrate diversity and distribution data. The socio-economic analysis is based on the willingness and ability of local community members to participate in the survey, which could introduce potential bias. Moreover, the study's findings might not be fully applicable to other wetland ecosystems due to variations in ecological, climatic, and socio-economic factors. Finally, the limitation of the study to one year might not capture the full complexity of long-term trends and changes in the wetland ecosystem.

CHAPTER TWO

LITERATURE REVIEW

2.1 Wetland, types of wetlands, occurrence and distribution

According to the Ramsar Convention, wetlands are defined as “areas of marsh, fen, peat land or water, whether natural or artificial, permanent or temporary, with water that is static or flowing, fresh, brackish or salt, including areas of marine water the depth of which at low tide does not exceed six meters” (Ramsar convention, 1971; De Klemm and Créteaux, 1995). Wetlands, in the simplest terms, are areas of land where water covers the soil or is present either at or near the surface of the soil all year or for varying periods of time during the year (Mitsch & Gosselink, 2007). The interface between terrestrial and aquatic ecosystems, they are uniquely characterized by specific hydrology, soils, and vegetation which collectively result in very productive ecosystems. Wetlands serve a myriad of important ecological functions such as water purification, water storage, processing of carbon and other nutrients, shoreline stabilization, and provision of habitats for a plethora of plants and animals (Barbier et al., 1997).

Wetlands are diverse and can vary widely due to differences in soils, topography, climate, water chemistry, vegetation, and many other factors. This diversity has resulted in a broad range of wetland types, including marshes, swamps, bogs, fens, and wet meadows in terrestrial environments, and estuaries, mangroves, and coral reefs in coastal zones (Mitsch & Gosselink, 2007). Inland wetlands are typically freshwater environments and are often seasonally or perennially inundated. Coastal wetlands, on the other hand, often experience a mix of fresh and saltwater conditions and are influenced by tidal fluctuations (Keddy, 2010). The global distribution and occurrence of wetlands are influenced by several factors such as precipitation, topography, and temperature. They occur on every continent, in every climate from the tropics to the tundra, and at every altitude from sea level to high mountains (Mitsch & Gosselink, 2007). However, their distribution is not even. For instance, approximately one-third of the global wetland area is found in Asia, followed by South America and Africa (Davidson, 2014). In terms of occurrence, the Northern Hemisphere contains 61% of all wetlands, with Russia hosting the largest area. Similarly, wetlands can be found in a variety of geological and ecological contexts, from river deltas and low-lying coastal areas to inland regions and mountainous terrains.

In Kenya, wetlands are significant and widely distributed, covering approximately 3-4% of the country's land surface (Kenya Wetlands Atlas, 2012). They can be found in various parts of the country, including the coastal region, the Lake Victoria basin, the Rift Valley, and the central highlands. The Kenyan wetlands, such as the King'wal wetland in Nandi County, not only support a rich biodiversity but also play crucial roles in the hydrological cycle, climate regulation, and provision of livelihoods for local communities (Kipkemboi et al., 2002). Despite their undeniable importance, wetlands in Kenya and worldwide are under threat due to anthropogenic activities, which underscores the need for sustainable management and conservation efforts (Dixon & Wood, 2003).

In conclusion, wetlands are unique and vital ecosystems that sustain a remarkable biodiversity and offer numerous ecosystem services. They exist in diverse forms and are widely distributed across the globe, albeit unevenly. Given their ecological importance and the increasing threats they face, a deep understanding of wetlands is essential to inform their effective management and conservation.

2.2 Spatial and Temporal Variation of Water physico-chemical variables in wetlands

Physico-chemical characteristics refer to the status of water quality variables such dissolved oxygen (DO), electrical conductivity (EC), temperature, pH, salinity, and nutrients (Effendi, 2016) whereas water quality refers to particular water's physical, chemical and biological characteristics for intended use (Bouwer, 2000). The physical and chemical characteristics of aquatic environments are controlled and influenced by a number of processes both natural and anthropogenic that operate at both spatial and temporal scales (Wang *et al.,* 2014).

Natural factors such as rainfall patterns, erosion, evaporation and sedimentation due to flooding activities as well as biological components of aquatic vegetation greatly influence the physical and chemical composition of aquatic systems (Barbour *et al*., 2007; Rebelo et al., 2009). Whereas anthropogenic factors such as human pressure, habitat fragmentation, removal of vegetation cover, and landuse/landcover conversion for agricultural purposes, particularly in riparian areas, have resulted in physical habitat degradation (Neff *et al*., 2020). Increased sedimentation rates and hydrological changes all emanating from the anthropogenic activities have resulted in reduced water quality (Ferreira *et al.*, 2012).

Changes in physico-chemical characteristics of wetlands can alter the whole ecosystem affecting all dependent floral and faunal species as well as human settlement around the swamps (Ajibola, 2012). Landscape-level processes such as riparian land-use or cover patterns, prevailing climate, channel slope and aspect, quaternary and bedrock geology, and hydrography (Shen *et al*., 2011), have been shown to provide the framework within which other processes operate on small spatial scales and shorter temporal scales to regulate supply, quality and availability (Barakat *et al.,* 2016).

Water quality in wetlands is considered impaired when physico-chemical variables change to a point where they negatively affect several or all resident organisms (Orwa *et al*., 2013; Garg *et al.*, 2022). It is significant to determine the levels at which the resident biota is negatively affected to have a proper planning and management strategy. Major physical factors that affect the physical environment in wetlands include temperature, pH, dissolved oxygen (DO), electrical conductivity (EC) and water depth (Chambers *et al*., 2007). Among these factors, variations in temperature, pH, DO, usually have the most pro-founding effects on the living aquatic resources (Masese *et al*., 2009; Garg *et al.,* 2022).

Temperature directly influences the rate of photosynthesis and biological functions of life through their effects in physiological functioning of the biota (Alvarez, 2001; Blumenfeld *et al*., 2009; Bover and Waters, 2009; Kahlon *et al.,* 2018). Temperature has a direct impact on the oxygen concentration in water, aquatic plant metabolic rates, and aquatic organism sensitivity to toxic stress (Ashley *et al*., 2004; Cavicchioli *et al.,* 2019). Dissolved oxygen (DO) refers to the amount of oxygen dissolved in a water system (Garcia *et al*., 2019). It is considered to be a critical parameter of water quality indicating the health of an aquatic system because aquatic organisms depend on the availability of dissolved oxygen for their survival (Barbour *et al*., 2007). The amount of dissolved oxygen in water is an important factor in determining the diversity and abundance of organisms that can live in that body of water (Kimirei *et al*., 2005). Temperature and salinity, which are regulated by climatic and geological dynamics, have an impact on dissolved oxygen levels (Espinosa-Díaz *et al*., 2021).

In aquatic ecosystems, DO levels can be affected by photosynthesis and respiration (Alvarez *et al*., 2001; Vachon *et al*., 2020) where DO increases rapidly during the day from photosynthesis of benthic algae, phytoplankton and aquatic vegetation in the presence of sunlight, and decreases after nightfall or on cloudy days when oxygen production ceases (Bouma-Gregson *et al*., 2017; Freeman *et al*., 2018). Oxygen consumption on the other hand continues through the day and night (Burns and Schallenburg, 2001; Kalff, 2002; Manya *et al*., 2006; Smith and Able, 2003).

From the foregoing, decomposition of organic matter, unlike photosynthesis, takes place both during the day and night therefore influencing the DO concentration levels (Manya *et al*. 2006; Stagg *et al*., 2018; Yarwood, 2018). The rate of consumption of DO, or the demand for oxygen, is governed by chemical and biological factors in the water column and bed sediments (Terry *et al*., 2017; Stagg *et al*., 2018). Research findings have shown that the rate of decomposition of biological matter is also temperature dependent varying with seasons with the daily mean DO concentrations being significantly higher in the cooler months than in the warm months (Burns and Schallenburg, 2001; Masese *et al*., 2014).

DO processes in wetlands, especially marshes and shallow open water wetlands have been found to be different from other aquatic ecosystems (Barakat *et al*., 2016). Such wetlands often exhibit low minimum DO concentrations, wide diel ranges, and experience DO depletion on a diel basis (Wang *et al*., 2014). Differences among wetland types and habitats must be considered when determining appropriate DO conditions within a wetland. While wetlands vary in terms of their DO dynamics, increased nutrient loads can cause similar trends in DO regardless of habitat type and background DO ranges (Reddy and DeLaune, 2008).

A pH value between 7.0 and 8.0 is usually considered optimal for supporting a diverse aquatic ecosystem (Masibayi, 2011; Blum *et al*., 2018). Water's pH influences the solubility and biological availability of chemical elements such as nutrients like nitrogen, phosphorus, and carbon, as well as heavy metals like cadmium, lead, and copper (Gaudet, 1979; Chambers *et al*., 2007; Moradet *et al*., 2013). Studies have indicated that metals are more toxic at lower pH, because at such pH they are more soluble (Wang *et al*., 2016). Small variations in pH levels may not have a big effect on aquatic life, but such changes may affect the availability and solubility of all chemical forms and make nutrient problems worse (McCartney, 2010). Surprisingly, when human activities in the aquatic environment increase, fundamental pH alterations are difficult to predict (Chambers *et al*., 2007; Cloern *et al*., 2016).

Electrical conductivity (EC) can be defined as a measure of the number of dissolved ions in water. The conductivity of a water body increases with increasing dissolved ion concentration. Higher EC indicates that the water is salty which is not favorable for most flora and fauna because they cannot tolerate such conditions (Carr & Rickwood, 2008). Inorganic dissolved particles such as nitrate, sulphate, and salt, as well as temperature, influence water electrical conductivity. Generally, fresh waters with more salts are more productive except where there are limiting nutrients or limiting environmental factors involved (Kalff and Knoechel, 2002; McCartney, 2010). Generally, most conductivity in freshwater range from 10 to 1000 μS/cm (WHO, 2011).

Most tropical environments exhibit seasonality, which is typically associated with presence or absence of rainfall (Kalff and Knoechel, 2002). In this sense, the tropical ecosystems represent a variant of fundamental type, that is, there is a strong tendency towards seasonality as the main agents of change (Lewis, 2006). Water moving into a wetland runs flows on rocks and soil and sometimes overflows on human settlements of its catchment area, dissolving out chemicals including salts on the way (Safary, 2016). The salts dissolve in the water to form ions (Weirich *et al*., 2005) some of which are positively charged (cations) such as Na^{+}, Ca^{2+} and Mg^{2+} or negatively charged (anions) such as $CO3^{-}$, SO^{2-} and $NO3^{-}$ Wetlands that receive water that has flowed over or through carbonate-rich rocks and soil have a high mineral composition, depending on the rock composition or the composition of the effluent discharged in the water (Rypel *et al*., 2009; Wang *et al*., 2016). Mineral nutrients are an important chemical factor in wetland ecosystems (McCartney, 2010; Wang *et al*., 2016). The most important nutrients are those that are often short in supply and limit growth of plants (Safary, 2016).

Both nitrogen and phosphorus are necessary for life processes in aquatic ecosystem. Although nitrogen is abundant, phosphorous is often in short supply, limiting plant growth (Reynolds, 2008). Kalff and Snoechel (2002) suggested that although nitrogen was usually abundant in temperate regions, it could be a limiting nutrient in a number of tropical ecosystems. Bioassays and limnological studies in a number of tropical wetlands show that nitrogen, phosphorus, or both limit primary production (McCartney, 2010). As noted by Mwakubo *et al*. (2008), the availability of these two elements within an ecosystem depends not only on allochthonous sources of nutrients but also from autochthonous biological processes within the system.

Leghari *et al*. (2016) reported that the principal forms of nitrogen for plant growth are nitrate, ammonia, urea and nitrite. Nitrate is the most oxidized form of nitrogen and is typically, the most abundant and important form of combined inorganic nitrogen in environments (Hemalatha, 2015). Higher concentration of nitrate occurs in oxic water than other forms since it is transported in a highly soluble form (US EPA, 2008; Blum *et al*., 2018). However, in areas of dense vegetation such in the wetlands, other factors also control autotrophic production but the influence of nitrogen must be known to evaluate the role of the production materials (Blum *et al*., 2018).

Aquatic ecosystems are exposed to phosphorus from upstream runoff and other land-based sources (Philipart, *et al.,* 2000; US EPA, 2008; Wurtsbaugh *et al*., 2019). Phosphorous from agricultural lands is mainly transported as phosphates adsorbed on the soil particles (Leghari *et al*., 2016). Phosphorus entering into the aquatic ecosystems supports the growth of algae and other aquatic plants although they can only absorb phosphorus as dissolved inorganic phosphates ($PO4^{-}$), despite the diverse nature of many phosphorus compounds (Philipart, *et al.,* 2000; Wieczorek *et al*., 2022).

Due to its shortage in drainage basins, phosphorous is the least abundant nutrient as compared to the rich natural supply of other key nutritional and structural components of the biota (Joanna, 2004; Wieczorek *et al*., 2022). Therefore, phosphorus availability appears to be the limiting factor that regulates the rate of growth of plants and thus the production of plant communities (Odum, 2008). Because of its importance in biological metabolism, Philipart *et al*. (2000) concluded that phosphorus is more likely than any other nutrient to limit primary production in aquatic ecosystems.

Despite their utility, the quality of water in wetlands is rapidly deteriorating on a daily basis mainly caused by human pressure exerted on them such as deforestation and utilization of catchment and riparian areas for agricultural activities, brick making and urbanization (Leemhuis *et al*., 2017; Mulei, 2018). Yet, such deterioration in the Kingwal wetland has not been documented. Therefore, this study was set to look at the physical, chemical and biological variables dependent on the water quality and how the variability in water quality in turn influences macrophyte and macroinvertebrate assemblages in the Kingwal wetland.

2.3 Distribution and diversity of wetland macrophyte species

Macrophytes are aquatic plants, growing in water and are usually emergent, submergent or floating (Achieng, 2011; Ali *et al*., 2020). They include macro-algae, mosses and liverworts (bryophytes), fern (Pteridophytes) and Tracheophytes (Sosiak, 2002). The life forms of macrophytes which include emergent, floating-leafed and submerged together with zonation and community patterns of these aquatic plants are also useful in describing the plants structures as well as the form and condition of the environment (Sosiak, 2002).

Macrophytes play a critical role in the functioning of aquatic ecosystems (Ciecierska *et al*., 2010). The spatial distribution of macrophytes, is influenced by the length of hydro-period, environmental factors, such as maximum depth, surface area, dissolved oxygen and nitrogen concentration in the water (Capon, 2003; Joanna, 2004; Valentina *et al*., 2008; Ali *et al*., 2020).

Macrophyte provide habitat for aquatic insects, help to maintain water quality, and prevent sediment re-suspension (Gidudu *et al*., 2011; Thomaz, 2021). Macrophytes are sensitive to anthropogenic influences and respond to disturbances in the ecosystems which negatively impacts their diversity and composition (Allan, 2004; Prusevich *et al*., 2010; Thomaz, 2021). The characteristics of macrophytes within a given wetland are therefore determined by a variety of abiotic and biotic factors

(Szoszkiewicz *et al*., 2006; Germ and Gaberscik, 2021). Macrophytes have been used effectively to distinguish environmental stressors like hydrologic alterations, excessive siltation, nutrient enrichment and overall human disturbance (Ghavzan *et al*., 2006; Alahuhta *et al*., 2011; Dubey and Dutta, 2020). They have for a long time been used as bioindicators of aquatic health. For example, Charophytes have since 1930 been used as indicators of good ecological state of water (Pelechaty *et al*., 2004) and eelgrass is regarded as a useful indicator of water quality since water clarity influences its distribution within a specific habitat (Krause-Jensen *et al*., 2005).

The extent of environmental perturbation on the macrophytes is determined by species composition, biomass, distribution in the water and surface area covered (Zedler and Kercher, 2004, 2005; Fennessy *et al*., 2015; Zhang *et al*., 2022). They are used as phyto-indicators of water condition (Hellsten, 2000, 2001; Hellsten *et al*., 2002; Dubey and Dutta, 2020) due to their relatively high levels of species richness, rapid growth rates and direct response to environmental changes (Dubey and Dutta, 2020; Zhang *et al*., 2022). Several studies have been conducted to investigate the impacts of environmental changes on macrophyte communities in wetland ecosystems (Lacoul and Freedman, 2006; Fu *et al*., 2014; Kipkorir, 2015; Wanjohi, 2019). According to the studies, the physical and chemical properties of the water and sediments influence the composition of the macrophyte community, which in turn influences the health of the ecosystems (Lee and McNaughton, 2004; Lacoul and Freedman, 2006; Henry-Silva *et al*., 2008; Fu *et al*., 2014). Other studies have identified herbivory by invertebrates, primary and secondary succession, and competitive interactions among plants as major biological factors influencing the composition and distribution of aquatic macrophytes in wetlands (Gidudu *et al*., 2011; Dar *et al*., 2014; Bakker *et al*., 2016; Albertoni *et al*., 2020). According to Mackay *et al* (2003), macrophytes are affected by biotic factors, namely the properties of species, interspecific competition, grazing, and allelopathy.

Human activities also have direct and indirect impacts on macrophytes. Studies have highlighted human factors as having fundamental influence over the floral composition in the environments (Allen *et al*., 2005; Abila *et al*., 2008; Zelnik *et al*., 2020). In many wetlands, human activities have been found to fundamentally alter the structure of the eukaryotic and prokaryotic community. The anthropogenic impacts however, depend on the type of activity, its frequency and intensity, and the resistance of the ecosystem to a single load (Zelnik *et al*., 2020). Intensive agricultural activities lead to physical modifications of aquatic habitats, such as stream channelization, which eventually modifies the key environmental conditions for biotic communities.

Many human-related alterations to the environment that act to degrade aquatic ecosystems cause a shift in plant community composition as environmental conditions vary. Plant communities have been shown to change in response to hydrologic alterations (Zedler and Kercher, 2005; Zelnik *et al*., 2020), nutrient enrichment (Johnson and Rejmankova, 2005; Dubey and Dutta, 2020), sediment loading and turbidity (Verhoeren *et al*., 2006; Vukov *et al*., 2018), metals and other pollutants (Vukov *et al*., 2018). The effect of nutrient loading on species composition (both plants & animals) and the resultant structure and function of wetlands has been largely ignored when considering their ability to absorb nutrients (Verhoeren *et al*., 2006; Dubey and Dutta, 2020). Failure to understand interactions between nutrient loading and change in species composition may lead to underestimating the impacts of these stresses.

Studies on the wetland vegetation community structure and the role of environmental change are a fundamental step towards redefining these ecosystems. Each wetland has its own unique species community structure that is subjected to changes (Ashley *et al*., 2002; Ssegawa *et al*., 2004; Roshith *et al*., 2018). Despite the fact that great diversity in plant species composition has been seen in various types of wetlands (Ruppel *et al*., 2002; Monique-Arguenes, 2005; Grytnes *et al*., 2006; Anguilla-Manjarez *et al*., 2008; Rainbow *et al*., 2009; Janousek, 2009), many African wetlands are characterized by tropical species *Phragmites*, *Typha,* and many species of *Cyperus* (Keddy and Fraser, 2000; Owino and Ryan, 2007; Kipasika *et al*., 2016). The abundance of these species may be influenced by nutrient availability (Ciecierska and Kolada, 2013; Zhang *et al*., 2022). According to Willby *et al.* (2009), macrophytes are used to improve water quality of rivers and other water bodies by suppressing the re-suspension of bottom sediments.

Wetland vegetation also provide critical habitat structure for other taxonomic groups such as epiphytes, bacteria, phytoplankton and some species of algae, periphyton, macroinvertebrates, amphibians and fishes. It also help in maintaining aquatic biodiversity (Takeda *et al*., 2003; Kayima *et al*., 2018). Dubey and Dutta (2020) observed that agriculture, fire and grazing by livestock in the wetland's lower species diversity in homogenous environments compared to heterogeneous environments. Habitat influence by man such as in clearing land for cultivation or construction; or draining wetlands, change the habitat and cause local extinction of some species which reduces species diversity (Allen *et al*., 2005; Kayima *et al*., 2018).

The structure of plant species within a plant community reflects the diversity in the physical, chemical and human environment (Sundt-Hansen *et al*., 2006; Whittacker, 2006; Moss, 2008; Zhang *et al*., 2022) so does the change in the community structure.

Their relationship between floral composition and water quality characteristics have been used by various researchers to describe the nature and extent of species structural changes due to predictive factors (Irina *et al*., 2001; Fung-Yee *et al*., 2005; Fennessy *et al*., 2015). The use of a multivariate approach in describing the links between environmental conditions and species community structure in most wetland ecosystems is one way that has yet to garner considerable attention (Fung-Yee *et al*., 2005). Nevertheless, for the available studies, there are strong relationships between environmental quality and vegetation composition and abundance with strong coupling effects being in those areas that are prone to anthropogenic disturbances in the catchment (Fung-Yee *et al*., 2005).

Although a number of authors have highlighted the environmental change as the major driving factor in regulating plant species composition in wetlands (Tekeuchi, 2005; Abila *et al*., 2008; Stumm *et al*., 2009; Kipkorir, 2015), the role of each environmental factor is unique in retrospect (Alvarez, 2001; Whittacker, 2006). There is a large pool of literature that argues or models the influence of water quality in the environment and brings out generalized conclusions (Hrinvak, 2005; Reynolds, 2008; Calderon *et al*., 2019). Such generalizations yield limited information as far as vegetation in wetland areas is concerned. Many of the commonly studied terrestrial environments are hampered by a complex set of conditions that limit the biologically available nutrients to the vegetation (Zhang *et al*., 2022). For all the environments, abiotic factors provide the force that drives the temporal and spatial variability in species abundance and changes even before the competition principle is considered (Ludwig and Reynolds, 1988; Hrinvak, 2005; Reynolds, 2008; Calderon *et al*., 2019) thus validating protocols for determining the species changes in such ecosystems.

Adaptations to changing environment with phases of fluctuating events can subject the community to dominance by the most competitive species. Van Mooy *et al* (2006) established that diversity is changed by the environmental disturbance to a point where dominance by a few, long-lived, large sized species reverses the trend. The temporal scale is strictly connected with the spatial scale and the study of seasonal variability in the abundance of higher plants cannot be correctly interpreted without good description of the environmental variables (Štrojsovă *et al*., 2003; Harris, 2004; Dai *et al*., 2017).

Geremew and Triest (2019) stressed the importance of studying the fundamental periodicity of vegetation community structure relative to the prevailing environment. However, the vegetation community structure in wetlands of Kenya has not been well studied. One anthropogenic activity that controls plant species in Kenyan wetlands is the selective removal of species. Plant products are harvested for wood fuel, vegetables, roots and construction materials that fundamentally shift the energy flow in the environment and thus cause changes in the plant species structure (Dai *et al*., 2017).

A wetland where the riparian community greatly depends on its macrophytes for livelihood, as is the case at Kingwal wetland, is likely to be of poor ecological integrity (Harris, 2004; Dai *et al*., 2017). The situation is worsened when the use is extractive (harvesting of the wetland macrophytes) since the buffering capacity is reduced. In Nandi County, a study by Chepkwony (2019) indicated that unregulated harvesting of wetland vegetation for fuelwood, thatching materials and vegetables is common. Such activities fundamentally shift the energy flow in the environment and thus cause changes in the plant species structure. However, the exact nature of vegetation change as a result of such harvesting in the wetland is not well known. The study of variation in macrophytes community attributes at different disturbance gradients is therefore essential for biomonitoring (Hrivnak, 2005), thus necessitated this study.

2.4 Benthic Macroinvertebrate Assemblages and IBI of Wetland Ecosystems

2.4.1 Community structure

Assessment of water quality conditions using physical and chemical criteria provide useful information about the environmental setting of aquatic environment but fail to evaluate the biological health or integrity of stream ecosystems (O'Brien *et al*., 2016). By sampling the various forms of life found in water, one can obtain a direct measure of the ecological suitability of aquatic habitats (Wrona, 2010; O'Brien *et al*., 2016). The biota assemblage present in a wetland can be used to indicate the health of the habitat (Lung'ayia *et al*., 2000; Lemly and King, 2002).

Assessment of water quality and overall degradation of aquatic ecosystems has relied for long on the measurement of physico-chemical parameters, which is an expensive method and also lacks the integrative capacity to inform about the effects of pollutants on biodiversity and the ecological integrity of aquatic resources. The fundamental benefit of using a biological approach (such as macroinvertebrates) is that it examines organisms that are constantly exposed to pollution. As a result, species found in riverine ecosystems reflect both the current and previous history of the system's water quality, enabling for the detection of perturbations that would otherwise go unnoticed (Taylor *et al*., 2005; O'Brien *et al*., 2016).

Several studies within the region have indicated that land use change from natural forests to conversions for agricultural activities and urbanization as the main nonpoint sources of pollution, affecting diversity and abundance of macroinvertebrate assemblages due to fertilizers, waste discharge, urban runoff and pesticides loading to the watercourses (Raburu, 2003; Masese *et al.*, 2014; Lubanga *et al.*, 2021; Sitati *et al.*, 2021; Yegon *et al.*, 2021). However, there are few studies that document long-term trends on the effect in biota in relation to increased nutrient loadings in wetlands in Kenya. It is likely that any such effects will impact on other biota such as macroinvertebrates that rely on aquatic plants for habitat (Orwa *et al.*, 2013).

The benthos is defined as a lower ecological region in a body of water. For wetlands, this includes the bottom sediment layer as well as the habitat underneath the surface of the sediment layer (Smith and Voshell, 2007). Many heavy metals and organic contaminants, such as mercury, can bind to benthic organic matter, a major food source for invertebrates, exposing the fauna to potentially toxic and inhibiting effects (Sarkar *et al.*, 2002; Creed *et al.*, 2018; Sonone *et al.*, 2020). Most aquatic macroinvertebrates are benthic because they reside in the benthic habitat for at least part of their life and are relatively immobile for part or most of their life cycle (Morse *et al.*, 2007).

Benthic macroinvertebrates play an important role in the environment because of their crucial link in the food chain, in which they are a source of nourishment for other organisms (Wright and Smock, 2011; Masese *et al.*, 2014; Orwa *et al.*, 2015). Most benthic invertebrates have short life cycles, respond rapidly to alterations in habitat (Rankin, 2005), are relatively sedentary, adapt to, and are easily affected by environmental stress (Johnson *et al.*, 2005; Poff *et al.* 2007; Orwa *et al.*, 2015). In terms of their functional importance, benthic macroinvertebrates aid in the breakdown of course particulate organic matter (CPOM), fine particulate organic matter (FPOM), microbes, diatoms, macrophytes, and other invertebrates, as well as constitute a major food source for other invertebrates, fishes, and waterfowl (Vannote *et al*., 1980, Pavluk *et al*., 2000; Masese *et al*., 2014; Sitati *et al*., 2021).

Since several benthic invertebrate taxa respond to ecosystem changes, estimates of diversity and abundance of those known to respond to certain factors are commonly used as indicators of habitat quality in comparing assemblages or sites (Morse *et al*., 2007; Lubanga *et al*., 2021; Yegon *et al*., 2021). The benthic macroinvertebrate assemblages are most widely used in the bio-assessment of aquatic environments because they are diverse, exhibit a range of pollutant level tolerance and are abundant in most of the streams and wetlands (Harlow, 2003; Masese and Raburu, 2017).

Macroinvertebrate species composition is a function of responses to the trophic state (Aspin *et al*., 2020) for example, tubificid oligochaetes increase in number with organic enrichment (Fiero *et al*., 2021). The number of species appears to be inversely related to the amount of available nutrients. It is not clear whether this relation is positive or negative, although some studies have shown that slight eutrophication seems to favour increased diversity (Orwa *et al*., 2015). Excess nutrients, on the other hand, result in increased primary production and, as a result, oxygen depletion, which has a negative impact on diversity (Alexander *et al*., 2017). A study by Raburu (2003), reported that nutrient enrichment is the main factor affecting water quality and macroinvertebrate diversity in wetlands.

The response of benthic fauna to environmental changes within aquatic systems renders the benthic macroinvertebrates to effectively distinguish environmental stressors like hydrologic alterations, excessive siltation, nutrient enrichment and human disturbance (Brosse *et al*., 2003; Camargo, 2003; Beche *et al*., 2006; Boulton *et al*., 2007; Alahuhta *et al*., 2014; Gichana *et al*., 2015). The degree of their influence on ecosystem depends on species composition, biomass, distribution in the water and surface covered (Carter *et al*., 2006).

Benthic macroinvertebrate communities have also been reported to change in response to hydrologic alterations, sediment loading and turbidity, metals and other pollutants (Collier, 2008) and thus ideal bioindicators of water condition (Quadroni et al., 2017). However, the main reason why macroinvertebrates act as bioindicators stems from their relatively high levels of species richness, slow growth rates and direct response to environmental changes (Charvet *et al*., 2000; Helms *et al*., 2009).

It is well documented that structure of benthic macroinvertebrates community reflects the diversity in the physical, chemical and human environment so does the change in the community structure (Masese *et al*., 2014; Lubanga *et al*., 2021; Sitati *et al*., 2021; Yegon *et al*., 2021). However, when the water is stressed especially in presence of a pollutant, the deviations from the normal benthic macroinvertebrate attributes may be extreme (Masese *et al*., 2009; Buss *et al*., 2012; Sitati *et al*., 2021).

2.4.2 Biomonitoring using macroinvertebrates

Monitoring designs using macroinvertebrate indicators use indices protocols that detect changes in the macroinvertebrate attributes and not the actual counts of the macroinvertebrates. The simplest form of the index was the absence/presence index which is used as a biological indicator of presence or absence of any disturbances and stressors (Alexander and Allan, 2007; Alexander *et al*., 2010). Other useful metrics include measures of taxonomic richness, taxonomic composition, and dominance by tolerant and sensitive taxa. Tolerance values for specific taxa have been developed by ranking the ability of a taxon to survive during exposure to stresses resulting from pollution, habitat degradation, or modifications in hydrology (Nguyen *et al*., 2014).

Benthic macroinvertebrate biological indices generally include the following orders: Plathelminthes, Polychaeta, Oligochaeta, Hirudinea, Aryhnchobdellida, Mollusca, Hydracarina, Crustacea, Diptera, Megaloptera, Lepidoptera, Coleoptera, Hemiptera, Odonata, Ephemeroptera, Trichoptera and Plecoptera (Gabriels *et al*., 2010). Each order has evidenced certain sensitivities which are used to evaluate the water quality in wetland streams. For instance, Oligochaeta, Diptera (*Chironomidae* family*)* and Crustacea orders are preferred as indicators of level of oxygen saturation and trophic status (Goethals, 2005; Rossaro *et al*., 2007). Oligochaeta and Diptera orders are not good indicators of presence of harmful substances (De Haas *et al*., 2002; De Hass, 2004), while Crustacea order has proved its sensitivity to heavy metals such as lead and arsenic (Goethals, 2005).

Ephemeroptera, Plecoptera and Trichoptera orders are commonly called EPT taxa (Barbour *et al.*, 1999; Damásio *et al*., 2008; Canobbio *et al*., 2009; Munné and Prat, 2009; Cheimonopoulou *et al*., 2011; Masese and Raburu, 2017), and are considered sensitive to pollution, thus higher diversity and abundance is directly related to good water quality (Mandaville, 2002; Masese and Raburu, 2017). The causal factors that are known to influence macroinvertebrate assemblages change seasonally. For example, flow regime, water physico-chemistry, leaf-litter fall, and habitat quality all change seasonally (Rossaro *et al*., 2007). The scales at which macroinvertebrates exhibit the greatest variation are those over which important physical and chemical gradients (e.g., discharge and temperature) or biotic interactions (e.g., predation and competition) occur (Li *et al*., 2001; Wilcox *et al.*, 2002; Cai *et al.*, 2017). Studies have shown that variation of causal factors over both space and time determines assemblage composition (Rossaro *et al*., 2007).

The EPT index has thus been used to directly assess the cumulative effects of all activities in the watershed of a lotic water system (Friberg *et al*., 2010; Masese and Raburu, 2017). Non-insects, especially aquatic worms, and midges and other true fly larvae are less sensitive to pollution thus high relative abundances of these taxa are indicators of poor water quality (Barbour *et al*. 1999; Wang and Lyons, 2003; Zhang *et al*., 2010; Villeneuve *et al*., 2015; Lubanga et al., 2021). The human-related alterations to the environment that act to degrade river ecosystems cause a shift in benthic macroinvertebrates community composition as environmental conditions vary (Chatzinikolaou *et al*., 2006; Bernatowicz *et al*., 2009; Gichana *et al*., 2015). Macroinvertebrate composition, diversity and abundance in the environment and their relationships with various environmental and human activities have also been reported for several waterbodies to describe the nature and extent of species structural changes due to predictive factors (Harlow, 2003; Kibichii *et al*., 2007; Arimoro and Ikomi, 2008; Collier, 2008; Helms *et al*., 2009; Munné *et al*., 2012; Gichana *et al*., 2015; Lubanga *et al.*, 2021). Many of these studies demonstrated strong relationships between environmental quality and macroinvertebrates composition and abundance with strong coupling effects relationships between macroinvertebrate community structure and land use, both present and historic, at a variety of spatial scales from riparian zones to entire watersheds.

2.4.2.1 Index of biotic integrity (IBI)

There are a variety of composite invertebrate community indices that combine numerous metrics of community structure, allowing measurements of multiple facets of communities into a single value (Townsend *et al.*, 2003; Simpson and Norris, 2012; Nguyen *et al*., 2014). The multi-metric approaches use several metrics such as the structural, functional and compositional metrics of biota assemblages into a single index (Chen *et al.,* 2019). Studies on the riverine benthic macroinvertebrate's community structures and the role of human induced changes are fundamental step towards redefining these ecosystems. The multi-metric approaches also use the multivariate approach which is a measure of mathematical relationship among samples for two or more variables (Lu *et al.,* 2019). Conceptually, this technique is good because it is dependent on sample size, ecologically sound, easy to understand, interpret and apply by aquatic water managers (Barbour *et al*., 2010). Though the multivariate approach has higher precision than the micrometric approach, it is more difficult method to understand, interpret and apply by aquatic resource managers and hence, it is less preferred.

Biotic integrity can be defined as the capability of a system to support and maintain a balanced, integrated and adaptive community of organisms having species composition, diversity and functional organization comparable to that of a natural habitat of the region (Andreasen *et al*., 2001). Index of Biotic Integrity (IBI) relates to the use of characteristics of the communities, populations, and individual organisms to determine the biological integrity based on accurate measures of the relative abundance (Lyons *et al*., 2000; Wilcox *et al*., 2002; Lunde and Resh, 2012). An IBI is a broad-based ecological index that is sensitive to various sources of perturbation and degradation and produces reproducible results. This indicates that the use of IBI is a reliable approach in assessment of ecological integrity of ecosystems (Aura *et al*., 2010, 2016). The macroinvertebrate trend in this study was subjected to a final M- IBI to show the strength of nutrient enrichment to macroinvertebrate metrics. An effective IBI should be relevant, simple and easily understood by laymen, scientifically justifiable, quantitative and acceptable in terms of cost. The variables to be used may include the tolerant and intolerant genera, other biotic indices and the abundance of macroinvetebrates in a given station; (Griffith *et al*., 2005).

2.4.2.2 Functional composition

Other than the structural composition, macroinvertebrates also have functional classification. Functional classification of macroinvertebrates (FFGs) is a classification centered on morpho-behavioral mechanisms used by the various macroinvertebrates to obtain food material (Cummins & Klug, 1979). As opposed to the structural classification, the macroinvertebrate FFGs classification has the advantage of combining both the morphological characteristics such as mouth part specialization and behavioral mechanisms such as food acquisition when consuming food resources (Cummins *et al.*, 2005). This method of classifying the macroinvertebrates broadens the understanding of trophic dynamics in aquatic systems by simplifying the benthic community into trophic guilds (Merritt & Cummins, 1996, 2006).

When assigning macroinvertebrates to functional feeding groups, knowledge of macroinvertebrates numerical abundance and richness in the rivers and streams is important for determining the effects of change in human activities such as land-use change and riparian alterations (Baptista *et al*., 2007; Masese *et al*., 2014). Masese *et al*. (2014) noted that the duty to allocate macroinvertebrates to FFGs is not clear and is generally problematic in some cases, especially when the assignment isn't backed up by information on feeding patterns and mouthparts morphology.

2.4.2.3 Structural composition

The most common macroinvertebrates FFGs are shredders, collectors (gatherers and filterers), scrapers (also known as grazers) and predators (Cummins *et al*., 2005). Shredders (mainly composed of the cased Trichopterans) and scrapers (mainly the Ephemeropterans) are considered sensitive to pollution, while predators (odonates and hemipterans) are considered resistant. Studies have shown that some shredder taxa are restricted to cooler and shaded forested waters, while the FFGs that are tolerant to poorer water quality and habitat degradation (Yule *et al*., 2009; Masese *et al*., 2014), such as collectors, can be more widespread (Masese *et al*., 2009; Buss *et al*., 2015). Comparatively, forested streams have a higher taxon richness of macroinvertebrates compared to adjacent streams under other uses, such as agriculture or grazing (Minaya *et al*., 2013; García *et al*., 2017; Fugère *et al*., 2018).

Community composition keep changing because of the stresses within the system itself and the impact of pollution on the individual organisms (Richards *et al*., 2007), and this may act as an early warning sign of degradation in a biological community (such as macroinvertebrates). Indicators of macroinvertebrate populations, such as abundance, diversity, richness and overall health, have been established to correlate well with the health of water source in which the macroinvertebrates live (Gichana *et al*., 2015). These indicators can then be measured comparatively against similar freshwater streams with the same ecological parameters to determine the overall health of one system in relation to the other (Masese *et al*., 2009; Aura *et al*., 2010).

The development of biological criteria to assess the biological integrity of an ecosystem is based on the regionalization, multi-metric approach and the use of reference conditions (Barbour *et al*., 1999). According to Karr and Chu (1997), geographic separation of within region- homogeneity and between region- heterogeneity (discrete units) is an integral part of bioassessment. The IBI quickly became popular, and was used by many investigators to assess warm water streams throughout the United States. Karr and his colleagues explored the sampling protocol and effectiveness in several different regions and different types of streams.

As the IBI became widely used, different versions were developed for different regions and ecosystems. The original version had 12 metrics that reflected fish species richness and composition, number and abundance of species, trophic organization and function, reproductive behavior, fish abundance, and condition of individual fish. The metrics were scored and summed to arrive at an index ranging from 60 (best) to 12 (worst). Most of the original metrics were retained in newer versions, but some metrics were changed to improve sensitivity to environmental degradation in a specific location or kind of stream. The IBI has also been tailored to reflect differences in species in a region, and other types of ecosystems such as estuaries, impoundments, and natural lakes. In 1993, the first macroinvertebrate Benthic-Index of Biotic Integrity (B-IBI) was developed (Kerans and Karr, 1994). The B-IBI included 13 metrics based on benthic macroinvertebrate data collected from rivers in the Tennessee Valley (Kerans and Karr, 1994). The B-IBI has not been as widely tested or used as the fish IBI, but some agencies and universities include the B-IBI in stream health assessments.

In Kenya, IBI has been developed to monitor water quality status of Rivers Sosiani and Kipkaren in Nzoia Basin, River Nyando (Raburu *et al*., 2009b), rivers in the upper catchment of Lake Victoria Basin (Raburu *et al*., 2009), Moiben River (Masese *et al*., 2009) as well as River Tana (Aura *et al*., 2016). However, most of these studies were based on river systems not in wetlands with only one study focusing on the wetlands (Orwa *et al*., 2013) but again the study did not relate macroinvertebrates assemblages to nutrient levels in the system. The current study sought to investigate macroinvertebrate communities along the Kesses River, traversing Kingwal wetland in relation to nutrient levels and to establish a macroinvertebrate index of biotic integrity as a biomonitoring tool for the wetland and similar other ecosystems.

2.5 Socio-economic status and utilization regimes of wetland resources in King'wal Wetland

Wetland resources have several socio-economic benefits to man (Safary, 2016). Due to lack of understanding of the usefulness of wetland, they were considered wastelands and barriers to economic progress (Conathan *et al*., 2014; Ramirez, 2019) thus cleared or drained and used for other purposes such as human settlement, livestock and/ or crop farming, establishment of industries among other human activities (Chepkwony, 2019). Wetlands have been reported to be a source of livelihoods in developing countries for centuries through crop cultivation, food, herbal medicine, cosmetics, building materials, and livestock grazing areas among others (Allen *et al*., 2002; Mwakubo, 2008; Bezabih and Mosissa, 2017). They further play a critical eco-hydrological role such as water purification, water storage (Conathan *et al*., 2014) and water flow regulation (flood control), ecosystem balance through biodiversity preservation and conservation (Griffin, 2012; Baral *et al*., 2016), carbon sequestration (Baral *et al*., 2016) and water provision (Mwakubo *et al*., 2008; Mwakaje, 2009). Initially, wetlands were commonly perceived as wastelands and impediments to economic development, leading to their clearance or drainage for alternative purposes such as human settlement, livestock and/or crop farming, and industrial establishments (Conathan et al., 2014; Ramirez, 2019). However, this perception disregarded the diverse socio-economic benefits that wetland resources offer to mankind (Safary, 2016).

Characteristics of healthy wetlands include high biodiversity and sustainable livelihoods (Orwa *et al.,* 2013). The importance of wetlands as wildlife habitats and areas of some migratory species especially waterfowls that depend on wetlands for resting, breeding and sheltering led to the development of The Convention of Wetlands of International Importance (RAMSAR Convention) in 1971. The Convention was put into force in 1975 with the objectives of controlling the loss of wetlands and ensuring that wetlands are conserved (Griffin, 2012). Based on Ramsar Convention Bureau (2000), millions of waterfouls are supported by the floodplains of the Senegal, Niger and Chad basins while the Djoudj National Bird Park, Senegal and Diawling National Park, Mauritania are home to migratory birds in West Africa, providing habitat for over three million birds belonging to nearly 400 species Bezabih and Mosissa, 2017). Wetlands in areas of high rainfall and warm climates, such as the Congo Basin, display richer species diversity than those of drier regions (Ramsar Convention, 2000; Ssegawa *et al*., 2004; Scerri *et al.,* 2022). Previous research findings have shown that biodiversity decrease with habitat degradation resulting from unsustainable utilization of wetland ecosystem (Raburu and Masese, 2012; Njue *et al.,* 2016).

Arising from the fact that wetlands are one of the most multifunctional ecosystems of the world that provide a range of economical, biological, ecological, social, and cultural functions and services to human beings, they are globally facing overuse and misuse pressure leading to degradation and loss of benefits to society (Mutepfa *et al*., 2010; Mengesha, 2017). It is believed that wetlands of highest endemism and of international significance in Africa such as the Niger Delta in Mali, the seasonally inundated floodplain of northern Central African Republic and southern Chad, the Sudd region of southern Sudan, Lake Victoria and Kyoga in Uganda, the swamps of western Tanzania and various parts of Zambia, and the Okavango region of northern Botswana are shrinking at an alarming rate (Stumm *et al*., 2009; Van Deventer *et al.*, 2021). These changes in size affects wetlands functionality resulting into changes and alterations in wetland biodiversity hence affecting the wetland ecosystems.

In Kenya, wetlands are threatened by land use changes on various catchments, human encroachment, wetland reclamation, and unsustainable agricultural activities (UNEP, 2006; GEF, 2007; Aura *et al.*, 2010; Osoro *et al.*, 2020). The wetlands areas in Kenya usually fluctuates between approximately 3 - 4% of the country’s surface area depending on the dry and wet season (e.g., floods) (GOK, 2014; Osoro *et al.*, 2020). In Lake Victoria Basin about 50% of the wetlands have been lost between 1969 and 2000 (Owino & Ryan, 2006; Khisa *et al*., 2013). These can be attributed to increased deforestation and unsustainable agriculture coupled with agro-industrial activities and rapid urbanization pose threats to the wellbeing of aquatic ecosystems (FAO 2005; Raburu *et al.,* 2009; Osoro *et al.,* 2020). Some of the major wetlands that have been subjected to biodiversity studies include the Yala and Sondu wetlands (Thenya, 2001; Thenya and Ngecu, 2017), Nyando wetlands (Orwa *et al*., 2013; Oduor *et al*., 2015), Saiwa wetland (Awuor, 2018), Ewaso Nyiro wetland (Masibayi, 2011) and Ewaso Narok Wetland (Nyandika, 2019) in Laikipia County.

In Nandi County some wetlands have been reclaimed for crop production and most of the remaining ones are under varying degrees of threat and minimal measures have been taken to protect them, with minimal evidence of biodiversity studies in them (Njuguna, 1996; Jones and Muthuri, 1997; Mulie, 2018; Chepkwony, 2019). With most of the wetland resources being used as food, medicines, cosmetics, building, tools, clothing, rituals, and music, among others, the indigenous knowledge and recognition of flora and fauna used by the local community members is historical (Gichuki *et al*., 2001; Gichuki, 2003; Osuji, 2007; Nyandika, 2019). The rapid loss of natural habitats and alteration of native plant and animal communities by human encroachment and invasion of exotic plants threaten natural areas and compromise the potential of future exploitation of the resources (Allen *et al*., 2002; Junk *et al*., 2013; Mulei, 2018).

The documentation of potential plant and animal resources is critical for understanding how people exploit the wetlands' resources (Ramsey and Rosen, 2016). Some products obtained from King’wal wetland plants are offered for sale in different markets and they form a source of income to the local communities (Chepkwony, 2019). They include mats, baskets, hats, brooms, stools and chairs, among others. Artifacts from *Typha* inflorescence especially *T. domigensis* are a source of income for inhabitants. Despite the usefulness of the wetland to the local community in Nandi, land use activities around the wetlands continue to increase mainly dominated by cultivation, livestock grazing and settlements (Kirui, 2010; Mulei, 2018; Chepkwony, 2019). These intensification in the recent years are of particular concern as they have led to other forms of disturbance to the wetlands such as pollution, burning and increased harvesting of papyrus (Bennun and Njoroge, 1999; Kairu 2001; Kirui, 2010; Mulei, 2018; Chepkwony and Ipara, 2018; Chepkwony, 2019).

Communities around the wetlands will be motivated to conserve resources that they perceive more useful to them, in contrast to those resources perceived as less useful (Bullock and Acreman, 2003; Garibaldi and Turner, 2004; Abila, 2005). The need to feed a large population has resulted in the conversion of most wetlands into agricultural areas, while expanding industries and urban centers discharge their waste water into the neighboring wetlands, hence causing pollution. In 1990, Kenya ratified the Ramsar Convention, most of the country’s wetlands had been degraded (Mironga, 2005b). Despite the protection of wetlands being clearly reflected in the Ramsar convention at international level, assessing the conservation status of all wetlands is challenging because information on wetland distribution is geographically variable and because existing inventories differ greatly in wetland definitions (broad versus restricted scope), resolution (local versus regional scale), and the accuracy of wetland delineations, making it difficult to compare regions to detect broadscale trends in wetland status (Junk *et al*., 2013; Reis *et al*., 2017). In Kenya the full protection of the remaining wetlands can only be achieved through implementation of management strategies at national or local levels if up to date information on these wetlands is available. Integrated and innovative management and conservation approaches are therefore required based on the multiple uses of wetlands.

Most of the studies have emphasized the ecological aspects of wetlands with only limited aspects on their socio-economics and conservation (Jones, 1983, 1984; Johnstone, 1991; Crafter *et al*., 1992; Corwadin, 1999; Harper *et al*., 1999; Gichuki, 2003; Orwa *et al*., 2013). Moreover, the linkages between socio-economics and ecology of the wetlands are not well documented. The factors driving wetland utilization as well as the relationship of these factors to the wetland ecology need to be studied to facilitate sustainable management of the wetlands. Therefore, this study was set to bridge that gap by determining the utilization and management regimes for the wetland resources of King'wal Wetland by the local community members.

2.6. Conservation and Management of Wetlands

Wetlands, due to their rich biodiversity and crucial ecosystem services, necessitate careful conservation and management to sustain their functions and benefits (Ramsar Convention, 1971). Conservation refers to the protection, preservation, management, or restoration of natural environments and wildlife, while management involves the integration of policy, practice, and science to sustain and enhance the values of the environment. Historically, wetlands were often seen as wastelands to be drained for agriculture, urban development, or disease control. However, this perspective has shifted significantly over the past several decades, recognizing the essential roles wetlands play in providing clean water, buffering against floods and droughts, sequestering carbon, and serving as habitats for numerous species (Mitsch & Gosselink, 2007). Today, wetland conservation is a critical part of global efforts to preserve biodiversity, combat climate change, and sustain human livelihoods.

Effective wetland conservation and management rely on comprehensive understanding and application of ecological principles, robust legal and policy frameworks, active stakeholder participation, and continuous monitoring and research. At the heart of wetland management is the maintenance of their ecological character, which is the combination of the ecosystem components, processes, and benefits that characterize the wetland at a given point (Ramsar Convention, 2005). Wetland management plans, ideally, should be developed based on thorough ecological and socio-economic assessments and clearly defined management objectives. These plans ought to consider not only the wetland itself but also its catchment, as wetlands are often impacted by activities occurring far outside their boundaries (Kingsford, 2000). For example, upstream land use changes can affect the quantity and quality of water reaching a wetland, thereby influencing its health and functioning.

Legal and policy frameworks are integral to wetland conservation. Internationally, the Ramsar Convention is the main intergovernmental treaty providing the framework for the conservation and wise use of wetlands (Ramsar Convention, 1971). Nationally, governments should enact and enforce laws and regulations that protect wetlands from degradation and loss, control pollution, and regulate activities such as water extraction, land reclamation, and resource extraction. Stakeholder participation is another crucial aspect of wetland management. Wetlands often support numerous stakeholders, including local communities, farmers, fishers, industry, scientists, and conservation organizations, who may have differed and sometimes conflicting interests and values (Reed, 2008). Therefore, successful wetland management requires meaningful engagement with these stakeholders, incorporating their knowledge, values, and needs into decision-making processes.

Continuous monitoring and research are also vital to track changes in wetland health over time, assess the effectiveness of management interventions, and adapt to new challenges and opportunities. For example, biomonitoring methods that use biological indicators, such as macroinvertebrates, to assess water quality and ecological health have proven effective in many wetland management contexts (Rosenberg & Resh, 1993). In summary, wetland conservation and management are multifaceted and complex tasks that require an integrated and adaptive approach, underpinned by strong scientific understanding, robust legal and policy frameworks, active stakeholder participation, and continuous monitoring and research. Despite the many challenges, effective wetland management has the potential to deliver significant benefits for both biodiversity and human wellbeing.

2.7 Research Gaps

Several studies have been conducted in the field of wetland research, focusing on socio-economic aspects, ecological integrity, and resource utilization. These studies have contributed valuable insights and knowledge to the understanding of wetland ecosystems. However, certain research gaps still exist, which have necessitated the current study on the socio-economic status, resource utilization, and ecological integrity of King'wal Wetland in Nandi County, Kenya. This sub-section will discuss specific research that has been carried out in relevant areas and identify the research gaps that have led to the need for this study.

2.7.1 Spatial-temporal Variations in Water Physico-chemical Variables and Nutrient Levels

The evaluation of spatio-temporal variations in water physico-chemical variables and nutrient levels is crucial for understanding the ecological health of wetlands. Previous research has examined similar aspects in various wetland ecosystems. For example, Raburu and Masese (2012) conducted a study on water quality and nutrient levels in wetlands, emphasizing the role of these variables in supporting wetland biodiversity and ecosystem functioning. However, there is a research gap in assessing the spatio-temporal variations in water physico-chemical variables and nutrient levels specifically in King'wal Wetland. Therefore, this study aims to address this gap by evaluating the fluctuations and patterns of these variables in the wetland, providing insights into the ecological dynamics of King'wal Wetland.

2.7.2 Changes in Species Distribution and Diversity of Wetland Macrophytes

Understanding the changes in species distribution and diversity of wetland macrophytes is essential for monitoring ecological changes and assessing the health of wetland ecosystems. Previous research has investigated macrophyte communities in wetlands, highlighting their importance as indicators of ecosystem health. For example, Orwa et al. (2013) conducted a study on wetland biodiversity, focusing on the Nyando wetlands in Kenya, and examined the changes in macrophyte diversity over time. However, there is a research gap in assessing the changes in species distribution and diversity of wetland macrophytes specifically in King'wal Wetland. This study aims to bridge this gap by investigating the patterns and dynamics of macrophyte communities in King'wal Wetland, providing valuable insights into the ecological changes occurring in the wetland.

2.7.3 Use of Macroinvertebrate Assemblages as Indicators of Ecological Integrity

Macroinvertebrates are often used as bioindicators to assess the ecological integrity and water quality of wetland ecosystems. Previous research has explored the use of macroinvertebrate assemblages in assessing ecological conditions in various wetlands. For example, Njue et al. (2016) conducted a study on macroinvertebrates as indicators of ecological health in wetlands, emphasizing their role in monitoring water quality and ecosystem functioning. However, there is a research gap in investigating the use of macroinvertebrate assemblages as indicators of ecological integrity specifically in King'wal Wetland. This study aims to fill this gap by examining the macroinvertebrate communities in the wetland and assessing their potential as indicators of ecological health.

2.7.4 Socio-economic Status and Resource Utilization of Wetland Resources

Various studies have explored the socio-economic aspects and resource utilization practices in wetland ecosystems. For instance, Gichuki et al. (2001) investigated the indigenous knowledge and recognition of flora and fauna used by local community members in wetlands. They highlighted the historical importance of wetland resources for food, medicines, cosmetics, and other cultural purposes. Similarly, Bullock and Acreman (2003) examined the economic value of wetland products, such as mats, baskets, hats, brooms, stools, and chairs, derived from wetland plants. Despite these contributions, there is a research gap in understanding the socio-economic status and utilization regimes specific to King'wal Wetland in Nandi County. Therefore, this study aims to fill this gap by comprehensively assessing the socio-economic aspects and resource utilization practices of local community members in King'wal Wetland.

In conclusion, previous research has contributed valuable knowledge in the field of wetland research. However, specific research gaps exist regarding the socio-economic status, resource utilization, spatial-temporal variations in water physico-chemical variables, changes in species distribution and diversity of wetland macrophytes, and the use of macroinvertebrates as indicators of ecological integrity in King'wal Wetland. This study aims to address these gaps and provide comprehensive insights into the socio-economic and ecological aspects of King'wal Wetland in Nandi County, Kenya.

Table 2.1 Research gaps

Research Gap	Relevant Studies
Socio-economic status and utilization of wetland resources specific to King'wal Wetland in Nandi County	Gichuki et al. (2001); Bullock and Acreman (2003)
Spatio-temporal variations in water physico-chemical variables and nutrient levels in King'wal Wetland	Raburu and Masese (2012)
Changes in species distribution and diversity of wetland macrophytes in King'wal Wetland over time	Orwa et al. (2013)
Use of macroinvertebrate assemblages as indicators of the ecological integrity of King'wal Wetland	Njue et al. (2016)

CHAPTER THREE

MATERIALS AND METHODS

3.1 Study area

3.1.1 Background, location and size

This study was done in Nandi County (Latitude: 34°48’31.2” E to 35°26’88.1” E, Longitude: 0°32’41.7” N to 0°06’31.8” S) bordered to the North and West by Kakamega County, to the South West by Vihiga County, to the South by Kisumu County, South East by Kericho County and East by Uasin Gishu County. Kingwal wetland is located 25 Kilometers from Eldoret town along the Eldoret-Kapsabet road (Momanyi and Ariya, 2015) and runs from Kiptenden through Mosoriot towards Nandi North Forest in Mosop Constituency between latitude: 35°08’34.1” E to 35°11’22.0” E and longitude: 0°15’11.3” N to 0°16’13.6” S (Figure 3.1). The wetland is within Lake Victoria basin and catchment zone. The total surface area of the swamp is about 1218 km^2. It receives water mainly from Kesses River and streams and springs around Kesses area which flows from east and drains into Kingwal (Kimondi) River while flowing to the west (Momanyi and Ariya, 2015).

3.1.2 Climate and Hydrology

Kingwal received reliable and evenly distributed rainfall with a bimodal pattern with long rains from March to May and short rains from August to September (GoK, 2002). The wetland also experiences a drier spell from November to February (GoK, 2002; Lesiyampe *et al.*, 2018) with February as the hottest month, and June as the coolest month. King’wal wetland, found within the Lake Victoria basin, receives reliable and rainfall with two peaks, coming in March to August, (long rains) and September to November, (short rains). The northern parts of the County receive 1,300mm to 1,600mm of rain annually while the Southern part, affected by the lake basin atmospheric conditions get up to 2000mm annually. The average annual rainfall amount for the county ranges from 1200 to 2000 mm (County integrated development plan [CIDP] Nandi County, 2018).

The mean temperature ranges from 18 ^{0}C to 22 ^{0}C in the rainy season but the part of the county next to the Nyando escarpment has a mean temperature of 26 ^{0}C. In the dry months of December to January, the mean temperature is usually 23 ^{0}C while in the cold months, the night temperature is as low as 14 ^{0}C. Generally, Nandi County has moderate to warm temperatures all year round (CIDP Nandi County, 2018). Rainfall and altitude determine the agricultural activities in the County. Twelve percent of the county is under forest cover characterized by diverse species of trees found in the Tinderet, Serengonik, Nandi South and Nandi North Forests that form part of the Kakamega Tropical Rain Forest. The area under shrubs and bushes mainly occurs on the eastern plateau and portions of the escarpment below the Nyando plains (CIDP Nandi County, 2018).

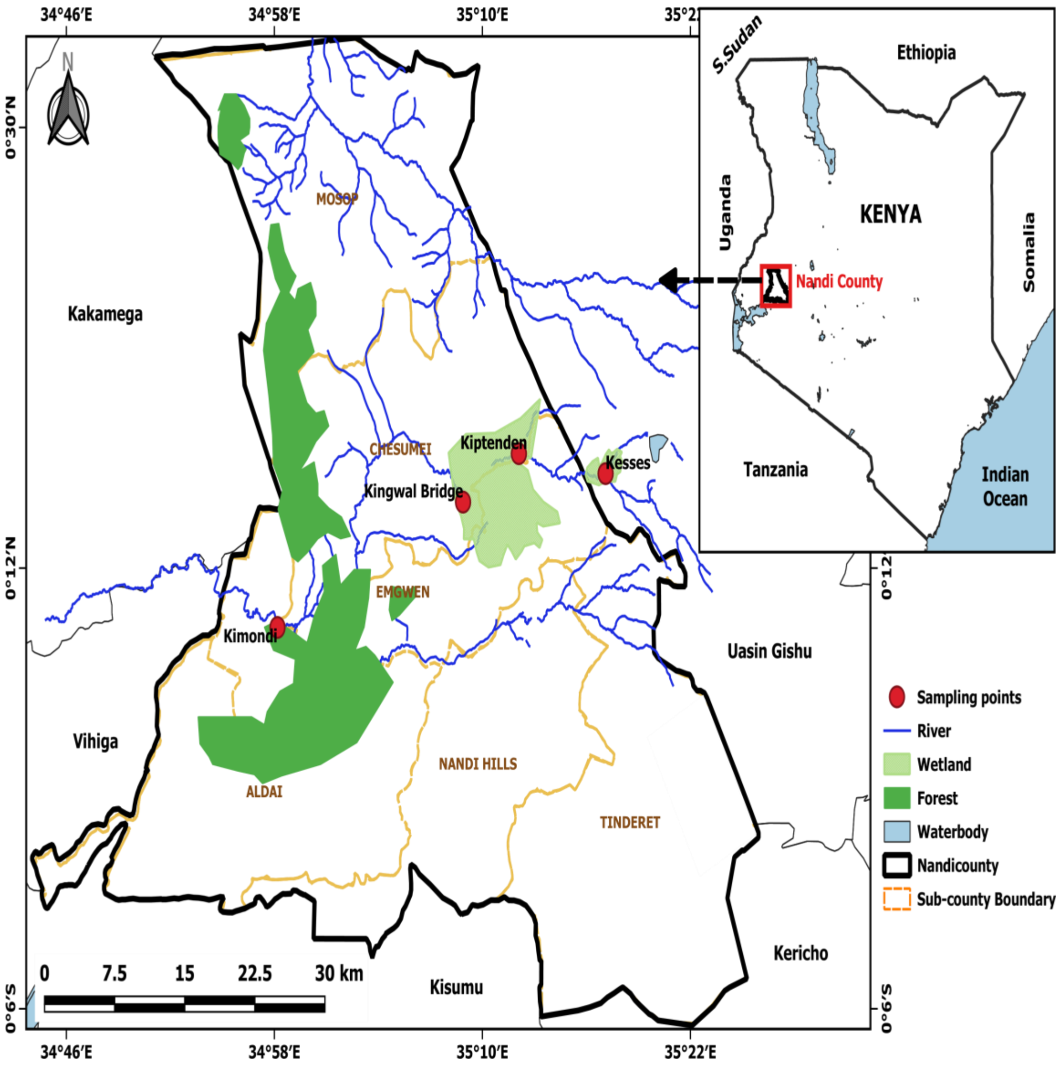


Figure 3.1: Map of Nandi County showing the location of study sites (sampling points) along Kingwal Swamp (Source: Nandi County government website)

3.1.3 Soils and geology

Nandi County is made up of five distinct topographic and geological features, namely, the rolling hills on the west, the Kapsabet plateau, the Tinderet volcanic mass, King'wal swamp and the Nyando escarpment on the southern border. Similar to the case in the neighboring Uasin Gishu County, soils in the area are typically reddish to brown (GoK, 2002). They are thin, drain freely and have a friable texture with layers of cellular ironstone. Brown loam soils occur in high altitude areas and they are derived from the Tinderet volcanic masses and volcanic rocks found in the area. Soils within King'wal wetland are however clay, characteristic of wetlands.

3.1.4 Fauna and flora

Kingwal wetland is inhabited by different organisms including wild, domestic animals and plants. It is well known as a habitat for the endangered Sitatunga antelope (*Tragelaphus spekei*). Other wild animals found in Kingwal wetland are mongoose, foxes, otters, and ant bears, birds like the cranes, snakes, frogs, and different species of fish (Chepkwony, 2019). The wetland also harbors plants including trees, grasses, and shrubs (Sitienei *et al*., 2012), herbs, papyrus, sedges, reeds and water lilies.

3.1.5 Human activities

The study area is characterized by increase in human population pressure as a major cause for wetland degradation. Agricultural activities (carried out on most part of the catchment, continues to have significant impacts on the environment. Other human activities that threaten the wetland are overgrazing, human settlement and encroachment, brick making, maize roasting, siltation, pollution (mainly from agriculture and industrial sources), introduction of exotic species such as blue gum trees (*Eucalyptus spp*.) and overharvesting of water dependent plants.

The major agricultural activities around the wetland include farming of maize (*Zea mays* L.), beans (*Phaseolus vulgaris* L.) and wheat (*Triticum aestivum* L.), and a group of other non-cereal crops on a smaller scale, including cabbage (*Brassica oleracee var capitata* L. (Alef.), kales (*Brassica oleracea var acephala* L. (DC.) and spinach (*Spinacia oleracea*) (Chepkwony and Ipara, 2018).

Socio-cultural factors, such as traditions, lifestyles and informal natural resource abstraction by local communities have also influenced the perception of wetland, their use and management. Lack of adequate and appropriate knowledge about the functions and values of wetlands have hindered active management, including rehabilitation of degraded areas by local communities.

Papyrus (*Cyperus papyrus*) in the wetland is threatened by drainage, clearing, filling and reclamation for subsistence crop production, overgrazing, road building, construction of dams or barrages for water storage, flood protection, irrigation and hydroelectric schemes, construction of waterways and irrigation. Unsustainable utilization of the papyrus has been found to cause complete loss of the wetlands through biodiversity loss (Morrison *et al.*, 2012).

Further within the wetlands, there exists human-wildlife conflicts in addition to conflicts over papyrus and agricultural space which to the local communities is a common resource. According to Mafabi (2000) land use activities around papyrus swamps of Lake Victoria are dominated by cultivation, livestock grazing and settlements that offer major threats.

3.2 Sampling Sites

During the preliminary reconnaissance survey, four sampling sites were identified based on their accessibility and human activities (Figure 3.1) as follows. Each of the four sites had three replicate sites separated by one meter. The sites are as follows:

Site S1: Kesses site, was the upstream site located at the source of River Kesses. The riffles at the station had stone substrate, the pools contained mud and detritus material, while the runs had mud substrates. The station had an average depth of 0.6 m with an average width of 2 m. The riparian zone was swampy with black clay soils dominating the area. Human activities around the station were minimal. The station was used as a reference station in the development of the IBI because of minimal anthropogenic disturbance observed. No household was located around the site.

Site S2: Kiptenden, was located midstream of River Kesses. The riffles at the station had substrates made of stones; pools consisted of mud and detrital material, while runs had mud substrates. The station had an average depth of 0.6 m with an average width of 2m. The riparian zone was less swampy with black loam soils dominating the area. Human activities around the station were prominent with agricultural farms and grazing land. The station was marked by human interference and the presence of surrounding homesteads.

Site S3: Kingwal Bridge, was located further down midstream of River Kesses. The pools and runs at the station had substrates consisting of mud and detritus material. The station was much deeper than the first two sites with an average depth of 1.0 m and an average width of 2.5 m. The riparian zone was swampy with black clay soils dominating the area. Human activities around the station were prominent including brick making, agriculture, tree nurseries, horticulture and papyrus harvesting. There were many papyrus stems decomposing in the stream hence an expected low DO and high biological oxygen demand (BOD). There were many households located around the site.

Site S4: Kimondi, was located downstream of River Kesses. The pools and runs at the station had substrates consisting of mud and detritus material. The station, like station S3, was also deeper with an average depth of about 1.0 m and an average width of 2.5 m. The riparian zone was swampy with black clay soils dominating the area. Human activities around the station were prominent including brick making, agriculture, tree nurseries, horticulture and papyrus harvesting. There were many households located around the site. As S3, there were many papyrus stems decomposing in the stream, hence the DO and BOD levels were expected to be low.

3.3 Sampling and Data Collection

3.3.1 Water quality Parameters

3.3.1.1 Field sampling

Sampling for water quality variables was done on a monthly basis from January to December, 2011. Before disturbing the water, dissolved oxygen (DO), conductivity and pH were measured *in situ* by directly inserting a YSI multi-probe water quality meter (556 MPS, Yellow Springs Instruments, Ohio, USA) into the water. A minimum of three replicate readings were recorded after the probe had stabilized at each site. Measurements were taken at a sensitivity of 0.01 for all parameters.

Three aliquots of 500 ml each were collected in acid-washed High-Density Poly-ethylene (HDPE) bottles at each site by hand dipping the bottle beneath the water surface. The filled bottles were fixed with sulphuric acid, and capped immediately, stored in a cooler box and transported to the laboratory where they were stored at 4^o C awaiting further chemical analyses of total nitrogen (TN) and total phosphorus (TP). Biological oxygen demand (BOD) samples were collected in 300 ml BOD bottles, wrapped with aluminium foil and were stored at 4^o C awaiting transportation to the laboratory for incubation and analysis.

3.3.1.2 Laboratory processing of the water samples

Biological oxygen demand (BOD) was analyzed following the winkler method, APHA (2005). Duplicate 300 milliliters (mL) Winkler bottles were completely filled with the collected water samples. The pH of the sample is adjusted to 7 with one normality sulphuric acid (1N.H_2SO_4) prior to the analysis to ensure that not all the oxygen of the sample is exhausted during incubation. The required volume of dilution water is carefully added into a graduated cylinder and the known quantity of the sample is added to it. The diluted sample is then transferred into two sets of BOD bottles.

One set of the sample is then incubated at 20 ^{0}C for 5 days in a BOD incubator. The dissolved oxygen in the other set is determined immediately. This will give the initial dissolved oxygen of the sample. The dissolved oxygen is determined following the Winkler method where in the sample bottle, 1ml of manganese sulphate and 1ml of alkaline iodide are added one after the other. The sample bottle is the stoppered without entrapping any air bubbles and carefully tilted for a precipitate to form and settle at the bottom. The stopper is the removed and 5ml of concentrated sulphuric acid is added. The bottle is the stoppered and tilted carefully till the precipitate dissolves and a clear straw yellow solution result.

From the bottle, 100ml is drawn and transferred to a 250ml conical flask for titration. This is then titrated with 0.025 N sodium thiosulphate solution until a straw pale yellow colour is obtained. Four drops of 1% starch solution is added which forms a blue solution. Titration then continues until the blue colour disappears (APHA, 2005).

The amount of dissolved oxygen is then determined as follows;

$$\text{Oxygen (mg/L)} = V1 * N * 8 * 1000 * 0.698$$
$$(V4 * (V2 - V3)/V2) \qquad \text{Equation 1}$$

Where;

V1 = Volume of titrant (ml)

N = Normality of tritant (0.025N)

V2 = Volume of sampling bottle after placing the stopper (ml)

V3 = Volume of manganese sulphate + iodide solutions added (ml)

V4 = Volume of fraction of the content used for tritation (ml) 8 = Equivalent weight of oxygen
0.698 = A factor to convert mg to ml

After incubation, the dissolved oxygen levels of all the samples and the blank dilution water is determined following the winkler method above (APHA, 2005). The amount of BOD is the then determined as follows;

BOD (mg/L) = (I – F) – (I’ – F’) * (X/Y)/D   Equation 2

Where;

I = Intial dissolved oxygen content of the sample F = Final dissolved oygen of the sample
I’ = Initial dissolved oxygen of the dilution water F’ = Final dissolved oxygen of the dilution water
X = Volume of the dilution water in the sample bottle (ml) Y = Volume of the sample with only dilution water
D = Dilution of the sample

Total nitrogen (TN) was analyzed using the Kjedhal digestion procedure APHA (2005). The Kjedhal procedure is a three-step process; digestion, distillation and titration. The digestion process involved putting 10 ml of the water sample into a 250 ml test tube using a pipette. For each sample, two (2) catalyst tablets, two (2) antifoam tablets and 20 ml concentrated sulphuric acid (96-98%) were used. A blank without the water sample was prepared using distled water and all the chemicals. The Digestion Unit was connected to a proper aspiration pump and a fume chamber to neutralize the acid fumes created during the digestion phase and digested for four hours (APHA, 2005). During the digestion phase, the water sample was heated in the presence of sulphuric acid to break down the organic nitrogen via oxidation and liberate reduced nitrogen in the form of ammonium sulphate. Potassium sulphate was added to increase the boiling point of the medium and copper was used as a catalyst. When the sample was fully decomposed, a clear and colorless solution was obtained.

After digestion, the test tubes were let to cool down to 50-60 °C. The samples were then distilled with 50 ml water and H_2SO_4 (0.1 N) and 70 mL NaOH as titrant solutions for a period of 4 minutes for one test. In the distillation phase, sodium hydroxide was added to the distilled solution to convert the ammonium salt to ammonia. The distilled vapours were then trapped in a special trapping solution of HCl (hydrochloric acid). The turning of the blue colour to pink was the indication of endpoint. The amount of the total nitrogen was the determined as follows;

Total nitrogen (mg/L) = $A - B * N * 1000 * 14/ V$ Equation 3

Where;

A = Volume of the hydrochloric acid used against sample (ml)

B = Volume of hydrochloric acid used against blank (ml) N = Normality of hydrochloric acid (0.01)

14 = Constant factor

The total phosphorus (TP) was analyzed following the ascorbic acid method after persulfate oxidation as described in APHA (2005). The determination of total phosphorus (TP) in an aqueous sample is based on digestion of the sample to convert phosphorus compounds into orthophosphate, which can then be determined based on spectrophotometry. The Potassium persulfate ($K_2S_2O_8$) solution of 50 g L^{-1} was prepared by dissolving 5 g potassium persulfate in 100 mL pure water, and stored at room temperature away from light exposure. The sodium persulfate ($Na_2S_2O_8$) solution of 250 g L^{-1} was prepared by dissolving 25 g sodium persulfate in 100 mL pure water, and stored at 4°C in a refrigerator. Ascorbic acid (AA) solution of 100 g L^{-1} was prepared fresh just before use. The mixed reagent (MR) solution of ammonium molybdate was prepared by mixing 100 mL of 130 g L^{-1} Ammonium molybdate ($(NH_4)_6Mo_7O_{24}\cdot4H_2O$) solution, 100 mL of 3.5 g L^{-1} potassium antimony tartrate, and 300 mL of diluted Sulphuric acid (H_2SO_4 (1 : 1, H_2O : H_2SO_4) and stored refrigerated at 4°C.

Phosphate stock solution of 8.00 mM was prepared by dissolving pre-dried potassium dihydrogen phosphate (KH_2PO_4) in 100ml of pure water and stored at 4°C. Fifty ml of the water sample was digested with 16ml persulphate solution. After the digestion, the flasks were allowed to cool and 25ml of the sample was drawn, added to the mixed reagent, and allowed to settle for an hour before reading the absorbance at a wavelength of 885 nm using a spectrophotometer (APHA, 2005). The absorbance of the distilled water blank (OD) was also measured.

Determination of the phosphorus concentration from the read absorbance was done from the standard curve. A standard curve was prepared by plotting the absorbance values of standards (10, 50, 100, 300 and 500 ml/L) diluted from the stock solution versus the corresponding phosphorus concentrations on a linear graph paper. Results were reported as P, mg/L.

3.3.2 Macrophytes sampling

Plant species diversity of the wetland was determined by laying three random belt transects per site that extend from the wet meadow (terrestrial portion of the wetland) to the aquatic portion of the wetland (Approximately 1-m depth contour; Albert and Minc, 2004). Sampling was done in 1 m * 1 m quadrats placed systematically after every 10 m (Bourdaghs *et al.*, 2006). All the species located within the quadrats were identified and their percent cover estimated subjectively. All the identified and recorded species within the quadrat were used to prepare a checklist of the different species found in the wetland. Data collected included macrophyte scientific, common and local names and their abundance. The specimen were identified and named as per taxonomic keys (Dale and Greenway, 1961; Beentje *et al.,* 1994; Phillips, 1996; Agnew, 2013). The selection of the study sites was based on several factors, including the distribution of wetland habitats, accessibility, and representativeness of the wetland ecosystem in the study area. The sites were chosen to cover a range of wetland types and hydrological conditions, ensuring the inclusion of both terrestrial and aquatic portions of the wetland. By selecting sites with different characteristics, the study aimed to capture the diversity of macrophytes and macroinvertebrates within the wetland and assess their response to environmental factors.

3.3.3 Macroinvertebrates sampling

Macroinvertebrate sampling was conducted following a semi-quantitative kick-net sampling method (Dickens & Graham, 2002). Three major biotopes were delineated and sampled within each site: riffles, runs and pools. The sampling process involved kicking/ disturbing the benthos in an area of approximately 1 m^2 upstream of the kick net (500-µm mesh size), so that water current can wash the dislodged macroinvertebrates into the net. A total of 3 benthic samples were collected at random locations in each of the selected site and all the contents of the net were emptied into ziplock bags. The macroinvertebrates collected were preserved using 95% ethanol, and transported to the Department of Fisheries and Aquatic Sceinces laboratory, University of Eldoret for sorting, identification and enumeration.

3.4 Laboratory processing of macroinvertebrate

In the laboratory, each sample was handled individually. The samples were washed through running water in sieves of 250 µm mesh size to remove mud, sand and other debris. The benthic macroinvertebrates were transferred to labelled bottles and preserved in 70% ethanol until indentified whereas the inorganic debris components were discarded. The macroinvertebrates were later removed from the bottles and identified to the lowest-possible taxonomic level (mainly genera) with the aid of several keys and illustration (Day and de Moor, 2002; de Moor *et al.*, 2003; Stals and de Moor 2007; Merritt *et al.*, 2008) and counted using a stereomicroscope and dissecting microscope at ×50 magnifications.

Allocation of macroinvertebrates to their respective functional feeding groups (FFGs) (Shredder, Collecctor filterers, Collector gatherers, Predators and Scrapers) was done using available literature (Merritt and Cummins, 1996; Graca *et al.*, 2001; Dobson *et* *al.,* 2002; Polegatto and Froehlich, 2003; Molina, 2004; Masese *et al.,* 2014) (Appendix IV).

3.5 Macroinvertebrate metrics for the Index of Biological Integrity (IBI)

All macroinvertebrate count data for the twelve months for each site were pooled and used in the development of the metrics. Development of the biological integrity index followed a three-step approach that incorporated univariate, multivariate and multimeric analyses (Chipps, 2002). The first step was exploratory; candidate metrics were evaluated with univariate t-tests. The initial candidate metrics were from three broad categories that included proportional abundance, diversity and taxa richness. Within each of these categories, evaluation was performed at the genera, feeding guilds and voltinism levels.

A large number of candidate metrics (Table 3.1) was initially considered because limited information exists on how macroinvertebrate communities of floodplain wetlands are affected by disturbances. Candidate metrics were eliminated in the first step of metric development using an acceptance level of $p < 0.01$. In the second step, all candidate metrics identified from the t-tests were input into a stepwise-discriminant function analysis to yield the final M-IBI metrics (STEPDISC procedure, SAS Institute 1999). Once the macroinvertebrate index of biotic integrity (M-IBI) metrics was developed, a correlation matrix was run to determine if collinearity that existed between the metrics.

Sensitivity analysis was performed to identify which metrics were the most influential in determining the M-IBI score (Minns *et al*., 1994). Each of the metrics was removed from the overall M-IBI based on their correlation with the human disturbance scores (HDS). The overall evaluation of wetland condition was conducted by determining the average M-IBI scores of the selected study sites. The average scores were evaluated using the qualitative condition scores (Table 3.1) to determine overall wetland condition at each site.

The metrics (measures) listed below (Table 3.1) were used to assess the health of the wetland. An increase in each metric produces the shown predicted response of the wetland health. Each metric received a score of one, three, or five. The metrics were then totaled to produce an overall IBI score. The interval 1, 3, 5 scoring system used in developing macroinvertebrate IBIs (Barbour *et al.*, 1999; Masese *et al*., 2009; Aura *et al*., 2016) was adopted to normalize the ranges of the metrics. For the positive metrics (i.e., those that increased with improving conditions), the highest value of a metric across all sites was trisected (Barbour *et al.*, 1999). Values above the upper one-third received a score of 5, those in the middle received a score of 3 while those in the lower one-third received a score of 1, corresponding to unimpaired, intermediate and impaired biota, respectively (Barbour *et al.*, 1999). For negative metrics, which decreased with improving condition, the metric was trisected but scoring was done in reverse. The score was then interpreted into a general health rating of Excellent, Moderate or Poor.

Table 3.1: Initial metrics used to assess the health of the wetland

Metric	Metric definition	Predicted response
Metric #1 **Number Ephemeroptera genera**	Total number of mayfly genera	Decrease
Metric #2 **Number Plecoptera genera**	Total number of stonefly genera	Decrease
Metric #3 **Number Trichoptera genera**	Total number of caddisfly genera	Decrease
Metric #4 **Number Ephemeropter-Plecoptera- Trichoptera genera**	Total number of taxa from mayfly, stonefly and caddisfly orders	Decrease
Metric #5 **Total number of macroinveterbrate genera**	All different genera at a site	Decrease
Metric #6 **Percent EPT individuals**	% individuals from mayfly, stonefly and caddisfly orders	Decrease
Metric #7 **Number of Oligochaeta**	The number of Oligochaeta is greater in healthier wetlands.	Increase
Metric #8 **Percent Coleoptera proportion**	% beetles/bugs. Aquatic beetles feed on algae and detritus that increase in polluted wetlands.	Decrease
Metric #9 **Number of Odonata genera**	The number of dragonfly and damselfly larvae.	Decrease

Metric #10 **Percent non-insect individual**	% of individuals not belonging to the insect orders	Increase
Metric #11 **Percent Diptera individuals**	% of midges	Increase
Metric #12 **EPT: Diptera ratio**	Ratio of individuals belonging to mayfly, stonefly and caddisfly orders to that of midges	Decrease
Metric #13 **Percent dominant 3 genera**	% of individuals in 3 most dominant genera	No response
Metric #14 **Number intolerant genera**	Total number of taxa belonging to pollution intolerant genera	Increase
Metric #15 **Number of Pulmonata genera**	Number of snails. The number of snails is greater in higher quality wetlands than in disturbed wetlands.	Decrease
Metric #16 **Mullusca+ Crustacean genera**	% of mollusks and crustaceans	Increase
Metric #17 **EOT richness**	Ephemeroptera, Odonata and Trichoptera richness	Decrease
Metric #18 **Percent filterer individuals**	Filter fine organic material	Decrease
Metric #19	Feed on algae at the bottom	Decrease

Percent scraper individuals		
Metric #20 **Percent predator individuals**	Carnivores- scavangers, engulf or pierce prey	Decrease
Metric #21 **Percent gatherer individuals**	Collect fine deposited organic material	Increase
Metric #22 **Shannon diversity index**	Value of Shannon diversity index	Decrease
Metric #23 **Simpson richness index**	Value of the Simpson richness index	Decrease
IBI Score	Wetland Health Assessment Score	Rating
97-120	5	Excellent
49-96	3	Moderate
15-48	1	Poor

3.6 Estimation of Human Disturbance Score (HDS) from catchment's land uses

An indicative of the broader range of human disturbances to wetlands is needed to capture the full range of the sources of stress to wetland health. The Human Disturbance Gradient Score (HDS) for Kingwal Wetland was done for 12 points (the upstream, mid-stream and downstream of the 4 study sites) with the sampling points being about 1 km away from each other.

The method of Gernes and Helgen (2002) was applied for assessing the degree of disturbances to the wetlands from the catchment's land uses as a result of agriculture, settlement, grazing, papyrus harvesting and brick making. Data on the nature and degree of the Human Disturbance Gradient Score (HDS) was estimated from the scoring sheet (Table 3.2), and scored as five factors; each was judged and scored in one of the four categories from best to poor. Linear regression analysis was used to see the relation of biological data to the human disturbance gradient.

Table 3.2: Scoring sheet for human disturbance scores for wetlands degree of disturbance analysis (Gernes and Helgen, 2002)

Extent and intensity of disturbance	Point
Factor 1. Buffer landscape disturbance (within 50 m buffer around the wetland)	
Best – No evidence of disturbance at all	0-6
Moderate – Predominantly undisturbed, some human use Influence	7-13
Fair – Significant human influence, buffer area nearly filled with human use	14-20
Poor- nearly all or all of the buffer under human use, intensive land use surrounding the wetland	21-24
Factor 2. Landscape (immediate) Influence (Within less than 500m)	
Best - no evidence of disturbance	0-6
Moderate - Predominantly undisturbed, some human use Influence	7-13
Fair - Significant human influence, landscape area nearly filled with human use	14-20
Poor- nearly all or all of the land scope in human use isolating the wetland	21-24
Factor 3. Habitat and vegetation alteration - Immediate landscape (within and beyond buffer)	
Best- no evidence of disturbance	0-6
Moderate-Low intensity alteration	7-13
Fair- highly altered	14-20
Poor–almost no natural habitat present (extreme alteration)	21-24
Factor 4. Hydrologic Alteration (1-2 km radius)	
Best- no evidence of evidence of disturbance	0-6
Moderate –Low intensity alteration	7-13
Fair- less intense than Poor alteration	14-20

Poor- Major disturbance to natural hydrology	21-24
Factor 5. Human Pollution	
Best –no evidence of human in point	0-6
Moderate- little evidence of human of chemical	7-13
Fair- high Potential for human input	14-20
Poor- high potential for human helm	21-24

3.7 Socio-economic survey of wetland uses and management

In order to determine the socio-economics of the wetland uses and management, household surveys of the population within the sampling sites was done. The population was approximately 5,772 with about 1,325 homesteads (KNBS, 2019). From this population 119 households (9%) reported that they used resources of Kingwal Wetland. Therefore, the formula by Mugenda and Mugenda (2003) was used to determine the population size (n) as follows:

$$n = z^2\left(\frac{pq}{d^2}\right) \quad \text{……equation 4}$$

Where: n = the desired minimum sample size, z = the standard normal deviation at set confidence interval, d = the acceptable range of error (0.05), p = the proportion of individuals using the swamp (9%), and q = the proportion of individuals not accessing the swamp = 1–p (0.91).

Hence; d = 0.05, *p* = 0.09, z = 1.96 at 95% confidence level, q = 0.91. Thus;

$$n = 1.96^2\left(\frac{0.09*0.91}{0.05^2}\right) = 125.85 \qquad \text{……equation 5}$$

Therefore, the desired sample size was 126 households.

The sample size was distributed across the four study areas depending with population (KNBS, 2019) of the area and the portion of the individuals utilizing the wetland. Hence the sample was distributed as follows; Kimondi – 35, Kesses – 32, Kingwal – 31 and Kiptenden – 28 households respectively. Data was collected through stratified (based on administrative locations) random sampling using questionnaires, focus group discussions and key informant surveys. The questionnaire was pre-tested, corrected and the final fashion prepared (Appendix 5). The questionnaire comprised of closed-ended questions and it captured key information such as the socio-economic status of the sampled population, wetland use and economic activities by the local community members and the effect of population increase on the resources.

The questionnaire schedule also comprised information on the personal data (age, gender, level of education, and their occupations). Members of the local community were interviewed in the local language. Key informant interviews (KII) were done based on response from the Officers of Ministries of Agriculture, Water, Livestock and Officials from NGOs and CBOs (Kothari, 2004). Focus group discussions (FGD) were also done and explored in more detail's issues captured in the questionnaire (Kothari, 2004). The participants of the FGDs were persons involved in Community Forestry Management, social workers, heads of institutions such as schools and the herbalists.

3.8 Data analyses

All statistical analyses were performed with Statistical Package for Social Sciences (SPSS 23.1) statistical packages (Morgan *et al.*, 2004) and PAST software (Version 3.21). Normality and equality of variance of data distribution was checked by means of the skewness and kurtosis (Zar, 2001). In cases where data was found not to follow normal distribution (heteroscedastic), log (x+1) transformation was used to normalize all the biological data (Michael & Douglas, 2004) prior to statistical analyses.

Wetland's use and management as well as the species composition data were analyzed through frequency distribution, percentage frequencies and chi-square (χ^2). Differences in the physico-chemical variables (temperature, pH, conductivity, DO and the nutrients) among sites were analyzed using a one-way ANOVA followed by Tukey multiple *post hoc* comparisons of the means where there were significant differences. Differences in both spatial and temporal variability were analyzed by Two-way ANOVA. Where there were no significant differences, data were pooled and one-way ANOVA used to test for spatial differences followed by Tukey multiple *post hoc* comparisons of the means.

Spatial differences in the macrophytes and macroinvertebrates were analyzed using One-way ANOVA followed by Tukey multiple *post hoc* comparisons of the means where there were significant differences. Differences in macroinvertebrate community (abundance, richness, diversity, %OC, % EPT and % FFG) were also analyzed using One-way ANOVA. All results were declared significant at $p < 0.05$. Macroinvertebrates community structure was described in terms of taxon richness, abundance and community indices. Species occurrence (presence-absence) and distribution data were summarized for each study site and means calculated for each site using the number of taxa (S) and the total relative abundances. Relative abundance was calculated as follows;

Relative Abundance (%) = $Isi/\sum Nsi \times 100$ Equation 6
Where, Isi = Total Number of individual spp;
$\sum Nsi$ = Total Number of species population.

Several reach-scale diversity indices were calculated for each study site. Shannon's diversity index (H′) was derived as a measure of diversity (Magurran, 2004), and an associated H′/H′max index (Pielou, 1975) was used as a measure of evenness. Shannon Weiner diversity index was calculated as below:

$$H' = -\sum_{i=1}^{s} p_i \ln p_i$$ …………Equation 7

Where:H' = Shannon's diversity index

Pi = The abundance of the i^{th} species expressed as a proportion of the total macroinvertebrates

n = Number of species ln = Natural logarithm

The reciprocal form of the Simpson index (1-Ds) (Simpson, 1949) was used as a measure of species richness. Hill's number (i.e., gamma diversity; Hill, 1973) and Fisher's alpha (Fisher *et al.*, 1943) were used as extra measures of macroinvertebrates diversity. Hill's number was calculated as the ratio between H′ and 1/D (Hill, 1973).

Margalef's species richness index was also determined as an extra measure of taxon richness.

The average rank similarities of macroinvertebrate assemblages were compared among sites using one-way analysis of similarities (ANOSIM). ANOSIM calculates the R- statistic, which is a test statistic that varies between 0 and 1; higher values indicate bigger differences between factors.

Similarity percentages analysis (SIMPER) was performed to establish which key macroinvertebrates were accountable for the variations observed between sites (indicator macroinvertebrates for changes in human activities and water quality). The percentage contribution of the macroinvertebrates to the overall dissimilarity was quantified between sites. SIMPER is a restrictive pairwise analysis between two factor levels (Clarke & Warwick, 2001), and in this case, comparisons were done between Kesses and Kiptenden, Kesses and Kingwal, and finally between Kesses and Kimondi study sites.

The responsiveness of the metrics to disturbance was evaluated using linear regression analysis with human disturbance scores. Before performing any analyses, Arcsin-square root transformations normalized the metrics calculated as proportions. The generic richness and count data M-IBI scores were log10 (x+1) transformed prior to analysis. Socio-economic survey of wetland uses and management

CHAPTER FOUR

RESULTS

4.1. Physico-chemical properties and nutrients of the water in King'wal Wetland

A summary of the analyzed physico-chemical water quality variables of the four study sites within the King'wal Wetland is presented in Table 4.9. All the physico-chemical water quality variables displayed significant ($p < 0.05$) spatial variations. The water pH ranged from 5.1 to 7.7 and was highest at King'wal Bridge (7.72), followed by Kiptenden (6.90) and lowest in Kesses (6.07). The concentration of DO decrease downstream, in contrast to the trends for the BOD. Kesses recorded the highest DO levels (8.29 mg L^{-1}) and lowest BOD (2.44) while King'wal Bridge recorded the lowest DO levels (3.04 mg L^{-1}) and highest BOD levels (7.44) (Table 4.9). The conductivity measured in the water was highest at King'wal Bridge (182.3 µS cm^{-1}) while at Kesses conductivity values were the lowest (98.2 µS cm^{-1}). The Total nitrogen (TN) (2.72 mg L^{-1}) and total phosphorus (TP) (2.08 mg L^{-1}) were significantly highest at King'wal Bridge and lowest upstream at Kesses (TN – 1.02 mg L^{-1} and PT – 0.76 mg L^{-1}) (Table 4.1).

Table 4.1: Selected physico-chemical attributes (Mean ± SE) of the water in the four study locations

	Sites					
Parameter	Kesses	Kiptenden	King’wal Bridge	Kimondi	F-values	*P*-value
pH	6.07 ± 0.25^{a}	6.90 ± 0.19^{b}	7.72 ± 0.10^{c}	6.71 ± 0.21^{b}	44.221	<0.001
Dissolved oxygen (mg L^{-1})	8.29 ± 1.3^{c}	6.88 ± 1.01^{b}	3.04 ± 0.63^{a}	3.42 ± 0.22^{a}	19.332	0.001
Biological Oxygen Demand (BOD)	2.44 ± 0.22^{a}	2.41 ± 0.33^{a}	7.44 ± 0.22^{c}	5.11 ± 0.32^{b}	9.443	0.008
Conductivity (µS cm^{-1})	98.2 ± 13^{a}	140.5 ± 15.9^{b}	182.3 ± 8.9^{d}	144.1 ± 3.8^{c}	35.23	0.002
Total nitrogen (TN) (mg L^{-1})	1.02 ± 0.41^{a}	1.71 ± 0.3^{b}	2.72 ± 0.2^{c}	1.11 ± 0.2^{a}	19.551	0.005
Total phosphorus (TP) (mg L^{-1})	0.76 ± 0.46^{a}	1.01 ± 0.42^{b}	2.08 ± 0.19^{c}	1.23 ± 0.08^{b}	16.992	0.005

[1] Means with the same letters as superscripts are not significantly different ($p > 0.05$).

[2] SE: Standard Error of the mean.

During the entire study period, the pH was higher in King'wal and demonstrated significant ($p < 0.05$) spatio-temporal variations increasing to a peak in April to May and was low during the June-July-August period. The pH in Kesses was acidic (6.07) among all the sampling sites and displayed significant Spatio-temporal variation ($p < 0.05$) increasing to the highest values between March-April-May period and then reduced for the other part of the season. The concentration of pH in Kiptenden and Kimondi were intermediate between Kesses and King'wal and displayed significant Spatio- temporal variations (F = 23.123, $P < 0.05$) being highest in May (Figure 4.2).

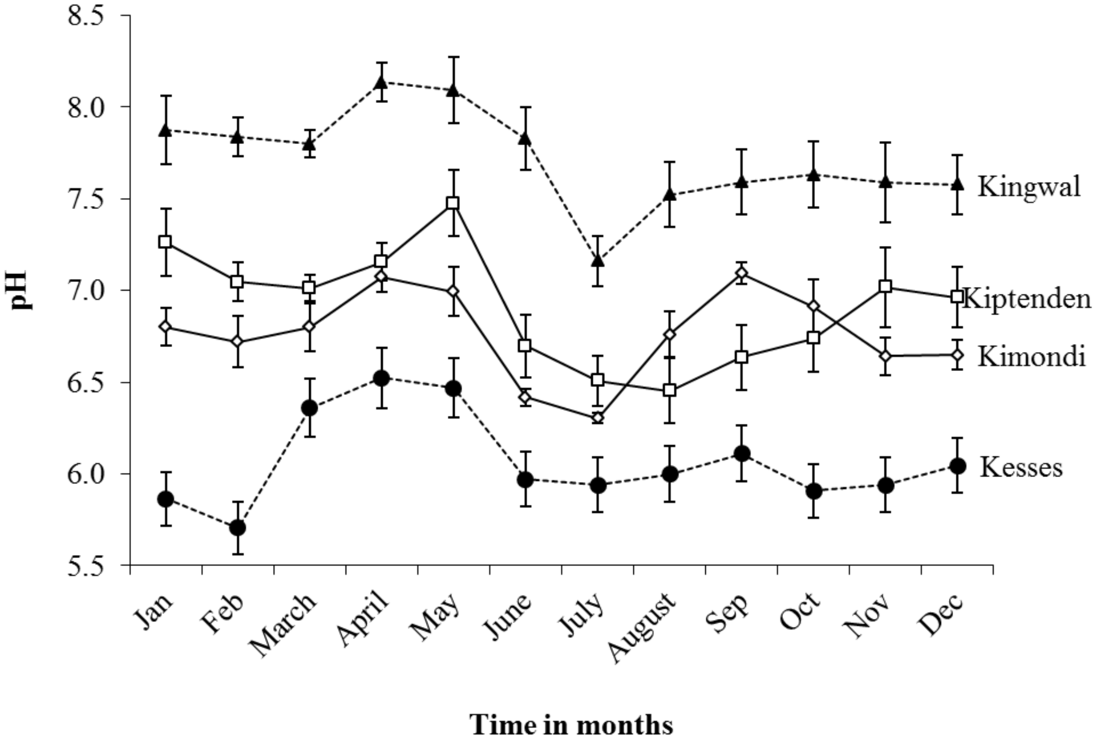


Figure 4.1: Spatio-temporal variation of water pH at Kesses, Kiptenden, King'wal Bridge and Kimondi along King'wal swamps between January and December 2011

Significant (F = 8.9232, $p = 0.0025$) temporal variations in surface water conductivity were recorded in Kesses, Kiptenden and King'wal Bridge but not in Kimondi

(Figure 4.2) and was generally lowest from July to December in all sites. However, from January to April, higher conductivities were recorded in all the study sites, except in Kimondi (Figure 4.1).

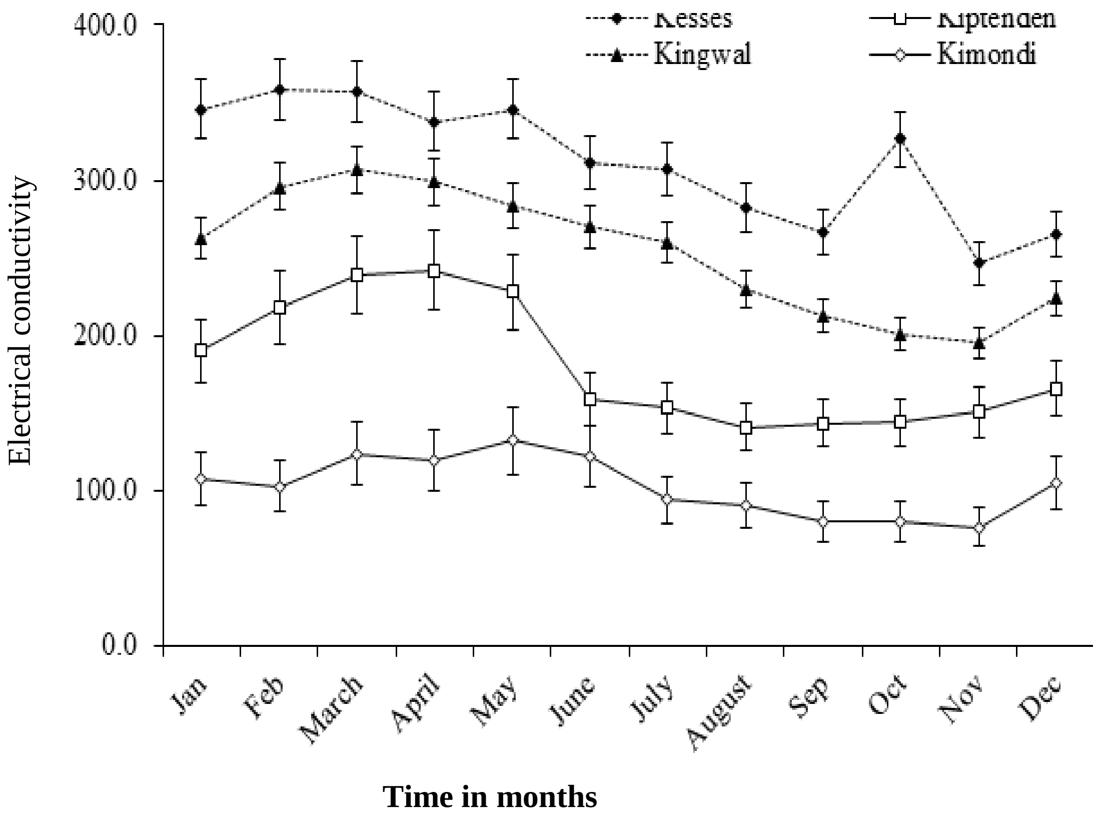


Figure 4.2: Spatio-temporal variation in electrical conductivity among Kesses, Kiptenden, King'wal Bridge and Kimondi sites within King'wal wetland

There were significant (F = 7.9732, *p* = 0.0002) temporal differences in DO among the sites except Kesses and King'wal Bridge (Figure 4.10). The widest fluctuation of DO was recorded in Kimondi Swamp, where higher DO occurred between May and August and lowest DO being in September and October (Figure 4.3).

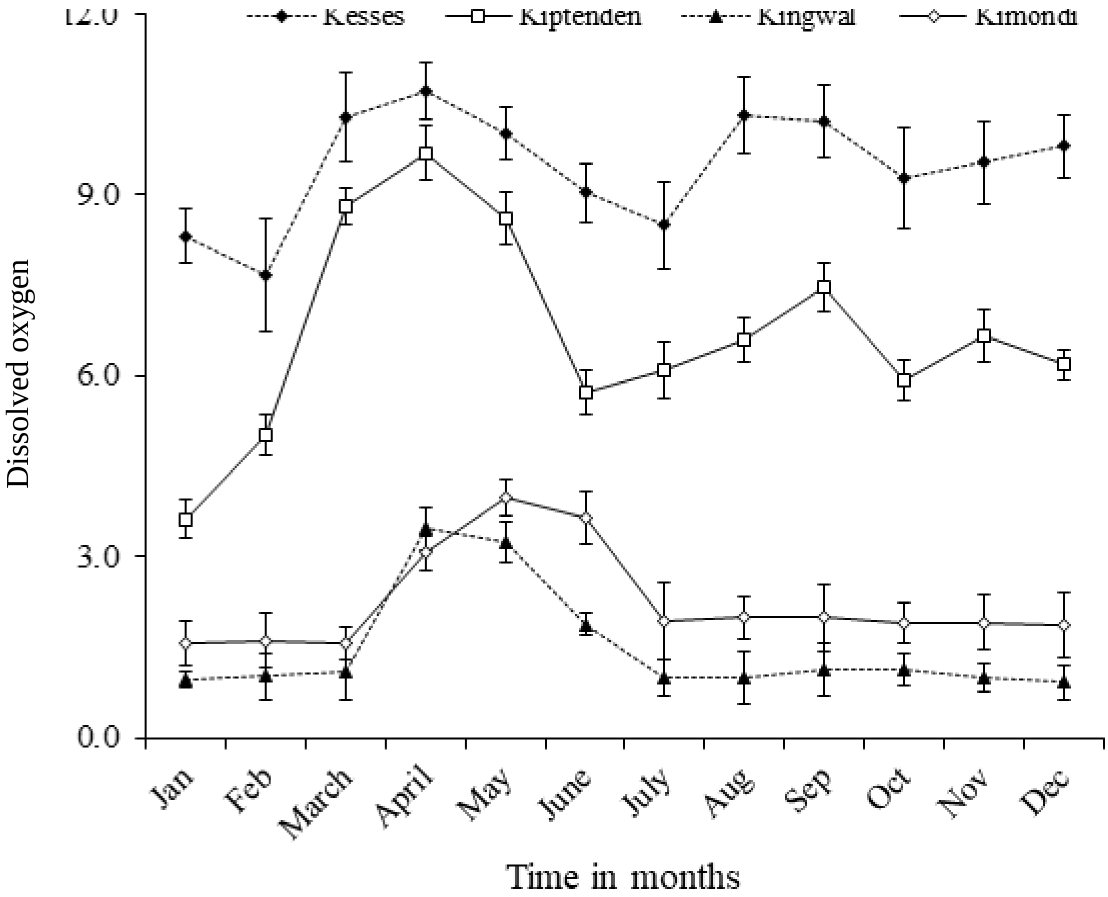
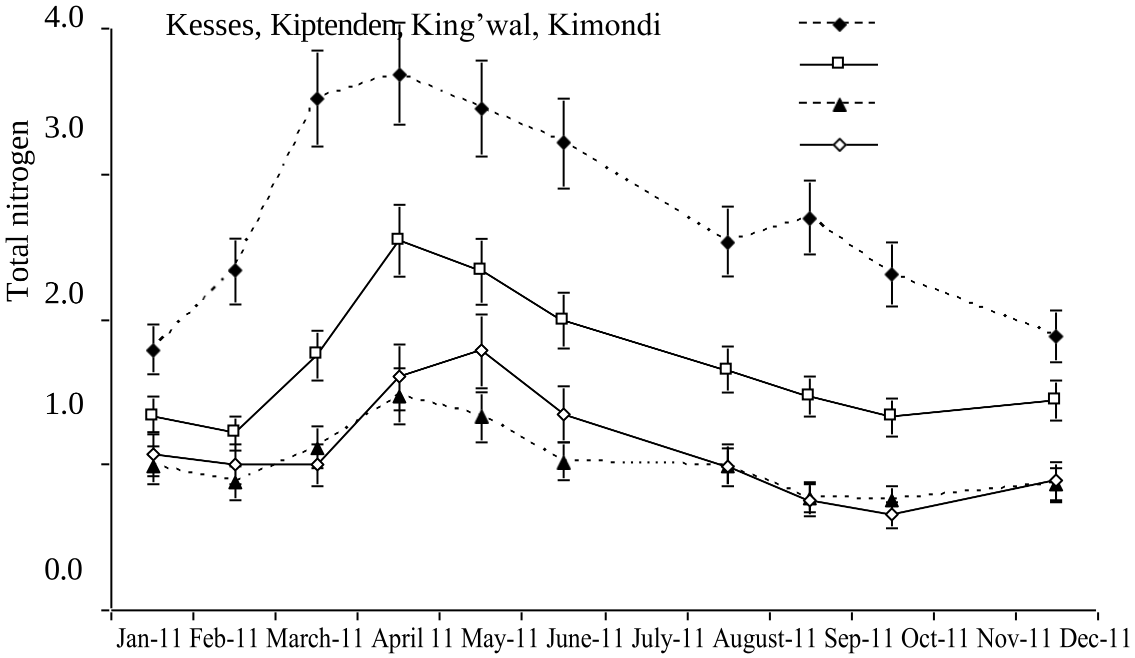


Figure 4.3: Spatio-temporal variation in dissolved oxygen (DO) among the Kesses, Kiptenden, King'wal Bridge and Kimondi Swamps between January and December

The concentration of Total Nitrogen (TN) in water was significantly different (F = 34.5343, *P* = < 0.001) between the sites (Figure 4.). In Kiptenden, TN was higher between January and August. King'wal Bridge on the other hand, maintained a high concentration between January and August. In Kesses, TN concentration was only high in April but lower in other months of the year (Figure 4.4).



Time in months

Figure 4.4: Spatio-temporal variation of Total nitrogen (TN) at Kesses, Kiptenden, King'wal Bridge and Kimondi sites between January and December

The concentration of total phosphorus (TP) in water differed significantly (F = 11.2321, p = 0.0001) during the sampling periods. Overall trends of TP in water were a general increase from January to December. However, Kingwal Bridge showed deviation from this trend from August to December. In Kimondi, decline in TP between January and April was preceded by a significant increase in this nutrient between April and December. In Kingwal Bridge, the concentration of TP was lowest between January and April but increased in the month of August (Figure 4.5).

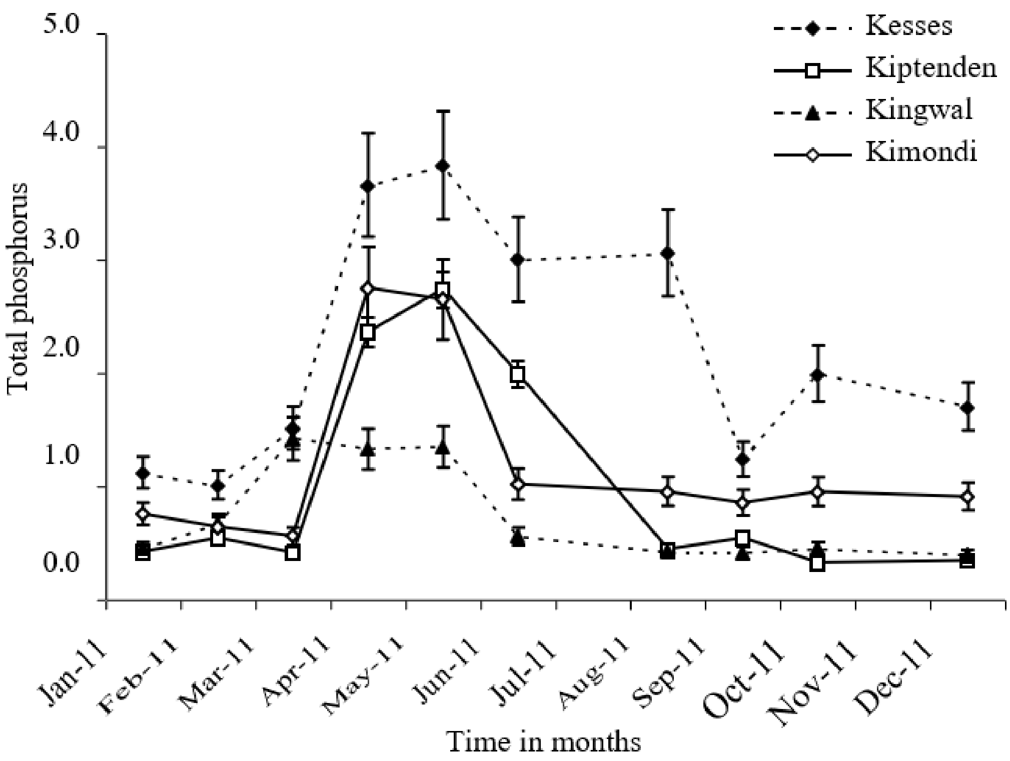


Figure 4.6: Spatio-temporal variation of Total Phosphorus (TP) at the Kesses, Kiptenden, King'wal Bridge and Kimondi sites between January and December

4.2 Species distribution and diversity of wetland macrophytes in Kingwal Wetland

A checklist of all floral species identified in Kesses together with their nomenclatural authorities are shown in Table 4.2. There was a total of 20 plant species belonging to 12 families and 8 habits. ~~T~~he number of species exhibited a marked significant difference among the families (χ^2 = 49.2, df = 11, *p* = 0.0001). Families with the highest number of species were Asteraceae (4 species), Poaceae (4 species) and Polygonaceae (3 species). Eight families had only one representative species (Table 4.10).

Table 4.2: Flora species of Kesses site, Nandi County between January and December 2011

Habit	Family	Species and nomeclatural authority
Algae	Chlorophyceae	Spyrogyra mirabilis (Hassall) Kützing.
	Hydrocharitaceae	*Elodea densa* (Planch) Casp.
Climbers	Convolvulaceae	Ipomoea tenuilostris Choisy.
Cimber/creeper	Pappilionaceae	Rhynchosia minima (L.) DC.
		Aeschenomene abyssinica (A.Rrich.) Vatke
Creeper	Acanthaceae	Dyschoriste randicans Nees
	Convolvulaceae	Dichondra repens J.R. & G. Forst.
Erect herbs	Asteraceae	Ageratum conyziodes L.
		Bidens pilosa L.
		Conyza stricta Willd.
		Vernonia syringifolia O. Hoffm.
Perennial herb	Polygonaceae	Polygonum amphibium L.
		Polygonum pulchrum Blume.
		Polygonum salicifolia Willd.
Grasses	Poaceae	Leersia hexandra SW.
		Panicum hymeniochilum Nees.
		Panicum poaeoides Stapf.
		Paspalum scrobiculatum L.
Succulent herb	Commelinaceae	*Floscopa glomerata* (Schult & Schult.f.) Hassk.
Sedges	Cyperaceae	Cyperus papyrus L.

A total of 27 plant species belonging to 16 families were recorded at Kiptenden (Table 4.3). The number of species exhibited a significant difference among the families (χ^2 = 169.2, df = 15, p < 0.001). This wetland was dominated by three families; Asteraceae (6 species), Cyperaceae (5 species) and Poaceae (4 species). The three families contributed 40% of the overall species composition in the wetland. Twelve (12) families were represented by only a single species (Table 4.3).

Table 4.3: Flora of Kiptenden, Nandi County between January and December 2011

Habit	Family	Species and nomeclatural authority
Algae	Chlorophyceae	*Spyrogyra mirabilis* (Hassall) Kützing.
Creepers	Acanthaceae	*Dyschoriste randicans* Nees
	Apiaceae	*Centella asiatica* (L.) Urb.
	Convolvulaceae	*Dichondra repens* J.R. & G. Forst.
Cimber/creeper	Acanthaceae	*Justicia anselliana* (Nees.) T.Anders.
Erect herbs	Asteraceae	*Conyza stricta* Willd., *Conyza suscaposa* O. Hoffm., *Crassocephalum picridifolium* (Dc.) S. Moore., *Emilia integrifolia* Bak., *Helichrysum forskahlii* (J.F.Gmell) Hilliard & Butt, *Helichrysum newii* Oliv & Hiern, *Carduus nyassanus* (R.E.Fries) C. Jeffrey
	Solanaceae	*Solanum incanum* L.
	Lamiaceae	*Pycnostachys stulmanii* Gueke
Grasses	Poaceae	*Digitaria scalarum* (Schweinf.) Chiov., *Eragrostis chalarothyrsus* C.E. Hubbard., *Leersia hexandra* SW., *Panicum poaeoides* Stapf.
Rooted floating herb	Potamogetonaceae	*Aponogeton stulmanii* Engl
Succulent herb	Commelinaceae	*Commelina africana* L., Floscopa glomerata (Schult & Schult.f.) Hassk.
	Crassulaceae	*Kalanchoe lanceolata* (Forsk.) Pers.
Sedges	Cyperaceae	*Cyperus papyrus* L., *Cyperus rigidifolius* Steud, *Cyperus* sp, *Cyperus* sp b, *Kyllinga breviflora* (Standl) Munz
Succulent herb	Euphorbiaceae	*Phyllanthus sepialis* (Muell.arg).
	Scrophulariaceae	*Alectra sessiliflora* (Vatke) Kuntze

A total of 58 plant species belonging to 33 families were recorded at Kingwal Bridge (Table 4.4). The number of plant species exhibited a marked significant difference among the families ($\chi^2 = 133.2$, df = 32, $p < 0.001$). The species composition of this wetland was dominated by 3 families; Poaceae (9 species), Asteraceae (7 species) and Cyperaceae (6 species). These three families contributed 12% of the overall species composition in the wetland (Table 4.4).

Table 4.4: Flora of Kingwal Bridge site, Nandi County between January and December 2011

Habit	Family	Species
Algae	Chlorophyceae	Spyrogyra mirabilis (Hassall) Kützing.
Shrub	Rosaceae	Rubus apetala Poir.
Creepers	Acanthaceae	Dyschoriste randicans Nees
	Apiaceae	Centella asiatica (L.) Urb.
	Asteraceae	Acmella calirhiza Del.
	Convolvulaceae	Dichondra repens J.R. & G. Forst.
	Pappilionaceae	Trifolium burchellianum Ser., Trifolium lugardii Bullock.
	Rosaceae	Alchemilla rothii Oliv.
	Rubiaceae	Oldenlandia goorensis (DC.) Summerhayes
	Violaceae	Viola abyssinica Oliv.
CR/EH	Acanthaceae	Justicia anselliana (Nees.) T. Anders.
DSH/EH	Asclepiadaceae	Gomphocarpus semilunatus A.Rich.
	Asteraceae	Bidens pilosa L., Conyza floribunda H.B.K., Conyza stricta Willd. Crassocephalum picridifolium (Dc.) S. Moore., Emilia integrifolia Bak., Helichrysum forskahlii (J.F.Gmell) Hilliard & Butt, Helichrysum schimperi Sch. Bip.
	Lamiaceae	Plectranthus edulis (Vatke) Agnew, Pycnostachys deflexifolia Bak., Pycnostachys stulmanii Gueke
	Melastomataceae	Dissotis senegambensis (Guill) & Perr
	Polygonaceae	Polygonum pulchrum Blume., Polygonum salicifolia Willd., Polygonum setosulum A.Rich., Polygonum strigosum R.Br.
EH/SH	Asteraceae	Guizortia scabra (Vis.) Chiov.
Grasses	Poaceae	Andropogon abyssinica, Digitaria scalarum (Schweinf.) Chiov., Echinochloa pyramidalis (Lam.) Hitch & Chase., Eragrostis chalarothyrsus C.E. Hubbard., Leersia hexandra SW., Panicum hymeniochilum Nees., Panicum poaeoides Stapf., Paspalum scrobiculatum L., Themeda triandra

		Forssk.
Rooted floating herb	Nymphaeaceae	Nymphaea nouchalii Burm.f.
	Potamogetonaceae	Aponogeton stulmanii Engl., Potamogeton schweinfurthii A. Bennett
RH	Asteraceae	Crepis carbonaria Sch. Bip
SBH	Lentibulariaceae	Utricularia prehensilis E.Mey
SCH	Commelinaceae	Commelina africana L., Floscopa glomerata (Schult & Schult.f.) Hassk.
	Crassulaceae	Kalanchoe lanceolata (Forsk.) Pers.
SD	Cyperaceae	Cyperus papyrus L., Cyperus rigidifolius Steud, Cyperus spp., Kyllinga bulbosa P.Beauv., Pycreus nitidus Lam., Schoenoplectus corymbosus (Roem & Schult.) J. Rayn
	Typhaceae	Typha domingensis Pers.
SH	Asteraceae	Carduus nyassanus (R.E.Fries) C. Jeffrey, Vernonia lasiopus O.Hoffm.
	Euphorbiaceae	Phyllanthus sepialis Muell.arg.
	Lamiaceae	Geniosporum rotundifolium Briq.
	Orchidaceae	Disperis reichenbachiana Reichb.
	Rubiaceae	Spermacose princei (K. Schum) Verdc

There were 52 plants species belonging to 28 families recored atKimondi (Table 4.13). The number of species exhibited a marked significant difference among the families ($\chi^2 = 87.212$, df = 44, $P < 0.001$). Four families, Asteraceae (7 species), Poaceae (7 species), Polygonaceae (5 species) and Cyperaceae (5 species) dominated this site (Table 4.5). The four families contributed 41% of the overall species composition of the wetland. A total of 19 families were represented by a single species only (Table 4.5).

Table 4.5: Flora of Kimondi swamp, Nandi County between January and December 2011

Habit	Family	Species and nomeclatural authority
Algae	Chlorophyceae	Spyrogyra mirabilis (Hassall) Kützing.
CL	Convolvulaceae	Ipomoea tenuilostris Choisy.
	Menispermaceae	*Stephania abyssinica* (Dillon & A.Rich.) Walp.
	Rosaceae	Rubus apetala Poir., Rubus steudneri Schweinf.
CL/CR	Pappilionaceae	Rhynchosia minima (L.) DC.
	Apiaceae	Centella asiatica (L.) Urb.
	Caesalpiniaceae	Chamaecrista mimosoides (L.) Greene.
	Convolvulaceae	Dichondra repens J.R. & G. Forst.
	Oxallidaceae	Oxalis corniculata L.
	Pappilionaceae	Trifolium cryptopodium A.Rich
DSH	Malvaceae	Sida cuneifolia Roxb.
EH	Amaranthaceae	Achyranthes aspera L.
	Asteraceae	Ageratum conyziodes L., Conyza floribunda H.B.K., Conyza gouanii L. Willd., Conyza suscaposa O. Hoffm., Helichrysum newii Oliv & Hiern., Sphaeranthus suaveolens (Forsk.) DC., Vernonia syringifolia O. Hoffm.
	Polygonaceae	Polygonum amphibium L., P. pulchrum Blume., P. P. senegalensis Meisn., P. setosulum A.Rich., P. strigosum R.Br.
FFH	Araceae	Pistia stratiotes L.
Grasses	Poaceae	Chloris pycnothrix, Digitaria scalarum (Schweinf.) Chiov., Leersia hexandra SW., Panicum hymeniochilum Nees., Panicum poaeoides Stapf., Paspalum scrobiculatum L., Setaria annua Chiov.
Rooted floating herb	Nymphaeaceae	Nymphaea nouchalii Burm.f.

	Potamogetonaceae	Potamogeton schweinfurthii A. Bennett
SCH	Commelinaceae	Commelina africana L., Commelina beghalensis L., *Floscopa glomerata* (Schult & Schult.f.) Hassk.
SD	Cyperaceae	Cyperus alternifolius L., Cyperus papyrus L., Kyllinga bulbosa P.Beauv., Pycreus nitidus Lam., Schoenoplectus corymbosus (Roem & Schult.) J. Rayn
	Typhaceae	Typha domingensis Pers.
SH	Asteraceae	Aspilia mossambiscensis (Oliv.) Willd.
	Euphorbiaceae	Phyllanthus sepialis Muell.arg.
	Solanaceae	Solanum incanum L.
SH/TR	Cerastraceae	Maytenus senegalensis (Lam.) Exell.
	Myrsinaceae	Maesa lanceolate
	Pappilionaceae	Aeschenomene abyssinica (A.Rrich.) Vatke, Sesbania sesban (L.) Merrill
	Rubiaceae	Spermacose princei (K. Schum) Verdc.

The plant species that were common in the four sampling locations are presented in (Table 4.6). A total of 6 habits, 8 families and 10 species commonly occurred across all the swamps. Among the 7 families, only Poaceae was represented by 2 species (*Leersia hexandra,* and *Panicum poaeoides*). Most of the species were creepers with three families (Acanthaceae, Convolvulaceae and Asteraceae) and three species (*Dyschoriste randicans, Dichondra repens* and *Conyza stricta*) (Table 4.6).

Table 4.6: Species common to the four sampling sites at the Kesses, Kiptenden, Kingwal Bridge and Kimondi between January and December 2011

Habit	Family	Species and nomeclatural authority
Algae	Chlorophyceae	Spyrogyra mirabilis (Hassall) Kützing.
Climbers	Convolvulaceae	Ipomoea tenuilostris Choisy.
Creeper	Acanthaceae	Dyschoriste randicans Nees
	Convolvulaceae	Dichondra repens J.R. & G. Forst.
	Asteraceae	Conyza stricta Willd.
		Eragrostis chalarothyrsus C.E. Hubbard. Grass
Grasses	Poaceae	Leersia hexandra SW.
		Panicum poaeoides Stapf.
Succulent herb	Commelinaceae	*Floscopa glomerata* (Schult & Schult.f.) Hassk.
Sedges	Cyperaceae	Cyperus papyrus L.

4.3 Macroinvertebrate assemblages and IBI of wetland ecological integrity

4.3.1 Spatial distribution of macroinvertebrate assemblages in King'wal Wetland

The macroinvertebrate distribution in the sampling locations of King'wal Wetland is provided in Table 4.7. A total of 11 orders, 34 families and 40 genera were collected from the four study sites (Table 4.15). Macroinvertebrate species richness was found to be highest upstream at Kesses with 26 taxa, followed by King'wal Bridge and Kimondi with 25 taxa each while Kiptenden recorded the least number of taxa (19 taxa) (Table 4.15). Of the 40 genera recorded, only 14 (*Lymnaea* sp.*, Physa sp., Planorbis* sp., *Gyrinus* sp., *Chironomus., Simulium., Baetis* sp., *Caenis* sp., *Heptagenia* sp., *Corixa* sp., *Gerris* sp., *Lestes sp.*, *Pyrrhosoma* sp., and *Hydropsyche* sp.) were present in all the sites (Table 4.15). A total of 11 taxa (*Phymata sp., Yola sp., Hydaticus sp., Dineutus* sp., *Tipula* sp., *Afrocaenis* sp., *Ephemeralla* sp., *Adenophlebia* sp., *Plea sp., Notonecta* sp., and *Neoperla* sp.) were each recorded only in a single site (Table 4.7).

Table 4.7: Distribution in terms of presence (+)/absence (-) of various genera of macroinverterbrates at the Kesses, Kiptenden, King'wal Bridge and Kimondi between January and December 2011

Order	Family	Genera	Kesses	Kiptenden	Kingwal Bridge	Ki'mondi
Pulmonata	Lymnaeidae	Lymnaea	+	+	+	+
	Physidae	Physa	+	+	+	+
		Phymata	-	-	+	-
	Thiaridae	Melanoides	+	-	-	-
	Planorbidae	Planorbis	+	+	+	+
Coleoptera	Dytiscidae	Yola	-	-	+	-
		Cybister	+	+	-	-
		Hydaticus	-	+	-	-
	Gyrinidae	Dineutus	+	-	-	-
		Gyrinus	+	+	+	+
	Haliplidae	Haliplus	-	-	+	+
	Noteridae	Hydrocanthus	+	+	-	+
Diptera	Tabanidae	Tabanus	-	-	+	+
	Chironomidae	Chironomus	+	+	+	+
	Tipulidae	Tipula	+	-	-	-
	Simuliidae	Simulium	+	+	+	+
Ephemeroptera	Baetidae	Baetis	+	+	+	+
	Caenidae	Caenis	+	+	+	+
		Afrocaenis	+	-	-	-
	Heptageniidae	Africanas	+	+	+	+
	Ephemerallidae	Ephemeralla	-	+	-	-
	Leptophlebiidae	Adenophlebia	+	-	-	-
Hemiptera	Corixidae	Corixa	+	+	+	+
	Gerridae	Gerris	+	+	+	+
	Hydrometridae	Hydrometra	-	-	+	+
	Mesoveliidae	Mesovelia	-	-	+	+
	Notonectidae	Notonecta	-	-	-	+
	Pleidae	Plea	-	-	+	-
Bivalvia	Sphaeriidae	Sphaerium	+	-	+	-
Odonata	Lestidae	Lestes	+	+	+	+
	Cordulegaste	Cordulegaster	+	-	-	+

	ridae					
	Gomphidae	Gomphus	+	+	-	+
	Coenagrionidae	Pyrrhosoma	+	+	+	+
		Enallagma	+	-	-	+
Trichoptera	Hydropsychidae	Hydropsyche	+	+	+	+
	Leptoceridae	Triaenodes	+	-	-	-
Plecoptera	Nemouridae	Nemouridae	+	+	-	-
	Perlidae	Neoperla	+	-	-	-
Oligochaeta	Lumbriculidae	Lumbricus	+	-	+	+
Decapoda	Potamonautidae	Potamonautes	+	-	+	+

Abundance of the various macroinverbrates sampled during the study is provided in Table 4.8. A total of 4407 macroinvertebrate individuals were collected during the study period. Kruskall-Wallis test revealed significant differences in the abundance of the macroinvertebrate assemblages among the study sampling sites (H = 7.987, df = 3, p = 0.0193). The upstream Kesses site had the highest abundance of macroinvertebrates (1896 individuals) and the abundance decreased downstream from Kesses to Kimondi with Kimondi recording the least abundance (680 individuals) (Table 4.8).

Table 4.8: Taxa occurrence and distribution of macroinvertebrates at the Kesses, Kiptenden, King'wal Bridge and Kimondi between January and December 2011

Order	Family	Genera	Kesses	Kiptenden	Kingwal Bridge	Kimondi	Total
Pulmonata	Lymnaeidae	Lymnaea	61	134	5	16	216
	Physidae	Physa	79	126	68	26	299
		Phymata	0	0	5	0	5
	Thiaridae	Melanoides	78	0	0	0	78
	Planorbidae	Planorbis	233	68	54	71	426
Coleoptera	Dytiscidae	Yola	0	0	30	0	30
		Cybister	5	37	0	0	42
		Hydaticus	0	71	0	0	71
	Gyrinidae	Dineutus	52	0	0	0	52
		Gyrinus	12	5	15	32	64
	Haliplidae	Haliplus	0	0	14	9	23
	Noteridae	Hydrocanthus	24	18	0	10	52
Diptera	Tabanidae	Tabanus	0	0	6	41	47
	Chironomidae	Chironomus	254	102	101	132	589

	Tipulidae	Tipula	9	0	0	0	9
	Simuliidae	Simulium	78	54	48	44	224
Ephemeroptera	Baetidae	Baetis	89	14	5	18	126
	Caenidae	Caenis	79	23	9	38	149
		Afrocaenis	54	0	0	0	54
	Heptageniidae	Heptagenia	7	9	6	9	31
	Ephemerallidae	Ephemeralla	0	11	0	0	11
	Leptophlebiidae	Adenophlebia	18	0	0	0	18
Hemiptera	Corixidae	Corixa	15	16	102	7	130
	Gerridae	Gerris	53	77	27	61	218
	Hydrometridae	Hydrometra	0	0	5	5	10
	Mesoveliidae	Mesovelia	0	0	5	15	20
	Notonectidae	Notonecta	0	0	0	18	18
	Pleidae	Plea	0	0	19	0	19
Bivalvia	Sphaeriidae	Sphaerium	64	0	104	0	168
Odonata	Lestidae	Lestes	204	75	28	11	318
	Cordulegasteridae	Cordulegaster	69	0	0	5	74
	Gomphidae	Gomphus	65	39	0	13	117
	Coenagrionidae	Pyrrhosoma	99	97	31	39	266

		Enallagma	26	0	0	7	33
Trichoptera	Hydropsychidae	Hydropsyche	104	95	23	5	227
	Leptoceridae	Triaenodes	4	0	0	0	4
Plecoptera	Nemouridae	Nemouridae	24	18	0	0	42
	Perlidae	Neoperla	12	0	0	0	12
Oligochaeta	Lumbriculidae	Lumbricus	13	0	21	33	67
Decapoda	Potamonautidae	Potamonautes	12	0	11	15	38
		Totals	1896	1089	742	680	

The total abundance of each order of the benthic macroinvertebrates in King'wal Wetland during the study is shown in Figure 4.7. There were significant differences in the abundance of macroinvertebrates orders (H = 17.907, df = 10, *p* = 0.006). Order Pulmonata (1024), Diptera (869) and Odonata (808) recorded the highest number of individuals while Oligochaeta (67), Plecoptera (54) and Decapoda (38) recorded the least number of individuals (Figure 4.13).

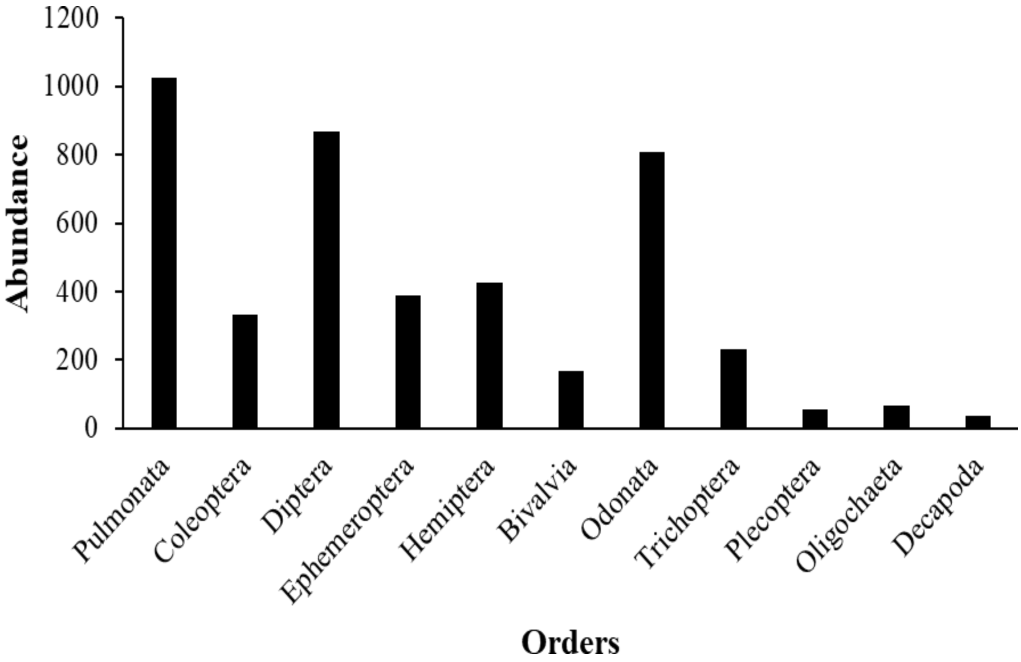


Figure 4.7: Total abundance of macroinvertebrate orders recorded during the study period

Higher abundance of Plecoptera was recorded at Kesses (67%) and Kiptenden (33%) (Figure 4.8). Similarly higher proportion of Trichoptera (41.1%) and Coleoptera (39%) were recorded at Kiptenden site (Figure 4.14). Bivalvia (62%) and Hemiptera (37%) recorded the highest proportions at King'wal while Oligochaetes (47.3%) and Diptera (38.2%) were recorded in high proportion at Kimondi (Figure 4.8). These abundances were significantly different across the study sites (H = 5.1322, df = 3, *p* =

.0.002).

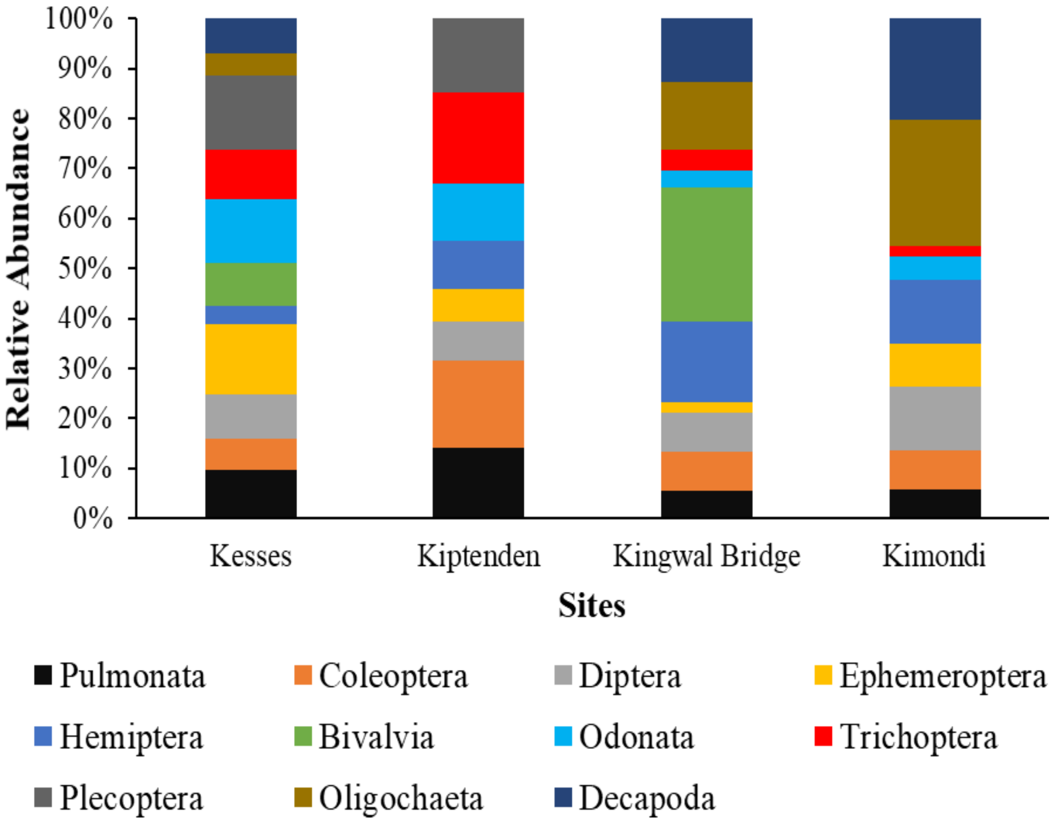


Figure 4.8: Relative abundance of macroinvertebrate orders recorded in the four study sites during the study period

The overall abundance of the percentage of oligochaetes and chironomids (%OC) relative to the total macroinvertebrate's abundance indicated that Kesses had the highest value followed by Kimondi then King'wal, while Kiptenden recorded the least proportion (Figure 4.9).

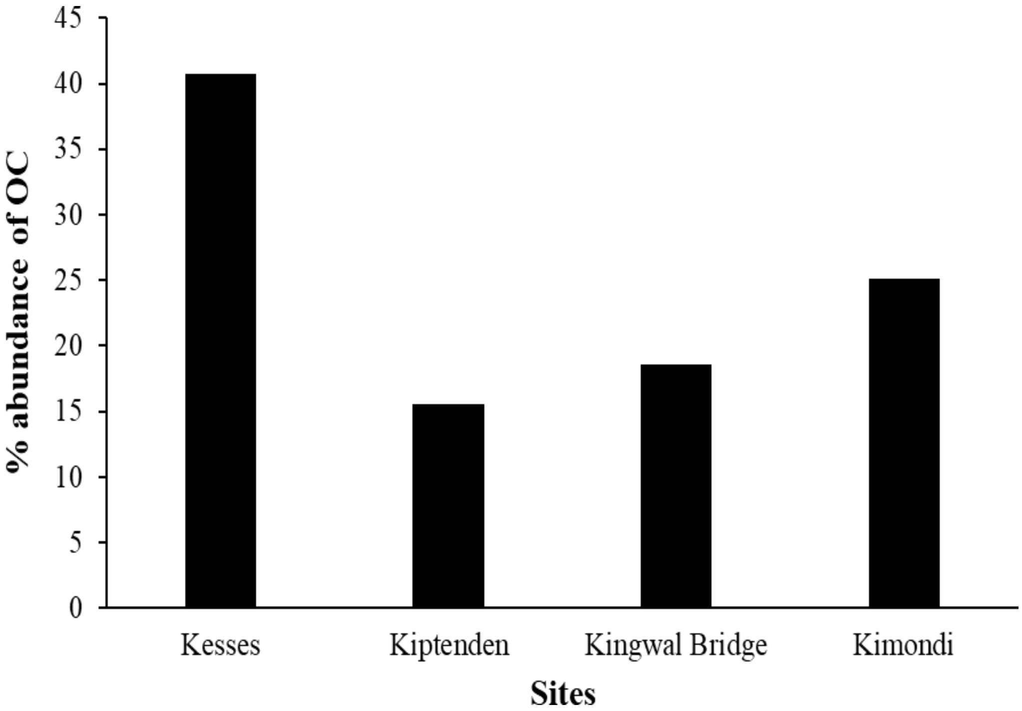


Figure 4.9: Relative abundance of Oligochaetes and Chironomids (% OC) at the Kesses, Kiptenden, Kingwal Bridge and Kimondi sites between January and December 2011

The overall percentage of Ephemeroptera, Plecoptera and Trichoptera (% EPT) was highest in Kesses and lowest in Kingwal and Kimondi sites (Figure 4.10). Only Kesses and Kiptenden recorded all the three taxa of EPT (Figure 4.16). Kesses and Kimondi were dominated by the Ephemeroptera taxa at 62% and 90% respectively. Kiptenden was dominated by Trichoptera (60%) (Figure 4.16). Kingwal site was co-dominated by both Ephemeroptera (50%) and Trichoptera (50%) (Figure 4.10).

The higher proportion of Trichoptera at Kiptenden was due to the abundant Hydropsychidae taxa collected at the site. Ephemeroptera taxa at King'wal and Kimondi sites was represented by only three taxa (Baetidae, Caenidae and Heptageniidae) while Trichoptera in all the sites other than Kimondi was represented by a single taxon (Hydropsychidae). Kimondi was represented by Hydropsychidae and Leptoceridae. A single taxon (Nemouridae) represented the Plecoptera in Kiptenden while Nemouridae and Perlidae were the two taxa that were present at Kesses (Figure 4.16).

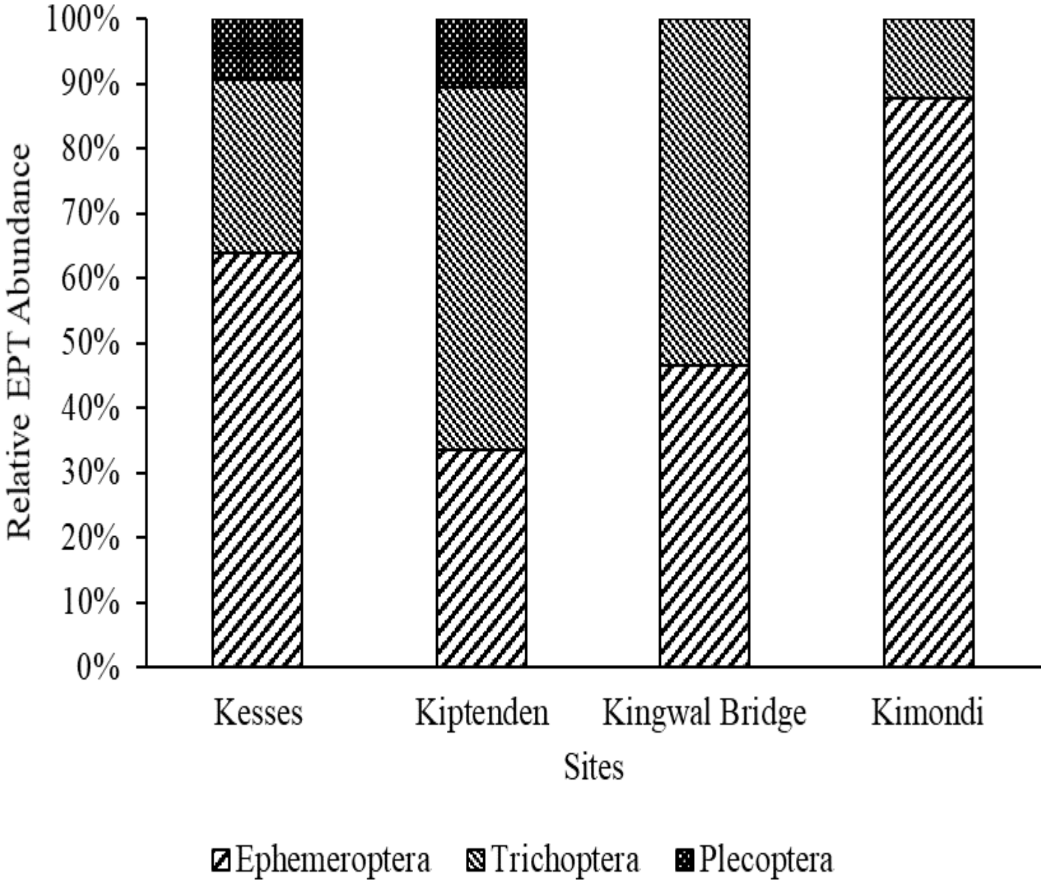


Figure 4.10: % EPT at Kesses, Kiptenden, King'wal Bridge and Kimondi between January to December 2011

The total abundance of each family of the benthic macroinvertebrates at the Kesses, Kiptenden, Kingwal Bridge and Kimondi between January and December 2011 is shown in Table 4.11. Families Chironomidae (589), Planorbidae (426) and Lestidae (318) recorded the highest abundance while Hydrometridae (10), Tipulidae (9) and Leptoceridae (4) recorded the lowest abundance (Table 4.9). Dytisadae, Hydropsychidae and Planorbidae were the most abundant in the macroinvertebrate families constituting over 8% of the macroinvertebrate abundance. The numeric abundance of Chironomidae, Planorbidae, Lestidae, Coenagrionidae, Simuliidae, Caenidae, Baetidae, Gomphidae, Gyrinidae, Thiaridae, Cordulegastridae, Leptophlebiidae, Perlidae and Tipulidae were significantly higher (Kruskall-Wallis; H = 43.2221, df = 3 p = 0.0001) in Kesses site compared to the other sites (Table 4.17).

Physidae, Gerridae, Lymnaeidae, Dytiscidae and Ephemerellidae were statistically higher in abundance in Kiptenden (Kruskall-Wallis; H = 15.987, df = 3, p = 0.0017). Sphaeriidae, Corixidae and Pleidae were the most dominant families in King'wal (Kruskall-Wallis; H = 5.987, df = 3, p = 0.0115). Meanwhile Kimondi was dominated with Lumbriculidae, Tabanidae, Mesoveliidae, Leptoceridae and Notonectidae (Table 4.9).

Table 4.9: Total abundance of each family of the benthic macroinvertebrates at Kesses, Kiptenden, Kingwal Bridge and Kimondi between January and December 2011

Family	Kesses	Kiptenden	Kingwal Bridge	Kimondi
Lymnaeidae	61	134	5	16
Physidae	79	126	73	26
Thiaridae	78	0	0	0
Planorbidae	233	68	54	71
Dytiscidae	5	108	30	0
Gyrinidae	64	5	15	32
Haliplidae	0	0	14	9
Noteridae	24	18	0	10
Tabanidae	0	0	6	41
Chironomidae	254	102	101	132
Tipulidae	9	0	0	0
Simuliidae	78	54	48	44

Baetidae	89	14	5	18
Caenidae	133	23	9	38
Heptageniidae	7	9	6	9
Ephemerallidae	0	11	0	0
Leptophlebiidae	18	0	0	0
Corixidae	15	16	102	7
Gerridae	53	77	27	61
Hydrometridae	0	0	5	5
Mesoveliidae	0	0	5	15
Notonectidae	0	0	0	18
Pleidae	0	0	19	0
Sphaeriidae	64	0	104	0
Lestidae	204	75	28	11
Cordulegasteridae	69	0	0	5
Gomphidae	65	39	0	13
Coenagrionidae	125	97	31	46
Hydropsychidae	104	95	23	5
Leptoceridae	4	0	0	0
Nemouridae	24	18	0	0
Perlidae	0	0	12	0
Lumbriculidae	13	0	21	33
Potamonautidae	12	0	11	15

Diversity indices used to measure community structure of macroinvertebrates at family level across the four study sites during the study period showed narrow ranges (Table 4.18). Shannon diversity index was higher (2.84) at Kesses while Kiptenden recorded the least diversity (2.65) (Table 4.18). Similarly, Kesses recorded the highest number of taxa (26) while Kiptenden recorded the least number of taxa (19). Simpson index (1/*Ds*) had higher values at Kesses site (0.93) and least at Kimondi site (0.91) (Table 4.10).

Pielou’s evenness index displayed slightly wider ranges with Kiptenden (0.74) recording the highest values while Kingwal Bridge (0.64) recorded the least value (Table 4.18). Similarly, Fisher’s alpha diversity showed widest range with the highest value (5.10) at Kimondi with again Kiptenden recording the least values (3.27) (Table 4.18).

Dominance followed the opposite trend as diversity index with the highest value (0.09) at Kingwal and Kimondi sites and the lowest value (0.07) at Kesses. Forested sites had the highest number of taxa (79 and 56) with mixed sites having the least taxa (62 and 27) during both seasons (Table 4.18). As Shannon diversity, gamma diversity also recorded the highest value at Kesses (4.84) but with the laest value being recorded at Kimondi (4.34) (Table 4.18).

Table 4.10: The diversity indices of macroinvertebrate communities at Kesses, Kiptenden, King'wal Bridge and Kimondi sites between January and December 2011

Diversity indices	Kesses	Kiptenden	King'wal Bridge	Kimondi
Taxa_S	26	19	25	25
Individuals	1896	1089	754	680
Dominance_D	0.07	0.08	0.09	0.09
Simpson_1-D	0.93	0.92	0.92	0.91
Shannon_H	2.84	2.65	2.77	2.82
Evenness_e^H/S	0.69	0.74	0.64	0.67
Margalef	3.18	2.57	3.62	3.68
Fisher_alpha	4.07	3.27	4.97	5.10
Hill's number (gamma diversity)	4.84	4.63	4.37	4.34

ANOSIM indicated significant differences in macroinvertebrate assemblages for un-transformed abundance data among sites (R-statistic = 0.21, $p < 0.012$). Abundance-based SIMPER's pair-wise comparison of Kesses site with Kiptenden site during the study period identified Planorbidae (12.45%) and Chironomidae (11.47%) to contribute the greatest dissimilarity between Kesses with Kiptenden sites, with higher abundance in Kesses (Table 4.19). Planorbidae (11.34%) and Lestidae (11.15%) contributed greatest dissimilarity between Kesses and Kingwal sites with higher abundance in Kesses (Table 4.11). Lestidae (13.24%) and Planorbidae (11.11%) accounted for greater dissimilarity between Kesses and Kimondi with higher abundance being recorded at Kesses (Table 4.11).

Table 4.11: Macroinvertebrates taxa-ranked abundance-based results of SIMPER analysis for mean abundance of macroinvertebrates at Kesses, Kiptenden, King’wal Bridge and Kimondi sites between January and December 2011

Taxon	Mean abundance Kesses	Mean abundance Kiptenden	% Contribution
Planorbidae	233	68	12.45
Chironomidae	254	102	11.47
Lestidae	204	75	9.74
Caenidae	133	23	8.30
Dytiscidae	5	108	7.77
Thiaridae	78	0	5.89
Baetidae	89	14	5.66
Lymnaeidae	61	134	5.51
Cordulegasteridae	69	0	5.21
	Mean abundance Kesses	Mean abundance King’wal Bridge	% Contribution
Planorbidae	233	54	11.34
Lestidae	204	28	11.15
Chironomidae	254	101	9.70
Caenidae	133	9	7.86
Coenagrionidae	125	31	5.96
Corixidae	15	102	5.51
Baetidae	89	5	5.32
Hydropsychidae	104	23	5.13
	Mean abundance Kesses	Mean abundance Kimondi	% Contribution
Lestidae	204	11	13.24
Planorbidae	233	71	11.11

Chironomidae	254	132	8.37
Hydropsychidae	104	5	6.79
Caenidae	133	38	6.52
Coenagrionidae	125	46	5.42
Thiaridae	78	0	5.35

4.3.2 Macroinvertebrate functional feeding groups (FFGs)

Five macroinvertebrates functional feeding groups (FFGs) collected in the study sites along the Kingwal Wetland were; scrapers, collector-gatherers (gatherers), collector-filterers (filterers), predators and shredders. Significant differences were recorded among the FFGs (Kruskall -Wallis; H = 9.378, df = 4, *p* = 0.0031). During the study period, predators (1668 individuals) were the most abundant, followed by scrapers (1192 individuals) while shredders were the least abundant (51 individuals) (Figure 4.11).

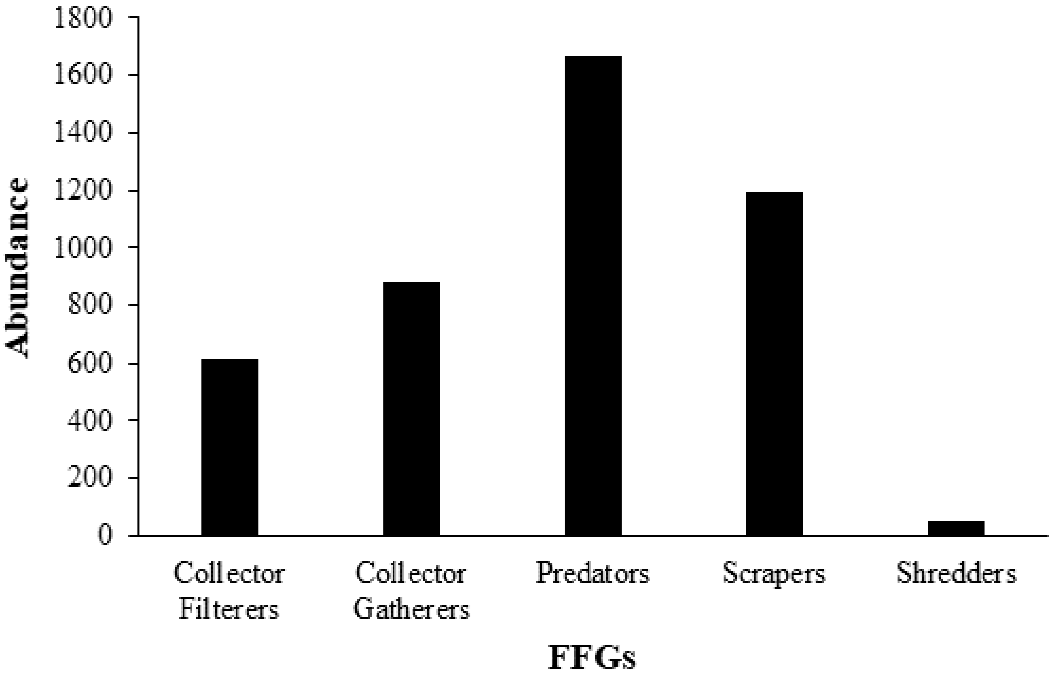


Figure 4.11: Abundance of macroinvertebrate functional feeding groups from the study sites recorded between January and December 2011

Shredder abundance (2.7%) was highest at Kesses while Predators numerical abundance dominated in all the sites and increased with increase in disturbance from Kesses to Kimondi (Figure 4.12). Scrapers were more abundant at Kiptenden and least at Kingwal sites (Figure 4.12). Collector gatherers were more abundant at Kimondi and least at Kiptenden (Figure 4.18). King'wal recorded the highest abundance of collector filterers while Kimondi recorded the least abundance (Figure 4.18).

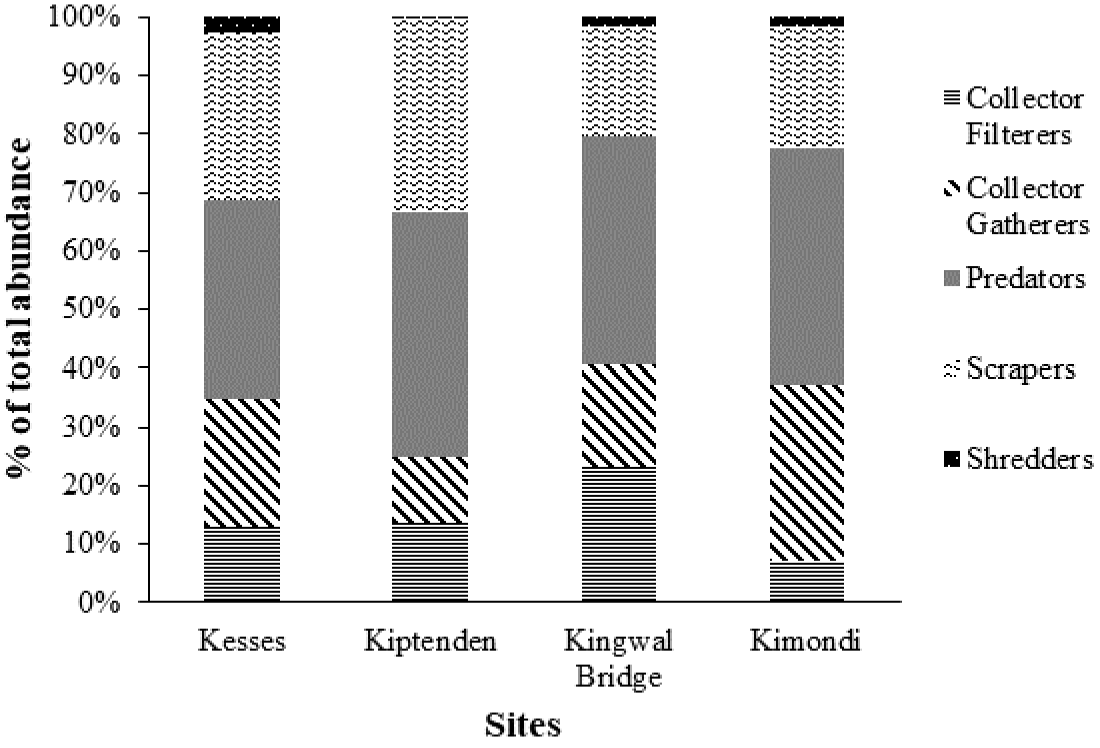


Figure 4.12: Percentage composition of macroinvertebrate FFGs in terms of total abundance at Kesses, Kiptenden, King'wal Bridge and Kimondi between January and December 2011

Similar to abundance, Kesses recorded the highest shredder richness (Figure 4.19). Kiptenden recorded the highest scrapers richness (Figure 4.19). Predators' richness increased downstream with increase in disturbance with higher richness being recorded at Kimondi with the least richness being recorded at Kesses (Figure 4.19). Collector gatherers highest richness was recorded at Kesses with Kiptenden recording the least richness (Figure 4.13). King'wal recorded the highest Collector filterers richness with Kiptenden and Kimondi recording their least richness (Figure 4.13).

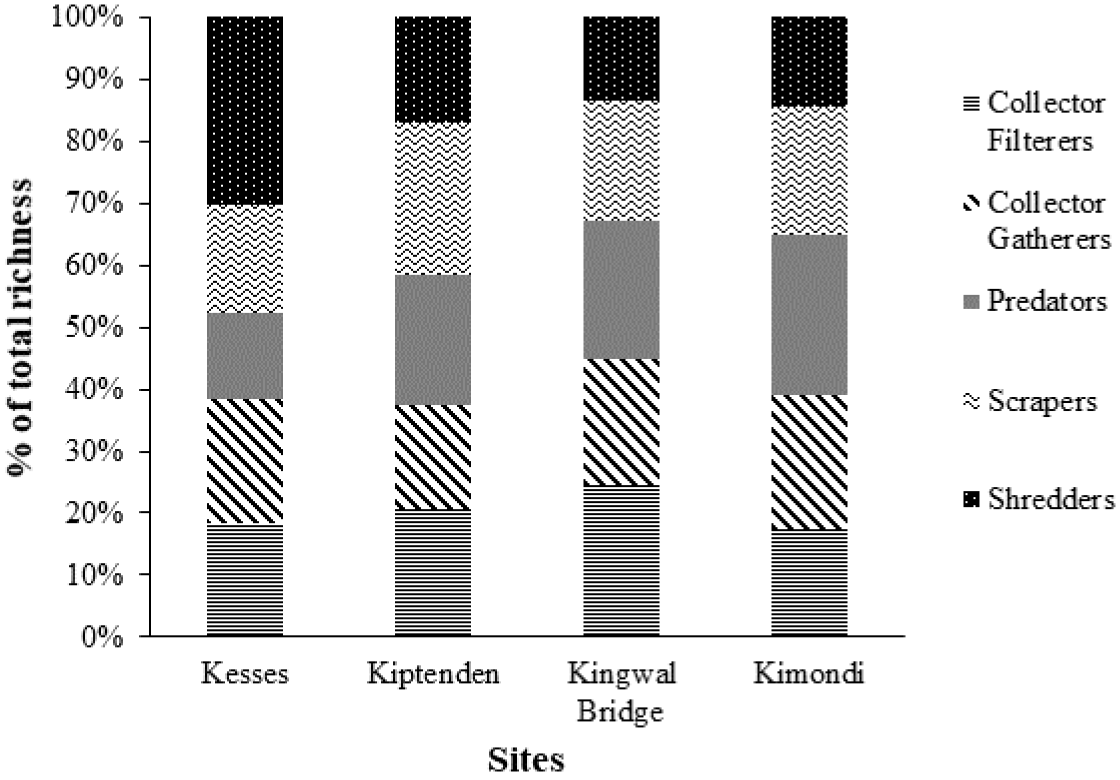


Figure 4.13: Percentage composition of macroinvertebrate FFGs in terms of taxon richness at Kesses, Kiptenden, Kingwal Bridge and Kimondi between January and December 2011

4.3.3 Human Disturbance Score (HDI)

The human disturbance scores (HDI score) are provided in Figure 4.14. The scores for sites 4 to 6 (Kiptenden upstream, midstream and downstream) were found to be 2.5 times higher than the reference sites while sites 7 to 12 (King'wal and Kimondi upstream, midstream and downstream) had HDI about 5 times higher than the reference sites (Kesses upstream, midstream and downstream) (Figure 4.14).

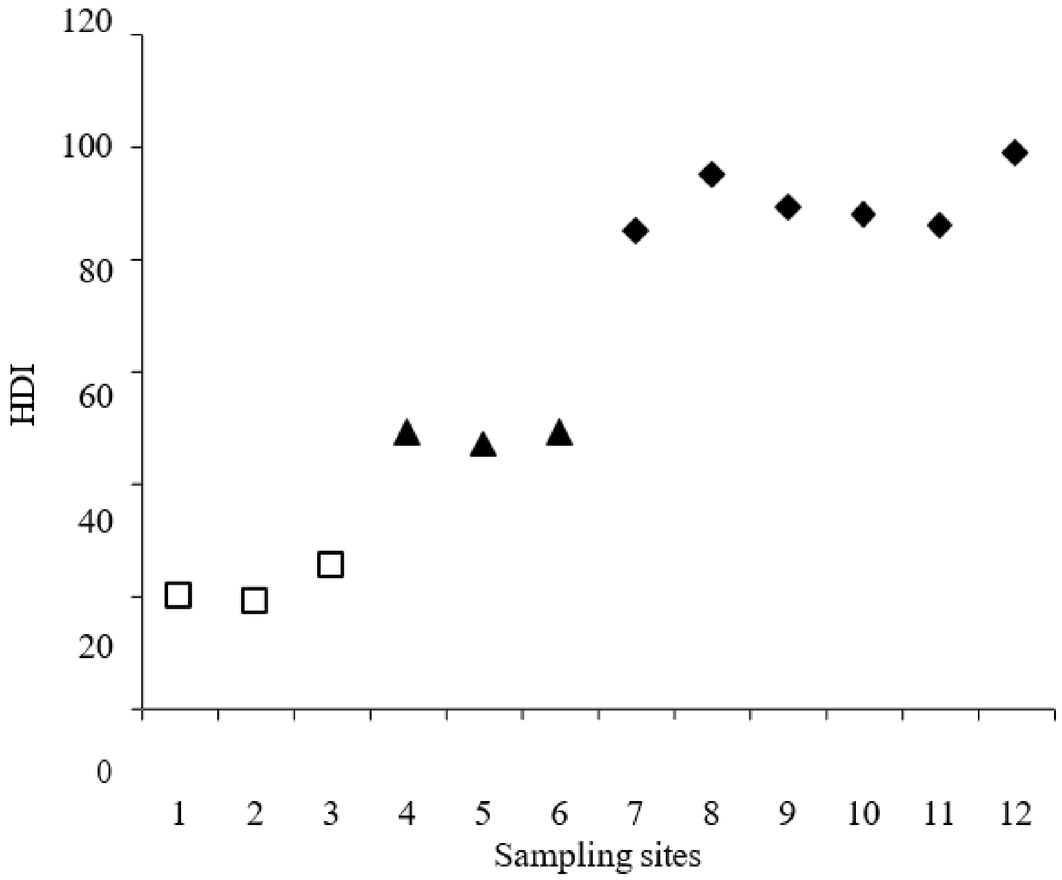


Figure 4.14: Distribution of the Human Disturbance Index Ranked from Lowest to highest Score. Site 1-3 (Kesses upstream, midstream and downstream), 4-6 (Kiptenden upstream, midstream and downstream), 7-9 (King’wal bridge upstream, midstream and downstream), 10-12 (Kimondi upstream, midstream and downstream)

4.3.4 Macroinvertebrates Index of Biotic Integrity (M-IBI)

The raw scores of the metrics of the 23 macroinvertebrates selected metrices was first conducted (Appendix 2). However, not all the metrices showed significant relationships to the human disturbance score in the sampling sites. Based on the significant scores of the selected metrices, 12 metrices were selected and used to develop the IBI (Appendix 3). The IBI Scores are provided in Figure 4.15. The reference site Kesse had a higher IBI score (60) and the scores decreased downstream with Kimondi recording the least score of 18 (Figure 4.15).

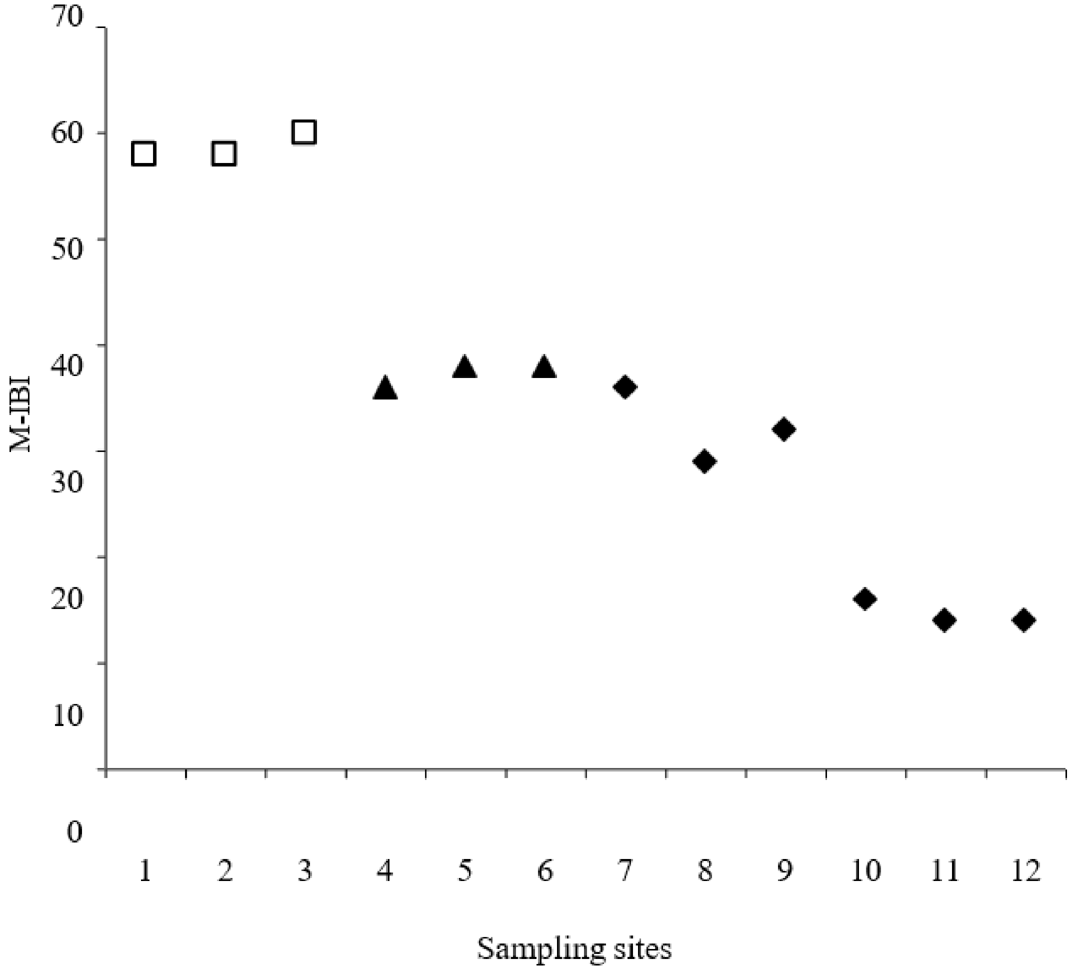


Figure 4.15: M-IBI developed to assess the status of various sampling sites along Kingwal Wetland. Site 1-3 (Kesses upstream, midstream and downstream), 4-6 (Kiptenden upstream, midstream and downstream), 7-9 (Kingwal upstream, midstream and downstream), 10-12 (Kimondi upstream, midstream and downstream)

From the developed M-IBI, other than Kesses site that exhibited moderate quality, all the other sites were categorized as of poor quality (Table 4.12). Kesses was categorized as a site with moderate quality as it had an assessment score of 3 while the rest had 1 (Table 4.12).

Table 4.12: Site assessment scores and rating according to the developed M-IBI

Site Name	Wetland Health Assessment Score	Site Category
Kesses	3	Moderate
Kiptenden	1	Poor
Kingwal Bridge	1	Poor
Kimondi	1	Poor

The linear regression between the HDI and the M-IBI developed in the study is shown in Figure 4.16. There was generally a significant ($p < 0.05$) negative relationship between H-IBI and M-IBI developed for the different sampling sites along the swamp (Figure 4.16).

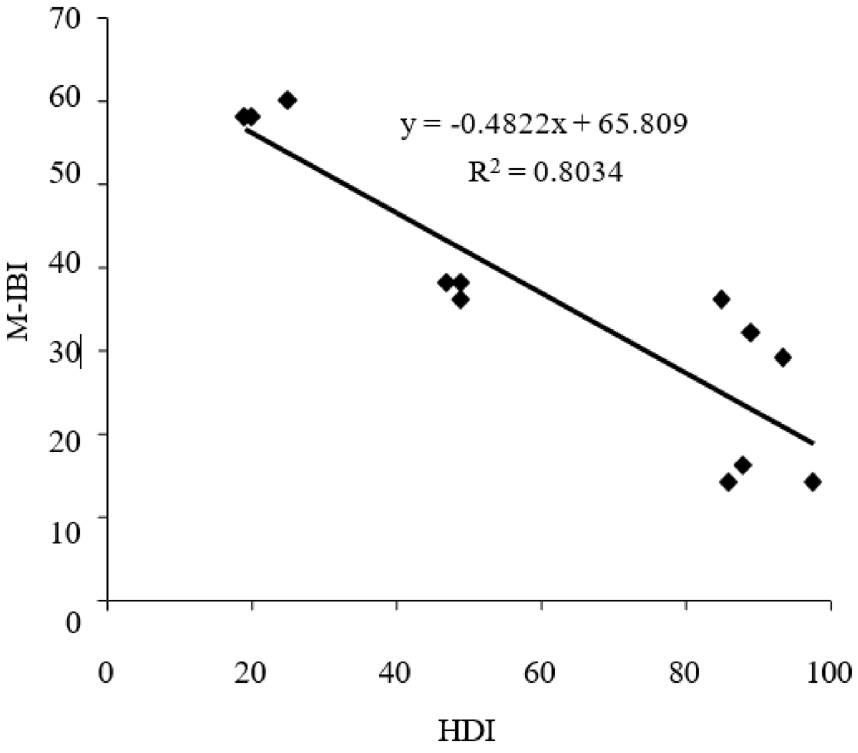


Figure 4.16: Linear regression between the M-IBI and HDI for different sampling sites of King'wal Wetland

4.4 Utilization and management of King'wal Wetland resources

4.4.1 Demographic structure of the sampled population

A total of 126 respondents from the four sampling sites participated in the study. The socio-economic status of the respondents is shown in Table 4.1 below. Age distribution indicated that more than two thirds (77%) of the respondents were aged between 31 to 60 years, there were up to 57.2% of the respondents aged 31 to 50 years while respondents aged below 30 years were only 15.8% (Table 4.1). There were no significant differences in the age distribution patterns of the respondents among the sampling sites (χ^2 = 2.334, df = 3, p = 0.531). Except in King'wal area, none of the sampling location had respondents aged below 20 years. Most of the respondents aged 21-30 years were sampled at Kiptenden while most of those aged 31-40 were from Kesses, King'wal and Kimondi. On the other hand, majority of the respondents aged 41 to 50 years category were sampled at Kiptenden as higher proportion of respondents aged over 60 years were sampled at King'wal (Table 4.1).

Close to four fifth of the respondents (77.8%) were males while a fifth (22.2%) were females. There were significant gender differences in the proportion of respondents between the sampling sites (χ^2 = 0.727, df = 3, p = 0.048), indicating that males were dominant in each sampling location. More than 90% of the respondents were married with few cases of single and widows in the sample. There were no significant differences in the marital status of the respondents among the sampling locations (χ^2 =1.745, df = 3, p = 0.043) suggesting that in all sampling locations married population were the dominant respondents (Table 4.13).

Table 4.13: Demographic status of respondents (% frequency) at the four study locations along King'wal Wetland, Kenya during the study period

Socio-economic attribute	Kesses (n = 32)	Kiptenden (n = 28)	King'wal (n = 31)	Kimondi (n = 35)
Age				
<20	12.0	18.2	12.0	10.7
21-30	32.0	4.5	36.0	32.1
31-40	28.0	31.8	20.0	35.7
41-50	16.0	40.9	4.0	21.4
51-60	12.0	4.5	20.0	0.0
>60	0.0	0.0	8.0	0.0
Gender				
Male	80.0	72.7	80.0	75.0
Female	20.0	27.3	20.0	25.0
Marital status				
Married	100.0	86.4	88.0	96.4
Single	0.0	0.0	12.0	0.0
Widowed	0.0	13.6	0.0	3.6
Occupation				
Farmer	68.0	90.9	60.9	75.0
Formal employment	4.0	0.0	13.0	0.0
No formal employment	12.0	9.1	4.3	14.3
Trader	16.0	0.0	21.7	10.7
Level of education				
None	0.0	0.0	8.0	0.0
Primary	60.0	72.7	40.0	82.1
Secondary	40.0	27.3	36.0	17.9
Colleges	0.0	0.0	16.0	0.0
Household head				
Male-headed	100.0	77.3	100.0	85.7
Female-headed	0.0	22.7	0.0	14.3

Although there were different types of occupation among the local community members, most of the respondents are mainly involved in farming activities and constituted close to three quarters of the population. Other respondents were civil servants, casual labourers, traders and housewifes (Table 4.13). There were no significant differences in the occupation of the respondents across the four study locations.

Concerning academic qualifications, the respondents were dominated by those who had attained upper primary levels of education followed by secondary school level of education. Very few respondents indicated that they had attained any middle level college training. The proportion of those without any formal education was equally low with only King'wal recording respondents without any formal education (Table 4.13). Majority of respondents with lower primary levels of education were sampled from Kimondi and none from King'wal.

On the contrary, most of the respondents with upper primary levels of education were sampled from Kimondi than in other sampling locations. Secondary levels of education dominated among respondents in Kesses and King'wal than other locations while respondents with middle level college education were sampled at King'wal only. The levels of education attainment across the study locations were significantly different between the sampling sites ($\chi^2 = 36.926$, df = 3, $p = 0.002$). Approximately 90% of the households were headed by males while the rest were headed by females (Table 4.1). The differences in the household heads were significantly different among the sampling locations ($\chi^2 = 6.666$, df = 3, $p = 0.015$).

4.4.2 Wetland use and economic activities by the local community members

The wetland goods provided to the local community members in King'wal Wetland are shown in Figure 4.17. Six most important resources in order of decreasing importance supplied to majority of the respondents (98.4%) were grains, vegetables (88.9%), papyrus (85.7%), grass (82.7%), water (77.8%) and fodder (77.8%) while less popular resources in the study area were saltlick (26.2%), timber (11.8%) and ornamental plants (0.8%). There were similarities in all the resource use among the four sites (Chi-square $p > 0.05$).

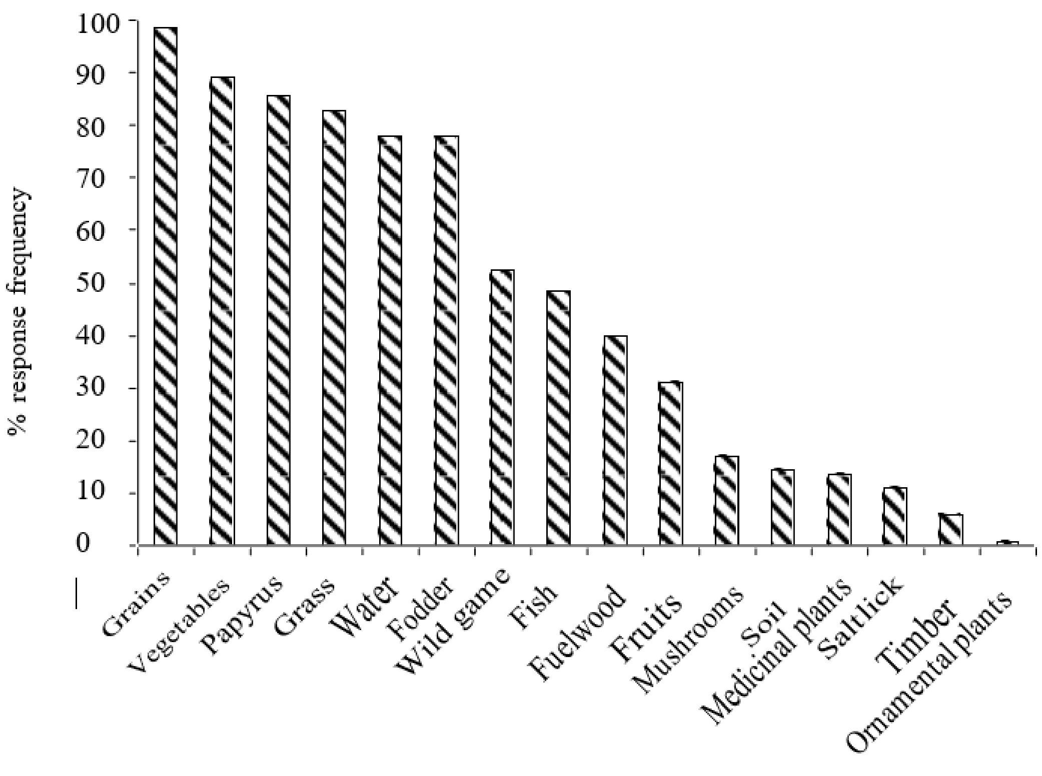


Figure 4.17: Wetland resources obtained by the local community members from the wetlands of King'wal during the study period

The availability of the aforementioned wetland resources currently and 20 years ago were also determined (Table 4.14). The availability of all the wetland resources except grains, water, timber, papyrus and vegetables were more plenty over the last 20 years as compared to the current present study with most of the resources being either moderately or inadequately available (Table 4.14).

Table 4.14: Availability of wetland resource currently and in the last 20 years. Value indicates the percentage of the various resources.

Wetland Resource		Current (%)	Last 20 years (%)
	Plenty	3.3	54.4
Fish	Moderate	63.3	17.8
	Inadequate	33.3	3.3
	Rare	0	24.4
	Plenty	2.1	58.9
Medicinal plants	Moderate	20.8	25
	Inadequate	77.1	16.1
	Plenty	36.3	88.6
Wild game	Moderate	44	68.2
	Inadequate	19.8	25
	Rare	0	25
	Plenty	6.5	23.4
Fruits	Moderate	17.7	2.1
	Inadequate	75.8	1.1
	Rare	0	73.4
	Plenty	40.3	13.7
Grains	Moderate	58.9	39.5
	Inadequate	0.8	12.9
	Rare	0	33.9
	Plenty	83.7	93.9
Water	Moderate	16.3	5.1
	Inadequate	0	1
	Plenty	44.6	62.2
Fuel wood	Moderate	3.6	32.9
	Inadequate	51.8	4.9
Timber	Plenty	86.7	0
	Inadequate	13.3	100
	Plenty	40.8	81.6

Fodder	Moderate	51	16.3
	Inadequate	8.2	1
	Rare	0	1
	Plenty	100	26.3
Papyrus	Moderate	0	29.8
	Inadequate	0	35.1
	Rare	0	8.8
	Plenty	24	85.6
Grass	Moderate	34.6	12.5
	Inadequate	41.3	1
	Rare	0	1
Ornamental plants	Plenty	0	100
	Inadequate	1.8	0
	Plenty	50.9	68.4
Soil	Moderate	19.3	3.5
	Inadequate	29.8	0
	Rare	0	28.1
	Plenty	6.1	75.8
Saltlick	Moderate	75.8	12.1
	Inadequate	18.2	12.1
	Plenty	0	30.1
Mushroom	Moderate	0.2	59.2
	Inadequate	0.8	7.8
	Rare	0	2.9
	Plenty	43.9	3.7
Vegetables	Moderate	47.7	22.4
	Inadequate	8.4	29
	Rare	0	44.9

The relative ranks score reflecting the importance of the wetland resources now and 20 years ago are provided in Table 4.15. Arranged in decreasing order of importance, the results indicate that currently, the most important resources from the wetland are water (82%), papyrus (57%), grains (50%), vegetables (47%) and fodder (40%) while over the last 20 years, water (92%), grass (89%), fodder (80%), ornamental plants (54%) and fuel wood (51%) were more important to the local community members (Table 4.3). Water and fodder have remained the most important resources relied mainly by the local community even though their relative importance (water (92% vs. 82%) and fodder (80% vs. 40%) have reduced (Table 4.15). Timber (0%) and vegetables (4%) were the least important resources in the past 20 years, while medicinal plants (1%), saltlick (2%) and mushrooms (2%) are currently the least important resources from the wetland (Table 4.15).

Table 4.15: Relative ranks score (%) reflecting the importance of the wetland resources now in comparison to 20 years ago

Wetland Resources	Current	20 years ago
Fish	3	49
Medicinal plants	1	33
Wild game	33	39
Fruits	4	22
Grains	50	17
Water	82	92
Fuel wood	37	51
Timber	13	0
Fodder	40	80
Papyrus	57	15
Grass	25	89
Ornamental plants	21	54
Soil	29	39
Saltlick	2	25
Mushroom	2	31
Vegetables	47	4

The amount of income earned from the wetland goods was also evaluated from the local community members (Table 4.16). There were significant differences in income earning among the various wetland resources in the local community members (χ^2 = 65.122, df = 11, p = < 0.001). Nearly all the resources except vegetables and grains from the wetlands fetched income levels of between Kshs 1000 to 3000 per month for most of the local community members (Table 4.16). Vegetables (42.1%) and Grains (65.1%) were the resources earning the locals the most money (Ksh 5,000 – Ksh 10, 000) (Table 4.16). The other most important resources that earned the locals an income of Ksh 1,000 – Ksh 3,000 were; fodder (69.0%), fuel wood (57.1%), fish (54.8%) and mushrooms (53.2%) (Table 4.16).

Table 4.16: Distribution of income earned from the wetland resources in King'wal Wetland

Wetland resource	Amount (in Kshs.)	Percent
Fish	1,000-3,000	54.8
	5,000-10,000	1.6
Medicinal plants	1,000-3,000	34.1
Wild game	1,000-3,000	30.2
Fruits	1,000-3,000	25.4
Grains	<1,000	3.2
	1,000-3,000	22.2
	3,000-5,000	7.9
	5,000-10,000	65.1
Water	1,000-3,000	37.3
	3,000-5,000	0.8
	5,000-10,000	0.8
Fuel wood	1,000-3,000	57.1
	3,000-5,000	0.8
Timber	1,000-3,000	1.6
	5,000-10,000	10.3
Fodder	1,000-3,000	69.0
Papyrus	1,000-3,000	27.8
	3,000-5,000	5.6
	5,000-10,000	10.3
Mushroom	1,000-3,000	53.2
	3,000-5,000	1.6
Vegetables	1,000-3,000	15.9
	3,000-5,000	28.6
	5,000-10,000	42.1

It was further established from respondents' interviews that there are four types of fish within the wetland. These were Nile tilapia (*Oreochromis niloticus*), catfish (*Clarias gariepinus*), Marble lungfish (Mudfish; *Protopterus aethipicus*) and several

Barbus spp. The frequency of occurrence of the species in the natural environment and under culture in Kingwal Wetland is provided in Figure 4.2. There were significant differences between the fish species cultured and those in the wild (χ^2 = 13.126, df = 3, p = 0.0001). Tilapia (39.5%) and catfish (31.0%) were the most dominant species in the natural environment and were the only species cultured while Marble lungfish and Barbus that were reported to be available in the wetland by 20% and 10% of the population respectively were not cultured (Figure 4.18).

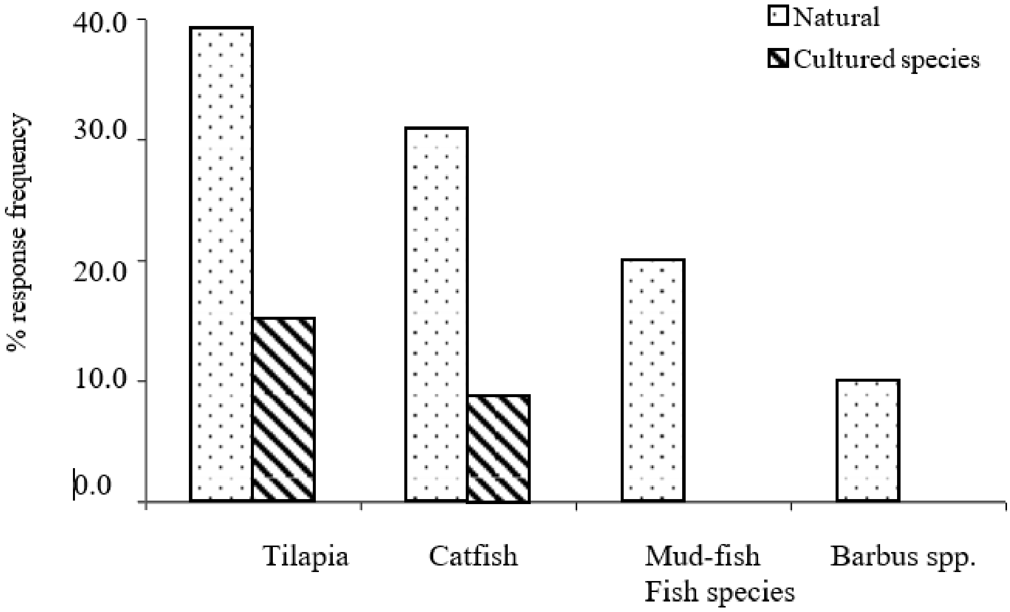


Figure 4.18: Frequency of occurrence of the fish species in the natural environment and under culture in King'wal Wetland

Economic activities practiced within the wetland by the local community members in King'wal Wetland is shown in Figure 4.19. There were significant differences in the types of economic activities practiced by the local community members (χ^2 = 9.122, df = 7, p = 0.0004). The key economic activities practiced by the local community members of King'wal were: poultry keeping (81.2%), tree nurseries (47.6%), and bee keeping (35.6%) while the least were zero grazing (5%), flower nursery (7%) and fish farming (8%) (Figure 4.3).

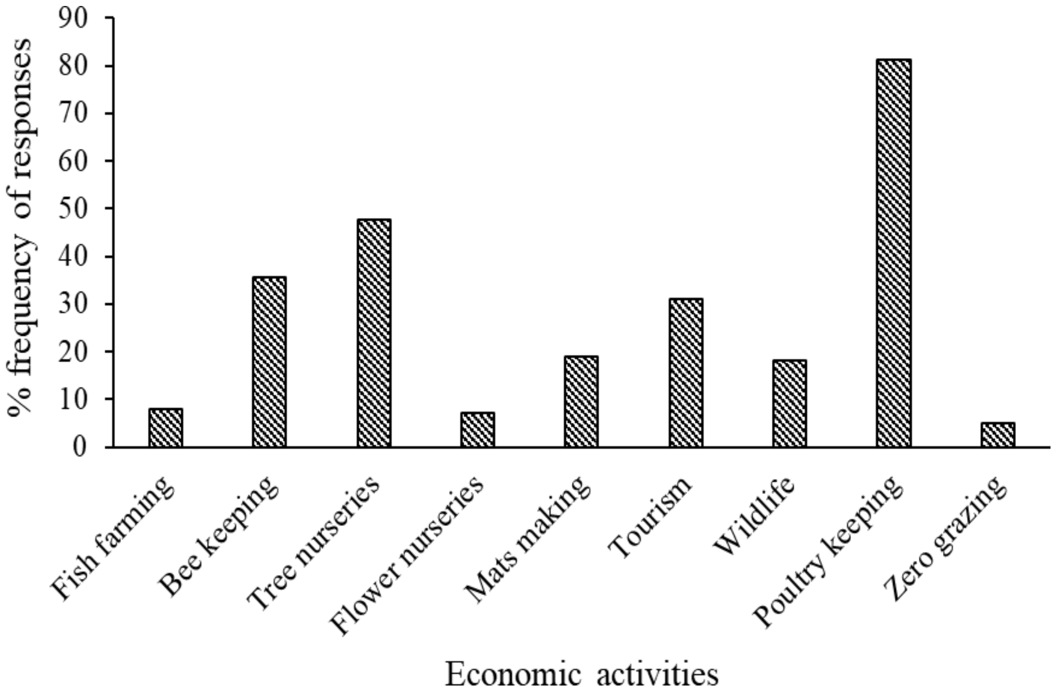


Figure 4.19: Economic activities practiced within the wetlands by the local community members in King'wal Wetland

The results of the study revealed that the local community derive several services from Kingwal wetland (Figure 4.20). The services were socio-cultural and ecological in nature. There were significant differences in the services offered through wetlands by the local community members (χ^2 = 25.143, df = 11, p = < 0.001). The services derived from the wetlands by all the respondents were climatic regulations, air quality regulation while majority of the local community members also derived other benefits such as water recharge (75.3%), cultural practices (circumcision) (54.6%), flood control (53.5%) and erosion protection (43.4%) (Figure 4.4).

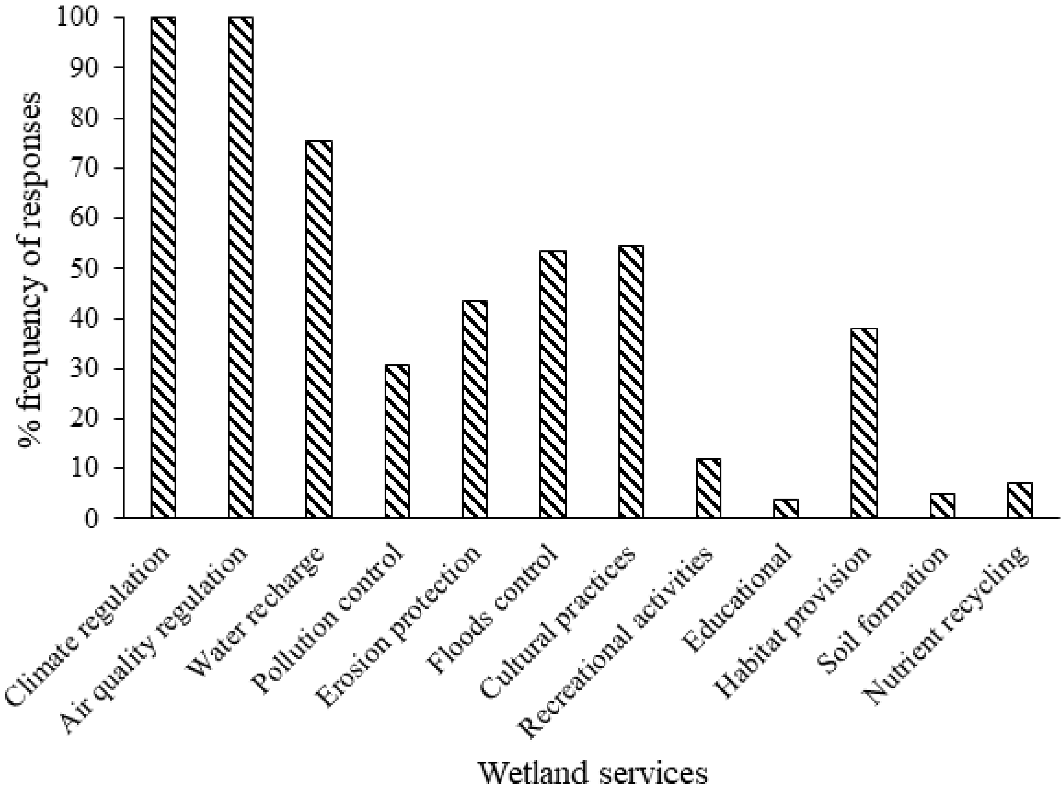


Figure 4.20: Services that the local community members derive from the wetlands

4.4.3 Occurrence and uses of wetland biodiversity

According to the respondents interviewed, the King'wal wetland has several flora as shown in Figure 4.21. There were significant differences in the biodiversity of wetland flora in the study area ($\chi^2 = 65.121$, df = 8, $p = < 0.001$). Most of the locals reported that the most dominant biodiversity in King'wal Wetland were: jointvetches (*Aeschynomene abyssinica*) (48.8%), sedge grasses (*Carex pendula*) (45.8%), papyrus reeds (*Cyperus papyrus*) (44.5%) and duckweeds (*Lemna minor*) (32.3%). A lower proportion of the respondents reported the availability of wild berry (*Solanum bahamense*) (18.5%), floating ferns (*Salvinia natans*) (12.3%), water lily (*Nymphaea alba*) (13.2%) and wondering Jew (*Tradescantia zebrine*) (5.4%) (Figure 4.21).

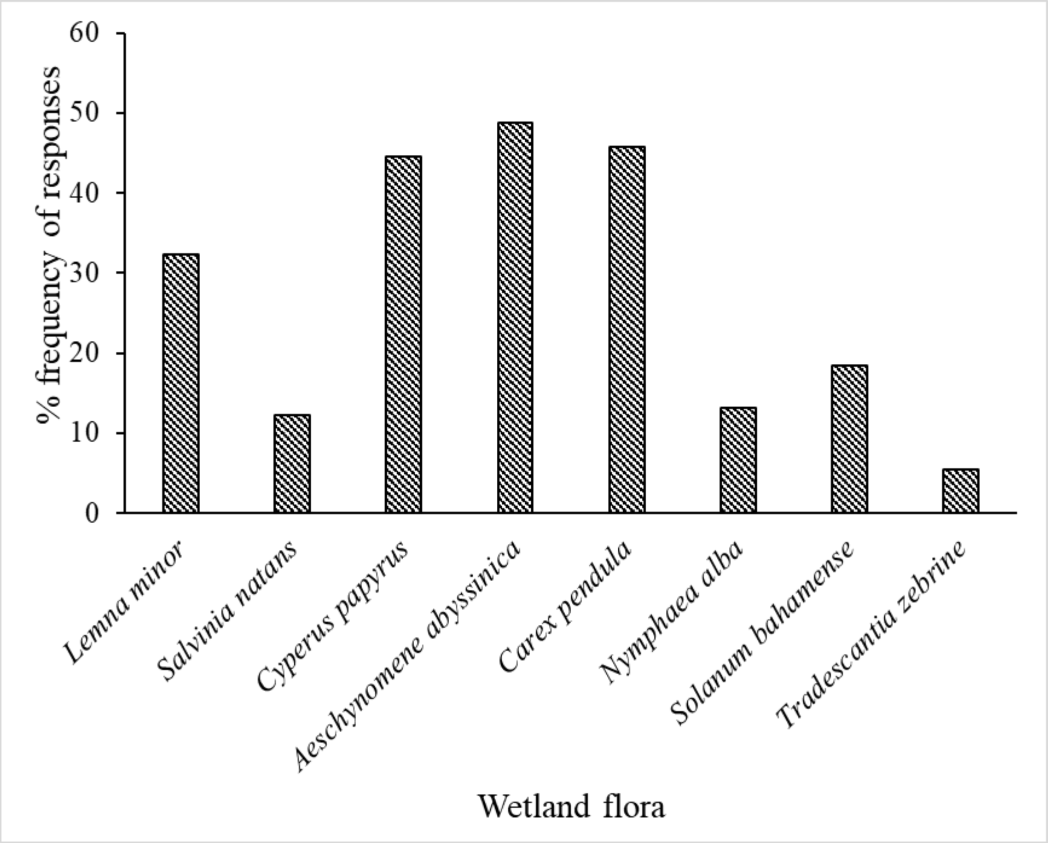


Figure 4.21: Floral biodiversity of wetland flora in King'wal Wetland according to the respondents

Information on the uses of the plants in King'wal Wetland is provided in Table 4.17. There was significant relationship between plant species and their uses ($\chi^2 = 33.122$, df = 6, $p = 0.0004$). *Lemna minor* were used mainly as fodder (32.5%), *Cyperus papyrus* was mainly used to make mats (38.1%), and *Aeschynomene abyssinica* was used as firewood (49.2%), while *Carex pendula* was mainly utilized in the brick making process (32.5%). The grass was mainly used to cover the bricks to prevent excess sun or rain from destroying the bricks. *Tradescantia zebrine*, *Solanum bahamense* and *Nymphaea alba* did not have major roles among the local community members. However, the *T. zebrine* was utilized as fodder and medicine, *S. bahamense* used as food and medicine (Table 4.17).

Table 4.17: Uses of plants in King’wal Wetlands. Values indicate the proportion of utilization of the various plants.

Plants	**Fodder**	**Brick making**	**Mat making**	**Fire wood**	**Cultural activities**	**Food**	**Medicine**
Lemna minor	32.5	0.8	0.0	0.0	0.0	0.0	0.0
Cyperus papyrus	1.6	0.0	38.1	2.4	0.8	0.0	0.0
Aeschynomene abyssinica	0.0	0.0	0.0	49.2	0.0	0.0	0.0
Carex pendula	5.6	32.5	5.6	0.0	0.0	0.0	0.0
Nymphaea alba	1.6	0.0	0.0	0.0	0.0	0.0	0.0
Solanum bahamense	0.0	0.0	0.0	0.0	0.0	3.2	0.8
Tradescantia zebrine	4.0	0.0	0.0	0.0	0.0	0.0	1.6

Different plant parts were reported to be used for different uses by the local community of Kingwal wetland (Table 4.18). There were significant association between plants species parts and their uses ($\chi^2 = 49.127$, df = 4, $p = < 0.001$). Among the various plant parts, the leaves of all the plants other than the *S. bahamense* were the most utilized by the respondents (Table 4.6). Whole plant utilization and the stem was also a common practice for most plants. Roots and barks were the least utilized plant parts with only the roots of *C. pendula* and the bark of *S. bahamense* and the *T. zebrine* being utilized by the community members (Table 4.18).

Table 4.18: Uses of different plant parts in King'wal Wetland. Values indicate the percentage utilization of the parts of the various plants.

Plants	Leaves	Stem	Roots	Bark	Whole plant
Lemna minor	33.3	0.0	0.0	0.0	0.0
Cyperus papyrus	0.8	42.1	0.0	0.0	0.0
Aeschynomene abyssinica	28.6	0.0	0.0	0.0	20.6
Carex pendula	6.3	6.3	0.8	0.0	30.2
Nymphaea alba	8.6	0.0	0.0	0.0	0.0
Solanum bahamense	0.0	0.0	0.0	0.8	2.4
Tradescantia zebrine	1.6	1.6	0.0	0.8	1.6

The relative importance value (RII) was calculated by dividing each variable importance score by the largest importance score of the variables, then multiplied by 100% of each of the plants used by the local community members (Table 4.19).

$RII = \Sigma W / (A*N)$ Equation 8

Where;

W = weighting given to each factor by the respondents (ranging from 1 to 5), 1

= no impacts, 2 = negligible impact, 3 = marginal impact, 4 = moderate impact and 5 = major impact
A = the highest weight (i.e. 5 in this case) N = the total number of respondents.

The higher the value of RII, the more important the factor. Among the plants, the species with economic value to the community had the highest levels of importance including the *C. papyrus* (95.7%), followed by *A. abyssinica* (89.1%) and then *C. pendula* (78.4%), while plant species with low use value from the rank scores were the *T. zebrine* (10.7%) and the *Nymphaea* (12.4%) (Table 4.19).

Table 4.19: Relative importance of each of the common plants in King'wal wetland. Values indicate frequency of relative importance of the various plant species.

Plant species	Least	Important	Very	Rank
Lemna minor	40	2	0	36.4
Cyperus papyrus	5	44	10	95.7
Aeschynomene abyssinica	6	42	14	89.1
Carex pendula	9	49	0	78.4
Nymphaea alba	15	0	0	12.4
Solanum bahamense	0	10	8	36.4
Tradescantia zebrine	1	6	0	10.7

The respondents revealed that King'wal Wetland is a home to a number of fauna as provided in Figure 4.22 below. There were significant differences in the faunal composition in the study area (χ^2 = 35.121, df = 15, p = 0.0012). The main species of animal reported by majority of the respondents were: sitatunga (80.2% of the respondents), duck (70%) of the respondents, fish (60%) of the respondents, hare (66.5%) and cranes (65.3%). Other animals such as shy otters, porcupines, owl and egrets were reported to exist in the wetland by a low number of respondents (Figure 4.22). However, the sitatunga was only reported by respondents at site 2 (Kiptenden) and site 3 (King'wal Bridge), as these two sites are within the King'wal wetland.

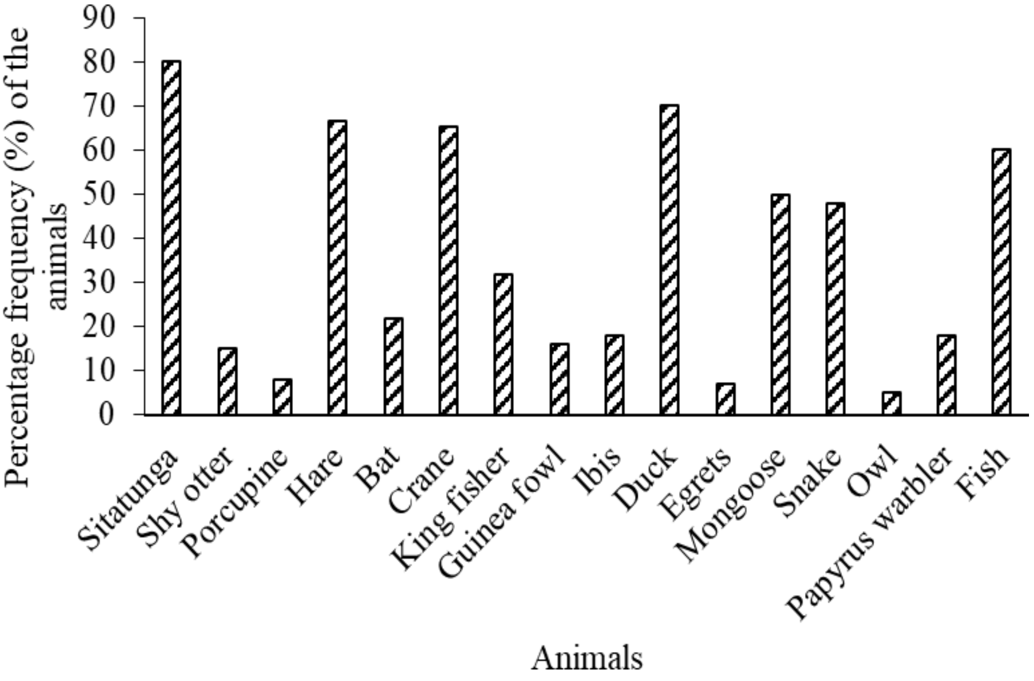


Figure 4.22: Percentage frequency of fauna of the King'wal Swamp during the study period

The uses of the animals identified by the local residents in King'wal Wetlands are provided in Table 4.20. There was significant relationship between animal species and their uses (χ^2 = 49.127, df = 4, p = < 0.001). A total of 30.2% of the respondents noted that main use of sitatunga and ducks was for food while 44.4% of the respondents reported that they are utilized for tourism. Also, 77.0% and 52.0% of the respondents indicated that fish, and hare are also utilized as food. On the other hand, cranes (36.0% of the respondents), Papyrus warbler (22.0% of the respondents) and kingfishers (33.0% of the respondents) indicated that they are mainly useful for tourists' attraction in the study area (Table 4.20). Ibis was used for tick control while mongoose was utilized for medicinal purposes by a few respondents.

Table 4.20: Use of the animals in King'wal Wetland during the study period. Value indicates the percentage of the respondents with respect to the specific utilization of the animals in the study area

Animals	Human food	Tourism	Pest Control	Medicine
Sitatunga	30.2	44.4	0.0	0.0
Porcupine	5.6	0.0	0.0	0.0
Hare	52.0	1.0	0.0	0.0
Bat	0.0	14.0	0.0	0.0
Crane	0.0	36.0	1.0	0.0
Kingfisher	0.0	33.0	0.0	0.0
Guinea fowl	19.0	0.0	0.0	0.0
Ibis	0.0	0.0	20.0	0.0
Duck	43.0	16.0	0.0	0.0
Egrets	1.0	4.0	0.0	0.0
Mongoose	12.0	0.0	0.0	5.0
Owl	0.0	4.0	0.0	0.0
Papyrus warbler	0.0	22.0	0.0	0.0
Fish	77.0	0.0	0.0	0.0

4.4.4 Towards wetland resource and resource use management

While examining the interaction between human beings and the wetland, several anthropogenic activities with the potential to affect the functional integrity of the wetlands were determined (Figure 4.23). There were significant differences in the knowledge of activities affecting wetlands among the respondents (χ^2 = 21.776, df = 4, p = < 0.001). Only 23.3% of the respondents attested that the wetland water resource was useful for consumption while 76.7% of them did not agree with the fact. Some of the activities likely to negatively affect the wetland according to the respondents included use of fertilizers (18.5%), release of sewages into the wetland (6.5%), runoffs (8%) and erosion from the adjacent farmlands (6.5%). However, approximately 40% of the respondents were not sure whether these activities are detrimental to the ecological integrity of the wetland (Figure 4.23).

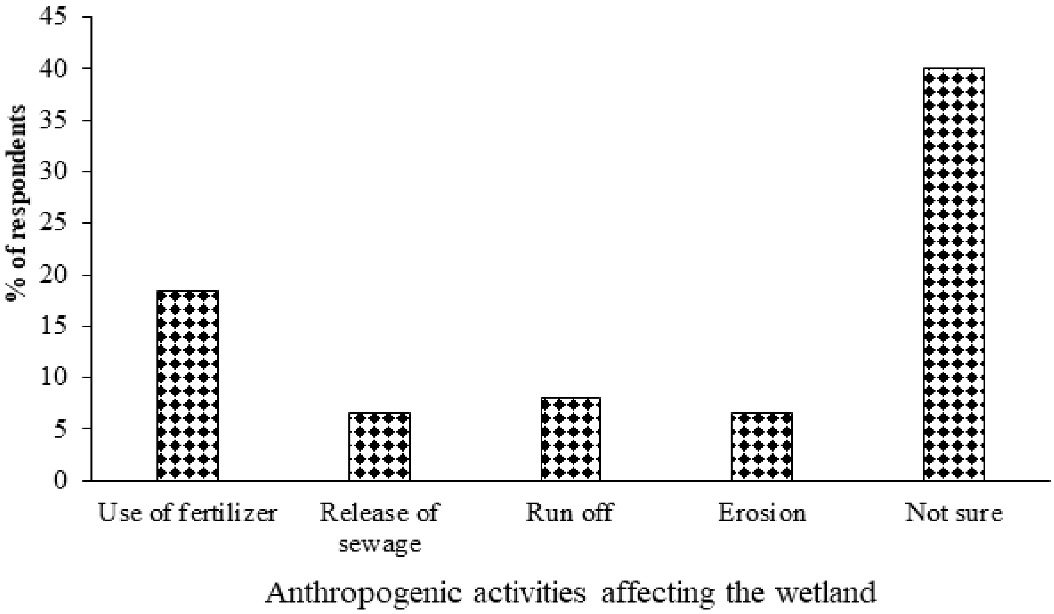


Figure 4.23: Activities affecting wetland integrity in King'wal Swamp during the study period

CHAPTER FIVE

DISCUSSION

5.1 Physico-chemical environment in King’wal wetland

Land-use activities played a significant role in influencing water quality and nutrients variables in the study. Changes in water quality across the sites were indicated by decreasing DO levels and increasing temperature, pH, conductivity, and nutrient levels. Wetlands have varying levels of water quality depending on the geological formation as well as human activities of the catchment and whether the inflow consists wastewater (Bendell-Young *et al*., 2000). In the current study, the physico-chemical environment of King’wal Wetland in Nandi varied along spatial and temporal scales.

The values of all water quality recorded in all the study sites showed significant spatial variations and were significantly lower compared to some of the wetlands in Kenya (e.g. Gichuki *et al*., 2001; Kondowe *et al*., 2022) and were largely different compared to the previous studies in similar wetlands around Uasin Gishu (Odongo, 1996), This suggest that this wetland has been impacted by human activities from the catchment in the recent years. The pH ranges in the current study ranged from 5.1 to 7.6, which are within the normal ranges of pH for fresh water wetlands with slightly low pH values at Kesses and higher pH at King’wal Bridge. Earlier studies by Lung’ayia *et al*. (2000) and that of Abila and Othina (2006), reported that the swamps dominating the wetlands of Lake Victoria, pH ranges between 7.0 and 8.5. Similarly, a study by Peters *et al*. (2005) in Saiwa Swamp, which is one of the conserved swamps, recorded annual pH ranges of 7.3 to 8.3. However, the pH ranges in the current study differed from findings in other swamps around Kenya and Uganda (Kamureny, 2004; Muchiri and Green, 2006; Maua *et al.,* 2022).

The current study exhibited spatial and temporal variations in pH. The study recorded high water pH along the wetland and during rainy season throughout the sampling period. This could be attributed to farming activities that utilize chemical fertilizers, frequently used by the farmers to increase yields and enhance plant growth. The farmers in this area use ammonia fertilizers including ammonium sulphate (NH_4SO_4), which dissociate liberating ammonium (NH_4^+) and sulphates (SO_4^{2-}) with the NH_4^+ often being responsible for increased pH in water (Lewis, 2006). The high pH in the current study relative to earlier report by Kairu, (1995) on water quality parameters of wetlands in Nandi suggests progressive wetland degradation. This is important component because water that gets into the wetland passes through large settlement areas where its quality can be impaired considerably.

The dissolved oxygen (DO) in King'wal wetland ranged from 6 to 6.7 mg L^{-1} in the upstream sites which was shallow and could absorb high concentration of DO from the surrounding environment. However, in the downstream the DO was as low as 1 mg L^{-1} in some sites. Compared with similar studies around Yala swamp (Owino and Ryan, 2007), Nyando Wetlands in Lake Victoria Basin (Obiero, 2008) and Saiwa Swamp (Lung'ayia *et al*., 2000), the DO levels recorded in the current study were lower. During the sampling period in the present study, cases of extreme anoxic conditions were common in areas with decaying vegetation in the lower parts of the streams, and this could explain the low DO levels recorded.

Studies have indicated that decomposition of dense amounts of vegetation and increased anthropogenic activities utilizes the oxygen in the water body and releases carbon dioxide and other organic compounds that leads to decreased DO levels in aquatic ecosystems (Kingston, 2003; Owino and Ryan, 2007). The low DO levels in the current study could also be attributed to fertilizer and manure runoff from the farms around the wetland. The fertilizer and manure runoff encourage the growth of too much algae, which uses up the oxygen in the system. In addition, the higher human activities in the area expose the water to pollutants such as sewage effluents that deplete oxygen from water. A study by Philipart *et al*. (2000) reported cases of high biological oxygen demand (BOD) in areas with high anthropogenic activities, and these diminished concentration of DO in the water.

Lowest levels of electrical conductivity (EC) were recorded at Kimondi while Site 1 (Kesses) had higher conductivity probably due to internal loading of the nutrients from the nearby university (Moi University). The lowest DO at Kimondi could be because it is receiving low amounts of dissolved ionic compounds from its catchment perhaps because the agriculture being practiced at this area is mainly small scale. However, Kimondi is also characterized by reduced wetland coverage and this could suggest absence of autochthonous inputs of nutrients and other dissolved substances from the vegetation. Even though this open riparian zone means increased allochthonous input into the site, the low EC at the site could be an indication of poor or infertile soils in the catchment. However, this reason can be affirmed due to absence of any studies on geology of the area and this calls for further research.

The concentration of TN ranged from 1 to 3.2 mg L^{-1} while the TP ranged from 0.6 to 3.1 mg L^{-1}. In the current study, N and P concentrations were high in relation to values reported for other wetlands (Harper *et al*., 1999; Raburu, 2003; Ashley *et al*., 2004; Owino and Ryan, 2007; Abila, 2005; Abila *et al*., 2008; Bover and Waters, 2009; Muasya *et al*., 2004; Obiero, 2009). Most of these and other studies revealed that N and P composition of the wetlands vary depending on their location (Muthuri and Jones, 1997; Keddy and Frazer, 2000), chemical conditions (Masese *et al*., 2008; Okoth *et al*., 2009), human impacts on the catchments (Raburu, 2003) as well as amount of water present (Ssegawa *et al*., 2004; Raburu, 2003; Abila, 2005). N and P status of the four sampling locations in King'wal were heterogeneous. The higher levels of N in the study area can be attributed to agricultural activities in the farms around the wetland that are using inorganic nitrogenous fertilizers.

Studies around African fresh waterbodies have established that most tropical aquatic ecosystems experience nitrogen deficient rather than phosphorus (Mellack *et al*., 1982; Okoth *et al*., 2009). Wetlands are shallow and therefore, greater percentage of water mass is in direct contact with the bottom. Since phosphorus has been reported to be adsorbed more at the sediment (Raburu, 2003), there could be more phosphorus adsorbed at the bottom of these wetland. Therefore, phosphorus may be frequently exchanged between the mud and water when wind stirs the water of a wetland.

The high levels of the nutrients recorded in the current study can also be attributed the dense papyrus (especially at site 2 and 3) which has been reported to be capable of accumulating large amounts of nutrients at high standing biomass (Kansiime *et al*., 2003). Studies have shown that the ability of wetlands to retain N and P depend on the vegetation structure and dispersion of runoff waters (Kansiime *et al*., 2003).

5.2 Changes in species composition, abundance and diversity of wetland macrophytes in King’wal Wetland

Species composition in any ecosystem determines the ecology and biodiversity of that habitat. Aquatic macrophytes are key components of aquatic and wetland ecosystems. As primary producers, they are at the base of herbivorous and detritivorous food chains, providing food to invertebrates, fish and birds, and organic carbon for bacteria. The number of plant species recorded in the selected study sites was 157, which were distributed in over 88 families.

King'wal Bridge had the highest number of species probably due to high levels of anthropogenic activities that may have encouraged thriving of species of grasses and shrubs resistant to degradation and tolerant to pollution. However earlier studies conducted in Saiwa Swamp found much higher species composition (Kavishe, 2001) than the current study in King'wal wetland which could be attributed to progressive biodiversity loss caused by environmental degradation.

Studies in Yala Swamp (that is currently under reclamation) recorded only 72 species (Were, 2007; Kondowe *et al.,* 2022) relative to over 600 species counted in the 1980’s (Owino and Ryan, 2007). Generally, most swamps in Kenya are undergoing biodiversity loss due to human encroachment (Koech, 2006; Maua *et al.,* 2022). The species count in unprotected swamps rarely exceeds 100 because of the continuous utilization of the plants mainly for medicinal purposes, construction, and fuelwood. Family Asteraceae, Papilonaceae and Poacea were the most common species recorded in the selected study sites. The higher species counts of Asteraceae in the Kingwal Wetland were attributed to their successful dispersal ability in the swamp because of their ease to be dispersed by wind and insect pollination. These findings are similar to assertions by Muthuri *et al.* (1989). Previous studies, such as Gichuki (2003), have reported that in the region's swamps, the most commonly found plant species are Vossia cuspidate, Miscanthidium violaceum, and Loudentia phragmites grasses, the Phragmites mauritianus reed, the Typha bulrush, and the Cladium jamaicense sedge.

Surprisingly and contrary to expectations, in the four sampling locations, species diversity was lowest at Kesses site (the reference site in the current study). This could be attributed to lower levels of human disturbances that increase canopy cover reducing the surface area exposed to light for photosynthetic activity of smaller plants thus little establishment by them. Kesses site, which had the least number of macrophyte species had relatively lower levels of Nitrogen in the water samples, an indication of lower levels of Nitrogen in the soil sediments that may have limited establishment of most plant species. The high species diversity in Kimondi and King’wal sites could be attributed to the massive farming activities around the site thus releasing nutrients to be utilized for establishment of plant species. Also, destruction of the swamp canopy by the local community living around the swamp has exposed these sites to sufficient light for photosynthetic activities that supported a wider range of plant species.

The lower water quality (increased nutrient levels) in the downstream sites could have allowed for a rich assemblage of plant life to develop; hence providing a rich source of macrophyte biodiversity (Mitsch and Gosselink, 1993). The species were found where the environment was optimal for its survival. The wetlands fringing Lake Victoria are dominated by a small number of macrophyte species, including papyrus (*Cyperus papyrus*), *Miscanthidium violaceum*, *Phragmites mauritianus* and *Typha domingensis* (Gichuki *et al*. 2001). Macrophytes are indeed highly sensitive to the environmental changes caused by both natural and anthropogenic effects. Similar studies including Merceline et al. (2022) while working at Sironga and Kapkatet Wetlands, Kenya, established that the distribution and composition of wetland macrophytes were influenced by anthropogenic activities in the specific sites.

In wetlands, the growth of emergent plants is so dense that vast areas of water may be entirely obscured from view (Gichuki *et al*. 2001; Gichuki, 2003). Species composition was similar in Kimondi, Kiptenden and King'wal Bridge swamps, which exhibited up to 95% similarity. However, species composition of Kesses Swamp was significantly different from the other three swamps. Both King'wal and Kimondi sites experienced increased levels of anthropogenic influences resulting from activities such as grazing, farming, brick making and replacement of indigenous vegetation with exotic trees which are known to lower the water table.

Several studies including Zedler and Kercher (2005) and Mutyavaviri (2006) observed that a decreased water table could be the main reason for the decline in species richness of macrophytes. Zedler and Kercher (2005) also reported that reduced water table disrupts microbial habitat and activity in surface waters, affecting the survival and growth of some macrophyte species. Studies have also reported that grazing activities in wetlands defoliates the vegetation cover which alters the ecosystem interactions leaving only the most resilient plants.

5.3 Macroinvertebrate assemblages and the ecological integrity of King'wal Wetland

The current study has indicated that it is possible to discern differences between reference and impaired sites in wetlands using macroinvertebrate community attributes with the metrics being selected for the final M-IBI in the study all having an ecological rationale. Previous ecological studies in the region have shown that macroinvertebrates data provide useful measures of ecological health in aquatic ecosystem including rivers (Raburu *et al.,* 2009; Aura *et al.,* 2010; Masese *et al.,* 2014; Lubanga *et al.,* 2021; Sitati *et al.,* 2021; Yegon *et al.,* 2021) and wetland biomonitoring (Orwa *et al*., 2013).

Higher abundance of Chironomidae was recorded at the upstream Kesses site. Chironomidae have long been associated with pollution (Rosenberg and Resh 1993; Hussain & Pandit, 2012; Masese *et al.,* 2014). In stream bioassessments, increase in the percentage of chironomid larvae has been used to indicate impairment (Masese *et al*., 2009; Raburu *et al.,* 2009; Lubanga *et al.,* 2021). In wetlands, this is not the case (King and Richardson, 2002). Whereas in streams the presence of chironomids indicates an increase in nutrients or reduction in oxygen, in wetlands these conditions occur naturally and large numbers of chironomids are commonly found. Gernes and Helgen (1999) found that chironomid abundance and richness decreased in response to anthropogenic disturbance in Minnesota wetlands. Similarly, the current findings indicate proportional abundance of chironomids decreased in impaired wetland sites with higher abundance being recorded upstream at Kesses site.

High abundance of the Lymnaeid snails which are longer-lived, less mobile residents of a wetland were recorded in the upstream sites. Their less mobile character makes them more susceptible to chronic disturbance than most other invertebrates (U. S. EPA 2002a). Snails are known to be susceptible to loss of plants and increased turbidity (Hann *et al*. 2001) and reportedly decrease in abundance with increased impairment in wetlands (Gernes and Helgen, 1999; Meza-Lopez and Siemann, 2020). The low abundance of the snails downstream can therefore be attributed to the loss of the loss of vegetation in the downstream sites.

The overall percentage of Ephemeroptera, Plecoptera and Trichoptera (% EPT) was highest in Kesses and lowest in King'wal and Kimondi sites. All the three taxa of EPT were only recorded in the upstream sites (Kesses and Kiptenden). The lower abundance and number of taxa of EPT taxa in the downstream study sites coincided with the deterioration in water quality. EPT taxa can therefore be referred to as good indicators of water quality change. Several studies have recognized the significant correlation between anthropogenic activities and macroinvertebrate communities, indicating that the total number of taxa and the percentage of groups like Ephemeroptera, Plecoptera, Trichoptera (EPT) and Coleoptera decreasing as the pollution and alterations in the water quality increases (Masese *et al.,* 2014; Lubanga *et al.,* 2021).

The abundance of macroinvertebrate shredders dominated in the upstream Kesses site compared to the other sites. This observation is in agreement with earlier studies in the tropical region, including Dobson *et al.* (2002), Cheshire *et al.* (2005), Uwadiae, (2009), Masese *et al.* (2014), Sitati *et al.* (2021) and Yegon *et al.* (2021) who reported more shredder abundance in the upstream sites with less human disturbance as compared to the impared sites. Shredders (most of them being Trichoptera) and scrapers (mostly Ephemeroptera) are more sensitive to environmental changes hence the low abundance and diverse recorded in the current study.

The low numbers of shredders in Kiptenden, King'wal Bridge and Kimondi sites can be attributed to the deforestation and clearance of indigenous riparian vegetation, water pollution and habitat disturbance caused by farming activities and grazing in these sites. Furthermore, the anoxic nature of wetlands leads to inadequate oxygen and the presence of exotic tree species dominating the wetland vegetation (mainly

Eucalyptus, Cypress and Pine trees) leads to inadequate quality and quantity of leaf litter input and may jointly cause the scarcity of shredders.

Macroinvertebrate collectors and predators recorded the highest abundance and they have been reported to be more tolerant to disturbance and organic pollution (Boyero *et al.*, 2009; Masese *et al.*, 2014; Masese and Raburu, 2017) hence their predominance in the current study. Similarly, an increase in the proportion of predators was noted in higher-quality wetlands in the IBI developed by Gernes and Helgen (1999), but was not selected as a metric.

The increase in proportional abundance of the dominant taxa tends to increase as impairment increases (U. S. EPA, 2002a). When an area is disturbed, intolerant taxa decline, opening up habitat and reducing competition for taxa tolerant to the disturbance. Taxa that made up the largest percentages (i.e., dominated) of the macroinvertebrate communities in the impaired sites were Culicidae, Oligocheata, and Physidae. All the three taxa are multivoltine which allow them to be rapid colonizers (Merrit and Cummins, 1996). Abundance of Culicidae has been shown to increase in impaired floodplain wetlands (Chipps, 2002). Domination of a site by a specific taxon has indicated the dominance of a pollution tolerant taxon and environmental stress in streams (Aura *et al*., 2010).

Taxa measures have always been a major component in IBI development (Karr and Chu 1999, Teels and Adamus, 2001). The coarseness of the identification used in this study did not yield many taxa metrics in the M-IBI. The family level identification was selected to allow the M-IBI to be used by individuals with minimal training in macroinvertebrate identification and to decrease sample-processing time due to the large number of samples (Lenat and Resh, 2001).

However, Odonata taxa did become part of the M-IBI. Odonata taxa have been shown to be correlated with chloride and phosphorus levels and generally declined in response to impairment in Minnesota wetlands (Gernes and Helgen, 1999). These insects have longer development times than many of the invertebrates found in wetlands and are top predators in wetland macroinvertebrate food webs. The presence of odonates in a wetland indicates that the environment within the wetland is stable (in relation to other seasonal floodplain wetlands) enough for odonates to develop and that the water chemistry is tolerable over extended periods of time (Gernes and Helgen 1999; Choi *et al.,* 2020).

A major assumption of the IBI approach is that metric values change linearly with increasing (or decreasing) disturbance (Karr and Chu, 1999; Aura *et al.,* 2010). Taxa richness for example is a commonly used metric because it is generally assumed that undisturbed wetlands support more species (Barbour *et al*. 1995, US. EPA, 2002a). Using an empirical approach, it was found that total taxa richness was not an important discriminatory variable for distinguishing reference and impaired wetlands. In fact, a biplot of the combined total macroinvertebrate and macrophyte taxa richness (macrophyte data supplied by Werlin, 2002) versus the M-IBI score revealed a curvilinear relationship ($r^2 = 0.37$, $P = 0.02$), supporting the intermediate disturbance hypothesis developed by Connell (1978). This hypothesis proposed that the greatest diversity would occur at intermediate levels of disturbance. It is possible that it is this nonlinear response to disturbance that precluded total taxa richness from becoming an important metric in the final M-IBI. Furthermore, this type of relationship suggests that those developing wetland IBI’s should be cautious when using total taxa richness as a metric in the final IBI.

According to Gernes and Helgen (2002), HDS ranges from 0 (no evidence of disturbance) to 100 for the most disturbed sites. The ranges 3-33, >33- 67 and > 67-100 HDS can be considered as the least disturbed, mid-disturbed (impaired wetlands) and the most disturbed sites, respectively. Accordingly, Kesses was established to have low HDS scores, followed by Kiptenden with Kimondi exhibiting higher HDS scores. This can be attributed the varying degree of human activities in the sites with Kesses site recording lower human activities while Kingwal and Kimondi sites exhibiting increased levels of human activities.

Evaluation of the randomly selected sites revealed that most wetlands rated in fair condition. Similar observations were made in earlier studies using vegetation-based (Werlin, 2002) and the multimetric-based indicators (macroinvertebrate, macrophyte, and algal data) (Chipps, 2002). This conclusion was not surprising because many of the randomly sites were generally impacted by human disturbance (personal observation). Many sites had signs of moderate grazing or were in proximity to row crop activities, although Kesses was isolated from these types of disturbances. The M-IBI was robust to year-to-year variation, but was sensitive to the time of year samples were collected (i.e., intra-year variation). High intra-year variation indicated the importance of completing invertebrate sampling within a specific timeframe. Loss of the flood pulse leaves many floodplain wetlands without floodwater inundation. Restoration of a flood pulse would change the connectivity between the floodplain wetlands and the main river

The multimetric IBI developed by Chipps (2002) was more comprehensive and took measures of macrophytes, periphyton and macroinvertebrates into consideration. In the current study, the relatively high correlation of the M-IBI with the HDI shows that the M-IBI is a suitable surrogate when time and funding are limited for complete faunal and floristic surveys. Both the multimetric IBI and the M-IBI cannot be used when wetlands have desiccated due the lack of aquatic macroinvertebrates. In this case, the vegetation-based IBI developed by Werlin (2002) may be used.

Wetland IBI’s can provide important tools to wetlands managers for assessing wetland condition. An IBI, once developed, allows for quick evaluation of a wetland’s condition. Metric development and IBI scores provide a baseline for continued monitoring and assessment of wetland condition. Resource managers can target wetlands that are in immediate need of restoration and use limited resources more efficiently (Danielson, 1999, Karr and Chu, 1999; Orwa *et al.,* 2013). IBI scores and qualitative rating criteria can be easily conveyed to the public. The public can be informed on the condition of the wetlands in their area without detailed explanation of the biological data used to compute the score. The implementation of an IBI can serve as a valuable tool for wetland managers.

5.4 Socio-economic status, utilization and management of wetland resources of King’wal Wetland

King’wal Wetland serves as a critical source of livelihood for various uses and users. However, a number of anthropogenic activities along the wetland, such as agricultural activities, bricks making, cutting down of wetland flora, washing of clothes around the wetland waters, water abstraction for domestic purposes, and grazing of livestock in the wetland pose threats to both habitat and water quality of the wetland. In this study, Kingwal Wetland supplied the local community with grains, vegetables, papyrus, grass, water and fodder. Also supplied were other items like salt lick to the livestock, timber and ornamental plants. These functions concord well with other uses of swamps worldwide (Zedler and Kercher, 2005) and in Kenya (Terer *et al*., 2004; Chpekwony *et al.,* 2018).

Previous studies in Nandi district, now Nandi County, for example, revealed that some parts of the wetland or other small swamps in the region have been reclaimed for crop production, while the majority of the remaining wetlands face varying degrees of threat (Chepkwony and Ipara, 2018). In the past decade, floral wetland exploitation in Kenya has been on a small scale and for subsistence purposes, primarily for mats, baskets, ropes, roofing material, and firewood (Abila, 1998; Otieno *et al*., 1998; Gichuki *et al*., 1998, 2001; Abila and Othina, 2006) however, this has currently changed with the exploitation of many swamp plants for commercial purposes (Oduor *et al.*, 2015; Chepkwony, 2019; Maua *et al.*, 2022).

The findings that currently, the most important resources from the wetland are grains, water, fodder, papyrus and vegetables while over the last 20 years, fish, wild games, water, fuelwood, fodder, grass, and ornamental plants were more important to the local community members indicate the extent of overexploitation of the wetland for agricultural activities in the recent past.

These activities enhance food production while diminishing other natural resources like natural fish, wild game, fuelwood and various plant species. This was confirmed by the degree of commercialization of agriculture in the area through selling of the crops and timber from the farmed lands within the wetland. The recognition that flora and fauna can be used by the local community members is well documented in Kenya (Feder and Umali, 1993; Gichuki *et al*., 2001; Gichuki, 2003; Osuji, 2007; Oduor *et al.,* 2015; Maua *et al.,* 2022).

Kenyans have used the plants and animal resources for various purposes including as sources of food, medicines, cosmetics, building, tools, clothing and rituals. Perhaps lack of enough water currently as compared to the past 20 years is limiting the full potential of aquaculture. This is because, few respondents reported aquaculture of 2 common fish species Nile tilapia (*Oreochromis niloticus*), and catfish (*Clarias gariepinus*) despite the dominance of these 2 species of fish in the natural waters of the wetlands. As in many other parts of Kenya, increasing populations near the wetlands, impose pressures leading to overexploitation of fisheries resources without elaborate efforts to start aquaculture projects (Kondowe *et al.,* 2022; Maua *et al.,* 2022).

Despite the occurrence of several resources in the study area, other key economic activities practiced by the local community members of Kingwal were: poultry keeping, tree nurseries, apiary among others practiced by few respondents including floriculture and dairying. These findings are in tandem with other studies which have found biological diversity of wetlands to be unevenly distributed, with some habitats being characterized by a richer range of species than others (Schuijt, 2012). In the current study, the local community members were also aware of the other social functions of the wetland such as water recharge, cultural practices, flood control and erosion protection. Few studies have reported the use of wetlands by the local community members in social functions.

Most of respondents from the local community reported that the most dominant biodiversity in Kingwal Swamp were: *Aeschynomene abyssinica* (48.8%), *C. pendula* (45.8%), *C. papyrus* (44.5%) and *L. minor* (32.3%). Yet lower proportion of the respondents reported the availability of *S. natans* (12.3%), *N. alba* (13.2%) and the *T. zebrine* (5.4%). The respondents also reported the various forms of utilizationof these plants in Kingwal Wetland. *Lemna minor* were used mainly as fodder, *C. papyrus* was mainly used to make mats, *A. abyssinica* was used as firewood, *C. pendula* had different uses such as brick making, fodder and making. *Tradescantia zebrine* and *N. alba* had few users among the local community members.

Among the various plant parts, the leaves of all the plants other than the *S. bahamense* were the most utilized by the respondents. Whole plant utilization and the stem was also a common practice for most plants. Roots and barks were the least utilized plant parts with only the roots of *C. pendula* and the bark of *S. bahamense* and the *T. zebrine* being utilized by the community members. A similar study by Odongo, (1996) identified 35 plant species used as fodder plants in Uasin Gishu swamps and 26 plant species useful as sources of food. Among the plants, *C. papyrus* had the highest level of importance among the plants, followed by *T. zebrine* and then the *C. pendula*. Other plant species recorded in the study area but with low use value were *S. bahamense* and *N. alba*. *Cyperus papyrus* had many uses in King’wal Swamp which included fencing, firewood, weaving mats, making seats, book cover, fodder, and for cultural purposes. The use of *Cyperus papyrus* has been documented in many other swamps around the country as useful for making mats, baskets and furniture (Odongo, 1996; Abila *et al*., 2005; Chepchumba, 2018; Hes, 2021).

Given that mats and baskets are utility products that have to be replaced on a regular basis in the households, they are popular and hence made more frequently. Elsewhere, baskets and mats are predominant in Busia, which has dense papyrus swamps while thatch and reeds are major products in Siaya County (Muthuri and Kinyamario, 1989; Otieno *et al*., 1998; Mutavi and Long’ora, 2019). Previous studies have also indicated tha papyrus can be utilized for paper and fodder (Muthuri and Kinyamario, 1989), and provision of energy (Chepkwony, 2019). Some Nandi swamp plant products, such as mats, were sold in the market, providing income to local communities.

The main species of animal in the wetland reported by a majority of the respondents were: sitatunga (80.2%), ducks (70%), fish (60%), hare (66.5%) and cranes (65.3%). Other animals such as shy otters, porcupines, owl and egrets were present but were identified in low numbers by the local respondents. The main use of sitatunga and ducks was for food and tourism, while porcupine, hare, guinea fowl and mongoose were mainly utilized as food. On the other hand, bats, cranes, kingfishers, and papyrus were mainly useful for tourists' attraction in the study area. The Ibis birds were used for tick control while mongoose were medicinal for some of the respondents.

Evidence to date indicates that local people's involvement in wetland management can contribute significantly to maintaining or restoring ecological integrity and community wellbeing. Building upon the recognition that every successful co-management initiative has the potential to stimulate positive initiatives elsewhere, the Dakar workshop encouraged participants to focus on solutions, and on honest assessments of practical experiences in participatory wetland management. Negative effects of these activities in the wetlands for majority of the respondents included: use of fertilizers, release of sewages, runoffs and erosion while up to 40% of the respondents were not sure of these detrimental activities.

CHAPTER SIX

CONCLUSIONS AND RECOMMENDATIONS

6.1 Conclusions

Temporal variations in the water physico-chemical attributes, macrophytes, and macroinvertebrate assemblages within the wetland were not found to be significant. However, significant spatial variations in water physico-chemical parameters were observed among the different sites of King'wal wetland, which can be attributed to the influence of extensive anthropogenic activities in these areas.

The dominant plant species in Kingwal wetland were *Cyperus papyrus* and other sedges such as *Pycreus nitidus*. The spatial distribution of plant species indicated that human activities had a profound impact on the structure of the plant community in the wetland. The site with the highest degree of impact, Kimondi, exhibited the lowest species diversity.

The abundance, distribution, and diversity of benthic macroinvertebrates were found to be influenced by the degree of human disturbance. Sensitive taxa, including Ephemeroptera (mayflies), Plecoptera (stoneflies), and Trichoptera (caddisflies), as well as shredders, were predominantly found in the less polluted Kesses site. In contrast, tolerant taxa were recorded in the more heavily polluted sites. This study contributes to the growing body of knowledge on the use of macroinvertebrate indices of biological integrity (IBI) in wetlands for ecosystem health assessment at both spatial and temporal scales. The IBI scores and individual metric data indicated significant impairment, as measured by human disturbance scores.

These results highlight the profound impacts of various human activities, such as agriculture, grazing, settlement, and brick making, on the current biological integrity of the wetland. The utilization and management of wetland resources in the King’wal Wetland exhibited significant variability, indicating a high level of utilization but a limited focus on wetland management practices. The findings suggest that there is intense exploitation of wetland resources without adequate measures for their sustainable management.

6.2. Recommendations

Based on the findings of this study, the following recommendations are proposed:

1. Conservation and Management Measures: Considering the negative impacts of human activities on flora and fauna in the wetland, it is crucial to implement conservation and management measures. The Index of Biological Integrity (IBI) developed in this study can be adopted as an early warning system for wetland degradation. It should be used as a tool to guide management decisions and promote sustainable practices.
2. Policy Implementation: The county and national governments should formulate and enforce policies to regulate human activities within and in proximity to the King’wal wetland. These policies should aim to safeguard the wetland from unwarranted threats and ensure its long-term sustainability.
3. Awareness and Capacity Building: There is a need for increased awareness among local farming communities, government staff, and local decision-makers about the sustainable management of the wetland. Interactive training programs focused on conservation activities, such as citizen science, should be conducted to enhance the capacity of local communities. Moreover, promoting the planting of indigenous tree species that preserve water and the environment, as opposed to water-intensive exotic species like eucalyptus, should be encouraged.

6.3 Recommendations for Further Research

In order to further enhance our understanding of the Kingwal Wetlands and support evidence-based management strategies, the following areas of research are recommended:

1. Seasonal Variations: Investigate seasonal changes in water physico-chemical attributes, macrophytes, and macroinvertebrate assemblages to assess their influence on wetland health and functioning throughout the year.
2. Long-term Monitoring: Implement long-term monitoring programs to track changes in the wetland ecosystem over time and evaluate the effectiveness of management interventions.
3. Socio-economic Studies: Conduct socio-economic studies to assess the economic value of wetland resources and explore sustainable livelihood options for local communities that depend on wetland resources.
4. Hydrological Studies: Investigate the hydrological dynamics of the wetland, including water flow patterns, groundwater interactions, and the impact of climate change on wetland hydrology.

By addressing these research gaps, we can further improve the understanding of the King'wal Wetland and develop more comprehensive and effective strategies for its conservation and sustainable management. In conclusion, the findings of this study underscore the urgent need for the conservation and sustainable management of the King'wal Wetland. The impacts of human activities on wetland health and integrity are evident, highlighting the importance of adopting appropriate measures and policies to mitigate these threats is a key measure. By implementing the recommended measures and conducting further research, we can work towards safeguarding the ecological health and long-term viability of the wetland, ensuring its benefits for both current and future generations.

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APPENDICES

Appendix I: The Initial 23 Metrices Considered for Inclusion in The Current Ibi Development

Metrics
Number Ephemeroptera genera
Number Plecoptera genera
Number Trichoptera genera
Number Ephemeropter-Plecoptera- Trichoptera genera
Total number of macro-inveterbrate genera
Percent EPT individuals
Number of Oligochaeta
Percent Coleoptera proportion metric
Number of Odonata genera
Percent non-insect individual
Percent Diptera individuals
EPT: Diptera ratio
Percent dominant 3 genera
Number intolerant genera
Number of Pulmonata genera
Mullusca+ Crustacean genera
EOT richness
Percent filterer individuals
Percent scraper individuals
Percent predator individuals
Percent gatherer individuals
Shannon diversity index
Simpson richness index

Appendix II: Raw Scores Of The Selected Macroinvertebrates Metrices From The Study Sites (Site 1- Kesses, Site 2- Kiptenden, Site 3- Kingwal Bridge, Site 4- Kimondi)

Metric	Predicted response	Site 1	Site 2	Site 3	Site 4
Number Ephemeroptera genera	Decrease	459	431	411	244
Number Plecoptera genera	Decrease	37	35	30	21
Number Trichoptera genera	Decrease	432	417	400	54
Number Ephemeropter- Plecoptera- Trichoptera genera	Decrease	928	883	841	319
Total number of macro-inveterbrate genera	Decrease	28	30	27	21
Percent EPT individuals	Decrease	39.6	39.3	34.9	16.0
Number of Oligochaeta	Increase	11	18	13	74
Percent Coleoptera proportion	Decrease	1.19	1.02	1.08	1.80
Number of Odonata genera	Decrease	90	93	84	301
Percent non-insect individual	Increase	8.6	9.4	8.3	9.6
Percent Diptera individuals	Increase	30	31.2	28.1	35.9
EPT: Diptera ratio	Decrease	1.32	1.26	1.24	0.44
Percent dominant 3 genera	Decrease	18.2	18.7	18.2	40.4
Number of Pulmonata genera	Decrease	82	77	87	71
Total abundance of macro-	Decrease	234	22	24	19

invertebrates		5	45	11	98
EOT richness	Decrease	981	941	895	599
Percent filterer individuals	Decrease	12.3	28.2	23.2	34.5
Percent scraper individuals	Decrease	15.9	22.1	28.1	39.2
Percent predator individuals	Decrease	14.6	11.8	36.4	26.4
Percent gatherer individuals	Increase	17.8	10.9	25.4	13.5
Shannon diversity index	Decrease	2.87	2.99	3.23	2.64
Simpson richness index	Decrease	1.9	1.2	2.5	3.2

Appendix III: Final Metrices Selected and Used to Develop the Ibi (Site 1- Kesses, Site 2- Kiptenden, Site 3- Kingwal Bridge, And Site 4- Kimondi)

Metrics	Site 1	Site 2	Site 3	Site 4
Number Ephemeroptera genera	5	5	1	1
Number Plecoptera genera	5	3	1	1
Number Trichoptera genera	5	3	3	1
Number Ephemeropter-Plecoptera-Trichoptera genera	5	3	3	3
Total number of macro-inveterbrate genera	5	3	3	1
Percent EPT individuals	5	5	3	1
Number of Oligochaeta	5	3	3	3
Percent Coleoptera proportion	5	3	1	1
EPT: Diptera ratio	5	3	3	1
Number of Pulmonata genera	5	5	3	3
EOT richness	5	3	3	1
Shannon diversity index	5	3	3	1
IBI Scores	60	42	30	18

Appendix IV: Allocation of Macroinvertebrates to Their Respective Ffgs (Merritt and Cummins, 1996; Graca *Et Al.*, 2001; Dobson *Et Al.*, 2002; Polegatto and Froehlich, 2003; Molina, 2004; Masese *Et Al.*, 2014)

Families	FFG
Simuliidae	Collector Filterers
Sphaeriidae	Collector Filterers
Hydropsychidae	Collector Filterers
Chironomidae	Collector Gatherers
Caenidae	Collector Gatherers
Leptophtebiidae	Collector Gatherers
Lumbriculidae	Collector Gatherers
Dytiscidae	Predators
Gyrinidae	Predators
Haliplidae	Predators
Noteridae	Predators
Tabanidae	Predators
Corixidae	Predators
Gerridae	Predators
Hydrometridae	Predators
Mesoveliidae	Predators
Notonectidae	Predators
Pleidae	Predators
Lestidae	Predators
Cordulegasteridae	Predators
Gomphidae	Predators
Coenagrionidae	Predators
Nemouridae	Predators
Perlidae	Predators
Lymnaeidae	Scrapers
Physidae	Scrapers
Thiaridae	Scrapers
Planorbidae	Scrapers

Baetidae	Scrapers
Heptageniidae	Scrapers
Ephemerallidae	Scrapers
Tipulidae	Shredders
Leptoceridae	Shredders
Potamonautidae	Shredders

Appendix V: Some the Anthropogenic Activities Along the Kingwal Wetland (A - Reclaimed Part of The Wetland for Maize Planting, B - Settlement Along the Wetland, C – Brick Making, D – Clearing and Buring of a Part of The Wetland for Agricultural Utilization).

(Source: Author, 2021)

Appendix VI: Developed Questionnaire Used to Collect Demographic Information of The Sampled Pollution, And the Distribution and Uses and Wetland Flora and Fauna for the Study

Dear respondent,

I am a Doctor of Philosophy student undertaking a research entitled "***Socio-Economic Status and Bioassessment of The Ecological Integrity of King'wal Wetland, Nandi County, Kenya***". I kindly request you to fill these questionnaires and interview schedules. Your unreserved response will be treated with utmost confidentiality and they will be exclusively used for the purpose of research only. There are neither right nor wrong answers, therefore respond to the items appropriately as specified herein. Do **NOT** write your name anywhere on this paper

Thank you.
Yours faithfully,

Wamalwa Stella Wanjala

Part 1: Demographic structure of the sampled population

In this section, indicate your answer by putting a tick [√] in the appropriate space provided.

1. Age: <20 [ ] 21-30 [ ]31-40 [ ]41-50 [ ]51-60 [ ] >60 [ ]
2. Gender: Male [ ] Female [ ]
3. Marital status: Married [ ] Single [ ] Widow [ ] Others [ ]
4. Occupation: Farmer [ ] Civil servant [ ] Casual labour [ ] Trader [ ] Housewife [ ] Other [ ]

5. Level of education: None [ ] Lower primary [ ] Upper primary [ ] Secondary [ ] College [ ]
6. Household head: Male head [ ] Female head [ ]

Part 2: Wetland use and economic activities by the local community members

1. Which of the following resources do you obtain from the wetland?

Grains [ ] Vegetables [ ] Papyrus [ ] Grass [ ] Water [ ]
Fodder [ ] Wild game [ ] Fish [ ] Fuel [ ] Fruits [ ]
Medicinal plants [ ] Saltlick [ ] Ornamental plants [ ] Others [ ]

2. Using a scale of 1 to 4, comments on the availability of the aforementioned wetland resources currently and 20 years ago. Where 4 = plenty, 3 = Moderate, 2 = Inadequate and 1 = Rare.

Grains [ ] Vegetables [ ] Papyrus [ ] Grass [ ] Water [ ]
Fodder [ ] Wild game [ ] Fish [ ] Fuel [ ] Fruits [ ]
Medicinal plants [ ] Saltlick [ ] Ornamental plants [ ] Others [ ]

3. Kindly estimate the amount of income derived from the wetlands resources.

Grains [ ] Vegetables [ ] Papyrus [ ] Grass [ ] Water [ ]
Fodder [ ] Wild game [ ] Fish [ ] Fuel [ ] Fruits [ ]
Medicinal plants [ ] Saltlick [ ] Ornamental plants [ ] Others [ ]

4. Which fish species occur in the wetlands?

Tilapia [ ] Catfish [ ] Mudfish [ ] Barbus [ ] and Others [ ]

5. Comment how frequently the species named above occur in the wetland

6. What economic activities do you practice within the wetlands??

Fish farming [ ] Bee keeping [ ] Tree nurseries [ ]
Floriculture [ ] Making mats [ ] Tourism [ ]
Wildlife [ ] Poultry keeping [ ] Zero grazing [ ]

7. What services do you derive from the wetlands?

Climate regulation [ ] Air quality regulation [ ] Water recharge [ ]
Pollution control [ ] Erosion protection [ ] Control of floods [ ]
Cultural practices [ ] Recreational activities [ ] Educational [ ] Habitat provision [ ] Soil formation [ ] Nutrient recycling [ ]

8. What are some of the flora in the wetlands?

Duckweed [ ] Floating fern [ ] Papyrus Reeds[ ]
Jointvetches [ ] Sedge grass [ ] Water lily [ ]
Algae [ ] Wildberyy [ ] Wondering Jew [ ] Others [ ]

9. Kindly indicate some of the uses of the plants mentioned. Kindly mark the following numbers to depict uses: 1. Fodder 2. Brick making 3. Mat making 4. Firewood 5. Cultral activities 5. Food 6. Medicine

Duckweed [ ] Floating fern [ ]
Jointvetches [ ]

Sedge grass [ ] Water lily [ ] Algae [ ] Wildberyy [ ]
Wondering jew [ ] Others [ ]

10. Which part of the wetland plant do you use. Kindly mark the following numbers to depict uses: 1. Leaves 2. Stem 3. Roots 4. Bark 5. Whole plant

11. How would you rate the relative important of each of the plants in the Swamp?.

Kindly mark the following numbers to depict ranks: 1. Least important 2. Important
3. Very important

Duckweed [ ] Floating fern [ ] Papyrus Reeds[ ] Jointvetches [ ]
Sedge grass [ ] Water lily [ ] Algae [ ] Wildbery [ ]
Wondering jew [ ] Others [ ]

12. What animals exist in the swamp?

Sitatunga [ ] Shy otter [ ] Porcupine [ ] Hare [ ] Bat [ ]
Crane [ ] Kingfisher [ ] Guinea fowl [ ] Ibis [ ] Duck [ ]
Egrets [ ] Mongoose [ ] Snake [ ] Owl [ ] Papyrus
Warbler [ ] Fish [ ]

13. Kindly indicate some of the uses of the animals mentioned. Kindly mark the following numbers to depict uses: 1. Food 2. Tourism 3. Control pests 4. Medicinal Sitatunga [ ] Shy otter [ ] Porcupine [ ] Hare [ ] Bat [ ] Crane [ ] Kingfisher [ ] Guinea fowl [ ] Ibis [ ] Duck [ ] Egrets [ ] Mongoose [ ] Snake [ ] Owl [ ] Papyrus warbler [ ] Fish [ ]

14. What human activities currently affect the integrity of the wetlands?

Use of fertilizers [ ] Release of sewage [ ] Run off [ ]Erosion [ ] Others [ ]

Thank you

Appendix VII: Similarity Report

AI –
WC –

DrillBit

The Report is Generated by DrillBit Plagiarism Detection Software

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Submission Information

Author Name	Wamalwa Stella Wanjala
Title	SOCIO-ECONOMIC STATUS AND BIOASSESSMENT OF THE ..
Paper/Submission ID	948817
Submission Date	2023-09-04 11:35:21
Total Pages	226
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