INFLUENCE OF LARGE MAMMALIAN HERBIVORES ON NUTRIENTS AND CARBON LOADING, AND BENTHIC ALGAL DEVELOPMENT IN THE MARA RIVER, KENYA

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Abstract

The Mara -Serengeti ecoregion is internationally renowned for having the highest density and most diverse combination of both wildlife and domestic large mammalian herbivores on earth. This study focused on how these large mammalian herbivores (cattle and hippos) influence the water quality which is central to the livelihoods of the resident pastoral community and their contribution to nutrients and organic matter input in the Mara River through their in-stream behaviour and its impact on benthic algal development. A total of 12 sites were selected based on the changing distribution and abundance of livestock and hippo populations along the Talek, Molibany and Olare Orok tributaries of the Mara River. The results showed a spatial significant variation ($p<0.05$) in water quality variables, organic matter and nutrient concentration among the livestock and hippo sites due to variation in livestock and hippo input amounts and their numbers among the sites. This was reflected by the strong significant positive correlation between the total livestock numbers and the levels of TN and DOC ($r>0.70$, $p<0.05$). The input of C, N and P by one cattle from direct defeacation into the river was estimated to be 5.41 g C, 0.17 g N and 0.04 g P per day. Based on the population estimates of cattle and hippos that egest directly in the Talek sub-catchment, the total input to the river by 13522 cattle was 856 Kg C, 26.7 Kg N and 6.7 Kg P per day and by the 648 hippos was 547 Kg C, 56.9 Kg N and 7.5 Kg P per day. The spatial variation in the development of benthic algae noted in the study was majorly affected by the nutrient input from livestock and hippos and the significant variation of TSS and POM (turbidity) levels at the livestock and hippo sites. Diatoms (*Craticula, Navicula, Nitzschia*) which are indicators of nutrient enrichment were the most dominant and abundant class of algae among the sites. Therefore, further research is recommended to also establish the spatial and temporal variation of nutrient and organic matter inputs and compare the different pathways, such as large mammalian herbivores vs overland flow which will help in the development of appropriate and effective management strategies in the Mara River basin.

CHAPTER ONE

1.0 INTRODUCTION

The Mara-Serengeti ecoregion is internationally renowned for having one of the highest densities and most diverse combination of large mammalian herbivores on earth (Sinclair and Arcese, 1995). It also hosts one of the great wonders of the natural world, the annual migration of over one million wildebeest. LVBC and WWF-ESARPO, (2010) put the estimates as of 2003 at about 1.3 million wildebeest, 200,000 zebras and 440,000 gazelles. In the middle reaches on the Kenyan side, the river and its tributaries host more than 4,000 hippos (Kanga et al., 2011) and over 220,000 cattle which utilize streams and rivers as watering points and crossings (Lamprey & Reid, 2004; Ogutu et al., 2011).

According to Ogutu et al., (2016), wildlife numbers have declined on average by 68% between 1977 and 2016 due to exponential human population growth, increasing livestock numbers, declining rainfall and a striking rise in temperatures. The magnitude of decline varied among species but was most extreme (72–88%) and now severely threatens the population viability and persistence of large mammalian herbivores in Kenya's rangelands. Although, the hippopotamus population has increased both within and outside the Maasai Mara National reserve (MMNR) according to the census done by Kanga et al., (2011) possibly due to increasing conservation measures in this region. Likewise, to wildlife, cattle numbers have decreased by 25.2% but numbers of sheep and goats has increased by 76.3% in the same period (Ogutu et al., 2016). As a result, livestock biomass was 8.1 times greater than that of wildlife in 2011–2013 compared to 3.5 times in 1977–1980 (Ogutu et al., 2016).

The direct and indirect inputs of nutrients and organic material from large mammalian herbivores (LMH) through excretion and egestion to watercourses has been of interest for several decades (Doran and Linn, 1979; Gary et al., 1983). Their influence on aquatic ecosystems have often been negative (Belsky et al., 1999) and these ecosystems have been fertile ground for understanding the extent to which animals can alter nutrient cycling and ecosystem structure. Most well researched aspect of water quality changes induced by LMH (cattle) excrement pertains to human health, and specifically the prevalence of *Escherichia coli* bacteria in water (Collins and Rutherford, 2004; Davies-Colley et al., 2004). Where nutrient loading indicators such as nitrogen and phosphorus have been measured, investigations are often concerned with pathogens and disease; methemoglobinemia (blue baby disease) and

carcinogenic materials from nitrogen, and the threat of cyanobacteria poisoning from phosphorus induced eutrophication (Hubbard et al., 2004). Animal inputs also have finer particulates that increase turbidity in the aquatic ecosystem (Dutton et al., 2013, Dutton et al., 2018a), which may reduce light penetration and limit primary production.

Despite the aforementioned negative effects associated with animals in the aquatic systems they can also be important in sustaining the terrestrial-aquatic linkages by acting as vectors for the movement of carbon and nutrients among these ecosystems (Kitchell et al., 1979, Vanni 2002, Atkinson et al., 2016), and these animal inputs can act as subsidies that influence the dynamics of the recipient ecosystem (Anderson et al., 2008, Subalusky and Post, 2018). Resource subsidies can strongly affect nutrient cycling (Kitchell et al., 1999, Atkinson et al. 2016), ecosystem productivity (Marcarelli et al., 2011, Samways and Cunjak, 2015), and food web structure and stability (Leroux and Loreau, 2008; Masese et al., 2018).

Hippos consume grass from the surrounding savannah grassland during night time, and spend their day basking in the river, transporting terrestrial carbon and nutrients through excretion and egestion (Eltringham 1999, Subalusky et al., 2015). Modelling estimates suggest hippos in the Mara basin contribute 3,125 tons dry mass (DM) to the river every year, and excretion accounts for 70% of the nitrogen (N) and 33% of the phosphorus (P) in these inputs. The daily loading into the river by hippo excretion and egestion equals 8563 kg DM, 3499 kg C, 492 kg N and 48 kg P, which is equivalent to 670% of course particulate organic matter (CPOM), 15% of dissolved organic carbon (DOC), 27% of total nitrogen (TN) and 29% of total phosphorous (TP) of loading from the upstream catchment (Subalusky et al., 2015).

Livestock also contribute substantial amounts of organic matter and nutrients into streams and rivers (Bond et al., 2014; Mesa et al., 2015). For instance, during an assessment of nutrient loading by cattle undertaken in an English Chalk stream, Bond et al. (2014) noted that, cattle faeces contain 0.79% TN, 0.43% TP and 0.43% potassium by wet mass and their loading to the stream during the study period was estimated to have increased in-stream nitrogen, phosphorus and potassium concentrations in the river reach by 0.0036mg L^{-1}, 0.002 mg $L^{-1}$and 0.002 mg L^{-1}, respectively.

From the stoichiometry ratio, the hippo faeces and urine have been estimated to be 222.8 C: 6.3 N: 1.0 P and 25.8 C: 15.8 N: 1.0 P, respectively, while cattle faeces and urine have been estimated to be 70.2 C: 12.8 N: 1.0 P and 2 C: 1 N: 1 P, respectively (Pramanik et al., 2007; Subalusky et al., 2015). The differences in the stoichiometry of major elements, especially in

hippo and cattle faeces, will likely influence ecosystem dynamics (Sardans et al., 2012), but data is limited. Therefore, this study focuses on quantifying the livestock (cattle) input in the African savannah aquatic systems which is unknown, and how these compare with the wildlife (hippos) they are replacing and potential ecosystem responses.

1.1 Problem statement and justification

Large populations of wildlife that were once key features of many landscapes have been decimated by human actions and replaced to some extent by domesticated livestock (Prins 2000; Wardle et al., 2011) which can also contribute substantial amounts of organic matter (in the form of faeces) and nutrients into streams and rivers (Bond et al., 2014; Mesa et al., 2015). Although, it's generally accepted that animal resource inputs can provide an important part of the nutrient and carbon budget for many aquatic ecosystems, the degree to which their relative importance can vary, and the drivers of this variability are not well understood (Subalusky and Post, 2018).

Therefore, the goal of this study was to quantify inputs (organic matter and nutrients) by large mammalian herbivore (cattle and hippos) in the Mara River and their contribution to nutrient enrichment through urine and faecal deposits and its impact to aquatic biota (benthic algae) which is yet to be explored in the African savannah tropics. Also, the importance of the Mara River to the downstream pastoral community in terms of water quality (Gereta et al., 2002) bears more credence to a need to understand the influence of large mammalian herbivores on the river ecosystem structure and functioning which will help in the development of appropriate management strategies.

1.2 General objective

To assess the influence of livestock and hippos on nutrient and organic matter loading, and benthic algal development in the Mara River.

1.3 Specific objectives

1. To determine the variation in water quality physico-chemical variables and nutrient concentration at livestock and hippo sites in the Mara River.
2. To quantify input of organic matter (OM) and nutrients by livestock and hippos and correlate with concentrations in the water column and sediments.
3. To determine variation in benthic algal development at the livestock and hippo sites in the Mara River.

1.4 Hypothesis

H_a: There is variation in water quality physico-chemical variables at the livestock and hippo sites in the Mara River.

H_a: Nutrient concentrations at the hippo sites are higher than at the livestock sites

H_a: Livestock and hippo input of organic matter and nutrients correlates with concentrations in the water column and sediments.

H_a: Benthic algal development is affected by the higher input of nutrients and organic matter by hippos compared to livestock.

1.5 Conceptual Framework

High grazing intensities especially during the dry season with frequent access to rivers by large mammalian herbivores can result in reduced plant cover and vitality around the riparian areas, leading to increased soil erosion and elevated sediment inputs impairing water quality and impacting aquatic biota (Kibichii et al., 2015; Figure 1).

Large mammalian herbivore damage to riparian vegetation and soils destabilizes the banks and leads to mobilization of fine sediment (Trimble, 1994), that in turn causes sedimentation in the channel and turbidity (reduced clarity) in the stream water column (Dutton et al., 2018b). In addition, more runoff of sediment occurs from soils disturbed and compacted by LMH trampling (Nguyen et al., 1998).

Large mammalian herbivores contribute nutrients directly to streams and riparian areas by excretion and egestion (Subalusky et al., 2015). Faecal material deposited in the riparian zone is readily washed overland into the stream with little opportunity for filtration of contaminants by (reduced, damaged or absent) vegetation or infiltration into (compacted) soil. Faecal contamination by direct deposition is expected to dominate during the dry season because livestock spend most of their time in the watering points during this season while overland flow contributions would be expected to dominate in wet season (Till et al., 2000). Research findings have shown generally much higher nutrient yields from grazed catchments (Cooper & Thomsen, 1988; Figure 1).

In river systems with low flows and shallow cross-sections, nutrient enrichment due to the input of organic matter from LMH stimulated algal blooms and induced eutrophication (Garnier et al., 2005; Bowes et al., 2008; Figure 1). Eutrophication, alongside the decomposition of allochthonous faecal and urinal organic material from LMH can deplete dissolved oxygen

content within a river (Singh et al., 2008; Dawson et al., 2016; Dutton et al., 2018a; Masese et al.,2018; Figure 1).

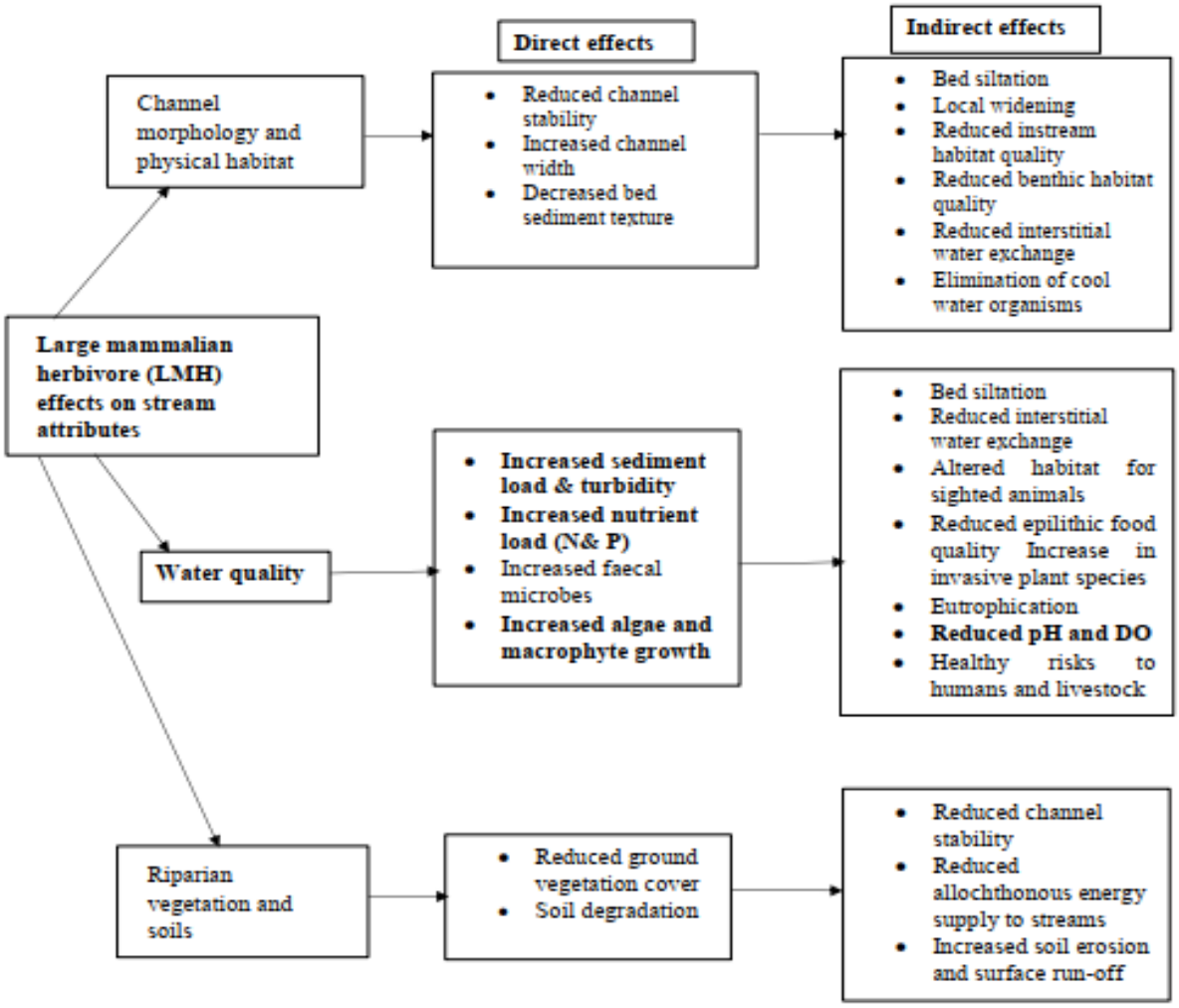

Figure 1:Conceptual diagram of large mammalian herbivore (LMH) effects on stream water quality and biota

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 Pre-human distribution of wildlife in the African savannas, land use and population changes

Africa is home to more large mammalian herbivores than any other continent, with the greatest species richness (30 species) found in the grass-dominated savannahs of East Africa (Du Toit and Cumming, 1999; Shorrocks and Bates, 2015). While the evolutionary timing and chronology of grassland ungulate evolution is uncertain (Christin et al., 2014), molecular phylogenies, isotopic analysis and palaeo-reconstruction all confirm that a diverse East African ungulate community, with a diet dominated by C4 savannah grasses, has existed for the last 8 - 10 Myr (Edwards et al., 2010; Lorenzen et al., 2012).

The Mara-Serengeti ecoregion is internationally renowned for having the highest density and most diverse combination of large herbivores on earth (Sinclair and Arcese, 1995). LVBC and WWF-ESARPO (2010) put the estimates as of 2003 at about 1.3 million wildebeest, 200,000 zebras and 440,000 gazelles. The Serengeti is home to the largest giraffe population in Africa, estimated at between 8,000 and 17,000.

The Mara, although only a quarter of the total ecosystem area, is crucial to the survival of the entire system because it is the source of forage for wildlife migrating through the Serengeti during critical points in the dry season (Ottichilo et al., 2001; Thirgood et al., 2004). Extensive grasslands in the pastoral areas adjacent to the Mara also provide wet season dispersal ranges for resident wildlife (Stelfox et al., 1986). Though, only 25% of the wildlife habitat in the Mara part of the ecosystem is protected (Maasai Mara National Reserve); the rest lies within pastoral and agricultural areas north of the reserve.

Pastoralism is the economic mainstay of most inhabitants of grasslands of East Africa like the Mara, who also often derive limited income from wildlife-based tourism. However, rapid human population growth, expansion of settlements (Lamprey and Reid 2004), cultivation (Serneels et al., 2001; Thompson and Homewood 2002) and transition from semi-nomadic pastoralism to a sedentary lifestyle (Western et al., 2009), are progressively altering the structure of these savannah grasslands. Concurrent with these processes, a transition from communal land tenure to private land ownership in the pastoral ranches, habitat fragmentation through land privatization and subsequent subdivision (Galvin et al., 2008; Homewood et al.,

2009), rising temperatures and recurrent severe droughts (Ogutu et al., 2007) threaten the future survival of large mammalian herbivore populations in some savannah ecosystems, such as the Mara-Serengeti of Kenya and Tanzania (Ottichilo et al., 2001; Ogutu et al., 2009).

A spectacular example of this expansion is found on pastoral ranches surrounding the Maasai Mara National Reserve (MMNR) in Kenya (Norton-Griffiths et al., 2008). The progressive intensification of land use, sedentarization and diversification of livelihoods are associated with rapidly declining wildlife numbers in the last three decades (Ottichilo et al., 2000; Ogutu et al., 2009). The declines are related to increasing numbers of settlements, people, livestock, poaching and major land use changes on the pastoral ranches (Serneels and Lambin, 2001; Georgiadis et al., 2007; Reid et al., 2008; Ogutu et al., 2009, Ogutu et al., 2016). Not only have resident populations decreased, but the numbers of migratory wildebeest and zebra entering the Mara region during the dry season have also shrunk, although no change in the source populations in the Serengeti ecosystems has been recorded (Sinclair et al., 2007). The patterns of declining wildlife in protected areas of East Africa (Stoner et al., 2007; Western et al., 2009) are consistent with early forecasts of major reductions, and even extinctions of many wildlife populations expected in East African reserves as a consequence of increasing insularization (Newmark, 1996) and displacement of wildlife by increasing livestock incursions into protected areas (Butt et al., 2009).

These changes progressively impede traditional seasonal wildlife movements between protected areas and their adjoining pastoral systems. Several studies have demonstrated seasonal movements by ungulates between protected areas and adjoining pastoral ranches in Amboseli (Mworia et al., 2008), Mara (Stelfox et al., 1986) and Athi Kaputiei Plains (Reid et al., 2008), thus supporting the prediction that the processes associated with land use change will continue to erode grazing areas so that livestock will compete increasingly with wildlife for resources (Homewood et al., 2009).

The biomass of livestock as a per cent of total livestock and wildlife biomass recorded within the reserve boundaries increased from an average of 2% in the 1970s to 23% in the 2000s and it's now 8.1 times greater than that of any resident wildlife species (Ogutu et al., 2011; Ogutu et al., 2016). The numbers of the small sized livestock such as goats and sheep (shoats) have increased hugely within the ranches, although relatively few enter the reserve (Ogutu et al., 2011, Ogutu et al., 2016). Given the rising number of shoats and their expanding distribution

in the Mara ranches, the competition between livestock and wildlife is expected to further intensify over time (Ogutu et al., 2011)

Despite the significance of pastoral areas to wildlife and livestock, few studies have evaluated the relative impact of pastoralism versus protection on wildlife population density and demography in African savannahs (Rannestad et al., 2006; Wallgren et al., 2009). Even fewer studies have investigated the impacts of pastoralism and protection on long-term changes on resources based on comparative changes in density (Reid et al., 2008). In this study therefore, the impacts of changing population density of the large mammalian herbivores (livestock vs hippos) on the Mara river water resource is assessed.

2.2 Large mammalian herbivore (wildlife and livestock) input rates

Large mammalian herbivores are (LMH) important vectors for the movement of carbon and nutrients among ecosystems (Atkinson et al., 2016), and these animal inputs can act as subsidies that influence the dynamics of the recipient ecosystem (Anderson et al., 2008; Subalusky and Post, 2018). LMH are particularly important subsidy vectors because they can create hotspots and hot moments of carbon and nutrient cycling when they aggregate in time and space (McClain et al., 2003; McIntyre et al. 2008), transport carbon and nutrients against naturally-established gradients (Naiman et al., 2009), or supply limiting carbon and nutrients (Vanni, 2002).

There are two primary forms in which LMH input organic matter and nutrients into recipient ecosystems: carcasses and waste excretion/egestion (Vanni, 2002; Subalusky and Post, 2018). When LMH dies in a recipient ecosystem, the carcass decomposes, providing a complex source of carbon and nutrients (Menninger et al., 2008; Walters et al., 2009). When animals spend time in a recipient ecosystem after feeding elsewhere, they contribute carbon and nutrients to that ecosystem through excretion of soluble organic and inorganic nutrients from assimilated resources, and egestion of particulate carbon and nutrients from consumed but not assimilated resources (Vanni, 2002; Janetski et al., 2009; Post and Walters, 2009; Roman and McCarthy, 2010). Differences in stoichiometry and bioavailability between these different forms of input can influence their effects on aspects of ecosystem function, such as decomposition, nutrient cycling and the balance between primary production of autochthonous carbon and microbial respiration of allochthonous carbon (Marcarelli et al., 2011; Tiegs et al., 2011; Sitters et al., 2015; Subalusky and Post, 2018).

Hippopotami (*Hippopotamus amphibius*) make daily feeding migrations between terrestrial ecosystems where they forage (typically savannah grasslands) and aquatic systems where they rest (Subalusky et al., 2015). This daily feeding migration is probably an important source of allochthonous subsidies to aquatic ecosystems in sub-Saharan Africa, particularly because the migration occurs year-round. Hippopotami travel 1–10 km inland during the night to feed, somewhat selectively, on grass (Olivier & Laurie, 1974) and return by dawn to spend the day basking in and near the water. Through this daily migration, hippopotami probably contribute a substantial amount of excretion and egestion to aquatic systems during daytime resting hours. Subalusky et al., 2015 outlined the important role played by hippos in influencing C and nutrient dynamics in the Mara River. They estimated the total loading by hippopotami into the Mara River to be approximately 3000 metric tons of dry matter, 1200 metric tons of C, 200 metric tons of N and 18 metric tons of P every year.

Livestock access to watercourses also (streams and rivers) contributes to organic, nutrient and bacterial loads through defeacation and urination (Davies-Colley et al., 2004; Oudshoorn et al., 2008; Bond et al., 2012). In the Mara, livestock usually congregate along river networks during the dry season for watering and use the river course as crossing points to the grazing areas (Ogutu et al., 2014) and by so doing, they deposit organic matter and nutrients into the river (Naiman et al., 2003). Therefore, areas where cattle have direct access to the watercourse may act as critical source areas, that is, specific areas within a catchment where source areas of nutrients and organic matter are connected to waterbodies through hydrologically active zones (Pionke et al., 2000; Thompson et al., 2012).

From the experiments done by Bond et al., (2014) in the English Chalk streams, they estimated that a herd of 33 cattle deposited over 8 tonnes of faeces into a 770 m reach of the River Meon (an English Chalk stream) over a seven-month period in 2010. Calculations suggested that direct cattle faecal inputs increased in-stream phosphorous, nitrogen and potassium concentrations by 0.0036 mgL^{-1}, 0.002 mgL^{-1} and 0.002 mgL^{-1} respectively. For all nutrients, these estimated increases in concentration due to direct faecal inputs were a fraction of background in-stream concentrations.

In this study therefore, the Carbon C, nitrogen (N) and phosphorus (P) loading into the Mara River through defeacation and urination by cattle, which has not been established yet is determined and compared by the existing average estimates by Subalusky et al., (2015) of C, N and P loading to the Mara river by the hippos.

2.3 Influence of large mammalian herbivore inputs on aquatic ecosystem processes

The transfer of material and energy across community boundaries shape the ecology of entire landscapes (Nakano et al., 1999; Sabo and Power, 2002; Baxter et al., 2004). Semi-aquatic species that rely on terrestrial sources of energy and nutrients (Doucett et al., 2007) can have large impacts on recipient aquatic habitats, affecting nutrient cycling, food web dynamics, and aquatic community structure, particularly if these recipient habitats are smaller than the sources of subsidies (Arthington et al., 2005).

Direct LMH access to streams can result in elevated nutrient levels (Bond et al., 2014; Stears et al., 2018). Cattle and hippos defeacate and urinate in streams (Davies Colley et al., 2004; Bond et al., 2012; Subalusky et al., 2015), resulting in elevated nitrogen and phosphorus levels (Davies-Colley et al., 2004; Bond et al., 2014). This is compounded by the addition of attached faeces washed from LMH legs (Davies-Colley et al., 2004) and the disturbance and re-suspension of nutrients sequestered in stream sediment (frequently contaminated with faecal material) (Muirhead et al., 2004; Terry et al., 2014) by cattle/hippo in-stream activity (Davies-Colley et al., 2004).

Elevated levels of nutrients not only pose direct toxicity difficulties for aquatic biota (Camargo et al., 2005), but also can also result in eutrophication (Stutter and Lumsdon, 2008). Although a natural process (Anderson et al., 2002; Hilton et al., 2006), eutrophication is accelerated considerably by nutrient additions resulting from anthropogenic activities. The most obvious symptom of eutrophication is the formation of algal blooms (Smith et al., 1999), most commonly as attached algae in rivers. Harmful algal blooms (including toxic forms) may occur with associated risk to livestock, organisms and human health (Bowling and Baker, 1996; Anderson et al., 2002; Ibelings et al., 2014), resulting in significant economic costs. Algal blooms can cause taste and odour problems, resulting in increased drinking water treatment costs.

Benthic diatom communities have been shown to respond positively to phosphorus inputs up to a point at which further enrichment causes no additional growth or biomass accrual (Horner et al., 1990). In contrast to the lower concentrations of phosphorus favoured by diatom communities, higher phosphorus concentrations have been shown to result in the proliferation of macrophytic algae such as *Phormidium* (cyanobacteria) (Bachoon et al., 2009; Burt et al., 2013).

Fine sediments deposits by LMH into the rivers can also increase turbidity, limit light penetration and reduce primary productivity (Davies-Colley et al., 2008; Izagirre et al., 2009), thus affecting benthic algae biomass, photosynthetic activity and community composition (Izagirre et al., 2009). Elevated suspended solids are known to limit algal growth and alter community composition in streams (Stevenson and Smol, 2003). Algal growth is diminished by reduced light penetration due to increased turbidity (Burt et al., 2013), resulting in reduced primary production by benthic communities (Horner et al., 1990). Where benthic growth is affected, algal communities become dominated by filamentous algae (Burt et al., 2013), with Scheffer et al., (1997) emphasising the competitive advantage that cyanobacterial species have in low light environments. Therefore, sediment inputs resulting from cattle/hippo riparian and in-stream activity may have implications for benthic algae community structure.

There are significant interactions between diatoms and sediments (Jones et al., 2014). In streams that are affected by sediment inputs, long stalked diatoms are common; this is an ecological adaptation to burial and light limitation that enables them to raise their frustules into photic areas (Hoagland et al., 1982; Horner et al., 1990). Substrate burial and competition for colonization space also drive shifts in community composition and structure such that competitive, opportunistic and motile diatom taxa (such as *Nitzschia* spp.) predominate where uncovered substrate becomes available (Kelly, 2003; Stevenson et al., 2008).

Changes in stream temperature and levels of dissolved oxygen (DO) are among the water physico-chemical alterations that can be related to LMH access and grazing practices. Increased in-stream temperatures are related to riparian zone degradation resulting in reduced shade of channels and reductions in stream width-to-depth ratio, which increases the area of stream channel on which solar radiation is incident (Ryan et al., 2013). DO depletion can be linked to reduced solubility because of higher in-stream temperatures (Sarriquet et al., 2006), proliferations of algal biomass and associated respiration and decomposition (Herringshaw et al., 2011) and biological oxygen demand (BOD), as a result of organic inputs such as slurries and faecal matter (Sovell et al., 2000). These phenomena can result in anoxic conditions with subsequent problems for aquatic biota. A total of 49 high flow events over 3 years that caused dissolved oxygen decreases, including 13 events resulting in hypoxia over 5 years has been documented in the Mara river (Dutton et al., 2018a).

When organic matter and nutrient loading rates by large mammalian herbivore inputs do not exceed ecosystem requirements, primary production increases with a shift in algal abundance

and species composition, which may in turn be beneficial to higher trophic levels (Del Rosario et al., 2002). LMH dung can also be directly consumed by both invertebrates and fish (McCauley et al., 2015; Mesa et al., 2016). These changes in consumer resource dynamics have been found to increase the abundance and alter the composition of invertebrate and fish communities (Townsend et al., 1997). This study therefore explores how the nutrient and organic matter input by cattle and hippos is influencing the water quality dynamics and benthic algae development in the Mara river.

CHAPTER THREE

3.0 MATERIALS AND METHODS

3.1 Description of the study area

3.1.1 Location

This study was conducted in the Mara River basin (MRB) in the Kenyan portion with the focus being in the Talek sub-catchment (Figure 2). The trans-boundary MRB (Kenya/ Tanzania) has a surface area of 13,835 km^2 and lies between latitudes 0°21'S and 1°54'S and longitudes 33°42'E and 35°54'E of which 65% is in Kenya and about 35% in Tanzania. The Mara River has its source in Enapuiyapui Swamp on the Eastern Mau Escarpment and is one of the ten drainage basins that feed into Lake Victoria. The Mara River basin is ecologically and hydrologically very significant to the world-renowned Maasai Mara-Serengeti ecosystem.

3.1.2 Topography and drainage

The upper catchment of the MRB ranges from 2,932 m above sea level around the sources in the Mau Escarpment and is typically mountainous and hilly. The lower catchment consists of gently sloping plains. The drainage within the MRB is determined by the type and arrangements of the bedrock units in the basin (Mutie, 2006): (i) The two permanent tributaries in the basin, Amala and Nyangores meet at the base of the escarpment to form the upper Mara River. (ii) In the midlands of the basin three key tributaries including the Talek river which starts from the Loita plains joining the Mara in Maasai Mara National Reserve (MMNR), the Engare Ngito, originating from the Ilmotyookoit ridges, and the Sand River, which joins the Mara at the Kenya-Tanzanian Border in the Serengeti plains.

3.1.3 Temperature, rainfall and hydrology

Temperature and rainfall in the basin vary with altitude. The upper catchment in Kenya has relatively cool temperatures throughout the year, with mean annual figures ranging from 12^o C to 16^{o}C. Average minimum temperatures within the middle catchment are in the range of 10^{o}C to 14^{o}C, whereas the mean maximum temperatures range from 22^{o}C to 26^{o}C.

The area receives a mean annual rainfall of between 1,000-1,800 mm. In the upper catchment rainfall seasons are bi-modal, falling between April and September, and between November and December.

The middle catchment is classified as semi-humid and semi-arid receiving between 900-1,000 mm of annual rainfall with the long rains occurring between March and May and the short rains between November and December, whereas the dry spell is between June and October.

The Mara River has two annual peaks in flow levels in March-June and November–December. In addition, volume and discharge rates increase with distance downstream with flood flows in the upper Mara ranging from 8 to over 150 cubic metres per second (m^3s^{-1}) with an average of 30 m^3s^{-1}, while in the lower reaches (at the Kenya/Tanzania border) the range is from 90 to over 400 m^3s^{-1} with an average of 300 m^3s^{-1}. In dry years low flows can fall to 1 m^3s^{-1}or less especially in the upper Mara, while tributaries like the Sand and Talek Rivers dry up completely (LVBC and WWF-ESARPO, 2010).

3.1.4 Geology and soils

The underlying strata in the MRB according to the report by MRB transboundary integrated natural resources (TINR) management plan, (2016) is composed of very old igneous and metamorphic rock of Cambrian and Pre-Cambrian age (more than 600 million years old) which form part of the 'Basement Complex'. The surface of this ancient landform was heavily eroded and then covered by younger rocks, including lava and other igneous extrusions released during the tertiary period when volcanoes were active in the Great Rift Valley. The youngest rocks include sedimentary deposits of sand and gravel and other lake sediments. The volcanic geology in the upper part and middle part of the sub-catchment support several groundwater springs both deep and shallow.

Soils of volcanic origin are rich and dark on the escarpment and rangelands. Shallow dark reddish-brown soils are found lower down. Poorly drained grey-brown and dark brown soils which support extensive grasslands are found on the plateau and plains. In Kenyan side, particularly the Amala and the Nyangores sub-basins have Mollic Andosols soils that were derived from tertiary volcanic materials. The steepest slopes of this region have Cambisols whereas in the Northern regions, Humic Nitisols are included. In the Mid-Mara sub-basin, the soils are generally rocky, sandy and are shallow. The region is dominated by brown clay soils which are waterlogged seasonally.

3.1.5 Social economic and livelihood activities

An approximate 1.1 million people live within the Mara catchment. High population densities exist in the upper and middle basin reaches, while the lower and middle reaches are sparsely

populated. The lower population density is due to the semi-arid nature of the lower catchment, the Maasai Mara Game Reserve and the Serengeti National Park. The total human population on the Kenyan side of the MRB based on the National Census carried out in 2009 stood at 564,266. With an annual growth rate of 2.8% current population is estimated at 665,900.

According to the MRB TINR management plan report, (2016) the basin economy is mainly defined through agriculture and livestock production, wildlife and tourism and cash crop production. Agriculture is the livelihood for a large proportion of the basin's population. There are three major agricultural activities: crops, livestock, and fisheries. The growing food requirements due to population increase and accessibility to more markets is driving the demand for more cultivated land, settlement space and more livestock products. In Kenya the major crops grown are tea, potatoes, maize, beans, wheat and pyrethrum.

Livestock rearing is the second most important contributor to the economy behind agriculture, and consists mainly of rearing cattle, goats, and sheep (Yanda and Majule, 2004). Small and middle scale livestock rearing is carried out within the upper region of MRB, while extensive ranching is carried out in the upper portions of the basin within the group ranches. Small and middle scale livestock rearing consists of pastoral herdsman, like the local Maasai tribesman, who herd their cattle based on environmental conditions, in search of both adequate grazing grounds and water supplies (Hoffman, 2007). At the Talek River sub-catchment, the Maasai community, graze over 220,000 cattle in this region and utilize streams and rivers as watering points and crossings (Lamprey & Reid, 2004; Ogutu et al., 2011).

Tourism is another important economic activity in this region. The MMNR and the Serengeti National Park (SNP) are internationally renowned for having the highest density and most diverse combination of large herbivores on earth. These also host one of the great wonders of the natural world—the annual migration of over one million wildebeest. LVBC and WWF-ESARPO (2010) put the estimates as of 2003 at about 1.3 million wildebeest, 200,000 zebras and 440,000 gazelles. In the middle reaches on the Kenyan side, the river and its tributaries host more than 4,000 hippos (Kanga et al., 2011)

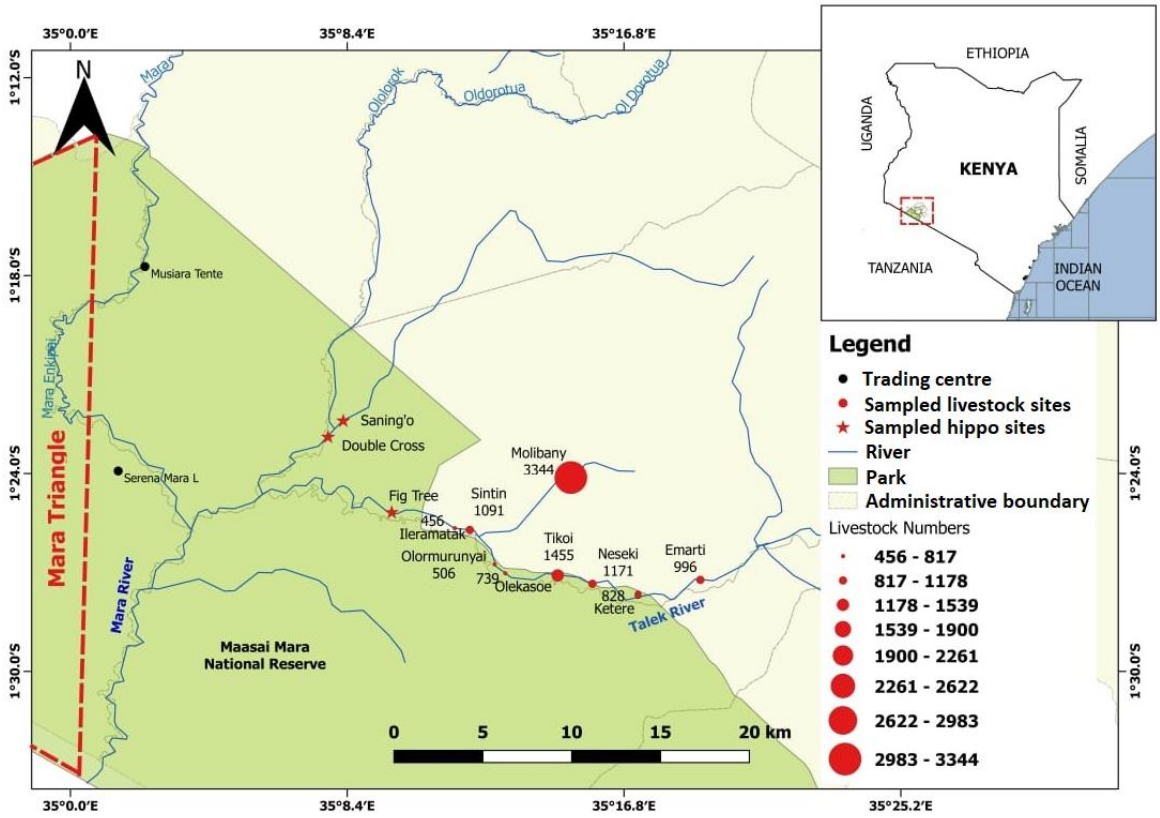

Figure 2:Map showing the sampled livestock and hippo sites

3.2 Sampling design

3.2.1 Site selection

A total of 12 sites were selected based on the changing distribution and abundance of livestock and hippos populations along the Talek, Molibany and Olare Orok tributaries of the Mara River following a before-after-control-impact (BACI) design (Smith, 2002), so as to capture the influence of livestock and hippo populations on the nutrient and organic matter dynamics at the river. (Figure 2). 8 livestock sites (Emarti, Ketere, Neseki, Tikoi, Olekasoe, Olormurunyai, Sintin and Ileramatak) selected were located along the Talek river tributary with one hippo site (Fig Tree) being located downstream of these sites. Molibany livestock site was located at Molibany tributary. The other 2 hippo sites selected (Double Cross and Saning'o) were located at Olare-Orok tributary which is inhabited by large population of hippos. Upstream and downstream areas were further identified at each of the livestock sites while only downstream areas were identified at the hippo sites. Grazing of the large mammalian herbivores (livestock, hippos, wildbeasts, antelopes, elephants etc.) was the major land use activity in this area.


Photo 1:Livestock watering site and a hippo site

3.2.2 Sample collection

Water quality

In-situ variables

Field sampling was done between October 12th and October 21st, 2018. Sample collection was done for one day at each site during the sampling period. Measurements of physico-chemical water quality variables (pH, dissolved oxygen, temperature, electrical conductivity, total dissolved solids and salinity) and discharge were done *in-situ* thrice per day (morning, afternoon and evening) in three replicates at the livestock and hippo sites. YSI multi-probe water quality meter (556 MPS, Yellow Springs Instruments, Ohio, USA) was used for determination of water quality variables. Discharge at the sites was determined from the measurements of river width, river depth and water flow velocity with the help of a propelling flow meter.

whereby: Discharge (Q) = River cross-sectional area (A) × Velocity (v).

Photo 2:In-situ measurement of water quality variables and discharge

Nutrient samples

Water samples for analysis of total nitrogen (TN), total dissolved nitrogen (TDN), total phosphorous (TP) nitrates NO_3), ammonium (NH_4) and soluble reactive phosphorous (SRP) were collected using acid washed 500 mL high density plolyethylene (HDPE) plastic bottles. The samples were collected in two replicates at the livestock sites thrice in a day (morning, afternoon and evening) and once each day at the hippo sites. Sediments, cow dung and hippo dung samples were also collected once each day in two replicates for nutrient analysis. The sediment samples were collected with the help of a corer at the livestock and hippo sites and stored in zip-lock bags. The water, sediment and dung samples were stored in a cooler box in the field using ice packs before being transported to the lab for analysis.

Dissolved organic carbon samples

The water samples were collected in two replicates at the livestock and hippo sites once in a day and filtered with the aid of a syringe through the filter holders containing Whatman glass-fibre GF/F filters (diameter 47mm, pore size, 0.7µm) into acid washed 40 mL glass vials. The samples were fixed with 250 uL H_3PO_4 and frozen until analysis.

Chlorophyll a samples

Water samples were collected at the livestock and hippo sites in two replicates and a known volume was filtered through GF/F filters for water column chlorophyll *a* determination. For benthic Chlorophyll *a* analysis, known area of stone substrate was scraped off and the slurry

was then filtered through GF/F filters and the volume filtered also noted. All chlorophyll *a* samples were wrapped in aluminium foil to prevent exposure to light, transported using a cooler box with ice, and stored frozen in the laboratory prior to analysis.

TSS samples

Water samples were collected in two replicates at the livestock and hippo sites and filtered through pre-weighed Whatman GF/F filters and the water volume filtered was noted for TSS determination. Samples were wrapped in aluminium envelopes and stored in a cooler box until further processing in the lab.


Photo 3:Preparation of water samples for nutrient, DOC, Chlorophyll a and TSS analysis

Quantification of input by livestock (cattle)

Quantification of livestock input was done by carrying out livestock census at the livestock watering sites with the aid of a score sheet. The livestock counting was done for one day at each site. Livestock behaviour was also noted in terms of defeacation, urination and the amount of time spent at the watering site. At each site and for one day, a minimum of six replicates of fresh cattle dung from both adult and sub-adult cattle were collected and weighed to determine the average dung wet weight per cattle. The dry weights of dung were later determined in the laboratory by drying the samples in the oven at 60 ^{o}C for 48 hours.

Photo 4: Variation in livestock numbers at the different livestock sites

Benthic algae composition

Stone substrates were collected at the livestock and hippo sites in two replicates. A known area of the substrates were scrapped with the aid of a brush and the biofilm was washed into a trough with distilled water then transferred into 50 mL vials and fixed with 0.35 mL 10% lugol solution until further processing in the lab.

Photo 5:Processing of the stone substrates for benthic algae identification

Laboratory analyses

Nutrient analyses

In the laboratory, water column nutrient analyses were done using standard colorimetric methods (APHA, 2005). The soluble nutrients, including TDN, SRP, NO_3, and NH_4 were analysed from filtered water samples, while unfiltered water sample was used for TP and TN analysis. Total Phosphorus (TP) after persulfate digestion and Soluble Reactive Phosphorous (SRP) were analyzed using the ascorbic acid method with absorbance read at a wavelength of 885 nm (APHA, 2005). Total nitrogen (TN) was determined using Koroleff method after persulphate digestion and absorbance read at a wavelength of 220 nm and 275 nm (APHA, 2005). Nitrate (NO_3) was analysed using the salicylate method with the spectrophotometric absorbance read at a wavelength of 420 nm (APHA, 2005). Ammonium (NH_4) was analyzed through the reaction between sodium salicylate and hypochlorid solutions with the spectrophotometric absorbance of the treated sample being read at a wavelength of 655 nm (APHA, 2005). Total dissolved nitrogen (TDN) was determined using total nitrate peroxodisulfate digestion standard method (APHA, 2005). The absorbance values obtained were used to calculate the concentration using equations generated from the standard calibration curves made for each of the nutrient.

For analysis of nutrients in sediment and dung, TN and TP were determined colorimetrically after acid digestion of the oven dried sediment material using a digestion mixture (hydrogen peroxide+sulpuric acid+selenium and salicylic acid). Colorimetric procedures were also applied in the determination of NO_3 and NH_4 from the wet sediment matreial after extraction using 0.5M K_2SO_4 solution. Inorganic phosphorous concentration from the sediments and dung were determined using Olsen method by extraction using 0.5M solution of sodium bicarbonate at pH 8.5 (Okalebo et al., 2002).

Dissolved organic carbon (DOC) analysis

DOC concentration was determined using a TOC analyser (GE-Sievers 900) operated with an inorganic carbon removal unit (Fasching et al., 2015).

Chlorophyll a analysis

In the laboratory chlorophyll *a* pigment was extracted using 90% acetone solution and the concentrations were determined spectrophotometrically (APHA, 2005). Light absorbance of the chlorophyll *a* extract placed in 1 cm cell cuvette was measured with a spectrophotometer at a wavelength of 750 nm and 663 nm. To correct for turbidity and other colours, absorption read at

750 nm was subtracted from the readings made at 663 nm. Lorenzen, (1967) formulae was used to estimate the chlorophyll *a* concentration as:

Chlorophyll *a*, µg l^{-1} = (11.40 (E663 – E750) *V_1)/(V_2 *L)

Where:

11.40 is the absorption coefficient for chlorophyll *a*,

V_1 = volume of extract in ml;

V_2 = volume of the filtered water sample in litres;

L = light path length of cuvette in cm;

E663, E750 = optical densities of the sample.

TSS analysis

The GF/F filters holding the suspended matter were dried in the oven at 60^{o}C for 48 hours to constant weight and TSS was determined using the below equation.

Equation: TSS (gL^{-1}) = (A – B)/V

Where: A = mass of filter + dried residue (g), B = mass of filter (tare weight) (g), and V = volume of sample filtered (L)

The filters were then combusted at 450 ^{o}C for 4 hours and re-weighed for the determination of POM as the difference between TSS and ash-free-dry weight (AFDW).

Benthic algae analysis

In the laboratory, the collected samples were analysed for composition by taking 1ml of a well shaken sample and placing it into the counting chamber of the inverted light microscope (Taylor et al., 2005). Taxonomic identification at the magnification of X200 and X400 was done to the genus level with the aid of algae identification keys (van Vuuren et al., 2006) and the total counts recorded.

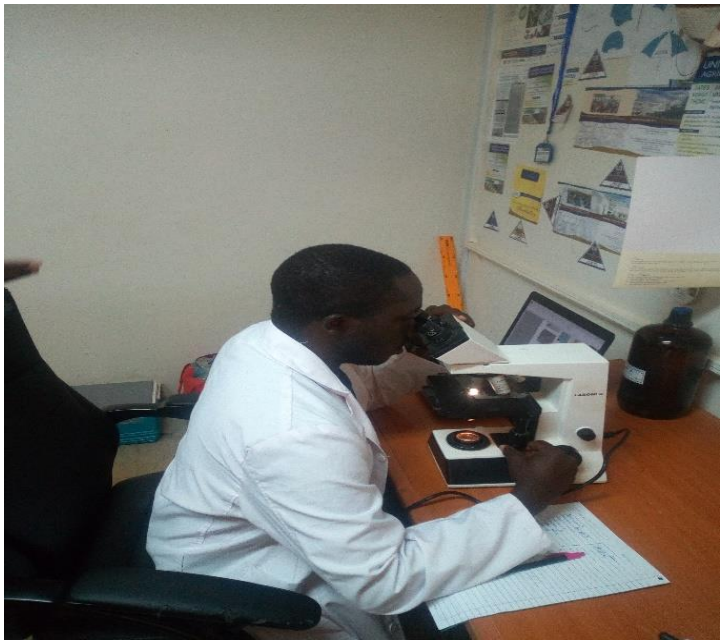

Photo 6:Benthic algae identification

Quantification of input by livestock (cattle)

The nutrient and organic matter input to the river per day by cattle was determined by multiplying the total dung dry weight input into the river (based on number of cattle defeacated on each site) by the amount of C, N and P in the dung. The input for one cattle was then determined by dividing the outcome with the total herd of cattle recorded at each site.

Input (g day^{-1}) = (total dung dry weight input × amount of C, N & P in the dung) ÷ Cattle herd on each site

The total input of C, N and P per day by cattle into the Talek sub-catchment was determined by estimating the total number of cattle which defeacate in the sub-catchment from the linear regression equation (Figure 4). Then the total input was determined using the equation below:

Total input (Kg day^{-1}) = (total dung dry weight input × amount of C, N & P in the dung)

The total cattle population estimate (220000) used in the linear regression equation was based on the livestock census by Ogutu et al., (2011). The results for the total C, N and P input by cattle to the sub-catchment were then compared by the total C, N and P input by the hippo population using estimates from the research findings by Subalusky et al., (2015).

3.3 Data analysis

Descriptive statistics (means and standard deviations) and plots were used to present spatial variation in water quality variables, nutrient and DOC concentrations at the livestock and hippo sites, differences in water quality variables, nutrient and DOC concentrations between upstream and downstream of livestock sites and comparison of water quality variables, nutrient and DOC concentration between livestock and hippo sites.

One-way Analysis of Variance test (ANOVA) was used to test for significant differences in water quality variables, nutrient and DOC concentrations among livestock and hippo sites. 2-sample t-tests were used to test for significant differences in water quality variables, nutrient and DOC concentrations between upstream and downstream of livestock sites and between livestock and hippo sites.

Linear correlation analysis was used to establish the correlation between differences in nutrient and DOC concentration and selected water quality variables at the upstream and downstream of livestock sites and total livestock numbers, livestock numbers that defeacated and livestock numbers that urinated. Principal component analysis (PCA) was used to establish the relationship between water quality variables, nutrient and DOC concentrations among livestock and hippo sites. Linear regression analysis was used to test the relationship between total livestock numbers (cattle) and the livestock numbers that defeacated and urinated at the sites.

The identified benthic algae taxa were presented in terms of taxa abundance (counts.cm^{-2}) per site. To establish the relationships among water quality variables, nutrient and DOC concentrations and identified benthic algae taxa in the livestock and hippo sites, canonical correspondence analysis (CCA) was done. The statistical software used to perform these analyses were Minitab version 17 and PAST after arrangement of data in Excel spreadsheet.

CHAPTER FOUR

4.0 RESULTS

4.1 Water quality variables

Comparison between livestock and hippo sites

The hippo sites recorded higher EC, TDS, salinity, TSS, POM and water column chlorophyll *a* level compared to the livestock sites (Table 2). Significant differences in temperature, DO, EC, TDS, salinity, pH, TSS, POM and chlorophyll *a* in the water column between the livestock and hippo sites (t-test, $p<0.05$, Table 1) was observed. Benthic chlorophyll *a* was the only variable which showed no significant difference between these sites ($p>0.05$, Table 1).

Table 1:Mean variation of water quality variables at the livestock and hippo sites (Mean±SD, livestock, N=162, hippo, N=9)

	Sites		t-test	
Variable	Livestock sites	Hippo sites	t-value	p-value
Temp (ºC)	25.28±0.29	22.43±0.21	2.30	0.023
DO (mgL^{-1})	6.64±0.09	3.06±0.38	9.66	<0.001
EC (μScm^{-1})	732.00±33.00	2007.00±333.00	7.96	<0.001
TDS (gL^{-1})	0.47±0.02	1.30±0.22	7.91	<0.001
Salinity	0.36±0.02	1.03±0.18	8.01	<0.001
pH	6.02±0.05	9.12±0.48	13.01	<0.001
TSS (mgL^{-1})	87.70±9.00	201.20±35.00	4.38	<0.001
POM (mgL^{-1})	20.00±2.20	76.50±16.00	7.01	<0.001
Water column Chl. *a* (μgL^{-1})	7.55±0.88	136.00±44.00	7.58	<0.001
Benthic Chl. *a* (μgcm^{-2})	0.32±0.06	0.13±0.06	1.29	**0.203**

Marked in bold is value for no significant difference

Livestock effect on water quality variables

In general, the downstream locations recorded higher EC, TDS, TSS, POM and water column and benthic Chlorophyll *a* level compared to upstream locations (Table 2). However, no significant differences in temperature, DO, EC, TDS, salinity, pH, water column chlorophyll *a* and benthic chlorophyll *a* between the upstream and downstream of the livestock sites (t-test,

p>0.05, Table 2) was noted. TSS and POM were the only variables that showed significant differences between the upstream and downstream of livestock sites (p<0.05, Table 2).

Table 2:Mean variation in water quality variables at the upstream and downstream of the livestock sites (Mean±SD, N=81)

	Site location		t-test	
Variable	Upstream	Downstream	t-value	p-value
Temp (ºC)	25.20±0.40	25.36±0.42	0.27	0.787
DO (mgL^{-1})	6.79±0.11	6.48±0.13	1.89	0.061
EC (μScm^{-1})	711.00±49.00	753.00±46.00	0.63	0.532
TDS (gL^{-1})	0.46±0.03	0.49±0.03	0.64	0.525
Salinity	0.35±0.03	0.37±0.02	0.65	0.514
pH	5.95±0.07	6.09±0.07	1.52	0.130
TSS (mgL^{-1})	62.00±7.90	113.40±14.00	3.22	**0.003**
POM (mgL^{-1})	13.34±1.50	26.70±3.50	3.49	**0.001**
Water column Chl. *a* (μgL^{-1})	6.64±1.40	8.47±1.00	1.07	0.307
Benthic Chl. *a* (μgcm^{-2})	0.27±0.08	0.38±0.08	0.95	0.348

Marked in bold are values for significant differences

4.2 Nutrient and DOC levels

Comparison between livestock and hippo sites

In general, the hippo sites recorded higher nutrient concentrations compared to the livestock sites with sediment TP being the only exception where it was higher in the livestock sites (Table 3). Significant differences in DOC, water and sediment nutrients between the livestock and hippo sites (t-test, p<0.05, Table 3) was observed. Water column TDN and NO_3 were the only nutrients that were not significantly different between these sites (p>0.05, Table 3).

Table 3:Mean Variation in nutrient and DOC concentrations at the livestock and hippo sites (Mean±SD).

		Sites		t-test	
Nutrients	Substrate	livestock sites	Hippo sites	t-value	p-value
TN (mgL^{-1})	water column	4.05±0.15	8.34±1.40	6.03	<0.001***
TDN (mgL^{-1})	water column	1.55±0.10	3.69±0.99	2.15	**0.084**
NO_3 (mgL^{-1})	water column	0.17±0.01	0.24±0.08	1.17	**0.246**
NH_4 (mgL^{-1})	water column	0.21±0.02	0.58±0.09	3.76	<0.001***
TP (mgL^{-1})	water column	0.56±0.02	2.76±0.66	12.91	<0.001***
SRP (mgL^{-1})	water column	0.02±0.00	0.03±0.01	2.62	0.010*
DOC (mgL^{-1})	water column	8.39±0.51	47.80±10.00	3.95	0,011*
TN (mgg^{-1})	Sediments	8.29±0.16	9.54±0.32	2.95	0.005**
NO_3 (mgg^{-1})	Sediments	3.67±0.27	5.13±0.32	2.16	0.037*
NH_4 (mgg^{-1})	Sediments	0.91±0.05	1.30±0.17	2.83	0.007**
TP (mgg^{-1})	Sediments	10.08±0.21	7.84±0.69	3.78	0.001**
Inorganic-P (mgg^{-1})	Sediments	0.92±0.04	2.24±0.14	12.64	<0.001***

Marked in bold are values for no significant differences

NB: *p < .05. **p < .01. ***p < .001.

Nutrient and DOC input by livestock

In general, the highest DOC and water column nutrient concentration difference for TN and TP was recorded at Molibany which also had the highest total number of livestock and the highest livestock number which defeacated and urinated at the site (Table 4). Spatial significant difference in DOC and water column nutrient concentration differences among the upstream and downstream of livestock sites (ANOVA test, $p<0.05$. Table 4) was observed.

Table 4:Nutrient and DOC concentration differences among the upstream and downstream of livestock sites (Mean±SD, N=108)

	Nutrient and DOC concentration difference, mgL^{-1} (downstream-upstream)									
Livestock sites	TN	TDN	NO_3	NH_4	TP	SRP	DOC	livestock defeacated	livestock urinated	Total livestock
Ileramatak	0.63±0.41	0.78±0.50	0.03±0.01	0.24±0.16	0.24±0.11	0.01±0.00	0.80±0.03	8	14	456
Olormurunyai	2.26±1.37	8.21±0.93	0.02±0.01	0.28±0.15	0.26±0.09	0.02±0.01	3.13±1.34	22	24	506
Olekasoe	1.14±0.31	0.09±0.01	0.05±0.01	0.02±0.01	0.02±0.01	0.004±0.000	0.90±0.04	77	68	739
Ketere	1.41±0.88	0.86±0.61	0.15±0.09	0.15±0.09	0.02±0.01	0.001±0.000	0.59±0.06	69	73	828
Emarti	1.13±0.44	1.60±0.32	0.16±0.08	0.02±0.01	0.25±0.13	0.01±0.00	2.48±0.15	95	134	996
Sintin	1.66±1.23	2.78±0.18	0.06±0.02	0.04±0.02	0.04±0.02	0.005±0.000	2.03±0.10	75	101	1091
Neseki	0.42±0.35	6.86±0.19	0.05±0.03	0.39±0.18	0.03±0.02	0.01±0.00	4.65±1.01	70	129	1171
Tikoi	0.52±0.42	6.42±0.81	0.28±0.08	0.01±0.00	0.02±0.01	0.01±0.00	1.53±1.33	86	84	1455
Molibany	**4.11±3.02**	8.98±0.32	0.001±0.00	0.36±0.10	**0.47±0.16**	0.01±0.00	**5.96±1.45**	**143**	**198**	**3344**
ANOVA- test	F=5.07	F=8.69	F=7.63	F=4.06	F=14.79	F=3.74	F=4.20			
	p<0.001	p=0.002	p<0.001	p=0.001	P<0.001	p=0.002	p=0.024			

Marked in bold are highest concentration difference values for TN, TP and DOC and highest recorded number for total livestock, livestock defeacated and livestock urinated

For sediment nutrients in general, Molibany which had the highest total number of livestock and the highest livestock number which defeacated and urinated recorded the highest concentration difference of inorganic nutrients (NO_3 and Inorganic-P, Table 5). Spatial significant difference in the measured sediment nutrients among the upstream and downstream of livestock sites (ANOVA test, $p<0.05$. Table 5) was noted.

Table 5:Nutrient concentration difference among the upstream and downstream of livestock sites (Mean±SD, N=36)

Nutrient concentration difference, mgg^{-1} (downstream-upstream)								
Livestock sites	TN	NO_3	NH_4	TP	Inorganic-P	livestock defeacated	livestock urinated	Total livestock
Ileramatak	1.08±0.05	0.89±0.11	0.78±0.06	3.14±0.04	0.19±0.03	8	14	456
Olormurunyai	1.22±0.08	2.18±0.57	0.03±0.01	3.75±0.01	0.16±0.02	22	24	506
Olekasoe	1.20±0.03	0.16±0.00	0.01±0.00	1.07±0.01	0.15±0.09	77	68	739
Ketere	1.41±0.03	2.09±0.46	0.89±0.00	1.09±0.02	0.02±0.01	69	73	828
Emarti	1.20±0.07	1.29±0.46	0.32±0.12	2.81±0.06	0.24±0.11	95	134	996
Sintin	1.60±0.03	1.13±0.91	0.06±0.06	2.27±0.02	0.34±0.09	75	101	1091
Neseki	1.88±0.02	1.45±0.23	0.38±0.05	0.45±0.03	0.18±0.03	70	129	1171
Tikoi	0.91±0.05	2.90±0.68	0.44±0.00	2.08±0.03	0.21±0.07	86	84	1455
Molibany	1.65±0.01	**3.23±0.23**	0.10±0.06	0.12±0.02	**0.38±0.10**	**143**	**198**	**3344**
ANOVA test	F=8.63	F=8.07	F=6.59	F=3.17	F=4.23			
	P<0.001	P=0.003	P<0.001	P<0.001	P=0.023			

Marked in bold are highest concentration difference values for NO_3 and in-organic P and highest values of recorded total livestock, livestock defeacated and livestock urinated

Comparison between upstream and downstream stations of livestock sites

In general, the nutrient concentrions were higher at the downstream stations compared to the upstream of the livestock sites (Table 6). Therefore, there was a percentage increase in nutrient concentration from the upstream to the downstream stations. Significant differences in the sediment nutrient concentrations between the upstream and downstream of livestock sites (t-test. $p<0.05$. Table 6) was observed. Although, for the water column nutrients only TN and TDN were significantly different ($p<0.05$, Table 6).

Table 6:Variation in nutrient and DOC concentrations between the upstream and downstream of livestock sites (Mean±SD)

		Site location				t-test	
Nutrients	Substrate	Upstream	Downstream	Concentration difference	% increase in concentration	t-value	p-value
TN (mgL^{-1})	water column	3.32±0.13	4.79±0.23	1.47±0.10	30.7	5.50	<0.001
TDN (mgL^{-1})	water column	1.22±0.09	1.88±0.16	0.66±0.07	35.1	3.68	0.001
NO_3 (mgL^{-1})	water column	0.16±0.02	0.18±0.02	0.02±0.00	11.1	0.50	**0.621**
NH_4 (mgL^{-1})	water column	0.18±0.03	0.23±0.04	0.05±0.01	21.7	1.42	**0.159**
TP (mgL^{-1})	water column	0.52±0.03	0.59±0.03	0.07±0.00	11.9	1.81	**0.074**
SRP (mgL^{-1})	water column	0.019±0.001	0.022±0.001	0.003±0.000	13.6	1.04	**0.303**
DOC (mgL^{-1})	water column	7.60±0.72	9.18±0.70	1.58±0.02	17.2	1.58	**0.123**
TN (mgg^{-1})	Sediments	7.61±0.17	8.97±0.17	1.36±0.00	17.2	5.65	<0.001
NO_3 (mgg^{-1})	Sediments	2.82±0.33	4.52±0.32	1.70±0.01	15.16	3.70	0.001
NH_4 (mgg^{-1})	Sediments	0.74±0.03	1.08±0.08	0.34±0.05	37.61	4.08	<0.001
TP (mgg^{-1})	Sediments	9.15±0.29	11.01±0.07	1.86±0.22	31.48	6.28	<0.001
Inorganic-P (mgg^{-1})	Sediments	0.82±0.05	1.02±0.04	0.20±0.01	16.89	3.26	0.003

Marked in bold are values for no significant differences

4.3 Correlation of water quality, nutrient and DOC concentrations and livestock numbers

In general, a significant strong positive correlation between water column TN and the total livestock numbers (correlation test, $r=0.72$, $p<0.05$. Table 7) was observed. Also, DOC had a strong positive significant correlation with the total livestock numbers and livestock number that urinated ($r=0.73$, $p<0.05$. Table 7)

Table 7:Correlation analysis of water quality variables, nutrient and DOC concentrations and livestock numbers

	0	TN (mgL^{-1})	TP (mgL^{-1})	TN (mgg^{-1})	TP (mgg^{-1})	TSS (mgL^{-1})	POM (mgL^{-1})	DOC (mgL^{-1})	Livestock_defeacated	Livestock_urinated	Total_livestock
TN (mgL^{-1})		0									
TP (mgL^{-1})		**0.75***	0								
TN (mgg^{-1})		0.17	0.14	0							
TP (mgg^{-1})		0.16	0.02	-0.62	0						
TSS (mgL^{-1})		0.52	0.46	-0.56	-0.03	0					
POM (mgL^{-1})		0.39	0.34	-0.47	-0.12	**0.94*****	0				
DOC (mgL^{-1})		0.61	0.59	0.05	-0.12	0.38	0.27	0			
Livestock defeacated		0.50	0.23	-0.16	-0.25	0.42	0.41	0.52	0		
Livestock urinated		0.49	0.34	-0.32	-0.04	0.53	0.46	**0.73***	**0.92*****	0	
Total livestock		**0.72***	0.55	-0.01	-0.31	0.62	0.63	**0.73***	**0.84****	**0.85****	0

Marked in bold are values for significant positive correlations

NB: *p < .05. **p < .01. ***p < .001.

Water quality, DOC and nutrient concentration relationship

The PCA analysis for the selected water quality physico-chemical variables, nutrient and DOC concentrations showed a clear distinction between the livestock and hippo sites. The biplot showed most variables projecting towards the hippo sites (Figure 3). The PCA loadings showed 8 components with strong positive correlations (r>-0.50. Table 8). Four components of the analysis had Eigen values >1 with the first and second components accounting for 71% of the total variation in water quality, nutrient and DOC concentraions at the livestock and hippo sites (Table 8).

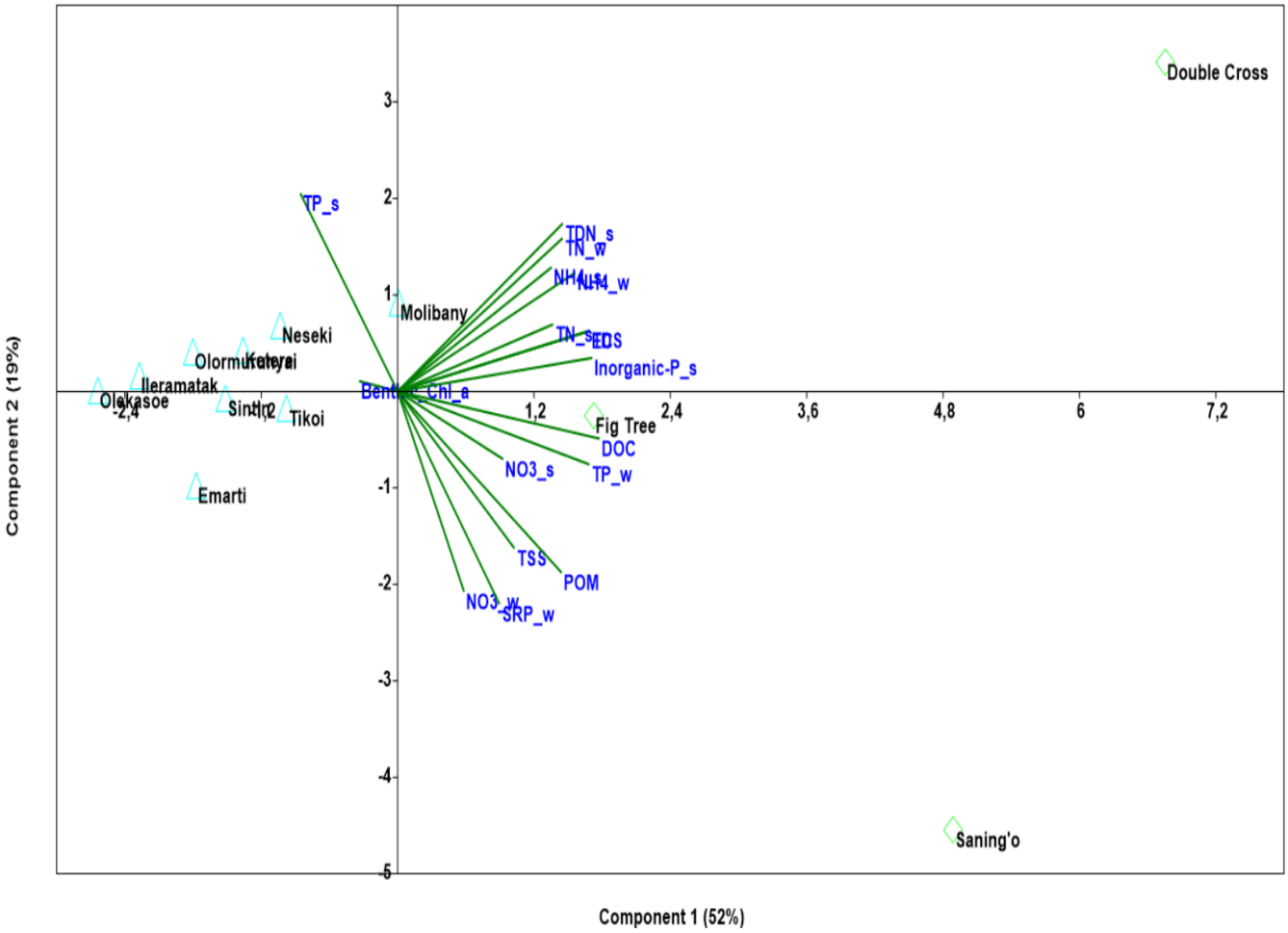

Figure 3:PCA scatter plot of water quality variables, DOC and nutrients

Table 8:PCA Eigen values, % variance and loadings

PC	Eigenvalue	% variance	Loadings
1	8.84	51.97	0.90
2	3.18	18.73	0.90
3	1.69	9.99	0.54
4	1.54	9.05	0.77
5	0.69	4.09	-0.18
6	0.45	2.63	0.95
7	0.24	1.43	0.77
8	0.17	0.97	0.31
9	0.12	0.69	0.83
10	0.05	0.29	0.90
11	0.03	0.15	0.47

Marked in bold are components with eigen values >1

4.4 Quantification of inputs by livestock (cattle) and hippos

Cattle behaviour

There was considerable variation in the number of cattle that defeacated and urinated at the livestock sites, also in the amount of time spent at each site. Emarti recorded the highest number of cattle that defeacated and urinated while Ileramatak recorded the lowest number. However, the herd of cattle spent most time in Molibany (10 minutes) and least time in Neseki and Olormurunyai (5 minutes; Table 9).

Table 9:Cattle behaviour at livestock sites

Site	Cattle defecated	Cattle Urinated	Total no. of cattle	Time spent at each site (min)
Emarti	**95**	**134**	996	6
Ileramatak	**8**	**13**	97	6
Ketere	42	48	348	7
Molibany	64	80	733	10
Neseki	55	103	803	5
Olekasoe	74	63	638	7
Olormurunyai	22	24	362	5
Sintin	66	97	828	8
Tikoi	86	84	1464	8

Marked in bold are the highest and lowest values of cattle which defeacated and urinated

From the linear regression analysis, there was a significant strong positive relationship between the total number of cattle and the cattle number which defeacated (R^2 = 0.75, $p<0.05$). The relationship between the total cattle numbers and the cattle numbers that urinated was significant and moderately strong (R^2 = 0.57, $p<0.05$, Figure 4).

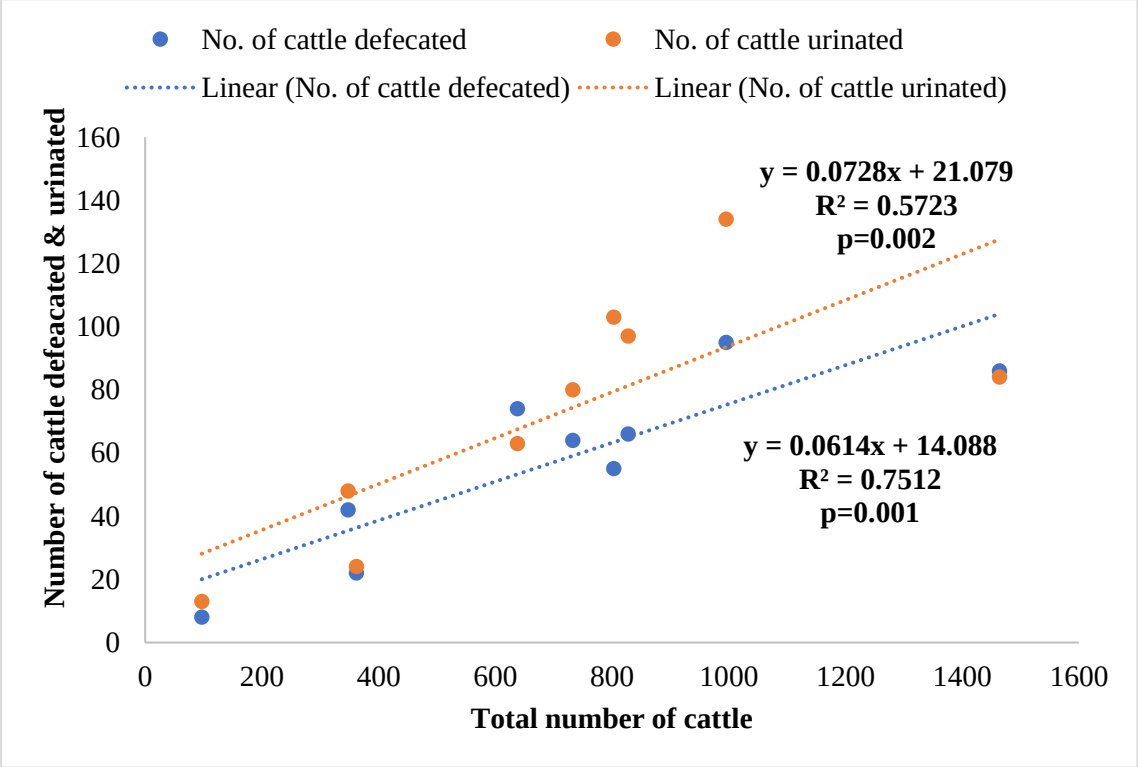

Figure 4:Regression analysis of total cattle numbers and the number which defeacated and urinated

Nutrient and organic matter input

In general, the highest input of C, N and P for one cattle was recorded at Ketere (7.64 g C, 0.23 g N and 0.06g P) and the lowest input was recorded at Tikoi (3.72g C, 0.12g N and 0.03 g P; Table 10).

Table 10: C, N and P input to the river per cattle per site

	Input (g day^{-1})		
Site	C	N	P
Emarti	6.04	0.19	0.05
Ileramatak	5.22	0.16	0.04
Ketere	**7.64**	**0.23**	**0.06**
Molibany	5.53	0.17	0.04
Neseki	4.34	0.14	0.03
Olekasoe	7.34	0.23	0.06
Olormurunyai	3.85	0.12	0.03

Sintin	5.04	0.16	0.04
Tikoi	**3.72**	**0.12**	**0.03**
Average	**5.41**	**0.17**	**0.04**

Marked in bold are the highest and lowest input values of C, N and P and their average values among sites

C, N and P input per cattle

Based on the dung characteristics (Annex Table 4), the estimated daily average input of C, N and P to the river by one cattle was 5.41 g C, 0.17 g N and 0.04 g P per day (Figure 5).

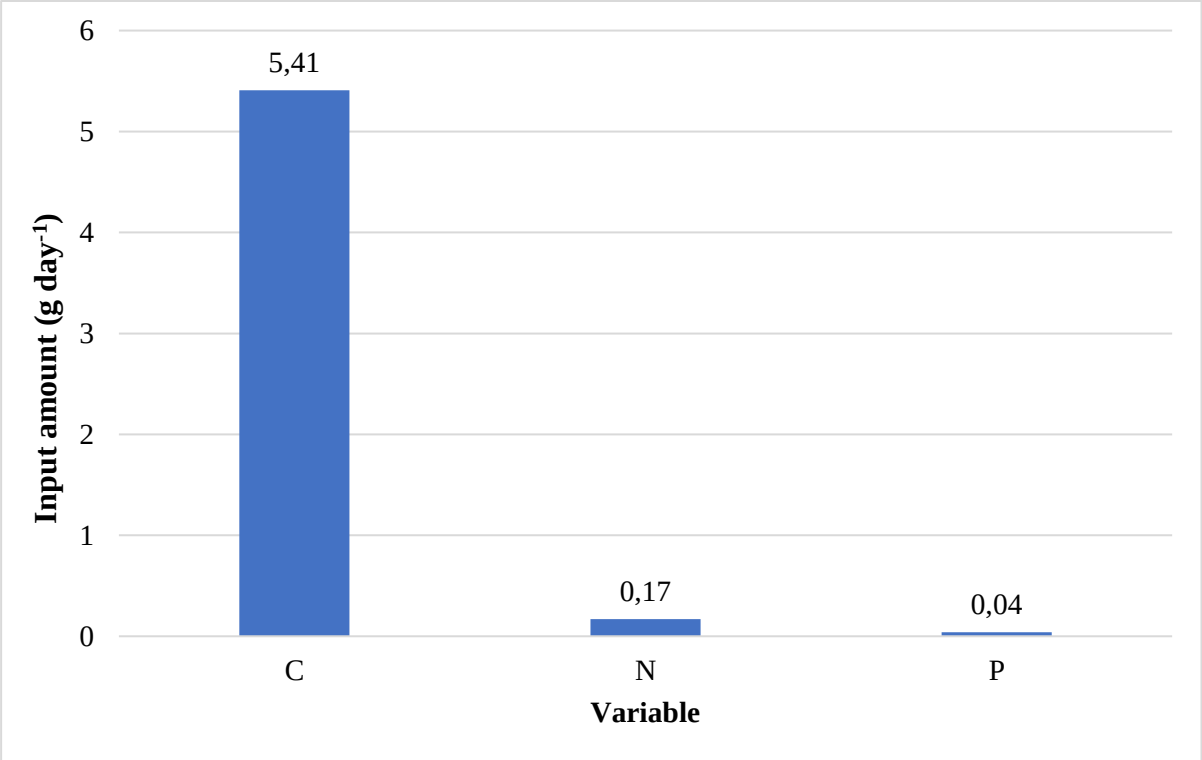

Figure 5: Daily C, N and P input to the river by one cattle

Comparison of cattle vs hippo total input

Based on the dung characteristics (Annex Table 4), a total estimate of 13522 cattle that defeacate directly daily into the river had a total input of 856 Kg C, 26.7 Kg N and 6.7 Kg P per day compared to 547 Kg C, 76.9 Kg N and 7.5 Kg P per day input by 648 hippo population as per the findings by Subalusky et al., (2015) (Figure 6).

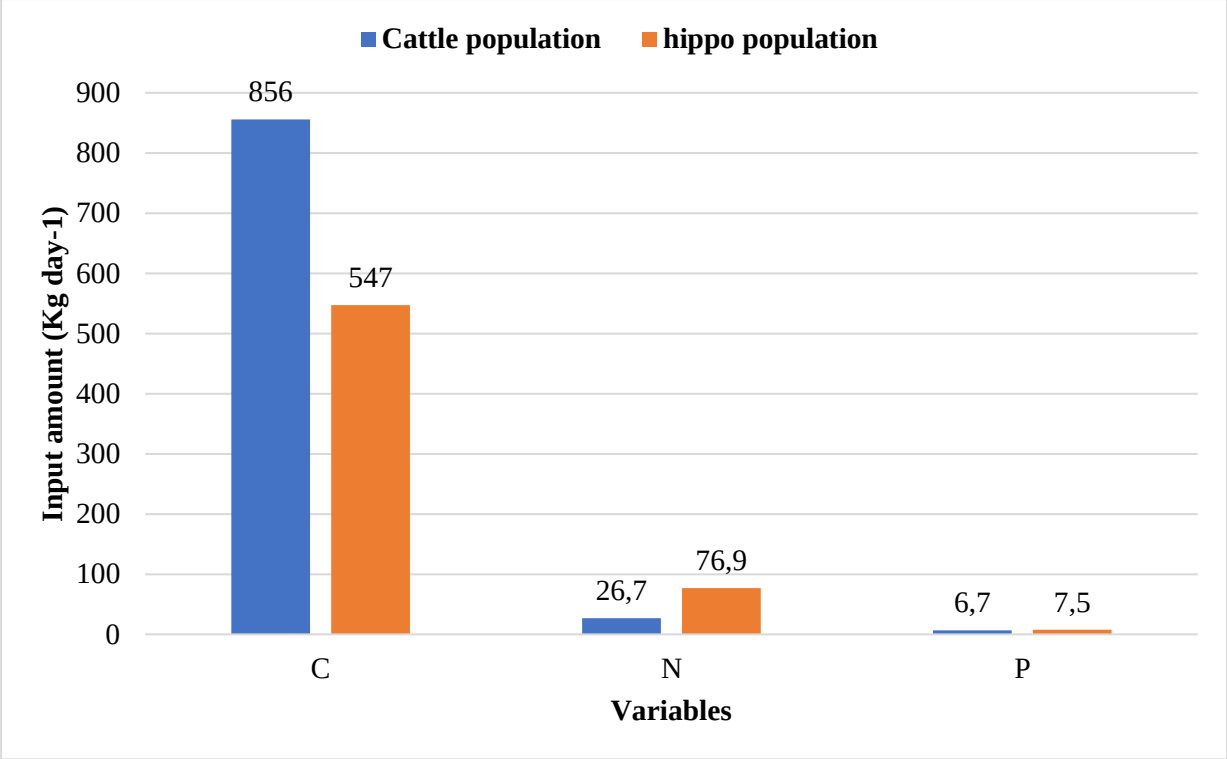

Figure 6:Comparison of daily C, N and P input to the river by the cattle and hippo population

4.5 Spatial variation in composition of benthic algae

There was considerable variation in the distribution and abundance of the identified benthic algae at the livestock and hippo sites (Table 11). Common classes were bacillariophyta (diatoms), chlorophyta (green algae), cyanophyta (blue-green algae) and euglenophyta. The genera of algae which were commonly distributed and abundant at the livestock and hippo sites were *Craticula, Synedra, Navicula, Cocconeis, Gyrosigma, Nitszchia, Stephanodiscus, Pinnularia, Closterium and Microcystis.* The genera of benthic algae which were dominant and abundant at a particular site were *Surirella* at Double Cross, *Spirogyra* at Molibany, *Pandorina, Chlamydomonas* and *Oscillatoria* at Ketere. Fig Tree recorded the lowest number of benthic algae taxa which were also in low abundance (Table 11).

Table 11:Benthic algae distribution and abundance (counts.cm^{-2}) in the livestock and hippo sites

		Livestock sites									Hippo sites		
Class	**Genus**	Emarti	Ileramatak	Ketere	Molibany	Neseki	Olekasoe	Olormurunyai	Sintin	Tikoi	Saning'o	Double Cross	Fig Tree
Bacillariophyta	*Craticula**	16	30	30	5	6	6	24	73	4	124	25	0
Bacillariophyta	*Gomphonema*	62	18	8	0	0	0	4	3	0	6	0	0
Bacillariophyta	*Synedra**	30	117	81	230	40	19	3	27	16	30	15	0
Bacillariophyta	*Navicula**	35	347	304	69	33	139	103	308	1	477	174	0
Bacillariophyta	*Cocconeis**	17	26	31	94	109	205	27	42	9	27	12	6
Bacillariophyta	*Pleorosigma*	1	406	0	1	8	45	86	70	0	2	0	0
Bacillariophyta	***Surirella***	**0**	**1**	**0**	**0**	**23**	**0**	**1**	**3**	**0**	**0**	**637**	**0**
Bacillariophyta	*Gyrosigma**	3	881	22	33	3	220	400	188	29	0	2	1
Bacillariophyta	*Nitszchia**	7	197	162	52	1	21	33	98	22	128	217	0
Bacillariophyta	*Aulacoseira spp.*	7	35	8	548	20	18	11	34	5	0	0	4
Bacillariophyta	*Cymbella*	83	296	18	5	8	142	26	642	2	5	8	0
Bacillariophyta	*Rhopalodia*	42	61	38	0	8	11	2	46	0	33	6	0
Bacillariophyta	*Stephanodiscus**	2	30	101	25	82	159	8	20	2	19	146	0
Bacillariophyta	*Tabellaria*	28	6	38	0	0	10	0	0	0	9	8	2
Bacillariophyta	*Diatoma*	4	18	10	1	1	2	16	39	0	10	1	0
Bacillariophyta	*Pinnularia**	45	89	21	22	18	74	11	30	3	149	28	0
Bacillariophyta	*Cyclotella*	11	0	0	0	0	2	3	1	0	0	0	0
Bacillariophyta	*Eunotia*	6	0	0	0	25	0	2	0	0	5	4	0
Chlorophyta	*Closterium**	11	65	16	1	12	414	367	4	67	6	1	0
Chlorophyta	*Stigeoclonium*	1	9	322	0	209	19	1	2	8	121	126	13
Chlorophyta	***Spirogyra***	**0**	**2**	**0**	**18**	**0**	**6**	**0**	**0**	**0**	**2**	**0**	**0**
Chlorophyta	***Pandorina***	**0**	**0**	**44**	**0**	**0**	**0**	**1**	**0**	**0**	**0**	**2**	**0**
Chlorophyta	***Chlamydomonas***	**0**	**2**	**39**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
Chlorophyta	*Scenedesmus*	0	2	0	0	0	12	3	0	0	0	8	0
Cyanophyta	*Microcystis**	68	92	783	89	363	530	251	236	168	158	26	49
Cyanophyta	*Anabaena*	1	0	7	0	2	5	1	0	66	0	0	0
Cyanophyta	***Oscillatoria***	**0**	**1**	**35**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
Euglenophyta	*Euglena*	6	25	5	45	11	8	4	5	7	0	19	0

Marked in bold are genera dominant at specific sites and * are genus that are commonly distributed and abundant

There was variation in the abundance of the identified benthic algae classes among the livestock and hippo sites (Figure 7). Bacillariophyta and Cyanophyta classes were the most commonly distributed and abundant among the livestock and hippo sites

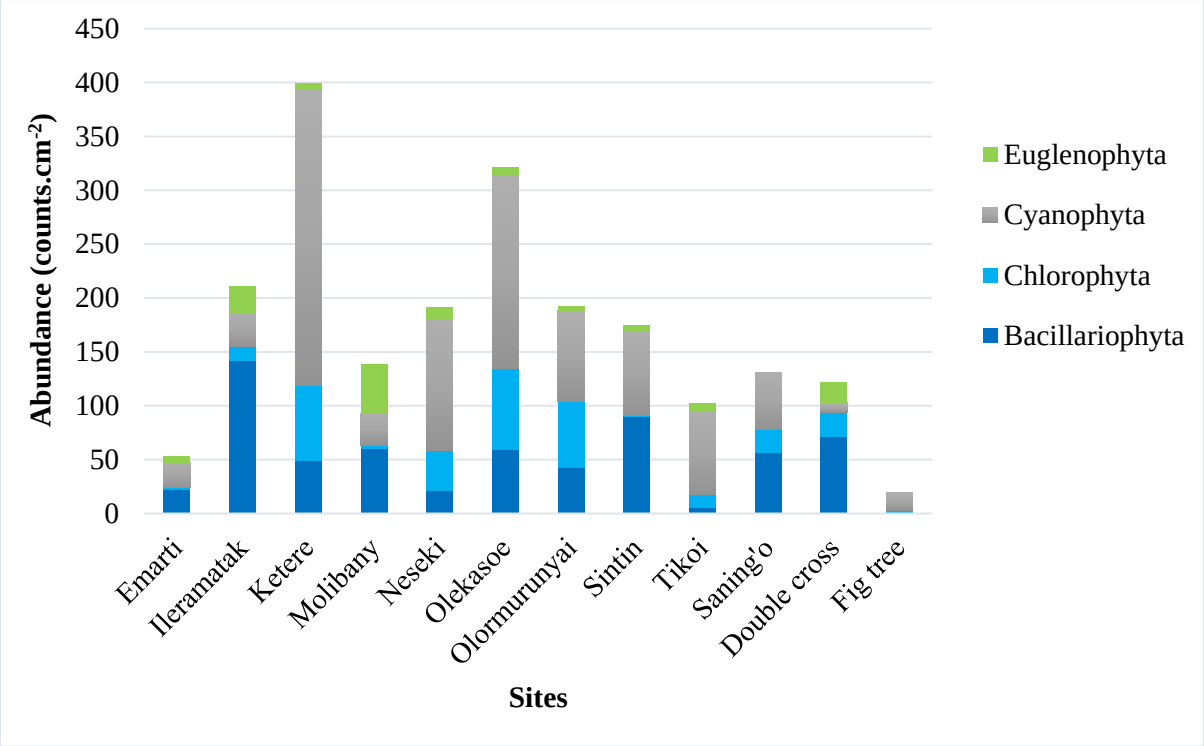

Figure 7:Distribution and abundance of benthic algae classes

4.6 Relationship among water quality, nutrients, DOC and benthic algae

The canonical correspondence analysis (CCA) biplot showed a clear pattern where most of the measured environmental variables (water quality variables, nutrients and DOC) projected towards the hippo sites due to high concentration levels in these sites with only a few environmental variables like temperature, DO and sediment TP projecting towards the livestock sites (Figure 8). The identified benthic algae taxa showed also a distinct association, with some taxa corresponding to the livestock sites (*Gyrosigma, Pleorosigma, Cymbella, Cyclotella, Anabaena, Rhopalodia)* and other taxa corresponding to the hippo sites (*Craticula, Scenedesmus, Surirella;* (Figure 8). The first axis accounted for 25% of the variation, while the second axis accounted for 21% of the variation. In total the 1st and 2nd axes of the CCA matrix explained 46% of the variation in water quality physico-chemical variables, nutrient concentration, DOC concentration and benthic algae composition at the livestock and hippo sites (Table 12).

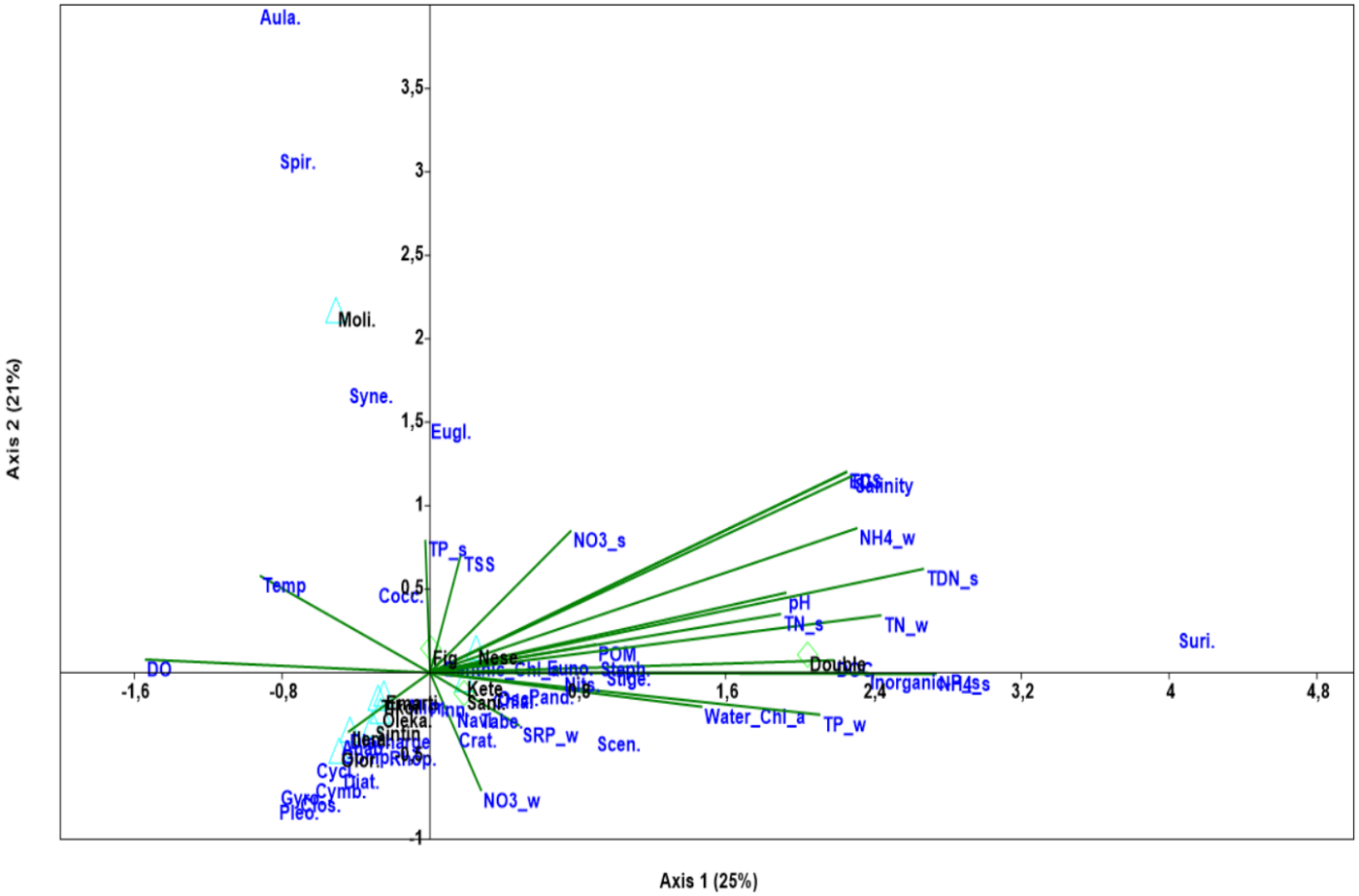

Figure 8:CCA analysis of water quality, nutrients, DOC and benthic algae

Table 12:CCA Eigen value and % variation

Axis	Eigenvalue	% variation
1	0.4863	24.74
2	0.4211	21.42
3	0.3151	16.03
4	0.2384	12.13
5	0.1294	6.582
6	0.1151	5.854
7	0.1036	5.271
8	0.0889	4.525
9	0.0481	2.445
10	0.0166	0.8437
11	0.0033	0.1667

5.0 DISCUSSION

5.1 Physico-chemical water quality variables

The significant spatial variation in water quality physico-chemical variables (EC, TDS, salinity, pH, TSS, POM, Annex; Table 1) among the livestock and hippo sites can be attributed to their differences in geology and soil characteristics, the variation in livestock and hippo input amounts and numbers among these sites. The geological differences among the sites was clearly reflected by the significant variation in EC and TDS levels across sites which are potential indicators of changing geology. For instance, Molibany recorded higher values of EC and TDS compared to the other livestock sites because it was in a different tributary (Molibany tributary), while the rest of other livestock sites were in the Talek tributary. While Double Cross and Saning'o located at Olare-Orok tributary recorded much higher EC and TDS levels compared to all the other sites. Therefore, the tributaries might be having variation in their geology and soil characteristics (MRB TINR management plan, 2016). The chemical characteristics of sediments and rocks in the river systems influence the salt sources (Boyd, 2015). The chemical composition of these rocks and soils can be affected by the age of the material, with salt levels being lower in ancient soils (Lambers et al., 2006).

Variation in livestock and hippo numbers among the livestock and hippo sites might have contributed to the significant variation especially of TSS and POM (Table 7). While comparing the variation of water quality physico-chemical variables between the upstream and downstream of the livestock sites, a significant variation was only noted in the levels of TSS and POM (Table 1). Also, a strong positive correlation was noted between the levels of TSS and POM and the total livestock numbers (Table 7). For instance, as noted in the study, sites with more total livestock numbers like Molibany and Sintin also had elevated levels of TSS and POM (Table 5, Annex Table 1) compared to the other sites. Saning'o and Fig Tree also had elevated levels of TSS and POM due to the higher population of hippos observed in the field at these sites compared to Double Cross (Annex Table 1). This justifies the fact that more access of large mammalian herbivores to the aquatic systems, elevates the sediment input and organic matter input from defeacation thus higher turbidity levels in the water column (Figure 1).

The livestock and hippos through their in-stream activities (defeacation, urination and movement), while watering contribute to subsidy input to the river and re-suspension of the sediments, therefore elevating the turbidity levels in the river waters. This is reflected by the

low levels of benthic chlorophyll-*a* levels among these sites showing light limitation effect due to high sediment input or direct physical disturbances by the livestock and hippos. In the Mara River, Dutton et al., (2013) and Dutton et al., (2018a) also noted elevated levels of turbidity (as high as 6,000 NTU) due to the sediment load by hippo to the river, which reduce light penetration and limit primary production, thus influencing the physical characteristics of the recipient ecosystem (Subalusky et al., 2018). In many studies, sediment losses from trampled and heavily grazed stream banks have been reported to exceed those observed for untrampled or ungrazed counterparts (Vidon et al., 2008; Collins et al., 2010; Herbst et al., 2012). Evans et al., (2006) found that livestock trampling through their movements caused damage to banks at a localised scale and led to selective patches of bare land being susceptible to further erosion. Furthermore, streambed sediments can be an important source of sediments and bacteria, which may be resuspended by cattle movement (Terry et al., 2014).

The variation in the livestock and hippo input amounts is reflected by the amount of time livestock and hippos spend in the river habitat. For instance, hippos mostly graze at night and spend day time (over 12 hours) in the river waters (Subalusky et al., 2015), while the livestock mostly graze at day time and only visit the watering points (river) mostly at noon time (river) to drink water and only spend an average of 7 minutes in or near the river (Table 9). Therefore, through their in-stream activities, the hippos contribute more subsidy input to the river compared to livestock due to the more time they spend in-stream. Thus, higher TSS and POM (turbidity) levels at the hippo sites compared to the livestock sites (Table 2). This also explains the reason for reduced DO levels at the hippo sites compared to the livestock sites as more oxygen is consumed during decomposition of subsidies coming from hippos. In the Mara river, Dutton et al., (2018) has reported repeated occurrence of hypoxia in some sections of the river due to the high organic matter loading from the hippos.

Photo 7:Deposits of hippo and cattle dung at the hippo site and livestock site

5.2 Nutrient and DOC levels

The significant variation in nutrient and DOC levels between the livestock and hippo sites can be attributed to the differences in the hippo and cattle input amounts. Due to the more time that hippos spend in the river channel (over 12 hours) compared to the livestock, the hippo would contribute more organic matter and nutrient input in the river system (Table 3). When livestock and hippos spend time in a recipient ecosystem after feeding elsewhere, they contribute organic matter and nutrient input to that ecosystem through excretion and egestion of particulate nutrients from consumed but not assimilated resources (Janetski et al. 2009, Post and Walters 2009, Roman and McCarthy 2010). This was reflected by the elevated levels of the measured nutrients and DOC at the downstream locations of the livestock sites (Table 6). These findings concur with the research findings of Bond et al., (2014) where cattle access to the river led to in-stream increase of nitrogen, phosphorus and potassium concentrations in the river reach by 0.0036mg L^{-1}, 0.002 mg $L^{-1}$and 0.002 mg L^{-1}, respectively. A strong significant positive correlation was also noted between the levels of TN and DOC and the total livestock numbers and the livestock numbers that urinated on the sites (Table 7). Subalusky et al., (2015) also estimated that hippos in the Mara basin contribute 3,125 tons dry matter (DM) to the river every year, and excretion accounts for 70% of the nitrogen (N) and 33% of the phosphorus (P) in these inputs. This shows the important contribution of livestock and hippo inputs to the levels of nutrients and organic matter into the river systems.

In this study the stoichiometry for the cattle dung was 155.2 C:5.1 N:1 P while for the hippo dung was 261.4 C:7.6 N:1 P (Annex Table 4). Therefore, these differences might have contributed to the variations of the C, N and P input by cattle and hippos into the river. In other studies, the hippo faeces and urine have been estimated to be 222.8 C: 6.3 N: 1.0 P and 25.8 C: 15.8 N: 1.0 P, respectively, while cattle faeces and urine have been estimated to be 70.2 C: 12.8 N: 1.0 P and 2 C: 1 N: 1 P, respectively (Pramanik et al., 2007; Subalusky et al., 2015). Though, in this study the C, N, P input through urination was not determined due to difficulties in estimating the amount of urine produced per cattle. The differences in the stoichiometry of these major elements, especially in hippo and cattle dung, will likely influence river ecosystem dynamics (Sardans et al., 2012).

5.3 Benthic algae development

The spatial variation in the composition of benthic algae at the livestock and hippo sites can be attributed to the variation in the physico-chemical water quality variables and nutrient levels among these sites. Water quality variables such temperature, pH, dissolved oxygen, electrical conductivity, discharge, light availability and nutrient concentrations are considered essential for growth and development of benthic algae (Hill and Knight, 1988). Nutrient and light availability have been documented to limit benthic algae growth in small streams (Hill and Fanta, 2008). In the study for instance, because of the highest TSS levels recorded at Fig Tree compared to other sites (Annex Table 1), it had the lowest number of benthic algae taxa (*Microcystis Stigeoclonium* being the notable taxa only,), which were also very low in abundance (Table 14). Therefore, the high turbidity level at this site inhibited benthic algae development due to light limitation. Research findings have shown that deposition of fine sediments increases turbidity, which limits light penetration and reduce primary productivity (Davies-Colley et al., 2008; Izagirre et al., 2009), thus affecting benthic algae biomass, photosynthetic activity and community composition (Izagirre et al., 2009).

For the four classes of benthic algae identified (bacillariophyta, chlorophyta, cyanophyta and euglenophyta), the genera of bacillariophyta (diatoms) were the most dominant and abundant at the livestock and hippo sites (Table 11). This concurs also with the findings of Mbao et al., (2013) in the Mara river, where bacillariophytes were the dominant and abundant class of algae. Diatoms are a key component of surface water ecosystems (Dixit et al., 1992) and are widely used bio-indicator in ecological assessments of freshwaters (Besse-Lototskaya et al., 2011; Kelly, 2011; Schneider et al., 2012). They are a diverse and widespread group (Stevenson and

Smol, 2003; Hering et al., 2006; Kireta et al., 2012) and as such can provide a large amount of ecological information for relatively little sampling effort (Dixit et al., 1992).

In relation to the pressures commonly associated with livestock and hippo access to the river systems, diatoms are particularly applicable in the detection of nutrient enrichment (Schneider et al., 2012; Burt et al., 2013; Mbao et al., 2013). In this study, the benthic algae genera that were commonly distributed and abundant (*Craticula, Nitszchia and Microcystis*) at the livestock and hippo sites are indicators of organic pollution and nutrient enrichment (van Vuuren et al., 2006).

For instance, *Craticula and Nitszchia* species tend to be associated with elevated levels of organic pollution. The genus can yield much ecological information since several taxa are indicative of nutrient enrichment (eutrophication), while others are useful indicators of elevated salinities (van Vuren et al., 2006). This is reflected in the study by the higher abundance of these genera at Saning'o and Double Cross hippo sites (Table 11), which had elevated nutrient concentrations (Annex Table 2) and salinity levels (Annex Table 1). *Microcystis* is a common cause of algal blooms, sometimes secreting chemicals that inhibit other algae. Dense growths may lead directly or indirectly to oxygen depletion. Blooms of *Microcystis* can also impart taste and odour to the water and interfere with recreational activities (van Vuren et al., 2006). In the study the evidence of algal blooms at some livestock sites (Ketere, Neseki and Olekasoe) indicated the dominance of *Microcystis* at these sites.

Photo 8:Algal bloom at a livestock site

6.0 CONCLUSIONS

From this study, it can be concluded that, there was a significant spatial variation in water quality physico-chemical variables, nutrients and organic matter levels among the livestock and hippo sites.

It can also be concluded that one cattle had an input of 5.41 g C, 0.17 g N and 0.04 g P per day from defeacation directly into the river and based on the population estimates of cattle and hippos that egest directly in the Talek sub-catchment, the total input of C, N and P to the river was 856 Kg C, 26.7 Kg N and 6.7 Kg P per day and by the hippos was 547 Kg C, 56.9 Kg N and 7.5 Kg P per day.

Furthermore, it can be concluded that there was a spatial variation in the composition of benthic algae among the livestock and hippo sites and diatoms which are indicators of nutrient enrichment were the most dominant and abundant class.

7.0 RECOMMENDATIONS

Due to other potential sources of nutrient and organic matter input to the river from the other livestock types (goats, sheep, donkeys) and wildlife which was not captured in this study, further research is recommended to quantify inputs also from these other sources. Further research is also recommended to establish the spatial and temporal variation in inputs and compare different pathways, such as LMH vs overland flow using other approaches which will help in the development of appropriate and effective management strategies for the Mara River basin.

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9.0 ANNEX

Table 1: Mean variation of water quality variables in the livestock and hippo sites (Mean±SD, livestock, N=81, hippo=9)

Site	Location	Temp (ºC)	DO (mgL^{-1})	EC (μScm^{-1})	TDS (gL^{-1})	Salinity	pH	TSS (mgL^{-1})	POM (mgL^{-1})	Water column Chl. *a* (μgL^{-1})	Benthic Chl. *a* (μgcm^{-2})
Emarti	Upstream	28.68±1.11	6.33±0.08	207.89±1.27	0.13±0.00	0.09±0.00	5.70±0.01	91.12±1.74	20.54±1.96	2.71±1.09	0.05±0.00
Ileramatak	Upstream	23.11±0.50	5.99±0.02	596.00±2.57	0.39±0.00	0.29±0.00	6.07±0.15	78.73±0.40	16.54±2.63	6.87±1.57	0.04±0.01
Ketere	Upstream	25.67±0.85	6.98±0.29	676.90±31.90	0.42±0.03	0.31±0.02	6.61±0.10	98.43±6.12	18.99±2.83	7.74±0.56	0.12±0.02
Molibany	Upstream	26.63±1.10	6.79±0.13	1865.00±3.01	1.21±0.00	0.94±0.00	6.40±0.07	87.50±44.20	15.83±5.28	3.54±1.45	0.33±0.03
Neseki	Upstream	24.81±1.09	7.97±0.13	809.10±10.40	0.53±0.01	0.40±0.01	6.61±0.13	58.85±4.01	13.20±0.35	4.10±1.25	1.17±0.31
Olekasoe	Upstream	23.19±0.94	6.13±0.34	514.60±32.50	0.34±0.02	0.25±0.02	5.19±0.17	14.21±0.14	3.97±0.10	2.54±0.26	0.23±0.06
Olormurunyai	Upstream	23.22±1.58	7.31±0.34	597.11±1.43	0.39±0.00	0.29±0.00	5.17±0.03	20.78±2.55	5.41±0.70	5.22±0.94	0.28±0.02
Sintin	Upstream	26.51±1.09	7.49±0.17	617.78±5.07	0.40±0.00	0.30±0.00	6.27±0.03	65.71±6.29	17.31±2.02	21.83±3.41	0.22±0.06
Tikoi	Upstream	25.02±1.39	6.17±0.44	512.67±4.09	0.33±0.00	0.25±0.00	5.50±0.20	42.74±5.52	8.22±3.44	5.19±1.93	0.002±0.00
ANOVA-test	**F-value**	2.9	7.53	8.57	5.44	5.9	2.34	4.04	5.21	13.36	9.74
	P-value	0.007	<0.001	<0.001	<0.001	<0.001	<0.001	0.026	0.012	<0.001	<0.001
Emarti	Downstream	30.5±0.99	7.03±0.30	459.80±17.00	0.27±0.02	0.22±0.01	6.37±0.05	87.23±0.83	16.10±3.30	4.56±1.14	0.02±0.01
Ileramatak	Downstream	25.21±0.85	6.67±0.26	606.33±3.26	0.39±0.00	0.29±0.00	6.17±0.15	114.20±21.70	29.58±9.58	13.30±1.90	0.26±0.02
Ketere	Downstream	25.46±1.01	6.54±0.15	680.20±25.10	0.45±0.02	0.33±0.01	6.60±0.11	117.98±0.77	25.04±2.46	10.12±2.23	0.51±0.03
Molibany	Downstream	25.53±0.55	6.07±0.40	1867.20±26.70	1.21±0.02	0.94±0.00	6.76±0.05	209.80±63.40	48.29±5.44	13.40±4.85	0.12±0.01
Neseki	Downstream	24.49±1.32	6.92±0.24	813.10±11.10	0.53±0.01	0.40±0.01	6.44±0.17	89.06±3.95	17.94±2.34	6.32±4.62	1.22±0.16
Olekasoe	Downstream	23.70±1.02	6.42±0.17	569.00±3.52	0.37±0.00	0.27±0.00	5.31±0.13	25.42±4.99	7.69±0.31	6.97±3.06	0.46±0.06
Olormurunyai	Downstream	23.82±1.40	6.89±0.60	599.22±1.51	0.39±0.00	0.29±0.00	5.61±0.13	88.40±31.60	16.92±3.59	6.59±1.64	0.27±0.03
Sintin	Downstream	24.85±1.33	5.67±0.23	650.78±1.71	0.42±0.00	0.32±0.00	6.24±0.10	180.00±16.50	39.41±6.47	10.69±0.71	0.11±0.01
Tikoi	Downstream	24.69±1.56	6.10±0.67	527.89±6.11	0.34±0.00	0.25±0.00	5.38±0.20	108.33±7.50	39.60±15.40	4.28±1.42	0.42±0.04
ANOVA-test	**F-value**	3.11	1.47	9.1	7.08	9.21	16.94	4.5	3.7	1.6	3.51
	P-value	0.005	**0.183**	<0.001	<0.001	<0.001	<0.001	0.019	0.034	**0.249**	<0.001
Double cross	Downstream	23.07±0.01	3.45±0.01	3112.30±1.45	2.03±0.00	1.63±0.01	9.63±0.02	92.92±1.15	48.62±3.92	125.79±2.46	0.10±0.02
Fig Tree	Downstream	22.58±0.01	4.13±0.01	813.33±0.33	0.52±0.00	10.47±0.01	255.80±10.10	57.95±7.95	30.29±0.80	0.003±0.00	

Saning'o	Downstream	21.63±0.01	1.61±0.01	2094.70±1.20	1.36±0.00	1.06±0.02	7.27±0.01	254.90±23.8	123.00±16.4	251.6±66.00	0.29±0.10
ANOVA-test	**F-value**	5.02	1.44	1.09	1.67	2.75	1.55	9.26	4.23	8.48	5.82
	P-value	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	0.007	0.029	**0.058**	**0.093**

Table 2: Mean variation of water column nutrient and DOC concentration at the livestock and hippo sites (Mean±SD, livestock, N=54, hippo=9)

Site	Location	TN (mgL^{-1})	TDN (mgL^{-1})	NO_3 (mgL^{-1})	NH_4 (mgL^{-1})	TP (mgL^{-1})	SRP (mgL^{-1})	DOC (mgL^{-1})
Emarti	Upstream	2.85±0.20	1.55±0.02	0.48±0.07	0.21±0.09	0.38±0.04	0.03±0.00	3.12±0.23
Ileramatak	Upstream	3.38±0.27	1.19±0.19	0.10±0.01	0.35±0.16	0.82±0.03	0.01±0.00	8.27±1.12
Ketere	Upstream	4.20±0.19	1.86±0.19	0.24±0.03	0.24±0.10	0.92±0.02	0.02±0.00	8.59±1.06
Molibany	Upstream	2.71±0.32	1.14±0.04	0.08±0.01	0.22±0.01	0.15±0.02	0.02±0.00	7.81±1.53
Neseki	Upstream	3.76±0.29	1.46±0.03	0.14±0.05	0.09±0.02	0.67±0.01	0.03±0.00	7.95±0.09
Olekasoe	Upstream	2.17±0.41	0.79±0.03	0.15±0.03	0.07±0.01	0.35±0.02	0.03±0.01	5.78±0.11
Olormurunyai	Upstream	3.44±0.36	0.89±0.26	0.13±0.02	0.09±0.02	0.32±0.05	0.01±0.00	13.54±3.36
Sintin	Upstream	3.75±0.55	0.89±0.02	0.08±0.00	0.26±0.03	0.46±0.07	0.01±0.00	7.13±0.12
Tikoi	Upstream	3.58±0.25	1.22±0.03	0.16±0.01	0.06±0.00	0.58±0.02	0.02±0.00	6.21±0.51
ANOVA-test	**F-value**	3.54	7.42	14.89	2.08	4.65	6.89	4.28
	P-value	0.003	0.003	<0.001	**0.058**	<0.001	<0.001	0.022
Emarti	Downstream	3.99±0.13	1.82±0.02	0.32±0.08	0.20±0.07	0.63±0.02	0.02±0.00	5.60±0.08
Ileramatak	Downstream	4.01±0.20	1.06±0.02	0.07±0.00	0.11±0.01	0.58±0.11	0.01±0.00	7.47±0.09
Ketere	Downstream	5.61±0.52	2.00±0.37	0.09±0.01	0.09±0.02	0.90±0.02	0.02±0.00	9.18±0.45
Molibany	Downstream	6.82±1.53	2.66±0.00	0.08±0.00	0.58±0.10	0.62±0.06	0.02±0.00	13.77±0.08
Neseki	Downstream	4.18±0.41	2.62±0.00	0.10±0.01	0.48±0.17	0.69±0.05	0.02±0.00	12.60±1.10
Olekasoe	Downstream	3.31±0.33	0.81±0.20	0.10±0.02	0.09±0.01	0.33±0.03	0.03±0.01	6.68±2.65
Olormurunyai	Downstream	7.70±0.31	2.29±0.15	0.11±0.00	0.37±0.16	0.58±0.04	0.03±0.01	10.41±2.02
Sintin	Downstream	5.41±0.11	1.37±0.01	0.14±0.02	0.22±0.05	0.42±0.03	0.02±0.00	9.16±0.02
Tikoi	Downstream	4.10±0.34	2.31±0.06	0.44±0.09	0.05±0.00	0.59±0.05	0.03±0.00	7.74±1.84
ANOVA-test	**F-value**	3.67	9.95	9.27	4.45	8.85	6.89	4.12
	P-value	0.002	<0.001	<0.001	0.001	<0.001	<0.001	0.025
Double cross	Downstream	11.94±0.01	6.79±0.38	0.17±0.00	0.84±0.00	3.38±0.04	0.02±0.00	62.00±1.61
Fig Tree	Downstream	8.69±0.02	2.10±0.28	0.07±0.00	0.54±0.00	0.71±0.00	0.01±0.00	16.41±0.83
Saning'o	Downstream	4.39±0.03	2.19±0.12	0.48±0.00	0.35±0.00	4.10±0.09	0.06±0.00	65.06±1.04
ANOVA-test	**F-value**	2.94	9.77	1.14	1.5	1.07	9.9	5.11
	P-value	<0.001	0.002	<0.001	<0.001	<0.001	0.002	<0.001

Table 3: Mean variation of sediment nutrient concentration at the livestock and hippo sites (Mean±SD, livestock, N=18, hippo=9)

Site	Location	TN (mgg^{-1})	NO_3 (mgg^{-1})	NH_4 (mgg^{-1})	TP (mgg^{-1})	Inorganic-P (mgg^{-1})
Emarti	Upstream	7.72±0.02	1.74±0.48	0.70±0.04	7.83±0.03	0.71±0.05
Ileramatak	Upstream	6.63±0.00	2.71±0.16	0.54±0.03	8.12±0.01	0.54±0.06
Ketere	Upstream	6.73±0.02	2.31±0.08	0.82±0.02	10.07±0.01	0.95±0.02
Molibany	Upstream	7.75±0.02	3.11±0.24	0.78±0.01	10.87±0.03	0.68±0.02
Neseki	Upstream	7.47±0.03	4.89±0.08	0.78±0.01	10.55±0.01	1.05±0.05
Olekasoe	Upstream	7.63±0.03	3.11±0.24	0.84±0.02	9.92±0.02	0.73±0.02
Olormurunyai	Upstream	7.75±0.05	1.26±0.16	0.70±0.02	7.43±0.01	0.89±0.02
Sintin	Upstream	7.57±0.01	5.05±0.24	0.62±0.04	9.18±0.01	0.65±0.02
Tikoi	Upstream	9.28±0.01	1.18±0.24	0.89±0.06	8.36±0.03	1.14±0.03
ANOVA-test	**F-value**	8.38	3.37	1.29	3.93	3.37
	P-value	<0.001	<0.001	<0.001	<0.001	<0.001
Emarti	Downstream	8.93±0.02	3.03±0.16	1.02±0.05	10.64±0.02	0.95±0.03
Ileramatak	Downstream	7.71±0.04	3.60±0.08	1.32±0.02	11.27±0.02	0.72±0.03
Ketere	Downstream	8.14±0.00	4.40±0.24	1.72±0.02	11.15±0.03	0.97±0.01
Molibany	Downstream	9.39±0.02	6.34±0.08	0.88±0.04	10.99±0.01	1.06±0.06
Neseki	Downstream	9.36±0.02	6.34±0.24	1.16±0.05	11.00±0.02	1.23±0.03
Olekasoe	Downstream	8.84±0.01	3.27±0.24	0.85±0.02	10.99±0.01	0.88±0.04
Olormurunyai	Downstream	8.97±0.01	3.44±0.24	0.72±0.01	11.18±0.03	1.05±0.03
Sintin	Downstream	9.18±0.02	6.18±0.40	0.69±0.01	11.44±0.03	0.99±0.04
Tikoi	Downstream	10.19±0.02	4.08±0.24	1.33±0.06	10.44±0.01	1.35±0.02
ANOVA-test	**F-value**	1.31	3.49	9.16	2.21	2.78
	P-value	<0.001	<0.001	<0.001	<0.001	<0.001
Double cross	Downstream	10.54±0.02	4.32±0.16	1.84±0.14	10.02±0.01	2.66±0.03
Fig Tree	Downstream	9.14±0.03	5.05±0.24	1.01±0.02	6.86±0.03	2.20±0.02
Saning'o	Downstream	8.94±0.01	6.02±0.08	1.06±0.00	6.63±0.01	1.87±0.03
ANOVA-test	**F-value**	1.75	2.38	3.39	11.92	2.45
	P-value	<0.001	0.014	0.009	<0.001	<0.001

Table 4: Dung characteristics

Parameter	Hippo dung	Cattle dung
Carbon (% of dry matter)	33.71	28.36
Nitrogen (% dry matter)	0.98	1.13
P ($mg\ g^{-1}$)	1.29	2.23
N ($mg\ g^{-1}$)	9.81	11.32
C:N:P	261.4:7.6:1.0	155.2:5.1:1.0
Wet weight (g)	-	868.48
Dry weight (g)	-	217.12