INFLUENCE OF LIGHT POLLUTION AND BIODIVERSITY AWARENESS ON HAWKMOTH (LEPIDOPTERA: SPHINGIDAE) DIVERSITY AND ABUNDANCE IN SELECTED SITES IN KENYA

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A thesis submitted in partial fulfilment of the requirements for the award of a degree of Master of Science in Environmental Management, South Eastern Kenya University.

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DECLARATION

I hereby, declare that this thesis is my original work and has not been presented to any other university or institution for the award of degree.

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DEDICATION

This work is dedicated to the memory of many outstanding people who tirelessly worked to improve the state of the environment. I for now single out three of them, Rachael Carson (1907– 964), author of the book, Silent Spring; Professor Thomas Odhiambo (1931–2003), founder of the International Centre of Insect Physiology and Ecology and Professor Wangari Maathai (1940 – 2011), founder of the Green Belt Movement and the 2004 Nobel Peace Prize Laureate.

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ABSTRACT

Light pollution is a key biodiversity threat and is defined as one of the global environmental problems threatening key species to extinction and posing a major challenge to biodiversity conservation. The absence of stringent law, good practice and nonexistent environmental standards on light pollution has been a major drawback to management of its effects on biodiversity. This study sought to establish the influence of light pollution and biodiversity awareness on hawkmoth diversity and abundance in Kenya with a focus on two sites, Alim High School within Mavoko Constituency and Mithanga, within Mwala Constituency in Machakos County, Kenya. It engrossed on three objectives; evaluation of the distribution pattern of hawkmoths based on the national insect reference collection at the National Museums of Kenya, determining the influence of light pollution on diversity and abundance of hawkmoths and evaluating the level of awareness by development projects on the impacts of light pollution on biodiversity in Machakos County. Descriptive research design as well as field experiments were adopted. Records were retrieved from hawkmoth specimens housed at the National Museums of Kenya. Field surveys using light trapping were done at two sites, the Alim High School and at Mithanga village. A sample of forty eight randomly selected Environment Impact Assessment (EIA) reports was obtained at the Machakos County NEMA office in Machakos town and outlined Environmental Management Plans reviewed for negative impacts on flora and fauna and possible mitigation measures. The results showed that the hawkmoth collection holds 3,540 hawkmoths records consisting of 210 species, 97 of which are from the whole of Kenya, 33 from the larger former Machakos District and 10 from Machakos County. Light trapping away from the street lights had 18 hawkmoth records consisting of 8 species, while the trap at the street lights had no hawkmoths recorded indicating a possibility of local extinction due to light pollution. A new species record *Theretra capensis* from Machakos County, was recorded at the Mithanga light trap. None of the EIA reports mentioned light pollution impacts or mitigation measures for light pollution. However, 62 % mentioned impacts and mitigation measures for flora only, 0% for fauna only, 10% for both flora and fauna and 38 % mentioned no issues on mitigation of impacts on flora and fauna. From this study results, it is concluded that hawkmoths are affected by light pollution and that development project proponents are not aware of light pollution and thus are not considering it in their impact mitigation plans. Among the recommendations given is that further field surveys be undertaken to examine hawkmoth species diversity and abundance in differently illuminated geographic areas capturing the effects of light pollution in their population dynamics.

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ABBREVIATIONSAND ACRONYMS

CBD	Convention on Biological Diversity
EIA	Environmental Impact Assessment
EMCA	Environmental Management and Coordination Act
FAO	Food and Agriculture Organization
GPS	Global Positioning System
IDA	International Dark –Sky Association
KEBS	Kenya Bureau of Standards
NEAP	National Environmental Action Plan
NEMA	National Environment Management Authority
NMK	National Museums of Kenya
MDG	Millennium Development Goals
RCEP	Royal Commission on Environmental Pollution
SEKU	South Eastern Kenya University
UV	Ultraviolet

DEFINITIONS OF TERMS

Light pollution is any alteration of light levels in the outdoor environment, from those present naturally, due to manmade sources of light. (IDA, 2014)

Lepidoptera is the insect order that consists of moths and butterflies (Holloway *et al.*, 1987).

Hawkmoths are insects that belong to the moth family, Sphingidae in the order Lepidoptera (Holloway *et al.*, 1987).

Diversity is used in this study to mean the number of species and their relative abundance (New, 1998).

Relative abundance is considered in the form of species-abundance frequency distributions, which show the relationship between the abundance of individuals and the number of species possessing that abundance (May, 1975).

CHAPTER ONE: INTRODUCTION

1.1 Introduction

Life on earth has evolved with a very delicate ecosystem and a natural daily cycle of dark and light whose balance is being disrupted by the effects of light pollution (Frank, 1988; Jones &Francis, 2003). Artificial light that modifies the natural patterns of light and dark in ecosystems has been termed as ecological light pollution. It comprises of direct glare, chronically increased illumination and temporary, unexpected fluctuations in lighting (IDA, 2014). The sources of ecological light pollution vary and are found in nearly every ecosystem in various forms such as sky glow, illuminated buildings and towers, streetlights, fishing boats, security lights, lights on vehicles, flares on offshore oil platforms, flood lit institutions, sports grounds, industrial parks and lights on undersea research vessels (Rich and Longscore, 2006; Bruce-White & Shardlow, 2011;IDA, 2014). Over the last few decades, light pollution has increased globally affecting many plant and animal species (Rydell, 1992; Nicholas, 2001; Bidwell, 2003; Jones and Francis, 2003; Rich and Longscore, 2006; FAO, 2007). The increase in pollution poses a major challenge to humankind in addressing biodiversity loss and its consequences such as reduced food yields and resulting economic challenges.

Studies have shown that moth populations are highly threatened by the effects of light pollution (Frank, 1988; Nowinszky, 2004). There is evidence that light pollution is among the reasons why many moth species are in rapid decline, as the light pollution interrupts their reproductive behaviour and also increases the rates of predation (Frank, 1988; Rydell, 1992; Langevelde *et al*., 2011). Hawkmoths belong to the insect order Lepidoptera, family Sphingidae and have a well-developed proboscis which makes them important in the pollination of plants. In Kenya, some hawkmoth studies have in the recent past increased the awareness of their role in the environment including the ecosystem services which they offer as pollinators (Martins and Johnson, 2007, 2009&2013; Oronje *et al*., 2012).

Earlier hawkmoth studies in Kenya include mainly surveys like those of Kühne (2008) who recorded 53 hawkmoth species for Kakamega forest and Carcasson (1976) who recorded 26 species for Kakamega forest and did a taxonomic catalogue of the African Sphingidae with descriptions of the East African species. The Hawkmoth species for the whole of Kenya were reported to be

100 species (Carcasson, 1976)]. Thus the understanding of the hawkmoth fauna of Kenya is still very limited.

The enactment of the Environmental Management and Coordination Act (EMCA) (GoK, 1999) has enhanced environmental awareness and empowered the citizens of Kenya to actively participate in environmental decisions making and taking responsibility for safe environment. The importance of the environment has also been captured in Kenya's development blueprint, Vision 2030, where the environmental sector has been extensively covered in the social pillar. Biodiversity and ecosystems are a major aspect of environmental well-being and invertebrates which include moths which make up the majority of living species globally (New, 1998). Light pollution has been shown to be a factor in invertebrate population and species decline (Crowson, 1981; Frank, 1988; Nowinszky, 2004).The increase in developmental activities in the Central and County Governments in Kenya is likely to lead to increased light pollution and consequently reducing biodiversity. Observed impacts of light pollution include changes in species distribution, population size, timing of reproduction and migration events among others (Rydell, 1992; Nicholas, 2001; Jones & Francis, 2003; FAO, 2007). All these points to the need to understand the potential for light pollution in development projects and to emphasise it at the scoping stage of the Environmental Impact Assessment process (Bruce-White & Shardlow, 2011). Light spill onto wildlife habitats should be avoided altogether where possible, but when not possible the impact should be considered as being likely to be significant and should be mitigated appropriately thus minimising the impacts of lighting on biodiversity. This study will assess the effect of light pollution on the distribution, diversity and abundance of hawkmoths and how the current development projects have been positioned to minimise night lighting impacts on biodiversity in Kenya with a focus on EIA reports from Machakos County. The results are expected to provide baseline data that can be used to monitor the situation over time and to influence the improvement of the current situation in designing and implementing development projects.

1.2 Research problem

The current global increase in artificial night lighting calls for urgency to study the effects of light pollution to support nature management options as light pollution is a key biodiversity threat. In Kenya, there is no over-arching national policy on ecological light pollution that guides the use of artificial lighting in the country. The absence of proper management measures to prevent exposure to excessive night lighting or light pollution in general may be resulting in adverse environmental health risks that affect our biodiversity as well as human health and food security. The ecological balance is negatively impacted interfering with rhythms of living things and especially moths that are nocturnal and highly sensitive to artificial lighting. Hawkmoths play a major role in food security and environmental health since they are key pollinators of crops and wild flora. However, their diversity and abundance are poorly known more so with regard to light pollution. This study assessed the hawkmoth species diversity and abundance based on collections at the NMK, the influence of light pollution on the diversity and abundance of hawkmoths in two sites within Machakos County, while checking on the levels of awareness to impacts of light pollution on biodiversity by development projects.

1.3 Objectives of study

The overall objective of the study was to assess the hawkmoth species diversity and abundance and the influence of light pollution on their diversity and relative abundance in two selected sites within Machakos County, Kenya.

The specific objectives were:-

i. To evaluate the hawkmoth species diversity and abundance in Kenya based on the national insect reference collection at the National Museums of Kenya.

ii. To determine the influence of light pollution on diversity and abundance of hawkmoths in two sites, Alim High School and Mithanga in Machakos County, Kenya.

iii. To evaluate the level of awareness by development projects on the impacts of light pollution on biodiversity in Machakos County.

1.4 Hypothesis

i) Historical data from museum hawkmoth specimens can map their species diversity and abundance in Kenya.

ii) Light pollution influences the diversity and abundance of hawk moths in Machakos County.

iii) Existing development projects are aware of night lighting impacts on biodiversity in Machakos County.

1.5 Scope of study

The study involved analysis of the effects of light pollution on hawkmoth species within Alim High School in Mavoko Constituency and Mithanga village in Mwala Constituency, Machakos County. The past distribution pattern of hawkmoths in Kenya was determined by using the historical reference moth collection at the National Museums of Kenya (NMK) backed by available literature. The influence of light pollution on the diversity and abundance of hawkmoth species was investigated along a light gradient. A randomly selected sample of 48 Environment Impact Assessment (EIA) reports for development projects in Machakos County was evaluated to determine the level of awareness on night lighting impacts on biodiversity. The study relied on both primary and secondary data collected from the NMK insect collections field studies, EIA reports submitted to Machakos County NEMA officer and published work.

CHAPTER TWO: LITERATURE REVIEW

2.1 Introduction

This chapter covers the literature review, which has been done in four sections. Section one covers the use of Museum collections to determine hawkmoth species distribution. Section two reviews the diversity and abundance of Hawkmoths while section three looks at literature on the effects of light pollution on moths. The fourth section reviews literature on legal framework that is relevant to biodiversity conservation in Kenya.

2.2 Use of Museum collections to determine hawkmoth species distribution

Species data from the Museum collections has been shown to be of great value as a tool for prioritising conservation actions in Africa (Fjelda &Tushabe, 2005). The National Museums of Kenya (NMK) has an entomology collection, housed in 4,000 drawers in cabinets that contain over 1.5 million specimens including the largest butterfly collection in Africa (Arnett *et al.*, 1997). Fifty eight drawers contain moths of the family Sphingidae which constitute the hawkmoths (personal observation). Lampe & Striebing (2005) demonstrated how to digitize large insect collections to make their associated label data into databases that can be used for functions such as making distribution maps. The NMK's 58 drawers of hawkmoths have not been digitized and there is need to capture the label data to create a database that can aid in mapping the distribution of the species in Kenya. According to Lampe & Striebing (2005), many Museum collections have not been databased because the process is tedious with one specimen taking about 9 minutes to be digitized. Lampe & Striebing (2005) noted that process of digitizing traditional entomological collections must follow a lock step program for databasing. To bring out the details for assisting in making of species distribution maps, the museum collection species data will require subjection to:

i. Capturing of taxonomic information
ii. Validity check of the systematics
iii. Setting up of a collection based catalogue of the taxa
iv. Secondary data capture of sampling information
v. Validity check of geography (geo-referencing)
vi. Setting up a collection based catalogue of named areas
vii. Final data entry of existing specimens into database

Digitization of collections such as the one held at NMK has not been normally integrated in the daily work of staff and hence the need to now put effort in doing it so that the existing data can be easily accessed. The proposed project will fill in this gap by digitizing the hawkmoths collection and using the database to map their distribution in Kenya focusing on Machakos County.

2.3 Factors that determine the diversity and abundance of Hawkmoths

Hawkmoths belong to the insect order Lepidoptera. The name Lepidoptera is derived from the Greek term for scaly wings, thus this is the major feature distinguishing the Lepidoptera from other insects (Pinhey, 1975).According to Holloway *et al*., (1987) the number of world species approaches 200,000 most of which are moths and only about 15,000 are butterflies. In this order, species identification is mostly based on the adults because the larval stages are insufficiently known taxonomically. Identification of the adults is based on taxonomic keys that are based on gross external characters such as size, wing shape, colour pattern and markings, wing venation, antennae, palpi among other external structures and genitalia features (Carcason, 1976, Holloway *et al*., 1987). The hawkmoths belong to the family Sphingidae and are one of the biggest and most impressive taxa in Lepidoptera and have diurnal and nocturnal activity (Lehmann & Kioko, 2005; Kühne, 2008). The adults have a streamlined body, robust forewings and small hind wings that enable them to have a strong and fast flight and also ability of hovering on a spot (Proctor *et al*., 1996). Carcasson (1976) noted that the Sphingidae had over 1,000 species, majority being tropical insects, and recorded 260 African species. Among the African species, 160 occurred in eastern Africa, 100 being in Kenya and 5 of these are recorded in Machakos. Other surveys on Sphingidae in Kenya are those of Kühne (2008) who recorded53 species in Kakamega forest. The surveys have shed some light into the diversity of hawkmoth species in Kenya and some ecological aspects like associated host-plants in some of the species. However, so far no study has looked at the effects of light pollution on the diversity and relative abundance of the species.

2.3.1 Biology and ecosystem functions of hawkmoths

Hawkmoths have a complete four stages metamorphosis, being the egg, the caterpillar which is the feeding and growing stage, the chrysalis or pupa which is a transition stage and the adult which is the dispersal and reproductive stage (Holloway *et al.*, 1987). The larvae of hawkmoths feed on plants while most of the adults have a fully functional proboscis used to suck-in nectar. Darwin (1862) argued that the long spurs (32 cm) of a Madagascan orchid (*Angraecum sesquipedale)* represented a floral specialization for pollination by a long-tongued hawkmoth and later this was confirmed by finding the hawkmoth, *Xanthopan morgani predicta*.

Biodiversity and ecosystem services underpin human well-being, peace and a secure future. Hawkmoths are considered important pollinators in tropical regions and virtually all adult hawkmoths with functional proboscis utilize flowers as a source of food in the form of nectar (Martins and Johnson, 2013). On farmlands around Kakamega forest, spider plant (*Cleome gynadra* L.) an economically important African indigenous leafy vegetable was shown to be pollinated by nocturnal flower visitors, the long-tongued hawkmoths (*Agrius convolvuli*, *Coelonia* and *Xanthopan morgani*) and short-tongued hawkmoths (*Hippotion eson*, *H.osiris* and *Nephele aequivalens*) (Oronje *et.al.*, 2012). In many vegetable plants, it is not the fruit that is eaten but insect cross-pollination is important in obtaining seed (FAO, 1995). In papaya (*Carica papaya*) the best fruits results from cross-pollination with hawkmoths being the normal pollinators (FAO, 1995). Martins and Johnson (2009) showed the role of hawkmoths in the pollination of papaya in the dry eastern parts of Kenya. Beyond crops and fruit trees, interactions of hawkmoths and wild flowering plants have been studied by Martins and Johnson (2013) who estimated that 277 plant species (about 4.61% of the total angiosperm flora) in Kenya are adapted for pollination by hawkmoths.

2.3.2 Hawkmoths as indicators of environmental quality

Increase in human population and advances in technology have subjected ecosystems to pressures, which they have not adapted to cope. There is thus a need for techniques to monitor changes such as degradation and regeneration (Hollway *et al.*, 1987). One such technique is to use indicator organisms. Pearson (1994) outlined criteria for selecting and using indicator taxa in different contexts and for monitoring, which includes specialization to habitat, well known and stable taxonomy, easily observed and manipulated, biology and natural history well known, patterns of response reflected in other taxa, occurs over broad geographic range and economic potential. Insects through their susceptibility to change are prime choice with hawkmoths being particularly suitable since they are readily sampled with light traps and relatively well collected and studied taxonomically (Kühne, 2008).

Monitoring has been defined as surveillance to detect changes in relation to baseline data based on taxa and may need to incorporate samples to be interpreted over a timescale well beyond that of a single survey to detect changes in single species or larger groups in response to management over a sequence of seasons or generations, or as a response of a taxonomic group or broad-based assemblage to change in environmental quality (New, 1998, Bruce-White & Shardlow, 2011). A terrestrial community may be monitored to assess effects of pollution and changes in composition and thereby becoming an important tool in assessing environmental quality and health (Bruce-White &, Shardlow, 2011).

Namu *et al*., (2008) while studying the butterfly species composition and abundance in Kakamega forest noted that the consequences of habitat destruction on the survival of invertebrate species are poorly understood and that it is necessary that species sensitive to environmental changes be identified as indicators of environmental health and biodiversity status.

So far, studies in Kenya have highlighted the importance of invertebrates including hawkmoths in ecosystem services (Martins & Johnson, 2007, 2009; Oronje *et al.*, 2012 and Martins &Johnson, 2013). However, there are no studies so far on how key drivers of biodiversity loss, mainly habitat change, climate change, invasive species, over exploitation and pollution may affect the populations of the hawkmoths. This calls for studies to build up baseline knowledge in biodiversity and ecosystem services to provide relevant data and information and generate knowledge that is relevant and robust for planning and decision making in order to address these challenges and provide solutions to the current biodiversity erosion.

2.4 Effects of light pollution on moths

Light pollution, also known as photo pollution or luminous pollution, is defined as the alteration of light levels in the outdoor environment, from those present naturally, due to manmade sources of light. Light pollution is divided into two main types which are; one, the annoying light that intrudes on an otherwise natural or low light setting and two, the excessive light (generally indoors) that leads to discomfort and adverse health effects. According to the International

Dark-Sky Association (IDA) the characteristics of light pollution include sky glow, glare, light trespass, light clutter, decreased visibility at night, and energy waste (IDA, 2014; Cinzano *et al*., 2001).

Light pollutionis a key biodiversity threat and produces 1,900 million tonnes of CO_2 emissions globally, more than three times that which is produced by aviation (Stone *et al*., 2012). Concern about the impacts of light pollution on the environment has been growing in recent years and was summarised in the 2009 Royal Commission on Environmental Pollution report on Artificial Light in the Environment in Britain (RCEP, 2009). Light pollution has the potential to significantly disrupt ecosystems and it has long been of concern to conservationists (Rich & Longcore, 2006). It is considered to be one of the major threats to moth populations (Frank, 1988; Langevelde *et al*., 2011, IDA, 2014). Insects have compound eyes that are sensitive to a broad range of light with most insects having a colour vision system that is based on three to sometimes five, types of colour receptor cells thus can perceive the spectral region from ultraviolet (UV) which has a short wavelength and high frequency (300 nm) to red which has a long wavelength and a low frequency (700 nm) (Inokuma & Eguchi, 1987).Langevelde *et al.*, (2011) carried out experiments which showed that higher species richness and higher abundance of moths are attracted to artificial light with smaller wavelengths than to light with larger wavelengths and the lamps attracted moths with anaverage larger body mass, larger wing dimensions and larger eye size. UV light is used by terrestrial invertebrates in a variety of activities including mate selection, navigation and foraging (Salcedo *et al.*, 2003). Nocturnal hawkmoths's superposition compound eyes are able to detect light at very low levels and are able to see in colour even at very low light intensities that are roughly equivalent to star light, while other insects like bees with apposition eyes, become colour-blind in dim light (Kelber *et al.*, 2002). Hawkmoth species have good vision at very low light intensities and are able to distinguish certain flower colours and variations in intensity of colours; hence vision suffices for their finding flowers andscent promotes their location of flowers and discrimination of visually equal flowers. (Proctol *et al*., 1996).

It has been shown that one of the most obvious effects of light pollutionis attraction of many nocturnal insects including moths (Worth & Muller, 1979; Frank, 1988; Langevelde *et al.*, 2011).The glow worm, *Lampyris noctiluca* L. (Coleoptera: Lampyridae), is a species whose survival in Britain is threatened by outdoor lighting (Crowson, 1981). Flying adult mayflies have been shown to become disorientated by artificial light and fail to successfully perform important aspects of their life-cycle, with disruptions to essential life events likely to cause local extinctions of the species and thus a reduction in abundance and biodiversity (Nowinszky, 2004). Moths have been known to be highly attracted to outdoor lighting leading to destruction as clumping near lamps increases predation by bats, birds, and other nocturnal and diurnal predators which have learnt to take advantage of these artificial feeding stations (Rydell, 1992). Light pollution might have several other effects on foraging and reproduction activities of moths and their interspecific interactions (Rich and Longcore, 2006; IDA, 2014).

Despite the evidences that outdoor lighting affects individual moths (Worth & Muller, 1979; Frank, 1988, Langevelde *et al.*, 2011), few studies have attempted to quantify lighting effects on moth populations. Faunal surveys, life history studies, and ecological studies can be used to examine Lepidoptera in differently illuminated environments. The method might include comparison of Lepidoptera sampled from large geographic regions that possess different levels or kinds of outdoor illumination. Similar study is hereby undertaken to examine the diversity and abundance of hawkmoths in two sites that have different night illumination levels in Machakos County.

2.5 Legal framework

Many countries have recognized the detrimental effects of light pollution and put in place strategies and legal framework to protect the environment from the negative impacts of artificial lighting (Crowson, 1981; Ramos-González, 2006; White & Shardlow, 2011). In 2006, the Conservation Trust of Puerto Rico established a light pollution management task force to strategise on ways of recovering the night scape for future generations in the island of Puerto Rico (Ramos-González, 2006). In the UK, the Local authorities and Government departments have taken a lead on reducing the impact of artificial light. The environmental impact of light for new developments has been made more prevalent in the planning process and more routinely a part of the Environmental Impact Assessment process. Public bodies have a 'biodiversity duty' under the

NERC Act 2006 and Nature Conservation (Scotland) Act 2004 and must consider the impact that lighting, polarisation and reflection will have on biodiversity (White & Shardlow, 2011). Lamp-free reserves such as sheltered hollows shielded from lighting have been suggested to save the glow worm, *Lampyris noctiluca* L. (Coleoptera: Lampyridae), a species whose survival in Britain may be threatened by outdoor lighting (Crowson, 1981).

The enactment of the Environmental Management and Coordination Act (EMCA, 1999) has enhanced environmental awareness and empowered the citizens of Kenya to actively participate in environmental decisions making and taking responsibility for safe environment. The importance of the environment has also been captured in Kenya's development blueprint, Vision 2030 where the environmental sector has been extensively covered in the social pillar (GoK, 2007). Several legal guidelines are also in place that supports biodiversity conservation. These include;

i. The National Environmental Action Plan (NEAP), 1994.

In the mid-1990s, the Kenya government policy shifted towards integration of environmental considerations into the country's economic and social development. This ensured that environmental management and the conservation of natural resources informed societal decision-making (GoK, 1994).

ii. The Environment and Development Policy (Sessional Paper No. 6 of 1999)

This sessional paper was geared towards a harmonized environmental and development goals to ensure resources are sustainability managed. This paper was key to the establishment for the platform on which institutions managing the environment evolved.

iii. The National Bio-Diversity Strategy

This national bio-diversity strategy and action plan (NBSAP) links national and international undertakings particularly article 6 of the Convention on Biological Diversity (CBD). Through this action plan, Kenya is challenged to take measures to ensure biological resources, including biodiversity are conserved for posterity.

iv. Environmental Management and Co-ordination Act No. 8 of 1999,

Part VI Environmental Impact Assessment (EIA)

This particular section of EMCA; 58 (1) articulates that any person being a proponent of a project shall before financing and/or commencing submit a project report to the Authority in a prescribed form, giving prescribed information. However, there are no guidelines or legal framework on the issues of light pollution in Kenya (Personal communication with NEMA and KEBS officers). For Kenya, several standards have been developed and confirmed mainly for road lighting (Table 2.1) but none addresses the impacts of night lighting on biodiversity (KEBS; 2013). The increase in developmental activities in the central and county governments has led to increased light pollution and consequently to great impact of outdoor lighting on biodiversity. This study will assess if the EIAs undertake at the research site are addressing the impacts of light pollution on biodiversity.

Table 2.1: Confirmed street lighting standards in Kenya (Source: KEBS, 2013)

KS Number	Title	Year
KS 1452-1:1999	Code of practice for road lighting - Part 1: Guide to the general principles.	1999(confirmed 2013)
KS 1452-10:1999	Code of practice for road lighting - Part 10: Code of practice for lighting of motorways.	1999(confirmed 2013)
KS 1452-2:1999	Code of practice for road lighting - Part 2: Code of practice for lighting of traffic routes.	1999(confirmed 2013)
KS 1452-3:1999	Code of practice for road lighting - Part 3: Code of practice for lighting subsidiary roads and associated pedestrian areas.	1999(confirmed 2013)
KS 1452-4:1999	Code of practice for road lighting - Part 4: Code of practice for lighting of single-level road junctions including roundabouts.	1999(confirmed 2013)
KS 1452-5:1999	Code of practice for road lighting - Part 5: Code of practice for lighting of grade - separated junctions.	1999(confirmed 2013)
KS 1452-6:1999	Code of practice for road lighting - Part 6: Code of practice for lighting of bridges and elevated roads.	1999(confirmed 2013)
KS 1452-7:1999	Code of practice for road lighting - Part 7: Code of practice for lighting of tunnels and underpasses.	1999(Confirmed 2013)
KS IEC60598-2-3:2002	Luminaires - Part 2: Particular requirements - Section 3: Luminaires for road and street lighting.	2002
KS 942:2010	Process colours for traffic signs- Specification	Kenya KEBS 2010
KS 1452-8:1999	Road lighting - Part 8: Code of practice for lighting that may affect the safe use of aerodromes, railways, harbours and navigable inland waterways.	1999(confirmed 2013)
KS 1452-9:2005	Road lighting - Part 9: Code of practice for lighting of urban centres centres and public amenity areas (Second Edition).	2005(confirmed 2013)

CHAPTER THREE: MATERIALS AND METHODS

3.1 The study area

The study area for effects of light pollution on hawkmoth species diversity and abundance was Mavoko Constituency and Mwala Constituency within Machakos County and Alim High School and Mithanga Village were the study sites (Figure 3.1). This is an area of agricultural and horticultural activities with a fast growing populations, and the indigenous fauna and flora are under enormous threat (GoK, 2013).The area is dominated by the Somali-Maasai arid Acacia (*Acacia commiphora*) bushland and grasslands (White, 1983). The vegetation usually consists of a single open stratum of *Acacia commiphora* thorn trees mostly 3 to 7 m high, but 9 to 20 m in a few species. The other common Acacias are *Acacia drepanolobium, Acacia gerrardii, Acacia hockii, Acacia nilotica, Acacia senegal, Acacia seyal, Acacia tortilis, Acacia polyacantha* and *Acacia xanthophloea* (White, 1983; Beentje, 1994).

Ecologically, the site is within the agro-climatic zone V, and is home to important animal species (Pratt and Gwynne, 1977). The fauna of the larger Machakos County consists of mammals like zebras, giraffes, Thomson's gazelle, grant gazelle, mostly being found in the private ranches while the farmlands areas are home to diverse fauna including butterflies and moths, with some insects in these groups being key pests including stem borer species (such as *Sesamia calamistis* (Noctuidae) and *Chilo partellus* (Pyralidae) of graminnae crops (De Groote, 2000). The small mammals include rodent species like the single-striped grass mouse that feeds on crops like millet, sorghum, and seed of other wild plants. Other rodent species recorded for the site include ground squirrels, Kenyan African mole rat, southern giant pouched rat, Nile grass rat, and Heuglin's grass mouse (Musila, *et al*, 2013; Ojwang and Oguge, 2003). The bird species of this area portray a high diversity of unique birds, including some Afro-tropical and Palaearctic migrants. Some species have been recorded which are used in designating sites as Important Bird Areas (IBA) (Coetzee &van der Straeten, 2008).

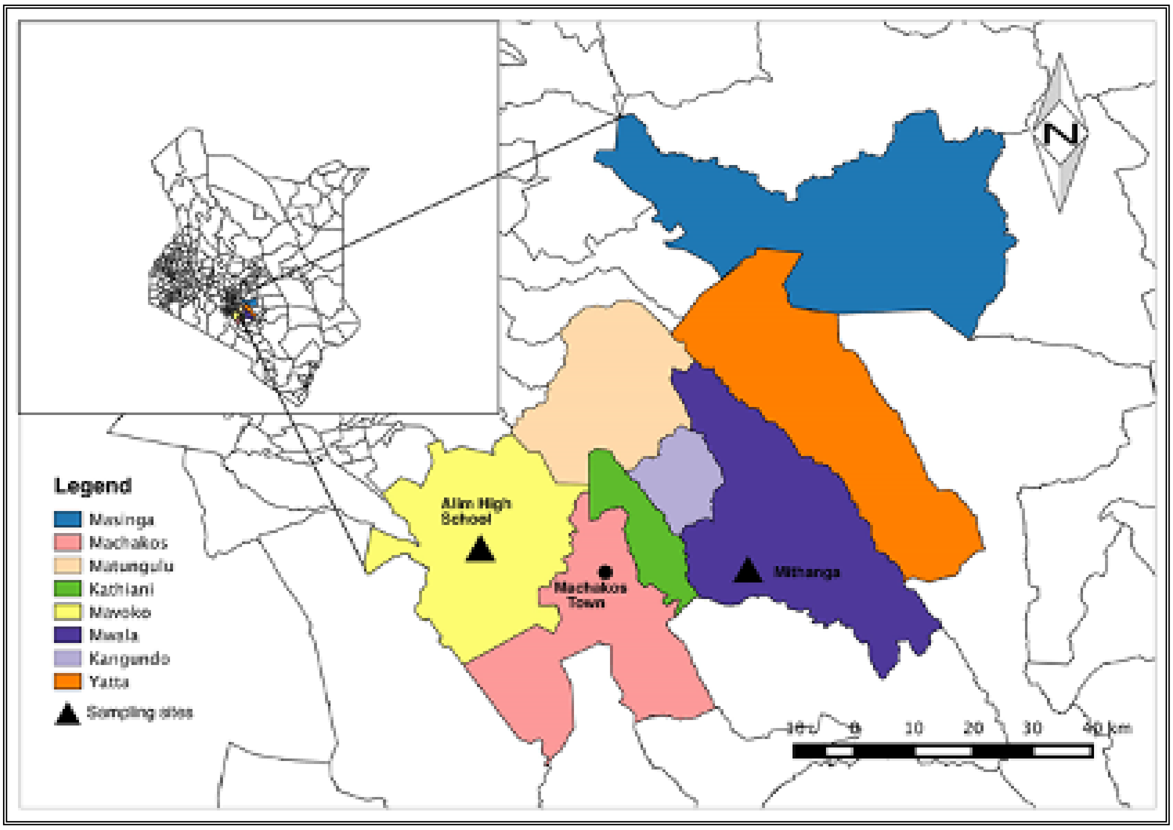

Figure 3.1: Map of Kenya showing location of the moth trapping study area, and study sites Alim High School in Mavoko Constituency and Mithanga in Mwala Constituency, Machakos County, in Kenya.

3.2 Capturing of specimen data for mapping of hawkmoth distribution

The method outlined by Lampe & Striebing (2005) was followed to collect data from hawkmoth specimens in 56 insect drawers housed at NMK entomological collections (Plate 3.1). Each specimen was removed from the drawer and all label information captured which includes:

i. Capturing of taxonomic information

ii. Validity check of the hawkmoth systematics

iii. Setting up of a collection based catalogue of the hawkmoths

iv. Secondary data capture of sampling information

v. Validity check of geography (geo-referencing by assigning co-ordinates)

vi. Setting up a collection based catalogue of named areas

Since the Museum specimens are historical, with some having been collected years ago, most of the locality data from where they were collected were not geo-referenced making the spatial analysis of hawkmoth species in Kenya complicated. The Kenyan Gazetteer from DIVA-GIS (Hijmans *et al.*, 2001) was used to improve data quality through automated assigning of co-ordinates to locality records. The data was then entered into a database. Quantum GIS (QGIS) programme was used for the data analysis and mapping (QGIS Development Team, 2012).

Plate 3.1: Samples of hawkmoths specimens at NMK

3.3 Light trapping of hawkmoths

Trapping of hawkmoths was done at three sites, two sites within Alim High School 1,646 m above sea, Latitude 01°32.321’S and Longitude 037° 11.216’E and the third one at Mithanga village located 22 km from Alim High School at 1,354 m above sea level, Latitude 01°27.447’S and Longitude 037° 23.173’E. 3.2). At Alim High School, two light trapping points were selected along a line transect, the first at the school gate, 5 meters from the street lights which are along the Machakos –Makutano road (Plate 3.2) and the second one at 300 M from the street lights. The school was selected because of the locality next to the street lights and has a large field that extends beyond 300m from the street lights and also for security of the trapping equipment. Mithanga village was selected because the area does not have street lights and it is similar to the Alim High school in terms of vegetation (Plate 3.3). A village member was also willing to offer security for the trapping equipment. Non-destructive moth light trapping was done thrice between November and December 2014 using a 12V car battery powered 6 watt actinic tube suspended over a butterfly net (Plate. 3.4) following the methods outlined by Fry & Waring (2001) and New (1998). Trapping was on three occasions; 24th to 27^{th} November 2014, 10^{th} to 13^{th} December 2014 and 23^{rd} to 26^{th} December 2014.Traps were set at 6pm and the catch collected at 7am the following morning. The trapping was done on moonless nights to avoid confusion of trap light with moonlight.

Plate 3.2: Street lights outside the Alim High School gate.

Plate 3.3: Sample of the Acacia vegetation common at the sampling sites

Plate 3.4: Sample of the moth light trap with 6 watt actinic tube suspended over a butterfly net.

3.3.1 Sample collection, treatment and identification of specimens

Hawkmoth specimens were individually removed from the light trap, taken in to a killing jar containing cotton wool dampened with ethyl acetate. The dead specimens were preserved in labelled butterfly envelops and later pinned and their wings spread out. The spreading exposed wing markings, that aided species identification using literature and the reference collection at the invertebrates section in NMK.

Plate 3.5: Pinning hawkmoth specimens for identification at the NMK

3.4 Development projects level of awareness to light pollution impacts

According to the Machakos County development profile (GoK, 2013) 154 EIAs had been endorsed by 2012. However, those available in Machakos County NEMA office are those undertaken after devolution took effect in 2013. A sample of 48 EIA reports was accessed at the Machakos County NEMA office. The environmental management (EMP) plans of these EIA reports were evaluated to see how many had taken into account the impacts of light pollution on biodiversity and if mitigation measures had been proposed for implementation in order to reduce effects of light on biodiversity.

3.5 Data analysis

A descriptive research design was adopted, which explored both the quantitative and qualitative aspects of the survey. QGIS software (QGIS Development Team, 2012) was used to map hawkmoth distribution in Machakos County and in Kenya. This involved the description of the status quo of the agenda as the researcher had no control over the historical collections already held at the NMK. For data analysis, R, an integrated suite of free software, was used (R core Team, 2013).

CHAPTER FOUR: RESULTS

4.1 Diversity and distribution pattern of hawkmoths from the National Museums of Kenya collection

From the sampled 56 drawers of hawkmoth collection at the National Museums of Kenya, 3,540 records were obtained consisting of 210 species. Out of these the Kenyan records were 1,097 specimens, comprising of 43 genera, consisting of 97 species (Figure 4.1, Appendix 1).

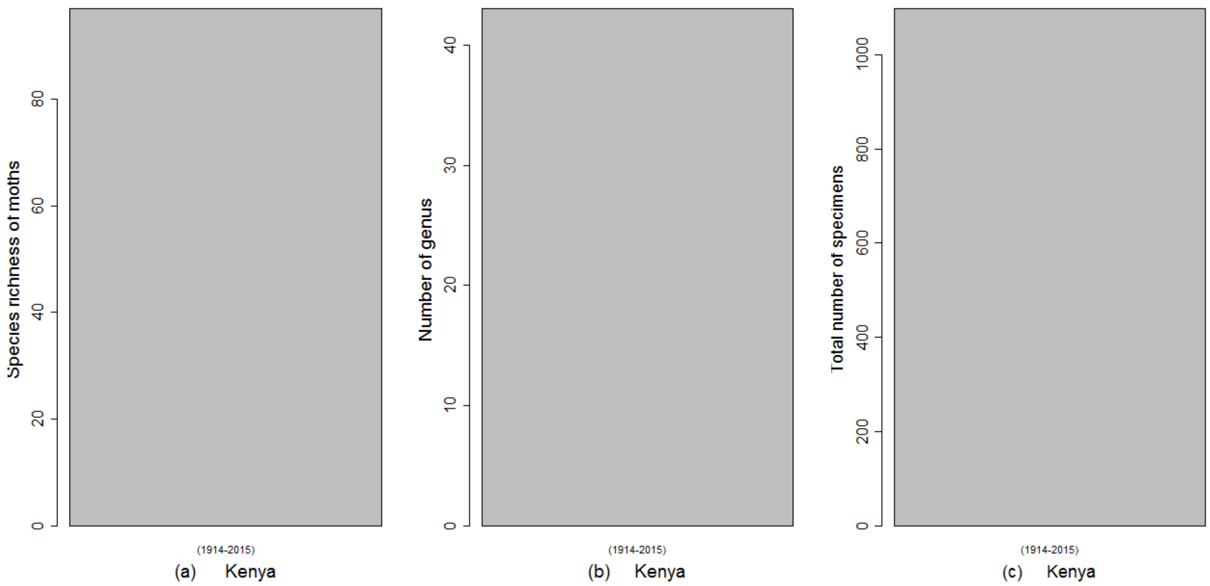

Figure 4.1: The species richness (a; 97), number of genus (b; 43) and total specimen abundance (c; 1097) of hawkmoths in the NMK collection.

The recorded 97 species of hawkmoths when mapped presented a distribution that was uneven. Some parts of Kenya had no species records at all while others had high, medium and low species richness (Figure 4.2).

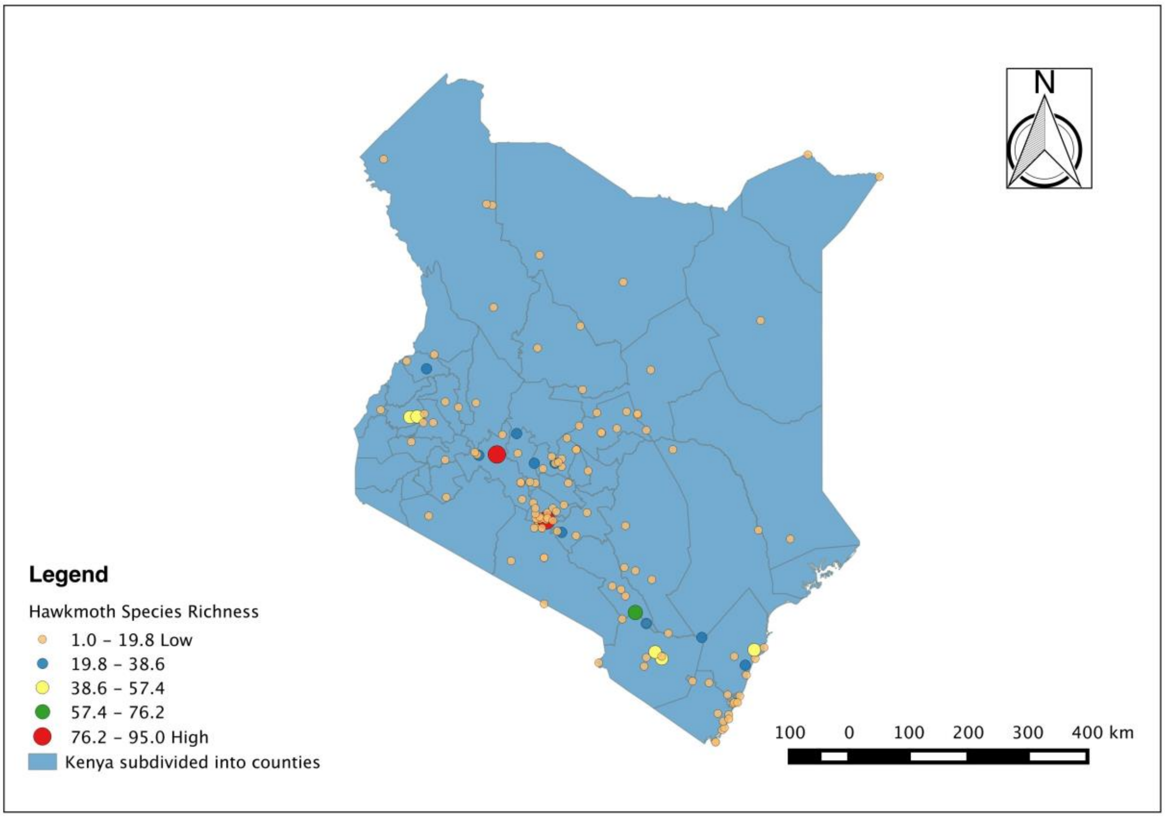

Figure 4.2: Hawkmoth species distribution in Kenya based on NMK records

When all the species represented were categorized into three habitats, coastal, dryland and forested, the species richness was higher in the forested areas with 65 species represented by 459 records, followed by the drylands with 45 species represented by 373 records and the coastal areas represented by 31 species from 265 records (Table 4.1).

Table 4.1: Hawkmoth species richness and total number of specimens in three habitats in Kenya based on NMK collections.

Kenyan Habitats	**Species Richness**	**Total abundance**
Coastal	31	265
Dryland	45	373
Forested	65	459
Total	**141**	**1097**

The hawkmoths specimens in the NMK had a collection history with the collections dating from 1914 to 2015. Species richness showed that 84 species, represented by 634 specimens were collected between 1914 to 1965 and 74 species represented by 463 specimens were collected between 1966 and 2015 (Figures 4.3 and 4.4).

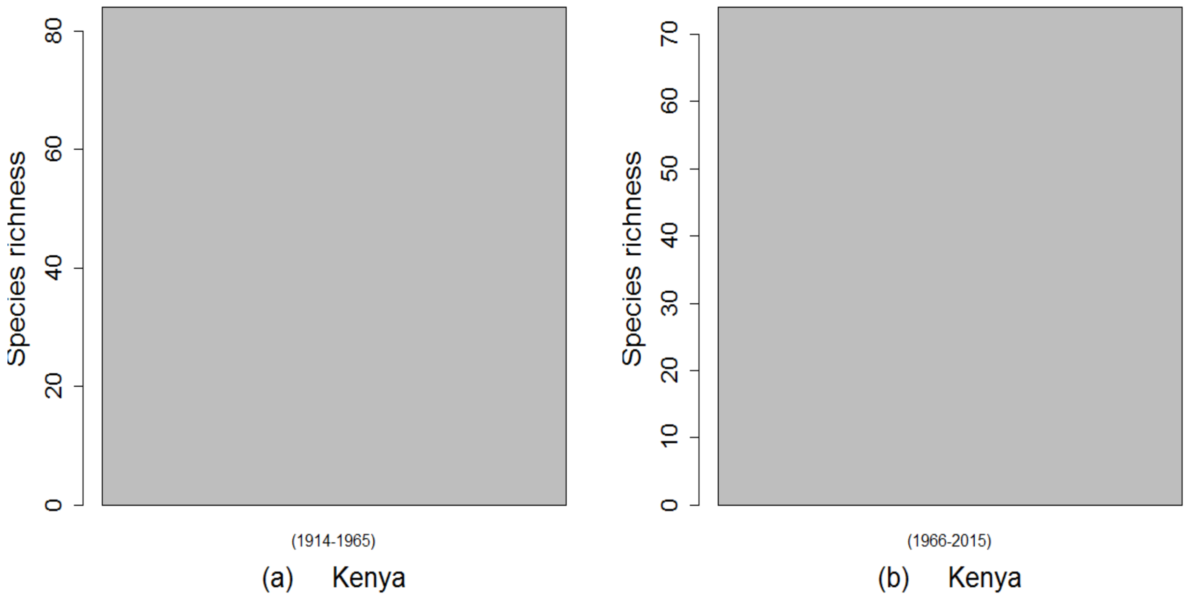

Figure 4.3: Hawkmoth species richness between 1914- 1965 (a; 84) and 1966- 2015 (b; 74) based on NMK collection.

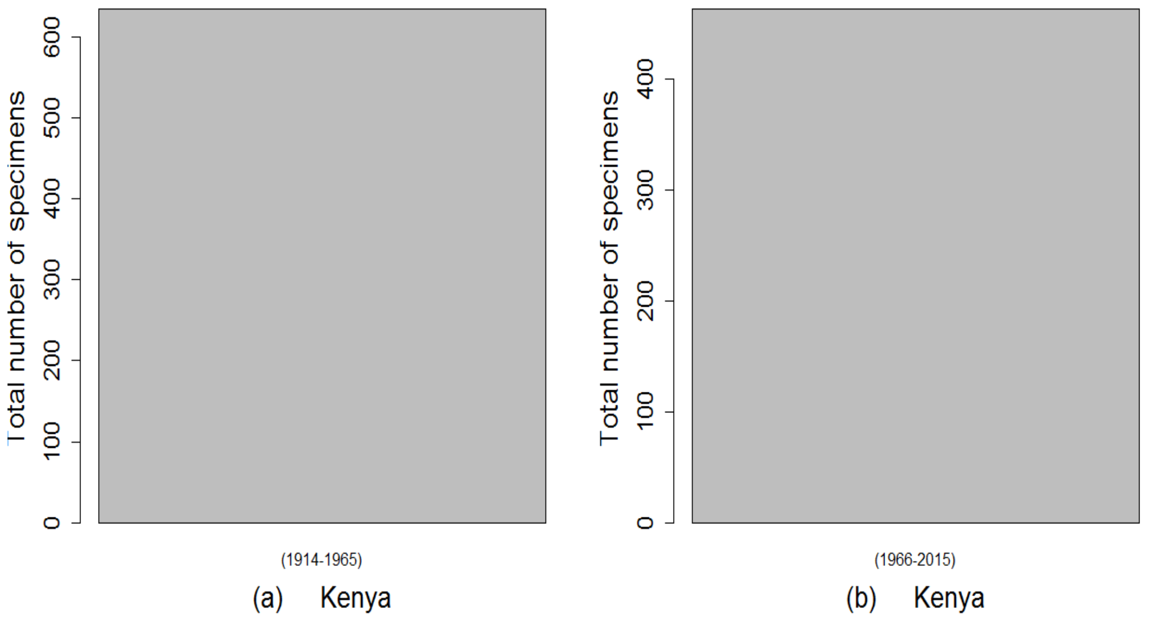

Figure 4.4: Hawkmoth specimens abundance between 1914- 1965 (a; 634) and 1966- 2015 (b; 463) based on the NMK collection.

In the larger Machakos area (before the devolution in 2013, Machakos and Makueni Counties were under one District, Machakos),33 species of hawkmoths were recorded in the NMK collection. These were in 24 genera represented in 142 specimens (Figure 4.5, Appendix II).

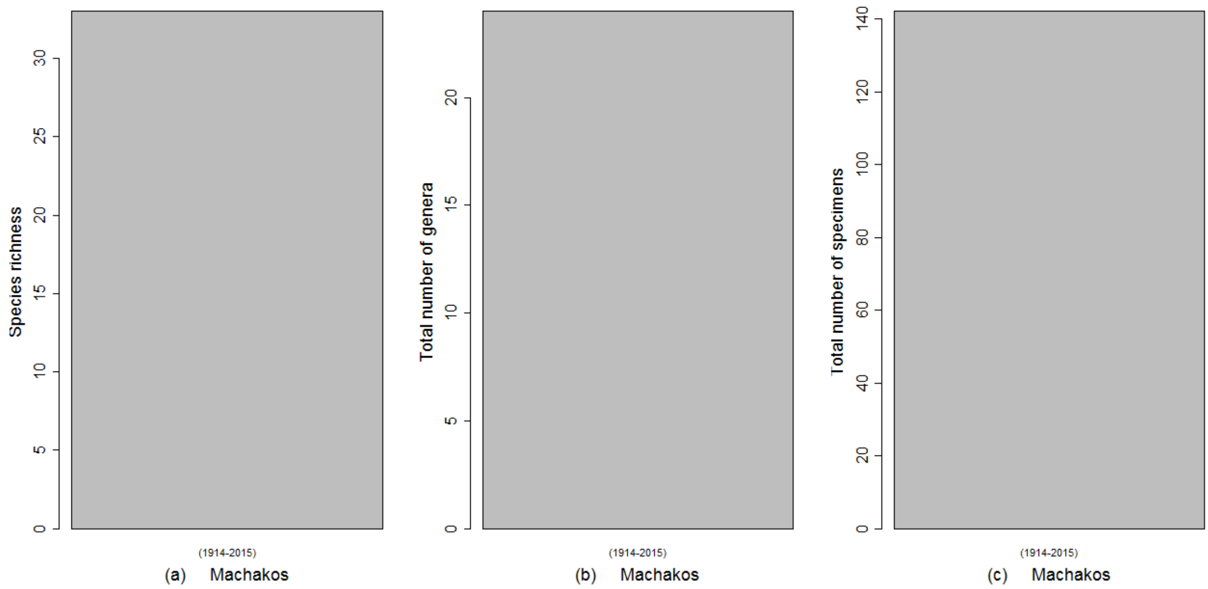

Figure 4.5: Larger Machakos area hawkmoth species richness (a; 33), number of genus (b; 24) and specimen abundance (c; 142, 2014-2015) based on NMK collection.

The hawkmoths species from the larger Machakos area represented in the NMK collection had the specimen collection dating from 1914 to 2015. Species richness showed that 19 species were collected between 1914 to 1965 and 18 species between 1966 and 2015 (Figures 4.6).

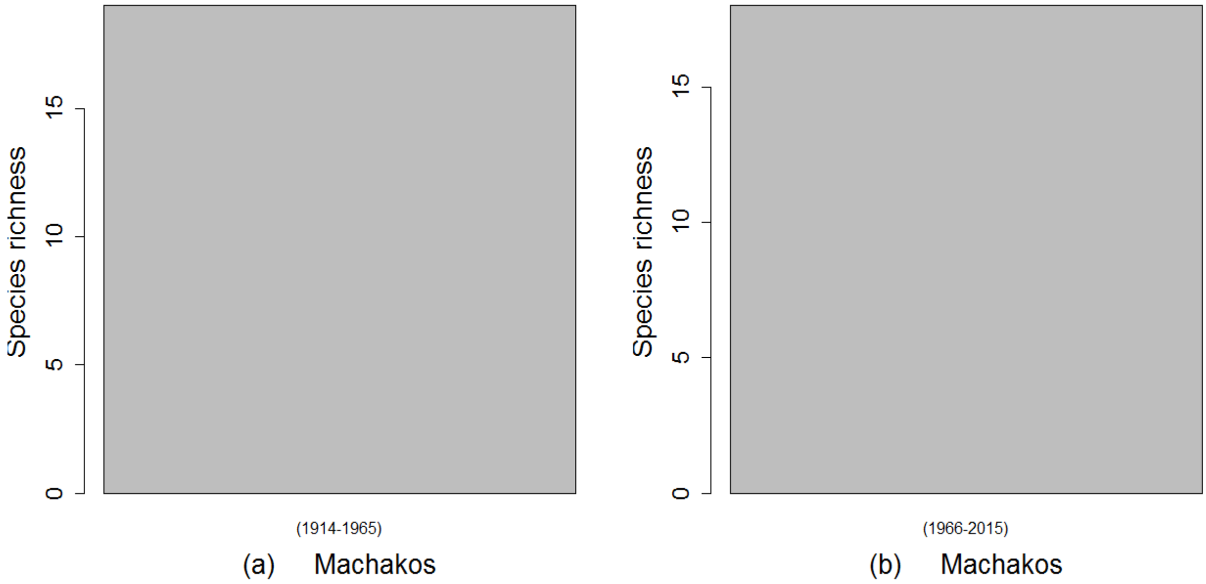

Figure 4.6: Larger Machakos area hawkmoth species richness between 1914-1965 (a; 19) and 1966- 2015 (b; 18) based on the NMK collection.

For the current Machakos County, 37 records were obtained consisting of ten species belonging to eight genera (Table 4.2,). The localities of the ten species recorded in Machakos County were mainly around Lukenya in Athi River area where seven of the ten species were collected. Of the other three species, two had a locality of Machakos town and the remaining one was from Yatta (Figure 4.7). The species distribution recorded for the Machakos County was uneven with 60% being recorded from Lukenya, Athi River. This was also the case for the entire country where the hawkmoths showed uneven distribution with some parts not giving any hawkmoth records (Plate 4:2).

Table 4.2: Hawkmoth species records for Machakos County based on the NMK Hawkmoth collection.

Genus	**Species**	**Species abundance in collection**	**Locality of collection**
Microclanis	*erlangeri*	1	Athi River, Kenya
Poliana	*micra*	1	Yatta, Machakos, Kenya
Macroglossum	*trochilus*	1	Lukenya, Athi River, Kenya,
Leucostrophus	*alterhirundo*	1	Lukenya ,Athi River, Kenya
Temnora	*argyropeza*	2	Lukenya, Athi River, Kenya
Temnora	*scheveni*	1	Machakos, Kenya
Nephele	*comma*	2	Lukenya, Athi River, Kenya
Nephele	*vau*	1	Machakos, Kenya
Hippotion	*celerio*	3	Lukenya, Athi River
Basiothia	*medea*	14	Lukenya, Athi River

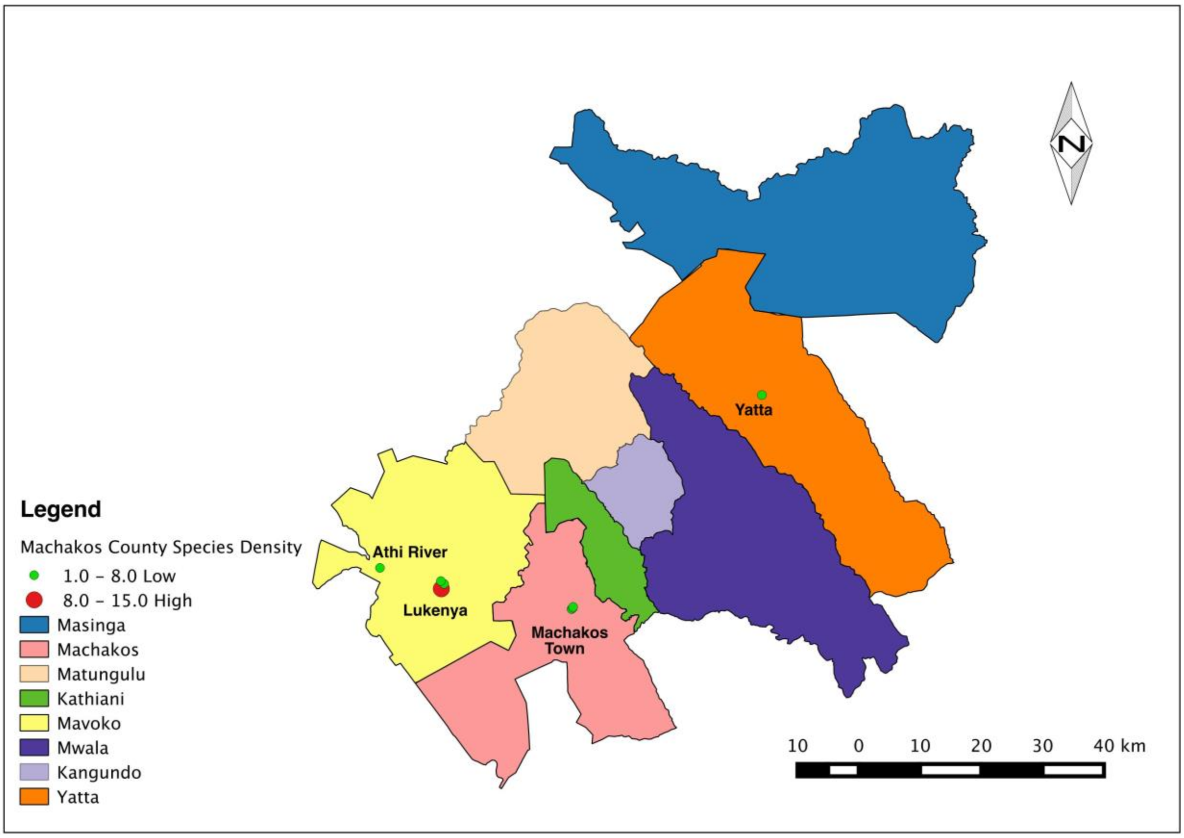

Figure 4.7: Distribution and abundance of hawkmoth species in Machakos based on NMK collection data.

4.2 Impact of light pollution on hawkmoth species diversity and abundance

All the three trapping sessions recorded 18 individual hawkmoth specimens representing 8 species. Light trap number one at the gate of Alim High School, 5 metres from the street lights, recorded 0 individuals for the entire three trapping sessions. Light trap number two, located 300m from the Machakos –Makutano road street lights, had 8 individuals consisting of four species as follows: *Hippotion celerio (*Linnaeus,1758*)* commonly known as the vine hawkmoth or Silver-striped hawkmoth (Plate 4.2). This species was recorded twice on two trapping nights. The first record was on 26th November 2014 with two specimens. The second record was on 12th December 2014 which had one record.

Plate 4.2: The hawkmoth *Hippotion celerio* recorded in both Alim and Mithanga sites.

Basiothia medea (Fabricius, 1781), commonly known as the small verdant hawk was recorded twice on 25th and 27th November 2014. Each of this records had one specimen (Plate 4.3).

Plate 4.3: The hawkmoth *Basiothia medea* recorded at Alim site.

Temnora fumosa, **(**Walker**,** 1856**)** commonly known as the Smokey Temnora was recorded twice during the trapping period. The first record was on 25th November and the second on 11th December 2014. Each record had one specimen (Plate 4.4).

Plate 4.4: The hawkmoth *Temnora fumosa* recorded at Alim site.

Polyptychoides grayi, (Walker, 1856) which is commonly known as Gray's Polyptychus, was recorded only once on 27th November 2014. This species had one specimen which was collected (Plate 4.5).

Plate 4.5: The hawkmoth *Polyptychoides grayi* recorded at Alim site.

The light trap number three, located in Mithanga village, recorded 10 specimens representing five species which included *Hippotion celerio,* shown in Plate 4.2. *Celerio lineata* (Fabricius,1775), commonly known as the white lined sphinx moth. This hawkmoth was recorded on 24th December 2014 represented by one specimen (Plate 4.6).

Plate 4.6: The hawkmoth C*elerio lineata* recorded in Mithanga.

Theretra capensis, (Linneaus, 1764) whose common name is the cape hawk was recorded once on 24th December 2014. This species was represented by one specimen (Plate 4.7). The specimen is the first record for the Machakos County for this species which had not been collected from the region before (Appendix IV).

Plate 4.7: The hawkmoth *Theretra capensis* recorded in Mithanga.

Leucostrophus alterhirundo, (d'Abrera, 1978), commonly known as the white barred hawkmoth was recorded once on 25th December 2014. One specimen was recorded and collected (Plate4:8).

Plate 4.8: The hawkmoth *Leucostrophus alterhirundo* recorded in Mithanga.

Agrius convolvuli (Linnaeus, 1758), with the common name, convolvulus hawkmoth was recorded once on 25th December 2014. The species was represented by one specimen (Plate 4.9).

Plate 4.9: The hawkmoth *Agrius convolvuli* recorded in Mithanga.

The maximum number of species caught per night per trap was 3 and the minimum was zero. During the light trapping, the highest hawkmoth catch during the entire trapping session at trap number two, 300 m from the street lights at Alim School, consisted of 3 species namely *Basiothia medea, Polyptychoides grayi* and *Temnora fumosa*. The highest number of hawk moths species caught at the same night at the Mithanga village, 22 km from the street lights was 4 species consisting of *Hippotion celerio, Agrius convolvuli* and *Leucostrop hishirundo*. At the two traps, *Hippotion celerio* was the most common species with 3 specimens recorded at trap 2 and 6 specimens recorded at trap 3 making up 50% of the species caught at all the traps during the survey. *Basiothia medea* and *Temnora fumosa* each made 11% of species recorded while the other five species *P. grayi, C. lineata, T. capensis, L. alterhirundo* and *A. convolvuli* each accounted for 5.5% of the species recorded. Statistical analysis of the trap catches showed no significance difference between the catches in trap 2 and trap 3 (Figure 4.8 and Table 4.3).

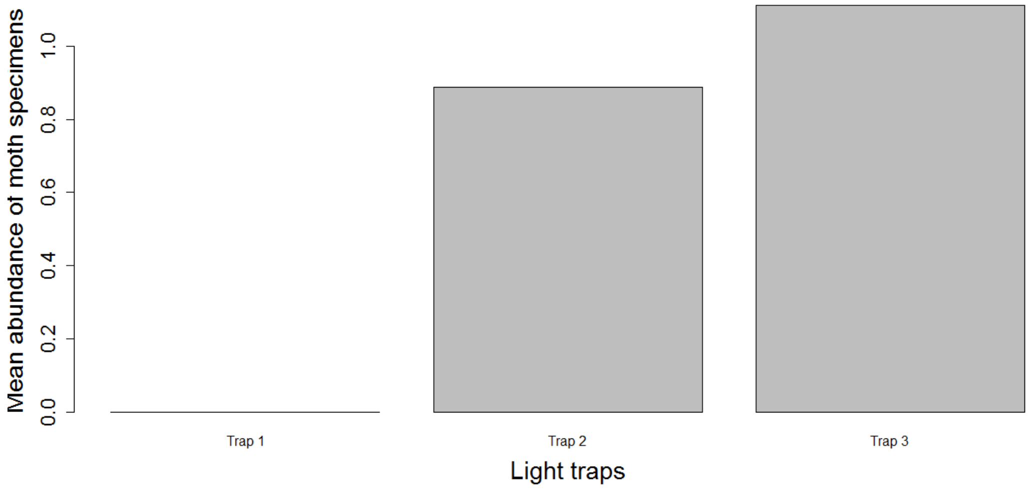

Figure 4.8: Mean abundance of abundance of light tarp catch. Trap 1 (0), number of Trap 2 (0.88) and Trap 3 (1.11). There was no significant difference in mean abundance within trap catches (p=0.06; Anova).

Table 4.3: Mean abundance of hawkmoth specimens in three traps in two sites in Machakos, Kenya.

	Mean (±se). **abundance**	**df**	**F**	**P**
Trap 3	1.11 ± 0.5[a]	2	3.14	0.06
Trap 2	0.88 ± 0.4 [a]			
Trap 1	0			

Means followed by the same letter in the column are not significantly different (p≤ 0.05)

4.3 Level of awareness by development projects on the impacts of light pollution on biodiversity

From the sample of forty eight EIA reports reviewed at Machakos County NEMA office, seven sectors namely were represented. These were, commercial housing making 35% of the reports, residential housing (17%), recreational/hospitality (12.5%), education (12.5 %), water (10%), mining (8%) and agriculture (4%). Within all these seven sectors covered by the EIA reports, 62% mentioned impacts on flora only, 10 % mentioned impacts on both flora and fauna, none mentioned impacts on fauna only and 38 % were silent on biodiversity without mentioning impacts on either flora or fauna (Figure 4.9). None of the reports mentioned impacts of light pollution.

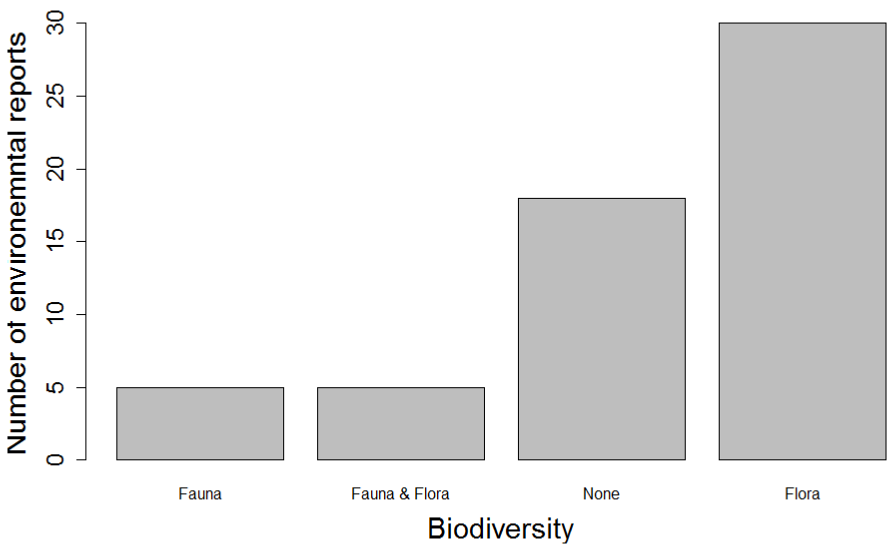

Figure 4.9: EIA reports mentioning biodiversity aspects, Fauna (5), Flora (30), Fauna & Flora combined (5) and 18 reports without factoring in biodiversity (None).

The EIA reports sampled covered two years, 2013 and 2014 and there was a significant bias on flora within the reports that mentioned impacts on biodiversity (Table 4.4). In both years, none of the reports mentioned light pollution as an issue that requires mitigation measures in development project implementation.

Table 4.4: Total and mean (±se) representation of EIA reports in Machakos County.

	Total number of reports	**Mean (±se)**	**df**	**F**
Flora	30	0.63 ± 0.07^{a}	3	17.97
None	18	0.38 ± 0.07^{b}		
Fauna & Flora combined	5	0.10 ± 0.04^{c}		
Fauna	5	0.10 ± 0.04^{c}		

Means followed by different letters are statistically different ($p<0.0001$; Anova).

Comparison of the trend in biodiversity mention in the EIA reports showed that from 2013 to 2014, the mean number of reports mentioning flora decreased while there was no significant change in terms of fauna impacts mention (Table 4.4).

Table 4.5: Comparison of EIA reports that utilized information on fauna and flora in 2013 and 2014

Biodiversity	Total number of reports	Mean (±se)	P	Test statistic
Flora 2013	9	0.81 ± 0.17^a	0.02	Mann-Whitney test
Flora 2014	21	0.57 ± 0.08^b		
Fauna 2013	1	0.03 ± 0.001^a	0.8	Mann-Whitney test
Fauna 2014	4	0.10 ± 0.001^a		

Means in same biodiversity category followed by different letters are statistically different ($p<0.05$; Mann-Whitney test).

CHAPTER FIVE: DISCUSSION

5.1 Discussion

The study has documented the hawkmoth diversity and abundance in Kenya based on the National Museums of Kenya (NMK) hawkmoth collection. A total of 1,097 Kenyan hawkmoth consisting of 97 species were recorded. Among these, the larger Machakos area (formely Machakos District) had 142 hawkmoth records consisting of 33 species. The current Machakos County had 36 records consisting of 10 species. The field survey recorded 18 specimens representing 8 species. Carcasson (1976) noted that the hawkmoth family, Sphingidae had 100 Kenyan species, 5 of these being recorded in Machakos. This study has recorded 97 species for Kenya differing from the 100 species noted by Carcasson (1976) by only three species. This could be due to some species that were recorded by Carcasson (1976) being housed in foreign Museums outside Kenya and hence their records were not captured during this study. As for the Machakos County species the number of species recorded from the NMK collection was 10 species and the number recorded from the light traps was 8 species thus a difference of 2 species. The probable reason could be that the short survey period was not capable of capturing all species represented in the Machakos County as trapping focused only on two sites namely Alim High School and Mithanga Village. However, it is important to note that insect communities are hyper diverse, and even intensive surveys often fail at cataloguing all the species present in an area (Thomas 1996; Landau *et al*., 1999; Summerville and Crist 2003). The overall number of hawkmoth species recorded for Machakos County from the NMK records and the light traps was 14 which is much lower compared to the numbers for other sites in Kenya: for example Kühne (2008) recorded 53 species in

Kakamega forest. These differences in the species number could be suggesting that hawkmoth species are rarer in the savannah dryland ecosystem than in the wet forests ecosystems probably due to the fragile dryland ecosystem of Machakos County and the associated limited natural resources, hence the need for intense conservation efforts.

During this study it was possible to digitize 3,540 hawkmoth records capturing data from specimen labels, building up a database that was useful in mapping their distribution in Kenya and in Machakos County. This is in agreement with Lampe & Striebing (2005) who demonstrated the digitization of large insect collections to make their associated label data into databases that can be used for functions such as making distribution maps. The development of a data base of the hawkmoth from NMK collection has also supported what has been shown by Fjelda & Tushabe (2005) that data from the Museum collections is of great value as a tool for prioritising conservation actions in Africa and that methods that allow objective accounting based on species data are needed. Indeed, one of the most significant challenges to insect conservation is lack of baseline information concerning species diversity and distribution (Summerville and Crist , 2005) and the results here have provided hawkmoth species diversity and distribution data that can be used to monitor their populations in the face of light pollution and other environmental degradation issues.

The light traps located at varying artificial light conditions at the study sites recorded eight species of hawkmoths in Alim High school and Mithanga village, Machakos County which was less than the ten recorded from the NMK collections. The trap catches in this study were also low compared to what some studies have recorded elsewhere (Taylor & Brown, 1972; Muirhead-Thomson, 1991). Low light trap catches for hawkmoths have also been recorded by Kitching *et al.,* (2000) in Australia where 8 W moth trap yielded a low average of six moths per night. The moth species diversity and abundance for the 6 W light trap at Alim High School sites and at Mithanga village showed a non significant difference in the abundance of species and no species showed equal abundance at the two trap sites. Even the most common species in the two traps, *Hippotion celerio*, and the only species recorded at the two sites had 3 individuals at Alim High School compared to 6 individuals recorded at the Mithanga village light trap.

Other studies using light traps to estimate moth species diversity (diversity meaning the number of species and their relative abundance) have shown that no community consists of species of equal abundance (Taylor and Brown 1972; Thomas, 1994). The data in this study has shown a random pattern with nightly trap catches varying greatly even at the same trapping site which agrees with what Taylor and Brown (1972) reported for two traps sampled in Kenya highlands for nine days. In this study, the 8 species recorded during the three trapping sessions in late November, mid-December and late December 2014 , showed the species occurrences to vary in space with only one hawkmoth species, *Hippotion celerio*, being recorded during the three trapping sessions and *Temnora fumosa* which was recorded during two light trap sessions during November and December 2014. A similar clear variation of moth species occurrence was recorded by Summerville and Crist (2003) indicating that patterns of evenness or dominance within a community appear less dynamic. Moth communities typically contain several common species and a much greater number of rare species, a pattern that may be relatively constant across a range of spatial and temporal scales (Worth & Muller, 1979; Thomas, 1996; Summerville& Crist, 2003; 2005) but in this study, one common species, *H. celerio* and seven less frequent species were recorded.

The trapping recorded a new species record for Machakos County, *Theretra capensis,* which was not present in the NMK records for the Machakos County or in the previous records for Machakos outlined in Carcasson (1976) (Appendix II & III). The NMK collections for *T. capensis* were from Tsavo National Park, Ruiru, Thego River in Mt. Kenya, Kibera, Nairobi and Ngao Forest in Taita Taveta. Carcasson (1979) has additional localities from where this species, *T. capensis* has been recorded including Kiganjo, Kitale and Mombasa. This is interesting as worldwide, hawkmoths are believed to be extensively collected (Kühne, 2008, Rougerie *et al.*, 2014). However, a recent study in Australia (Rougerie *et al.*, 2014) has recorded six new species. This points to the need to undertake hawkmoth surveys more so to further establish their diversity, abundance and distribution in Kenya if they are to be used as indicators of light pollution effects and as environmental indicators in the country.

The moth light trap located at 5m from the street lights at Alim High School yielded no hawkmoth species and this could be explained by what has been reported in past studies that the use of street lights, security lights and other lighting sources negatively affect many animal and plant species (Rich and Longcore, 2006; Settele, 2009; Langevelde *et al*., 2011). Since at this trap site two different types of artificial lights were at work, that of the trap and the street lights, which had different in light intensity and spectral composition, it is possible that the street light could have had a stronger attraction to the hawkmoths relative to the moth light trap. This agrees with some authors who have reported that light sources might largely differ in intensity and spectral composition, which determine their attraction to insects (Kelber *et al*., 2002). For example, it has been shown that high pressure sodium lights attract moths because of the presence of ultraviolet wavelengths, while low pressure sodium lights of the same intensity, but not producing ultraviolet light, have less attraction to moths (Rydell, 1992; Frank, 1988; Frank, 2006)). Moths are known to fly to light from distances varying from 3 to 130 m and therefore there could be a possibility that local extinction could be taking place along the street lights. Experiments conducted in Finland indicated that even the minimal amount of disturbance caused by moth traps could still lead to local extinctions of moths that have a very small population (Väisänen & Hublin, 1983).

During this study, the development projects in Machakos County were found to significantly focus on only impacts on flora while significantly ignoring impacts on fauna. Interestingly, a large percentage of the reports (38%) had no mention of impacts on either flora or fauna. This indicates a possible risk of loss of biodiversity from the human development agenda as also has been lamented by Sanderson & Redford (2003). The EIA reports in all the sectors covered had a bias on flora with 62 % mentioning impacts only related to vegetation loss, 10% impacts related to both flora and fauna and none mentioned impacts specifically on fauna. This is unfortunate since EIA is a powerful tool for ensuring that environmental issues are given due consideration during project design and implementation and hence allowing benefits of the project to be maximized while reducing environmental and social costs of development. The lack of attention, not just to biodiversity, but to environmental issues in general, is a widely perceived limitation to achieving the Millennium Development Goals (MDG) (Bojo & Reddy, 2002).

During this study, the seven development sectors covered by the reviewed EIA reports had a general trend of not considering impacts on fauna. This is of concern as development projects may enhance negative impacts on fauna and may eventually result in species extinction. Biodiversity conservation has been proved to provide options for improving the livelihoods of future generations, whereas ecosystem depletion and species extinction reduce the capacity to respond to future stresses such as climate change (Rietbergen *et al*., 2002). Also in dryland ecosystems like the one found in Machakos County, majority of the people have high dependence on biodiversity and other natural resources for their livelihoods. However, it has been noted that despite this, environmental goods and services are generally only unaccounted for in national statistics and thus not reflected as priorities in national policies (DFID, 2002). There is clearly much work to be done to bring biodiversity into mainstream conservation efforts and in this respect Sanderson & Redford (2003) called for 'partnerships between conservationists and developmentalists' to recognize their respective strengths and weaknesses.

Results from the survey of project EIA reports in Machakos County showed that there was no recommendation to reduce and mitigate the negative effects that artificial light has on fauna and flora. This general lack of awareness on the impacts of light pollution associated with human development activities could be due to lack of policy and guidelines on light pollution in Kenya. According to the National Environment Action Plan (GoK, 2009), Kenya recognizes that economic growth and environment are closely intertwined, and the Environment Management Coordination Act (GoK, 1999) provides for the formulation of environmental regulations. After the enactment of EMCA, some regulations have been developed and enacted. These include: The Environmental Management and Co-ordination (Prevention of Pollution in Coastal Zone and other Segments of the Environment) Regulations, 2003;The Environmental Management and Co-ordination (Impact Assessment and Audit) regulations, 2003; The Environmental Management and Co-ordination (waste management) Regulations 2006; The Environmental Management and Co- ordination (Controlled Substance) Regulations, 2007; The Environmental Management and Coordination (Noise and Excessive Vibration Pollution) (Control) Regulations, 2009. The Environmental Management and Co-ordination (Wetlands, River Banks, Lake Shores and Sea Shore Management) Regulations, 2009 (GoK, 1999; 2003, 2006; 2007, 2009). However, there has not been any regulation on light pollution. This is unlike various countries such as the UK, USA and the Carribean where regulations on light pollution have been established (Bruce-White and Shardlow, 2011).

According to IDA (2008), consequences of light pollution are widespread and detrimental to the environment. For example, outdoor light shined into the sky, wastes approximately $1.74 billion each year in the US alone, resulting in depleted natural resources and increased carbon emissions. Artificial light also kills endangered sea turtles and migratory birds by interfering with their natural sense of navigation. Studies indicate that light at night also endangers humans by suppressing production of melatonin, a hormone linked to breast and prostate cancer (IDA, 2008).

CHAPTER 6: CONCLUSIONS AND RECCOMENDATIONS

6.1 Conclusions

i. The diversity and distribution of hawkmoth species in Kenya and in Machakos County was determined from historical Museum collections. Out of 3,540 specimens encountered, Kenyan records were 1,097, consisting of 97 species while Machakos County had 37 records consisting of ten species belonging to eight genera. The localities of the ten species were mainly around Athi River area where seven of the ten species were collected leading to the conclusion that the distribution is not even and there is need to enhance sampling of hawkmoths in the county.

ii. The number of species recorded from the hawkmoth collection at the National Museums of Kenya collection was less by three species from what has been recorded in the literature for the Country. This indicates a possibility of some of the specimens from the Kenya being deposited elsewhere, especially in Museum collections outside the country.

iii. The species diversity and abundance recorded from the light trapping was low consisting of eight species which were recorded at the two light traps away from the street lights and none at the light trap five meters from the street lights. The zero record from the trap at the street light could be due to negative impacts of light pollution from the street lights on the hawkmoths species.

iv. The two light traps, one 300 m from the street light and the second at 22 km from the street lights showed no significant difference in the hawkmoth species diversity and abundance caught in the traps during the study period.

v. The hawkmoth light trapping yielded a new record of hawkmoth species, *Theretra capensis* for Machakos County.

vi. The EIA reports have limited or no information on the effects of light pollution on fauna and biodiversity in general indicating a general lack of awareness in Machakos County on the negative effects that light pollution has on biodiversity.

6.2 Recommendations

In view of the research findings obtained from this study, it is recommended that:

i. Further field research involving life history and ecological studies be undertaken to examine hawkmoth species diversity and abundance in differently illuminated geographic areas and the effects of light pollution in their population dynamics in Machakos County and Kenya as a whole.

ii. Field surveys should be undertaken to sample hawkmoths from various ecosystems to strengthen the baseline information available at the National Museums of Kenya collections for supporting monitoring the effects of light pollution on the current and future status of hawkmoths in Machakos County.

iii. Data on hawkmoth specimens held in collections outside the National reference collection at the National Museums of Kenya should be availed and consolidated with what is at NMK to inform biodiversity conservation initiatives.

iv. Regulations on light pollution be formulated and implemented to ensure that the potential impacts of light pollution on biodiversity are a routine consideration in the Environmental Impact Assessment process reducing, mitigating or eliminating risks associated with light pollution.

v. There should be effective enhancement of public and political awareness on hawkmoths and biodiversity and their role in ecosystem service and the public's management responsibilities. Thus, creating awareness to empower the public to reduce light pollution from domestic security lighting, with emphasis on negative impacts of excessive lighting.

vi. Information on lighting types, installation and maintenance should be given before purchase in order to reduce the impact of domestic, industrial and street lights. Retailers selling domestic/industry/street lights should be properly trained and informed on the impacts of light pollution.

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APPENDIX

APPENDIX I: Hawkmoth Species recorded for Kenya as per NMK Collection

Acherontia Atropos (Linnaeus, 1758)

Agrius convolvuli (Linnaeus, 1758)

Andriasa contraria (Walker, 1856)

Antinephele marcida (Holland, 1873)

Antinephele ssp.camerunensis (Clark, 1937)

Atemnora westermannii (Boisduval, 1875)

Basiothia aureata (Karsch, 1891)

Bosiothia charis (Walker, 1856)

Bosiothia medea (Fabricius, 1781)

Callosphingia circe (Fawcett, 1915)

Hyles(Celerio) lineata (Fabricius, 1781)

Centroctena imitans (Butler, 1882)

Centroctena rutherfodi (Druce, 1882)

Cephonodes hylas (Linnaeus, 1758)

Ceridia mira (Rothschild & Jordan, 1903)

Chaerocina dohertyi (Rothschild & Jordan, 1903)

Chloroclanis virescens (Butler, 1882)

Coelonia mauritii (Butler, 1876)

Daphnis(Deilephila) nerii (Linnaeus, 1758)

Dovania poecila (Rothschild & Jordan, 1903)

Ellenbeckia monospila (Rothschild & Jordan, 1903)

Euchloron Megaera (Linnaeus, 1758)

Falcatula falcatus (Rothschild & Jordan, 1903)

Hippotion aporodes (Rothschild & Jordan, 1910)

Hippotion balsaminae (Walker, 1856)

Hippotion celerio (Linnaeus, 1758)

Hippotion eson (Cramer, 1779)

Hippotion irregularis (Walker, 1856)

Hippotion moorei (Jordan, 1926)

Hippotion Osiris (Dalman, 1823)

Hippotion rebeli (Rothschild & Jordan, 1903)

Hippotion rosae (Butler, 1882)

Hippotion roseipennis (Butler, 1882)

Hippotion socotrensis (Rebel, 1899)

Leucostrophus hirundo (Gerstaecker, 1871)

Likoma apicalis (Rothschild & Jordan, 1903)

Likoma crenata (Rothschild & Jordan, 1907)

Lophostethus dumolinii (Angas, 1849)

Macroglossum trochilus (Hubner, 1823)

Macropoliana natalensis (Butler, 1875)

Macropoliana oheffernani (Gess, 1967)

Microclanis erlangeri (Rothschild & Jordan, 1903)

Neoclanis basalis (Walker, 1866)

Neopolyptychus compar (Rothschild & Jordan, 1903)

Neopolyptychus serrator (Jordan, 1929)

Nephele accentifera (Palisot de Beauvois, 1821)

Nephele aequivalens (Walker, 1856)

Nephele argentifera (Walker, 1856)

Nephele bipartita (Butler, 1878)

Nephele comma (Hopffer, 1857)

Nephele funebris (Fabricius, 1793)

Nephele innotata (Rothschild & Jordan, 1903)

Nephele monostigma (Clark, 1925)

Nephele oenopion (Hubner, 1824)

Nephele peneus (Cramer, 1776)

Nephele rosae (Butler, 1875)

Nephele vau (Walker, 1856)

Pemba favillacea (Walker, 1866)

Platysphinx constrigilis (Walker, 1869)

Platysphinx piabilis (Distant, 1897)

Poliana buchholzi (Plotz, 1880)

Poliana micra (Rothschild & Jordan, 1903)

Poliodes roseicornis (Rothschild & Jordan, 1903)

Polyptychoides assimilis (Rothschild & Jordan, 1903)

Polyptychoides digitatus (Karsch, 1891)

Polyptychoides erosus (Jordan, 1923)

Polyptychoides grayii (Walker, 1866)

Polyptychus affinis (Rothschild & Jordan, 1903)

Polyptychus andosa (Walker, 1866)

Praedora marshalli (Rothschild & Jordan, 1903)

Pseudoclanis postica (Walker, 1856)

Rhodafra marshalli (Rothschild & Jordan, 1903)

Rufoclanis jansei (Vari, 1964)

Rufoclanis numosae (Wallengren, 1860)

Sphingonaepiopsis ansorgei (Rothschild,1904)

Sphingonaepiopsis nana (Walker, 1856)

Temnora aequivalens

Temnora albilinea (Rothschild,1904)

Temnora angulosamarginata (Rothschild & Jordan, 1906)

Temnora argyropezafumosa ssp (Mabille, 1879)

Temnora crenulata (Holland, 1893)

Temnora curtula (Rothschild & Jordan, 1908)

Temnora elegans(Rothschild, 1895)

Temnora eranga (Holland, 1889)

Temnora fumosa (Walker, 1856)

Temnora iapygoides (Holland, 1889)

Temnora marginata (Walker, 1856)

Temnora mirabilis (Talbot, 1932)

Temnora plagiata (Walker, 1856)

Temnora sardanus (Walker, 1856)

Temnora scheveni (Carcasson, 1968)

Temnora stevensi (Rothschild & Jordan, 1903)

Temnora subapicalis (Rothschild & Jordan, 1903)

Temnora zantus (Herrich-Schaffer, 1854)

Theretra capensis (Linnaeus, 1764)

*Theretra Orpheus (*Herrich-Schaffer, 1854)

Xanthopan morganii (Walker, 1856)

APPENDIX II: Hawkmoth Species List for larger Machakos area as per NMK Collection

1	*Acherontia atropos*	18	*Macroglossum trochilus*
2	*Agrius convolvuli*	19	*Microclanis erlangeri*
3	*Bosiothia medea*	20	*Neoclanis basalis*
4	*Callosphingia circe*	21	*Nephele accentifera*
5	*Celerio lineata*	22	*Nephele innotata*
6	*Cephonodes hylas*	23	*Nephele vau*
7	*Ceridia mira*	24	*Platysphinx piabilis*
8	*Coelonia solani*	25	*Poliana buchholzi*
9	*Ellenbeckia monospila*	26	*Poliana micra*
10	*Hippotion celerio*	27	*Poliodes roseicornis*
11	*Hippotion moorei*	28	*Pseudoclanis postica*
12	*Hippotion rebeli*	29	*Rufoclanis numosae*
13	*Hippotion roseipennis*	30	*Temnora angulosamarginata*
14	*Hippotion socotrense*	31	*Temnora argyropezafumosa_ssp_*
15	*Leucostrophus hirundo*	32	*Temnora scheveni*
16	*Likoma apicalis*	33	*Theretra morteironis*
17	*Lophostethus dumolinii*		

APPENDIX III: Hawkmoth Species Details for Machakos County as per NMK Collection

No.	Catalogue Number	Order	Family	Genus	Species	Author
1	NMK/INV/LEP/000767	Lepidoptera	Sphingidae	Microclanis	erlangeri	Rothschild & Jordan
2	NMK/INV/LEP/001442	Lepidoptera	Sphingidae	Poliana	micra	Rothschild & Jordan
3	NMK/INV/LEP/001688	Lepidoptera	Sphingidae	Macroglossum	trochilus	Hubner
4	NMK/INV/LEP/001695	Lepidoptera	Sphingidae	Leucostrophus	hirundo	Gerst
5	NMK/INV/LEP/001832	Lepidoptera	Sphingidae	Temnora	argyropezafumosa (ssp)	Walk
6	NMK/INV/LEP/002314	Lepidoptera	Sphingidae	Temnora	scheveni	Carcasson
7	NMK/INV/LEP/002409	Lepidoptera	Sphingidae	Nephele	comma	Rothschild & Jordan
8	NMK/INV/LEP/002664	Lepidoptera	Sphingidae	Nephele	van	Walker
9	NMK/INV/LEP/002767	Lepidoptera	Sphingidae	Celerio	lineata	Fab
10	NMK/INV/LEP/003270	Lepidoptera	Sphingidae	Hippotion	celerio	L
11	NMK/INV/LEP/003466	Lepidoptera	Sphingidae	Bosiothia	medea	Felder

APPENDIX IV: Other localities recorded for species collected at Alim and Mithanga sites.

Species	Localities	Collection Period	Collector(s)
Hippotion celerio	Nakuru Bred(10), Kenani Mtito Andei(8)	4-1969 (Kenani Mtito Andei, vii.1935-ix.1950 (Nakuru Bred)	A.Townsend M.P Clifton
Basiothia medea	Lukenya Athi River(11), Nakuru Kenya(12)	i.1936-i.1954 (Nakuru Kenya) i.1970(Lukenya Athi River)	B. Watuluge A.Townsend
Temnora fumosa	Aberdares(2) Lukenya Athi River(2)	vi.1938 i.1970	G.H Stockley B. Watulege
Polyptychoides grayi	Mtito Andei Kenya(8), Namanga Hills Taita(7)	April, 1966 May, 1970 Dec, 1950	B. Watulege R.H.Carcasson MacArthur
Celerio lineata	Magadi Kenya(7)	May.1950	J.G Williams
Theretra capensis	Thego River. Mt. Kenya(2)	12.11.1955-vii.1965	M. Moore
Leucostrophus alterhirundo	Embu(3) Nairobi(4)	III.1937 II:1973 V:1941	R.H.N Simmonds J. Hiza Museum Staff
Agrius convolvuli	Nairobi Kenya(15), Nakuru Kenya(7)	VI.1942-VI.1977(Nairobi) IV.1938-25/V/1950(Nakuru)	S. J. Coupton B. Watulege T. H.E. Jackson A. Townsend J. P. L. Fleetwood

J. Leakey
D. Freeman
C. Moore
P. Karanja
M. Newton
E. Pinhey
Matolo
E. Mungai
A. Turner
B. Watulege
J. Kinyanjui
G. Rilling
J. G.
Williams