IMPACTS OF GEOTHERMAL POWER STATION ON AVIFAUNA AT HELL'S GATE NATIONAL PARK, NAKURU COUNTY, KENYA

Getonto Abrahams John
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DECLARATION

This thesis is my original work and has not been presented for the award of any degree in any University.

Signature………………………………………… Date……………………….

Getonto Abrahams John - N50/CE/22820/2012
Department of Environmental Sciences

SUPERVISORS

We confirm that the student carried out this research work under our supervision.

Signature………………………………………… Date……………………….

Prof. Shyam Manohar
Department of Environmental Sciences
Kenyatta University

Signature………………………………………… Date……………………….

Dr. Esther Kitur
Department of Environmental Sciences
Kenyatta University

DEDICATION

This thesis is dedicated to my wife Margaret, my son Tijan, parents, brothers, sisters and all my friends. You are all special to me.

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ABBREVIATIONS AND ACRONYMS

IBA	Important Bird Area
HNP	Hell's Gate National Park
USEPA	United States Environmental Protection Agency
KWS	Kenya Wildlife Service
UNEP	United Nations Environmental Programme
KNBS	Kenya National Bureau of Statistics
EMCA	Environmental Management and Coordination Act
IUCN	International Union for Conservation of Nature
WWF	World Wildlife Fund
EBA	Endemic Birds Area

ABSTRACT

Geothermal energy counts among renewable energies sources, with a long tradition, experience and great potential for the future. However, most of the geothermal power plants globally are located within important conservation sites where endemic and endangered species of birds inhabit. The presence of these geothermal power stations has an impact on biodiversity. The study was carried out between December 2015 to May 2016 within Hell's Gate National Park. The specific objectives of this study were to (i) Study the composition of avifauna species, (ii) Analyse guild structures of bird's species within the study area, and (iii) Assess the effects of geothermal power production on avian fauna within disturbed and undisturbed habitats. The study area was divided into four main habitats depending on terrain, vegetation, and distance from the geothermal power station. Point counts were performed at points closer to Olkaria Geothermal power plant (50 m-1 km) and control points (7-8 km) away. Forty-two (42) families composed of 68 genera and 99 species were studied in Hell's Gate National Park. In undisturbed habitats, 39 families made-up of 65 genera and 96 species were recorded while 33 families, 51 genera and 71 species were observed in disturbed habitats. Only 30 families composed of 48 genera and 68 species were common in both disturbed and undisturbed habitats. The number of families, genera, and species are significantly lower in areas closer to the geothermal power plant. The dominant feeding guilds in the park are insectivore (2651) followed by omnivore (1171), and the least is nectarivore (112). There was a significant difference between the number of birds of different feeding guilds at 95% confidence limit with ANOVA ($P = 0.0001$). Pearson correlation showed a significant negative correlation between the level of threats and species richness. There was also a significant negative correlation between noise level and the total number of birds ($r=-0.302$, $P=0.035$). Due to the impacts of geothermal power production activities at Hell's Gate National Park, bird species are declining. Therefore, it is recommended that KWS should enforce strongly the environmental laws in undisturbed sites so that no further human impact can affect the birds' habitats.

CHAPTER ONE: INTRODUCTION

1.1 Background Information

Worldwide leading geothermal power producers are United States of America, Philippines, Indonesia, Mexico, Italy, New Zealand, Iceland, Japan, Costa Rica, El Salvador, Turkey and Kenya. Geothermal energy is regarded as one of the renewable energy resources, and the current global installed capacity is about 12.8 GW and by 2020 it is expected to be between 14.4 GW and 17.6 GW (Matek, 2015).

Most of the geothermal plants in the world are located within the national parks where endemic and endangered species of birds live (Bayer *et. al.*, 2013). Geothermal power plants consist of production and reinjection wells, connecting delivery pipelines, standard equipment like silencers, separators, powerhouse (including turbines generators, controls), cooling towers components and overhead electrical cables. Each of the power stations has environmental effects (some impacts are temporary or long lasting) on the diversity, distribution and abundance of birds and fauna due to habitat loss and fragmentation (Hames *et. al.*, 2002), noise pollution (Ortega, 2012), chemical pollution through emissions (Eeva *et. al.*, 2005), and electrical power-lines (Smallie & Virani, 2010).

In Philippines, within Mt. Apo area where over 108 MW of electrical power is produced, there are one hundred and eleven (111) endemic species and the critically endangered species is the Philippine Eagle (Kakkar *et. al.*, 2012). At Hell's Gate National Park in Kenya, there is an endemic *Prionops poliolophus* (grey-crested helmet shrike) and endangered *Gyps rueppellii* (Ruppell's Griffon

Vulture), *Gyps africanus (*African White-Backed Vultures*)* and *Sagittarius serpentarius (*Secretary Bird*)*. The aim of this present study is to assess the impacts of the geothermal power station on bird's diversity, abundance, and guild structures within Hell's Gate National Park in Kenya.

1.2 Statement of the Problem

Hell's Gate National Park and its surrounding areas have a wide diversity of avifauna. Harper (1991) mentioned that 144 species of birds have been recorded within this park in which cliffs provide suitable breeding grounds for *Falcon biarmicus* (Lanner Falcon) and *Gyps rueppellii* (Ruppell's Griffon Vulture). According to BirdLife International (2015), Rueppell's vultures have endangered status in IUCN red list category.

The trend of bird's population and distribution is declining for the last twelve years at the national park and the surrounding habitats. Some species of vultures such as *Neophron percnopterus* (Egyptian Vulture) and *Gypaetus barbatus* (Lammergeier or Bearded Vulture), used to breed at the Park but now these bird species are extinct.

Hells Gate National Park is in proximity to Lake Naivasha Important Bird Area (IBA) that has threatened status (Bennun & Njoroge, 1999). Within this ecosystem, disturbances due to increase in air temperature, noise, H_2S, habitat loss and fragmentation caused by the geothermal power generation are significant (Ogola, *et. al*., 2011). These environmental threats and changes within the ecosystem of Hell's Gate National Park have not been studied thoroughly; there is no empirical evidence to show the rate at which the bird's population are affected.

There is the need to ascertain the rate at which geothermal power production is affecting birds' status. Therefore, this study was conducted to determine the impacts of geothermal energy production at Hell's Gate National Park in Kenya.

1.3 Objectives of the Study

The main aim of the study was to assess the impacts of the geothermal power station on avifauna at Hell's Gate National Park, Nakuru County, Kenya.

The specific objectives were to:

i. Study species composition of avifauna within Hell's Gate National Park.
ii. Analyse guild structures of bird species within Hell's Gate National Park.
iii. Assess the effects of geothermal power production on the species of avian fauna within disturbed and undisturbed areas of Hell's Gate National Park.

1.4 Research Questions

i. How does the composition of birds' species and guild structures vary within Hell's Gate National Park?
ii. What are the effects of geothermal station(s) on the composition and distribution of avifauna in the study area?

1.5 Hypothesis

For the purpose of this study, the following hypothesis was tested:

- H1: Olkaria geothermal power stations do influence composition, abundance, and guild structures of birds at Hells Gate National Park, Kenya.

1.6 Significance of the Study

According to Donald and Evans (2006), birds are excellent indicators of environmental health and very helpful in seed dispersal, pollination and to control population of vectors such as pests, animal parasites, worms reptiles, and are used as biological control agents and overall helpful in ecological balance.

BirdLife International (2015) carried out an evaluation and found that 1,313 species of birds are threatened with extinction over the globe. Pimm, *et. al.* (2014) mentioned that by the year 2100, about 6-14% of all important bird species would be extinct, 7–25% to be functionally extinct, and 13–52% will be functionally deficient.

This work will provide important baseline information to help understand the affected species of birds within the study area due to impacts of geothermal power generation in Kenya. Research findings will be useful for bird scholars to know the past, present and future status of avifauna.

1.7 Scope of the study/Limitations and assumptions

The study was conducted only in Hell's Gate National Park and not in any other area due to logistic constraints, and it highlights the impacts of the geothermal power station on avifauna and the environment of the park. The study assumes that geothermal development activities are invariable at experimental sites during study period.

1.8 Definition of Terms

I. **Important Bird Area (IBA):** Is an area identified using an internationally agreed set of criteria as being globally important for the conservation of bird populations (Bennun and Njoroge, 1999).

II. **Ecosystem Modification:** are actions that convert or degrade habitat in service of "managing" natural systems to improve human welfare (Wratten *et al.* 2013).

III. **Chemical pollution:** Is the release of toxic chemical waste in the form of liquid, solid, and gaseous to the environment that can alter the habitat and cause mortality of species within an ecosystem (Hassanien, 2009).

IV. **Habitat Fragmentation:** State of discontinuity resulting from a given set of mechanisms, in the spatial distribution of resources and conditions present in an area at a given scale that affects occupancy, reproduction, or survival in a particular species. The process of habitat fragmentation can be defined as a set of mechanisms leading to the division of large, continuous habitat into smaller and more isolated remnants (Lindenmayer and Fischer, 2013).

V. **Endemic species:** are unique to particular geographical location within an island, country or other defined zone, or habitat type of the state/country (Şener, 2002).

VI. **Endangered species:** These are species that are categorized under Red List by the International Union for Conservation of Nature (IUCN) likely to become extinct (Bennun and Njoroge, 1999).

VII. **Critically Endangered (CR) species:** Is a category by the International Union for Conservation of Nature (IUCN) for the species of organisms facing a very high risk of extinction in the world and mentioned on the red list of wild species (BirdLife International, 2015).

VIII. **Endemic Bird Area (EBA):** An area, encompasses the overlapping breeding ranges of restricted-range bird species, such that the complete range of two or more restricted range species is entirely included within the boundary of the EBA (BirdLife International, 2015).

CHAPTER TWO: LITERATURE REVIEW

2.1 Introduction

During the present 21st century, avifauna and other species are facing serious challenges for their survival due to habitat destruction, air and water pollution, noise, habitat fragmentation, and destruction of habitat ecosystems. Human beings are the most competitive and destructive creatures on this earth to imbalance the nature for their interest. BirdLife International (2015) mentioned that since 2011, worldwide critically endangered avifauna species have risen from 189 to 197 and the threatened species are from 381 to 389 globally. Out of the total 10,064 species of birds alive today, 1,313 species are threatened. However, in Africa 115 species are now listed endangered or critically endangered.

Hell's Gate National Park is the only protected breeding area for the critically endangered *Gyps rueppellii* in Kenya. Other breeding sites include Mount Nyiru in Samburu County, Ololokwe in Samburu County, Marsabit County and Kwenia in Kajiado County (Virani, *et. al.,* 2012). Most breeding sites for *Gyps rueppellii* are facing severe habitat destruction. *Gyps rueppellii* are currently experiencing a severe decline in its range. It is suspected that the range has been reduced due to the rapid decline of habitat and conversion to agro-pastoral systems, declines in wild ungulate populations, hunting for trade, persecution, collision and poisoning (BirdLife International, 2015). Study conducted by Harper (1991) found over 60 individual *Gyps rueppellii* nesting within Hell's Gate National Park.

The vertical cliffs within the National Park also offer nesting ground for swifts and scores of raptors such as *Buteo augur* (augur buzzard), *Aquila verreauxii* (Verraux eagle), *Falco biarmicus* (lanner falcon), *Neophron percnopterus* (Egyptian vulture), *Bubo africanus* (spotted eagle owl), and *Gypaetus barbatus* (Bearded Vulture) (Virani & Harper, 2004). Raptors have a high value in conservation and environmental monitoring. Vultures provide vital ecosystem services, and they are highly specialized in disposing carcasses thus playing a role in nutrient recycling, leading other scavengers to the carcass, and preventing the spread of pathogens by quickly consuming the remains. The following sections will give a general overview of impacts of geothermal exploitations especially on the species of birds.

2.2 Global Overview of Geothermal Power Production and its Impacts

The use of geothermal energy is more than 10,000 years old. Ancient communities including Romans, Chinese, and Native Americans used hot water springs for bathing, cooking, and heating. Prince Piero Ginori Conti invented geothermal energy in the year 1904 at Lardarello in Italy and the energy that was produced successfully lit four bulbs. In 1911, the first commercial geothermal power station was built at Larderello in Tuscany, Italy. In 1958, New Zealand became the second major industrial producer of geothermal electricity. In 1960, United States of America opened their first geothermal power station at Geysers steam field in northern California (Alan, 2010).

For the last few decades, geothermal energy production has increased due to high demand for energy and pressure to diversify energy sources away from fossil fuels. Currently, the global geothermal production stands at about 12.8 GW and spreads across 24 countries (Matek, 2015).

According to (Bayer, *et. al.,* 2013), the impact of the geothermal power station on birds and other organisms is explained in relation to its development phases such as road construction, piping, well drilling, plant construction, and power commissioning and operation. Activities in each phase can lead to habitat loss and fragmentation, noise and air pollution. According to (Fahrig, 1997), these environmental disturbances can affect the distribution and abundance of birds. Geothermal power production effects on the diversity, abundance, and spatial distribution of wildlife communities leading to edge effect (Buyer, *et. al.*, 2013).

Geothermal Power Production and Development in the USA

United States of America is the leading country in geothermal power production with 3525MW-installed capacity by the end of 2015 (Ronald, 2012). California is the leading state with 2,732.2 MW capacity followed by Nevada (517.5MW), Utah (48.1MW), Hawai (38.0MW), Oregon (33.3MW), Idaho (15.8MW), New Mexico (4.0MW), Alaska (0.7MW) and Wyoming (0.3MW). The Geysers geothermal fields in California are the largest geothermal power plant in the world, which contain 22 geothermal power plants with a net capacity of 1517 MW. (Michael, *et. al.,* 2007). The emissions from the Geysers geothermal fields spread to considerable distances causing the substantial death of California's long list of native species. The study conducted by (Stober and Bucher, 2013) showed that Boron from Geysers Geothermal areas affected an area of 247 acres. Climatically induced change by steam emissions increased air temperature and level of humidity in the vicinity. These climatically induced changes favoured the infection and spread of fungal diseases in black oak trees (DiPippo, 2011). Geothermal development in Puna Hawaiian rainforest resulted to a series of environmental opposition from the local community due to high levels of H_2S and geological instability (Wright, 2013).

A study carried out at Ormat Nevada Geothermal power plant projects, USA, identified habitat fragmentation caused by geothermal electricity generation as a threat to the endangered *Centrocercus urophasianus* (greater sage-grouse) (Rapport, *et al.*, 2002). Habitat loss and fragmentation decreases population and ecosystem productivity. Besides, fragmentation may lead to crowding of insects, small and large mammals and bird communities resulting in intense competition for food water and other resources. Geothermal power production effects on the diversity, abundance, and spatial distribution of wildlife communities leading to edge effect (Buyer *et. al.*, 2013).

Study conducted at Nazko and South Meager Geothermal power stations, Canada, by (Tit *et. al.* 2012) mention that, noise ranging between (90-120 dB) is produced during well drilling and testing. A study conducted at Ormat Nevada Geothermal power plant, USA (Siegel and Nelder, 2008) revealed that noise from the power station has a potential to influence negatively *Centrocercus urophasianus* (sage grouse). The potential impacts of noise included lekking, nesting/early-brood-rearing and late brood rearing. Experiments suggest that a decibel reading of 10dB above ambient levels has the possibility of influencing lekking activity making it difficult for female birds to hear the males call for mating (Ortega, 2012). High levels of noise reduce the suitability of habitat by masking and interfering with essential biological relevant signals such as vocal communication or sound made by predators.

Geothermal Power Production and Development in Europe

In Europe, geothermal power production spreads across six states. Italy is the leading geothermal producer in Europe with 940 MW installed capacity followed by Iceland (660 MW), Turkey (410 MW), Portugal (30MW), Germany (25MW), and Austria (1 MW) (Matek, 2015). The study conducted by (Pasvanoglu *et. al*. 2012) at Larderello (Italy), mentioned that geothermal fluids are diverse with many specific constituents and compositions depending on the geological setting, mode of production, time and technology used. Geothermal brine contains large amounts of Boron (B), Ammonia (NH3), Mercury(Hg), Lead (Pb), Arsenic (As), Cadmium (Cd), Iron(Fe), Zinc(Zn), Antimony(Sb), Lithium(Li), Barium(Ba), Carbon (IV)oxide (CO2), Hydrogen Sulphide (H2S) and Aluminium (Al) (Baldi, 1988).

Birds are exposed to these toxic chemical contaminations in many ways. Their main exposure is respiratory (to airborne contaminants), via their food, water, and through cleaning their feathers. High mercury level in the environment increases bird mortality and lowered hatching rates (Eeva, *et. al.*, 2002). Pollution may cause environmentally mediated stress effects in nestling and adult birds either directly or indirectly, via reduced food availability that affects a birds' condition and phenotype, such as carotenoid-based plumage coloration (Szymczyk and Zalewski, 2002). Eeva, *et. al.* (2002) noted a decreased population of earthworms and insects (the important source of food for ground feeding thrushes and other insect feeders) around the source of heavy metals pollution.

Geothermal power Production and development in Asia

In Asia, Philippines is the leading geothermal power producer with 1,915 MW installed capacity, followed by Indonesia with 1380 MW capacity, Japan (540 MW), Russia (95 MW), China (25 MW), and Thailand (0.3 MW) (Matek, 2015). Mt. Apo geothermal power plant in Philippines is one of the most controversial geothermal developments in the world. The project is located within a National Park and Association of Southeast Asian Nations (ASEAN) Heritage site. Apo is an ancestral home for indigenous cultural communities and also, a habitat for, the endangered, *Pithecophaga jefferyi* (Philippine eagle) and a hundred and eleven (111) endemic species (Alejo, 2000). Elevated amount of Arsenic acid has been reported at Mt. Apo geothermal fields (Laynes, *et. al*., 2005). Alejo (2000) identified geothermal power station within Mt. Apo National Park as the main threat to birds and other animals within the ecosystem.

Geothermal power production and development in Africa

Kenya is the leading geothermal producer in Africa with 607 MW installed capacity followed by Ethiopia with 8 MW installed capacity. The operational geothermal plants in Kenya are located at Hells Gate National Park near Lake Naivasha. At Olkaria geothermal power station, high levels of noise (65-120dB) has been recorded (Zemedkun, 2012). Research carried by (Wetang'ula, 2004) at Olkaria Geothermal fields identified significant levels of H_2S, Arsenic, Boron, Mercury, Lithium, Zinc, Lead, and Cadmium in geothermal emissions. The study conducted by Smallie and Virani, (2010) around Naivasha, Kenya, mention that large species such as vultures, eagles, hawks, storks, and owls are commonly killed through electrocution. The Augur Buzzards have already shown a 55 % decline at Lake Naivasha, with electrocution being a suspected contributing factor.

2.3 Status of Avifauna in Kenya

According to (Zimmerman & Turner, 2001), Kenya is ranked number 13 globally among the richest countries in avifauna because 1100 species are listed. There are 41 species considered globally threatened 5 critically endangered, 15 endangered species, 18 vulnerable species, 3 with deficient data. There are nine breeding endemic birds in Kenya.

Table 2.1: Summary of threatened species of birds in Kenya (BirdLife International, 2015).

IUCN Red-List status	Birs Species
Critically endangered	*Gyps rueppelli* (Rüppell's Vulture), *Necrosyrtes monachus* (Hooded Vulture), *Gyps africanus* (White-backed Vulture), *Apalis fuscigularis* (Taita Apalis) and *Turdus helleri* (Taita Thrush)
Endangered	*Aquila nipalensis* (Steppe Eagle), *Neophron pernopterus* (Egyptian Vulture), *Balearica regulorum* (Grey Crowned-crane), *Falco cherrug* (Saker Falcon), *Ardeola idea* (Madagascar Pond-heron), *Torgos tracheliotos* (Lappet-faced Vulture), *Otus ireneae* (Sokoke Scops-owl),

	Cisticola aberdare (Aberdare Cisticola), *Acrocephalus griseldis* (Basra Reed-warbler), *Eremomela turneri* (Turner's Eremomela), *Zoothera guttata* (Spotted Ground-thrush), *Anthreptes pallidigaster* (Amani Sunbird), *Ploceus golandi* (Clarke's Weaver), *Macronyx sharpie* (Sharpe's Longclaw) and *Anthus sokokensis* (Sokoke Pipit).
Species with deficient data	*Mirafra williamsi* (Williams's Lark), *Mirafra pulpa* (Friedmann's Lark) and *Cisticola restrictus* (Tana River Cisticola)
Vulnerable species	*Struthio molybdophanes* (Somali Ostrich), *Polemaetus bellicosus* (Martial Eagle), *Clanga clanga* (Greater Spotted Eagle), *Struthio molybdophanes* (Martial Eagle), *Aquila heliacal* (Eastern Imperial Eagle), *Psittacus erithacus* (Grey Parrot), *Hydrobates matsudairae* (Matsudaira's Storm-petrel), *Falco fasciinucha* (Taita Falcon), *Sagittarius serpentarius* (Secretarybird), *Balearica pavonina* (Black Crowned-crane), *Glareola ocularis* (Madagascar Pratincole), *Bucorvus leadbeateri* (Southern Ground-hornbill), *Hirundo atrocaerulea* (Blue Swallow), *Apalis chariessa* (White-winged Apalis), *Apalis karamojae* (Karamoja Apalis), *Chloropeta gracilirostris* (Papyrus Yellow Warbler), *Turdoides*

	hindei (Hinde's Pied-babbler), *Cinnyricinclus femoralis* (Abbott's Starling) and *Muscicapa lendu* (Chapin's Flycatcher)
Breeding endemic birds	*Lybius senex* (Brown-and-white Barbet), *Mirafra williamsi* (Williams's Lark), *Cisticola restrictus* (Tana River Cisticola),*Cisticola aberdare* (Aberdare Cisticola), *Apalis fuscigularis* (Taita Apalis), *Turdoides hindei* (Hinde's Pied-babbler), *Turdus helleri* (Taita Thrush), *Ploceus golandi* (Clarke's Weaver), *Macronyx sharpie* (Sharpe's Longclaw)

2.4 Bird Diversity within Hell's Gate National Park

Out of 1100, bird species studied in Kenya only 144 bird species have been recorded at Hell's Gate National Parks (Harper, 1991). Out of 144 species only 8 species are considered globally threatened which are *Gyps rueppelli, Gyps africanus, Necrosyrtes monachus, Neophron percnopterus, Sagittarius serpentarius, Ardeotis kori, Gypaetus barbatus* and *Terathopius ecaudatus*. *Prionops poliolophus* are in near threatened state. Specific species *Gypaetus barbatus meridionalis* feeds on bone marrow, and they inhabit on rocky vertical cliffs but now due to impacts of geothermal power station and human interference these birds was last recorded in 1991.

Hells Gate National Park is part of Serengeti endemic bird area (EBA) which is characterised by acacia scrub, grassland with open acacia woodland. In

Tanzania, the EBA extends southwards of Serengeti National Park to the south of Lake Eyasi Basin including Wembere steppe. In Kenya EBA, it continues northwards to Lakes Nakuru and Naivasha. The restricted range species in this EBA include Grey-breasted Spurfowl (*Francolinus rufopictus*), Fischer's Lovebird (*Agopornis fischeri*), Usambiro Barbet (*Trachyphonus usambiro*), Grey-crested Helmet-shrike (*Prionops poliolophus*), Karamoja Apalis (*Apalis karamojae*) and Rufous-tailed Weaver (*Histurgops ruficauda*). Of these, only two species have been recorded in Kenya, *Prionops poliolophus* and *Apalis karamojae*, where they both range northwards up the Rift Valley to sites around Lake Naivasha. *Prionops poliolophus* has been recorded at Hell's Gate National Park (BirdLife International, 1998).

It has emerged in literature review that geothermal energy is an imperative source of renewable energy in Kenya. It has also emerged that geothermal power has negative environmental impacts on plants and animal biodiversity (biological diversity). There is very little and scattered unpublished information on the effect of geothermal energy production on birds and other wildlife species and destruction of taxonomic diversity of flora at Hell's Gate National Park Kenya.

The literature reviewed has established the gap where research is required to build. The effects of geothermal energy production on indigenous bird species of Kenya have not been studied comprehensively. Therefore, the data collected during this study will bring into focus how industrial activities can disturb and degrade natural ecosystem and its components.

CHAPTER THREE: MATERIALS AND METHODS

The chapter deal with the description of the study area, its study design, sampling procedures, and data collection instruments and data analysis methods.

3.1 Study Area

Hell's Gate National Park, is located on the floor of the eastern Rift Valley and situated 100 km northwest of Nairobi, the capital city of Kenya, at an altitude of 2000m above sea level. It lies between latitudes $36^o15'$- 36^o $25'$ E and 0^o $37'$- 0^o $50'$S and is about 2km from Lake Naivasha (Figure 3.1). The park was gazetted in February 1984 and occupies an area of about 68.25 km^2. There are four geothermal power plants within the park, Olkaria (I) was commissioned in the year 1981; Olkaria II and III was commissioned 2003, 2000 respectively; and fourth power plant become operational in 2012.

3.1.1 Geothermal power development in Kenya

Extensive geothermal exploration and survey started in 1974 and extended to 1977 and produced a feasibility report that indicated Olkaria region has sufficient geothermal resource. In 1978, drilling of steam production wells began and continued until 1983. In 1981, the first unit of Olkaria I with 15 MW installed capacity was commissioned. Second and third units of Olkaria I, each producing 15 MW, were launched in 1982 and 1985 respectively bringing total capacity to 45 MW. In 2015, units 4 and 5 with a combined installed capacity of 140 MW were launched. The total installed capacity to supply power is about 185 MW at Olkaria I.

Geothermal Power Station Olkaria II

During 2003, the first two units of Olkaria II, each producing 35 MW, were commissioned and during the year 2010, the third unit of 35 MW was launched generating a total capacity of Olkaria II to 105 MW.

Geothermal Power Plant Olkaria III

During the year 2003, Olkaria III Geothermal Power Plant, which is owned and operated by Ormat Technologies Inc., was started with a generation capacity of 13 MW. In 2009, second unit with an operation capacity of 71 MW was launched while during the year 2014, the third and fourth units of 26 MW and 29 MW respectively were commissioned bringing the total generation capacity of Olkaria III to 139 MW.

Geothermal Power Station Olkaria IV

The 280 MW Olkaria IV geothermal power station is made up of four units which produce 70 MW each. Unit 1 and 2 were commissioned in 2014 while unit 3 and 4 were launched in 2015.

Wellhead Units

In wellhead geothermal power generation, steam is extracted from the underground wells and converted to electricity at the wellhead. The technology, therefore, reduces the construction of steam field and shortens the time between investment and revenue generation. Generated power is directly fed to local transmission networks. KenGen has 14 wellheads, which were started in the year 2009 and commissioned in 2016. Wellhead condensing technology produces a total capacity of 75.6 MW.

3.1.2 Climate

The annual temperature fluctuates between 8^0C and 30^0C with an average of 19^0C. January and February are the warmest months, while June/July are the coolest. Winds are south easterly, except in February - April, when they tend to have a noticeable northeasterly direction. Generally, wind velocity ranges between 10.8-28.8 km/h in the morning but in afternoons blows at 18-28.2 km/h. Winds are strongest in March to April when they reach a velocity of about 28..8 km/h. Humidity varies between 30% and 90%. Rainfall is bimodal, i.e., long rains (March-May) and short rains in (October-December) and fluctuate between 443-939 mm in a year with a mean of 626mm. In the area, December to February is the driest part with sunny days and cold, clear nights.

3.1.3 Geology and Soils

Soil parent materials are predominantly volcanic in origin and are porous volcanic ash derived from lava, pyroclastic rock, and lacustrine lake deposits. These volcanic ashes are very venerable to water erosion. Topography is uneven with volcanic hills, which are the Olkaria volcanoes and active geothermal sites at Hell's Gate National Park.

3.1.4 Flora and Fauna

In total, there are 35 families and 304 species of plants at Hell's Gate National Park (Knight, 1994). The natural vegetation is mainly shrubs dominated by *Tarchonanthus comphoratus* and *Acacia drepanolobium* rarely exceed 4m in height, and open grassland dominated by *Cynodon dactylon*, *Digitaria scalarum* but *Festuca Pilgeri* (Tussock grass) dominates on the cliff top.

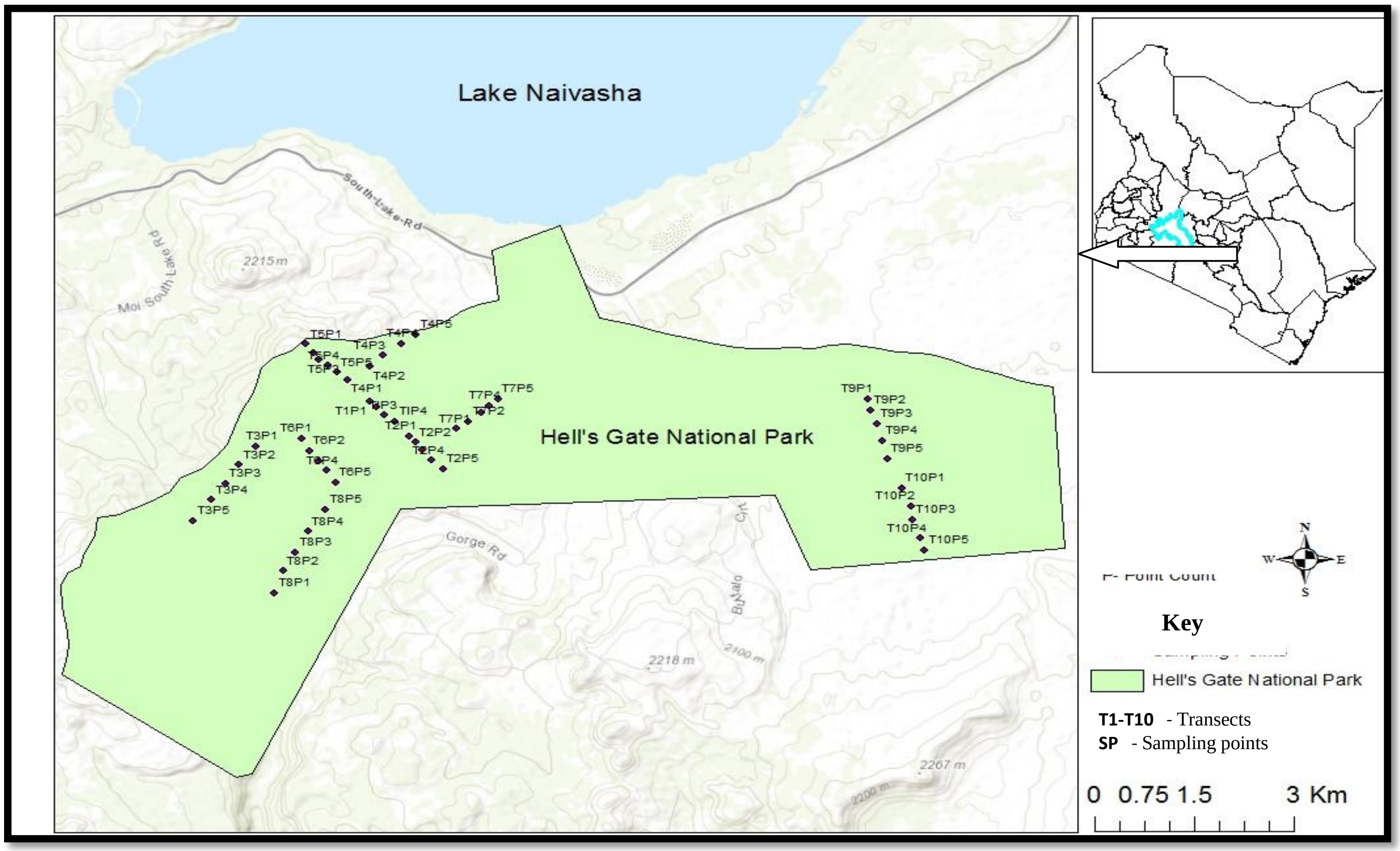

Figure 3.1. Map of Kenya shows study area with 50 sampling points along 10 line-transects within Hell's Gate National Park, Nakuru County.

The main tree species are *Cussonia spicata*, *Schefflera abyssinica*, *Acacia xanthophloea*, and *Euphorbia magnicapsular*. According to Kihima (2014), there are twenty three (23) species of mammals namely: *Syncerus caffer* (Buffalo), *Equus quagga* (Common Zebra), *Rendunca renduna* (Chanler's Mountain Reedbuck), *Gazella grantii* (Grant Gazelle), *Gazella thomsonii* (Thompson's Gazelle), *Giraffa cemelopardalis* (Maasai Giraffe), *Alcephalus buselaphus coki* (Coke's Hartebeest), *Taurotraqus oryx* (Eland), *Apyceros melampus* (Impala), *Phacochoerus aethiopicus* (Warthog), *Kobus defassa* (Dafassa Waterbuck), *Oreotragus oreotragus* (Klipspringer), *Rhaphicerus campestris* (Steinbok), *Rhynchotragus kirkii* (Kirk's Dik Dik), *Finisciurus* sp. (Squirrel), *Tachyorectes plendens* (Mole Rat), *Crocuta crocuta* (Spotted Hyena), *Panthera pardus* (Leopard), *Papio anubis* (Olive Baboon), Heterophyrax brucei (Rock Hyrax), *Orycteropus afer* (Aardvark), *Erinaceus albiventris* (Hedgehog), *Lepus microtis* (African Hare) and *Pedetes capensis* (Spring Hare). Harper (1991) studied Hell's Gate National Park and mentioned that there are 144 species of birds. The cliffs and gorges found in the park are important breeding areas for vultures and swifts.

3.1.5 Socio-economic Activities

Land-use activities at Hell's Gate National Park are recreational and geothermal power production. The land-use patterns in the surrounding environment vary from intensive to moderate horticulture and cattle grazing, within large and small-scale human settlements.

Around Hell's Gate National Park, there are five main urban settlements (Kasarani, DCK, Kwamuia, Kamere and Kongoni) with a total population of

75,000. Flower farms, KenGen, tourism and accommodation, construction, trade, and services employ the majority of the people. The local community, Maasai, who resides at Narasha and Maasai village practices pastoralism in which each family has an average of 70 Cattle, 200 Sheep, and goats and 11 donkeys. However, livestock holding is declining in the recent past due to reduced grazing pastures. The education level of the majority of the population is semi-illiterate (Wiesmann *et al.,* 2014).

3.2 Research Design

3.2.1 Preliminary Survey

A preliminary survey was carried out to assess accessibility, collect background information, to view bird habitats, natural vegetation types and cover, soils, ecological characteristics and identify sampling sites. It was noticed that the National Park has important nesting and sheltering sites for specific bird species such as swifts, vultures, and Eagles.

3.2.2 Sampling Procedure

Intensive timed point count survey was done to determine the presence or absence of bird species and their numbers (Bibby *et al.*, 2000) along with characterization of the landscape, which was divided into four main habitats depending on terrain, vegetation, and brine-pond. (i) Open grassland dominated by *Cynodon dactylon* with less than 10% shrub cover. (ii) Shrubland dominated by *Tarchonanthus camphoratus* and *Acacia drepanolobium* with undergrowth of *Cymbopogon* sp, *Themeda sp* and *Digitaria* sp. (iii) Cliff faces with open grassland, having less than 10% shrub cover. (iv) Brine bond next to Olkaria I power station.

These habitats were also classified as disturbed and undisturbed during geothermal construction activities based on the distance from the geothermal power station. A total of ten (10) transects at one-kilometre intervals were laid out of which six transects were on disturbed habitats and four (4) transects on undisturbed habitats were studied.

(i) Disturbed habitats

Transect number 1, 3,4,5,6 and 8 were within disturbed sites, which was characterised by extensive pipelines, well drilling, presence of an open electrical power-line, habitat loss, and fragmentation due to vegetation clearing, high level of noise, Hydrogen Sulphide, and other geothermal power production activities. Transects 1, 3, 4 and 6 were considered within open savanna close to Olkaria I and II. Transect number 5 was within disturbed grassland close to Olkaria II and Transect 8 was located along the brine-pond next to Olkaria I.

(ii) Undisturbed habitats

Transect number 2, 7, 9 and 10 were considered under undisturbed habitats characterised by limited geothermal activities such as piping, drilling, vegetation clearing and habitat modification. Transect number 2 and 7 were on cliff face and transect 9 and 10 were selected within grassland and shrub-land respectively.

Point counts were conducted systematically along all transects and at the distance of two hundred metres (200 m) between two adjacent points adding up to five points per transect. Birds were counted within the radius of fifty meters. In total, fifty points were selected based on the type of vegetation and distance from the geothermal power generating station.

3.3 Data Collection

Hell's Gate maps, GPS, binoculars, compass, Camera, Bird guide and digital noise and hydrogen sulphide (H_2S) metre were used for data collection.

(a). Bird Sampling

During the field survey, all birds seen or heard within the point count circle were recorded. The number of birds, species, and the number of individuals of each species were identified with the help of a trained bird observer and confirmed by the use of Bird of Kenya and Northern Tanzania field guidebook and recorded. Bird survey was carried out during wet season (May 2016) and dry season (December 2015 to February 2016). Point locations for all observations were marked using GPS.

The censuses were carried out during morning hours between 6.00 am and 10.00 am, avoiding windy and rainy days. At each point, birds were given 10 minutes to settle down. All bird species seen or heard for about 10 minutes were identified and recorded. Each point was also surveyed three times during the month of December, February, and May 2016. In addition, power-lines and the brine pond were studied by patrolling within the study sites. Bird species identified were categorized according to their main feeding guilds (Prajapati and Prajapati, 2013).

(b). Habitat assessment

Habitats always influence the changes in animal communities near and far from geothermal power station. Decibel meter was used to monitoring levels of Noise and 5-in-1 portable gas meter was used to monitor H_2S (Hydrogen Sulphide).

Cameras were set at important sites to monitor movement of birds in 24 hours. Habitat loss and fragmentation changes in vegetation cover were determined and recorded at each point. Total vegetation cover of each layer was estimated according to Braun-Blanquet (1932) cover and abundance scale (which is: 5 = >75 percent cover; 4 = 50-75 percent cover; 3 = 25-50 percent cover; 2 = 5-25 percent cover; 1 = numerous, but less than 5 percent cover, or scattered, with cover up to 5 percent; + = few, with small cover; and r = rare, solitary, with small cover). Species with over 10% cover were identified and recorded. An average height of vegetation at the lower and upper layers was estimated and recorded to nearest decimetre (0.1m). Tree species name and number of sub-layers were observed and recorded. In addition, diameter at breast height and depth of leaf litter were measured and recorded.

3.4 Data Analysis

Birds' analyses were done separately for both disturbed and undisturbed habitats. Densities of species based on the observations in the censuses were calculated in standard units of total number/km^2. Pearson correlation coefficient was used to test the relationship between the amount of threats due to geothermal energy production activities and the birds' population. One way ANOVA was used to test for differences in bird diversity between the disturbed and undisturbed habitats

CHAPTER FOUR: RESULTS AND DISCUSSION

4.0 Introduction

Research data was collected for frequency, density, dominance, abundance, feeding guild, vegetation cover to study its diversity and impacts due to Olkaria's geothermal activities. These research results are based on the field survey and were analysed to assess the impacts of the geothermal power production on avifauna due to noise, hydrogen sulphide, habitat fragmentation, and ground vegetation clearance.

4.1 Bird species composition in disturded and undisturbed habitats

Surveys were conducted within disturbed and undisturbed habitats at Hell's Gate National Park (HGNP), and 42 families composed of 68 genera and 99 species were identified and recorded (table 4.4).

Only eight migratory species were recorded during the month of December 2015, February and May 2016. *Bubulcus ibis* (Cattle Egret), and *Cuculus solitarius* (Red-chested cuckoo) are intra-African migrant while, *Oenanthe isabellina* (Isabelline Wheatear), *Phylloscopus trochilus* (Willow Warbler), *Motacilla flava* (Yellow wagtail), *Hirundo rustica* (Barn Swallow), and *Riparia riparia* (Sand Martin) are Palaearctic migrant. In the month of December (2015), 32 families, 43 genera and 59 species were recorded in disturbed habitats while 34 families, 48 genera and 67 species were recorded in undisturbed habitats (Table 4.1).

Table 4.1: Bird species composition and their families in both disturbed and undisturbed habitats along ten transects within Hell's Gate National Park (December 2015).

Family	Bird Species	Number of birds within disturbed habitats							Number of birds within undisturbed habitats				
		T1	T3	T4	T5	T6	T8	Total birds	T2	T7	T9	T10	Total birds
1. Accipitridae	*1. Aquila verreauxii*	(-)	(-)	(-)	(-)	(-)	(-)	**(-)**	(-)	2	(-)	(-)	**(2)**
	2. Buteo augur	(-)	(-)	1	(-)	(-)	(-)	**(1)**	(-)	5	1	(-)	**(6)**
	3. Elanus caeruleus	(-)	(-)	(-)	1	(-)	(-)	**(1)**	(-)	(-)	(-)	2	**(2)**
	4. Gyps africanus	(-)	(-)	(-)	(-)	(-)	(-)	**(-)**	(-)	1	(-)	(-)	**(1)**
	5. G. rueppellii	(-)	(-)	2	(-)	1	(-)	**(3)**	14	74	(-)	1	**(89)**
	6. Hieraaetus spilogaster	(-)	(-)	(-)	(-)	(-)	(-)	**(-)**	(-)	(-)	1	(-)	**(1)**
	7. Polyboroides typus	(-)	(-)	(-)	(-)	1	(-)	**(1)**	1	(-)	(-)	(-)	**(1)**
2.Alaudidae	*Calandrella cinerea*	(-)	(-)	(-)	(-)	(-)	(-)	**(-)**	(-)	(-)	5	(-)	**(5)**
3.Apodidae	*1. Apus aequatorialis*	(-)	(-)	(-)	(-)	(-)	(-)	**(-)**	>4000	>4500	50	(-)	**(>8550)**
	2. A. caffer	(-)	(-)	(-)	(-)	(-)	(-)	**(-)**	>4000	>3900	(-)	(-)	**(>7900)**
	3. A. horus	(-)	(-)	(-)	(-)	(-)	(-)	**(-)**	>4000	>4500	(-)	(-)	**(>8500)**
	4. A. melba africanus	(-)	(-)	(-)	(-)	(-)	(-)	**(-)**	>4000	>3680	(-)	(-)	**(>7680)**
	5. A. niansae	(-)	(-)	(-)	(-)	(-)	(-)	**(-)**	>4000	>5600	(-)	(-)	**(>9600)**
	6. A. affinis	(-)	(-)	(-)	(-)	(-)	(-)	**(-)**	>1000	>1000	(-)	(-)	**(>2000)**
4.Ardeidae	*Bubulcus ibis*	(-)	(-)	(-)	(-)	(-)	(-)	**(-)**	(-)	160	8	(-)	**(168)**
5.Coliidae	*Colius striatus*	(-)	(-)	4	(-)	(-)	(-)	**(4)**	(-)	(-)	4	(-)	**(4)**
6.Columbidae	*1. Columba guinea*	(-)	(-)	(-)	(-)	(-)	(-)	**(-)**	(-)	(-)	3	(-)	**(3)**
	2. Streptopelia capicola	(-)	(-)	2	12	5	4	**(23)**	6	2	(-)	4	**(12)**
	3. S. lugens	(-)	(-)	(-)	(-)	(-)	(-)	**(-)**	(-)	(-)	(-)	2	**(2)**
	4. S. semitorquata	2	2	(-)	4	(-)	4	**(12)**	2	2	(-)	2	**(6)**
	5. S. senegalensis	2	(-)	(-)	(-)	(-)	(-)	**(2)**	(-)	(-)	(-)	4	**(4)**
7.Corvidae	*Corvus albus*	(-)	4	(-)	(-)	(-)	(-)	**(4)**	(-)	(-)	(-)	(-)	**(-)**
8. Dicruridae	*Dicrurus adsimilis*	2	4	7	4	2	3	**(22)**	4	(-)	(-)	4	**(8)**
9. Emberizidae	*Emberiza flaviventris kalaharica*	(-)	(-)	(-)	(-)	(-)	(-)	**(-)**	(-)	(-)	(-)	3	**(3)**
10.Estrildidae	*1. Uraeginthus bengalus*	(-)	(-)	2	(-)	(-)	(-)	**(2)**	(-)	(-)	(-)	(-)	**(-)**

Family	Bird Species	Number of birds within disturbed habitats							Number of birds within undisturbed habitats				
		T1	**T3**	**T4**	**T5**	**T6**	**T8**	**Total birds**	**T2**	**T7**	**T9**	**T10**	**Total birds**
	2. U. ianthinogaster	(-)	(-)	2	(-)	(-)	(-)	**(2)**	2	(-)	2	10	**(14)**
11.Falconidae	*Falco biarmicus*	(-)	(-)	(-)	(-)	(-)	(-)	**(-)**	(-)	6	(-)	(-)	**(6)**
12.Fringillidae	*1. Serinus citrinelloides*	(-)	2	(-)	(-)	(-)	(-)	**(2)**	(-)	(-)	(-)	(-)	**(-)**
	2. S. striolatus	2	(-)	(-)	(-)	(-)	(-)	**(2)**	(-)	(-)	3	8	**(11)**
13. Hirundinidae	*1. Hirundo daurica emini*	(-)	(-)	(-)	(-)	4	(-)	**(4)**	(-)	(-)	4	(-)	**(4)**
	2. H. fuligula fusciventris	(-)	(-)	53	(-)	(-)	(-)	**(53)**	(-)	(-)	2	10	**(12)**
	3. H. rustica	(-)	(-)	(-)	(-)	(-)	(-)	**(-)**	(-)	(-)	5	10	**(15)**
	4. Riparia riparia	1	(-)	(-)	(-)	(-)	(-)	**(1)**	(-)	(-)	2	(-)	**(2)**
14. Laniidae	*1. Lanius collaris humeralis*	(-)	(-)	(-)	4	(-)	(-)	**(4)**	4	1	1	2	**(8)**
	2. L. excubitoroides	(-)	(-)	(-)	1	(-)	(-)	**(1)**	(-)	(-)	(-)	(-)	**(-)**
	3. L. cabanisi	1	(-)	(-)	(-)	(-)	(-)	**(1)**	(-)	(-)	(-)	(-)	**(-)**
15. Malaconotidae	*Laniarius aethiopicus*	3	10	4	4	4	1	**(26)**	2	(-)	1	14	**(17)**
16. Meropidae	*1. Merops oreobates*	(-)	(-)	(-)	(-)	(-)	(-)	**(-)**	7	(-)	(-)	4	**(11)**
	2. M. bullockoides	2	(-)	(-)	(-)	(-)	(-)	**(2)**	13	(-)	(-)	3	**(16)**
17. Monarchidae	*1. Terpsiphone viridis*	(-)	(-)	(-)	(-)	(-)	(-)	**(-)**	1	(-)	(-)	2	**(3)**
	2. T. nigromitratus	(-)	(-)	(-)	(-)	1	(-)	**1)**	(-)	2	(-)	2	**(4)**
18. Motacillidae	*1. Motacilla flava*	(-)	(-)	(-)	(-)	(-)	(-)	**(-)**	(-)	(-)	2	(-)	**(2)**
	2. M. aguimp vidua	(-)	(-)	(-)	(-)	(-)	(-)	**(-)**	(-)	(-)	2	(-)	**(2)**
	3. Anthus cinnamomeus	4	3	2	4	3	(-)	**(16)**	4	(-)	18	2	**(24)**
19. Muscicapidae	*1. Melaenornis fischer*	(-)	(-)	(-)	3	(-)	(-)	**(3)**	2	(-)	2	(-)	**(4)**
	2. Myrmecocichla aethiops cryptoleuca	(-)	(-)	2	13	2	(-)	**(17)**	2	6	13	4	**(25)**
	3. Bradornis microrhynchus	2	(-)	(-)	(-)	(-)	(-)	**(2)**	6	(-)	(-)	11	**(17)**
20. Nectariniidae	*1. Nectarinia hunter*	(-)	(-)	(-)	(-)	(-)	2	**(2)**	(-)	(-)	(-)	(-)	**(-)**
	2. N. amethystine	1	2	1	(-)	3	(-)	**(7)**	(-)	(-)	(-)	2	**(2)**
	3. N. venusta	7	6	2	(-)	2	2	**(19)**	8	(-)	(-)	2	**(10)**
21. Numididae	*Numida meleagris*	3	(-)	(-)	10	(-)	(-)	**(13)**	(-)	120	5	(-)	**(125)**
22. Oriolidae	*Oriolus larvatus rolleti*	2	8	6	2	4	(-)	**(22)**	(-)	(-)	(-)	6	**(6)**

Family	Bird Species	Number of birds within disturbed habitats							Number of birds within undisturbed habitats				
		T1	T3	T4	T5	T6	T8	Total birds	T2	T7	T9	T10	Total birds
23. Paridae	*Parus albiventris*	4	(-)	(-)	(-)	(-)	2	**(6)**	(-)	(-)	(-)	2	**(2)**
24. Passeridae	*1. Passer rufocinctus*	(-)	(-)	(-)	(-)	7	(-)	**(7)**	(-)	(-)	3	4	**(7)**
	2. P. domestica indicus	6	(-)	(-)	(-)	(-)	(-)	**(6)**	2	(-)	(-)	10	**(12)**
25. Phasianidae	*1.Francolinus coqui*	7	(-)	(-)	(-)	(-)	(-)	**(7)**	(-)	(-)	3	(-)	**(3)**
	2.F. hildebrandti	(-)	7	(-)	(-)	(-)	(-)	**(7)**	(-)	(-)	(-)	(-)	**(-)**
26. Picidae	*Dendropicos goertae*	1	(-)	(-)	2	(-)	(-)	**(3)**	(-)	(-)	(-)	1	**(1)**
27. Ploceidae	*1.Anaplectes rubriceps*	(-)	(-)	1	(-)	(-)	(-)	**(1)**	(-)	(-)	(-)	(-)	**(-)**
	2.Ploceus baglafecht	(-)	2	(-)	(-)	(-)	(-)	**(2)**	2	2	1	3	**(8)**
	3.P. cucullatus	(-)	(-)	(-)	(-)	(-)	(-)	**(-)**	(-)	(-)	(-)	2	**(2)**
	4.Euplectes capensis crassirostirs	1	2	(-)	(-)	(-)	(-)	**(3)**	(-)	(-)	(-)	(-)	**(-)**
28. Podicipedidae	*Tachybaptus ruficollis capensis*	(-)	(-)	(-)	(-)	(-)	5	**(5)**	(-)	(-)	(-)	(-)	**(-)**
29.Prionopidae	*Prionops poliolophus*	(-)	(-)	6	(-)	(-)	(-)	**(6)**	6	(-)	(-)	(-)	**(6)**
30. Pycnonotidae	*Pycnonotus barbatus*	(-)	4	(-)	2	(-)	4	**(10)**	2	(-)	3	7	**(12)**
31. Sagittariidae	*Sagittarius serpentarius*	(-)	(-)	(-)	(-)	(-)	(-)	**(-)**	(-)	2	3	(-)	**(5)**
32. Scopidae	*Scopus umbretta*	(-)	(-)	(-)	2	(-)	(-)	**(2)**	(-)	(-)	(-)	(-)	**(-)**
33. Struthionidae	*Struthio camelus*	(-)	(-)	(-)	(-)	(-)	(-)	**(-)**	(-)	3	(-)	(-)	**(3)**
34. Sturnidae	*1. Buphagus erythrorhynchus*	(-)	(-)	(-)	(-)	(-)	(-)	**(-)**	(-)	100	115	(-)	**(215)**
	2. Onychognathus morio	(-)	(-)	(-)	(-)	(-)	(-)	**(-)**	(-)	6	2	(-)	**(8)**
	3. Lamprotornis superbus	2	(-)	(-)	(-)	(-)	(-)	**(2)**	2	(-)	7	(-)	**(9)**
	4. L. purpuropterus	(-)	(-)	2	(-)	(-)	(-)	**(2)**	(-)	(-)	(-)	(-)	**(-)**
35. Sylviidae	*1.Prinia subflava melanorhyncha*	(-)	2	(-)	(-)	(-)	(-)	**(2)**	(-)	(-)	(-)	(-)	**(-)**
	2.Camaroptera brachyura	(-)	4	4	(-)	2	(-)	**(10)**	(-)	(-)	(-)	10	**(10)**
	3.Cisticola chinianus	(-)	(-)	6	6	3	(-)	**(15)**	2	2	4	4	**(12)**
	4.C. erythrops sylvius	(-)	2	(-)	(-)	(-)	(-)	**(2)**	(-)	(-)	(-)	2	**(2)**
	5.Cisticola galactotes	2	(-)	(-)	(-)	(-)	(-)	**(2)**	(-)	(-)	(-)	(-)	**(-)**
	6.Sylvietta whytii	(-)	(-)	2	(-)	2	(-)	**(4)**	2	(-)	(-)	(-)	**(2)**
	7.Phylloscopus trochilus	(-)	1	(-)	(-)	(-)	(-)	**(1)**	3	(-)	2	4	**(9)**

Family	Bird Species	Number of birds within disturbed habitats							Number of birds within undisturbed habitats				
		T1	T3	T4	T5	T6	T8	Total birds	T2	T7	T9	T10	Total birds
36.Threskiornithidae	*Bostrychia hegedash brevirostris*	(-)	(-)	(-)	2	(-)	(-)	**(2)**	(-)	(-)	(-)	(-)	**(-)**
37. Turdidae	1. *Cossypha caffra iolaema*	(-)	(-)	2	(-)	(-)	(-)	**(2)**	(-)	(-)	(-)	(-)	**(-)**
	2. *C. heuglini*	(-)	(-)	2	(-)	(-)	(-)	**(2)**	(-)	(-)	(-)	(-)	**(-)**
	3. *Oenanthe isabellina*	(-)	(-)	(-)	(-)	(-)	(-)	**(-)**	4	(-)	(-)	(-)	**(4)**
	4. *O. lugubris schalowi*	(-)	(-)	(-)	(-)	2	(-)	**(2)**	4	2	7	(-)	**(13)**
	5. *O. pleschanka*	(-)	(-)	(-)	(-)	2	(-)	**(2)**	(-)	4	(-)	(-)	**(4)**
38. Zosteropidae	*Zosterops abyssinicus*	(-)	(-)	1	(-)	(-)	4	**(5)**	2	(-)	(-)	2	**(4)**
Number of genera in each transect		**19**	**14**	**19**	**15**	**16**	**8**	**(43)**	**24**	**18**	**28**	**26**	**(48)**
Number of species in each transect		**21**	**16**	**23**	**17**	**18**	**10**	**(59)**	**31**	**26**	**31**	**34**	**(67)**
Number of birds present in each transect		**57**	**64**	**116**	**76**	**50**	**31**	**(394)**	**106**	**502**	**282**	**161**	**(1001)**

Key: (-) Absent during study

Table 4.2: Bird species composition and their families in both disturbed and undisturbed habitats along ten transects within Hell's Gate National Park (February 2016).

Family	Bird Species	Number of birds within disturbed habitats							Number of birds within undisturbed habitats				
		T1	**T3**	**T4**	**T5**	**T6**	**T8**	**Total birds**	**T2**	**T7**	**T9**	**T10**	**Total birds**
1. Accipitridae	1. *Aquila verreauxii*	(-)	(-)	(-)	(-)	(-)	(-)	**(-)**	(-)	2	(-)	(-)	**(2)**
	2. *Buteo augur*	(-)	(-)	(-)	(-)	(-)	(-)	**(-)**	(-)	5	(-)	(-)	**(5)**
	3. *Gyps africanus*	(-)	(-)	(-)	(-)	(-)	(-)	**(-)**	(-)	1	(-)	(-)	**(1)**
	4. *G. rueppellii*	(-)	(-)	(-)	(-)	(-)	(-)	**(-)**	8	74	(-)	(-)	**(82)**
2. Apodidae	1.*Apus aequatorialis*	(-)	(-)	(-)	(-)	(-)	(-)	**(-)**	>1000	>1500	(-)	(-)	**(>2500)**
	2.*A.affinis*	(-)	(-)	(-)	(-)	(-)	(-)	**(-)**	(-)	>2450	(-)	(-)	**(>2450)**
	3.*A. caffer*	(-)	(-)	(-)	(-)	(-)	(-)	**(-)**	>1500	>1500	(-)	(-)	**(>3000)**
	4.*A. horus*	(-)	(-)	(-)	(-)	(-)	(-)	**(-)**	>100	>1893	(-)	(-)	**(>1993)**
	5.*A. melba africanus*	(-)	(-)	(-)	(-)	(-)	(-)	**(-)**	>3000	>4100	(-)	(-)	**(>7100)**
	6.*A. niansae*	(-)	(-)	(-)	(-)	(-)	(-)	**(-)**	>2000	>1400	(-)	(-)	**(>3400)**
3.Ardeidae	*Bubulcus ibis*	(-)	(-)	(-)	(-)	(-)	(-)	**(-)**	(-)	200	(-)	(-)	**(200)**
4.Charadriidae	*Venellus coronatus*	(-)	(-)	(-)	(-)	(-)	(-)	**(-)**	(-)	(-)	2	(-)	**(2)**
5. Columbidae	1. *Columba guinea*	(-)	(-)	(-)	(-)	(-)	(-)	**(-)**	(-)	(-)	2	(-)	**(2)**
	2. *Streptopelia capicola*	(-)	(-)	2	3	5	4	**(14)**	2	2	4	3	**(11)**
	3. *S. semitorquata*	(-)	(-)	(-)	(-)	(-)	4	**(4)**	(-)	2	(-)	4	**(6)**
6. Dicruridae	*Dicrurus adsimilis*	4	4	4	(-)	2	1	**(15)**	6	2	(-)	3	**(11)**
7.Emberizidae	*Emberiza tahapisi*	(-)	(-)	(-)	(-)	(-)	(-)	**(-)**	2	(-)	(-)	2	**(4)**
8.Estrildidae	1. *Uraeginthus bengalus*	(-)	(-)	(-)	2	(-)	(-)	**(2)**	(-)	(-)	(-)	2	**(2)**
	2. *U. ianthinogaster*	(-)	(-)	2	(-)	(-)	(-)	**(2)**	2	(-)	2	10	**(14)**
9.Falconidae	*Falco biarmicus*	(-)	(-)	(-)	(-)	(-)	(-)	**(-)**	(-)	4	(-)	(-)	**(4)**
10.Fringillidae	1. *Serinus sulphuratus sharpii*	(-)	(-)	(-)	(-)	(-)	(-)	**(-)**	(-)	(-)	(-)	4	**(4)**
	2. *S. striolatus*	3	2	(-)	(-)	(-)	(-)	**(5)**	2	(-)	(-)	2	**(4)**
11. Hirundinidae	1. *Hirundo daurica emini*	(-)	(-)	(-)	(-)	(-)	6	**(6)**	(-)	1	(-)	2	**(3)**
	2. *H. fuligula fusciventris*	(-)	(-)	30	(-)	(-)	(-)	**(30)**	(-)	(-)	6	(-)	**(6)**
	3. *Riparia riparia*	(-)	8	(-)	(-)	(-)	(-)	**(8)**	(-)	(-)	15	8	**(23)**

Family	Bird Species	Number of birds within disturbed habitats							Number of birds within undisturbed habitats				
		T1	T3	T4	T5	T6	T8	Total birds	T2	T7	T9	T10	Total birds
12. Laniidae	*1. Lanius excubitoroides*	(-)	(-)	(-)	2	(-)	(-)	**(2)**	1	(-)	(-)	1	**(2)**
	2. L. cabanisi	1	(-)	(-)	1	(-)	(-)	**(2)**	(-)	(-)	(-)	(-)	**(-)**
	3. L. collaris humeralis	2	1	4	3	(-)	(-)	**(10)**	2	1	1	(-)	**(4)**
13. Malaconotidae	*Laniarius aethiopicus*	3	8	4	1	(-)	1	**(17)**	(-)	(-)	1	3	**(4)**
14. Meropidae	*1. Merops bullockoides*	(-)	(-)	(-)	(-)	(-)	(-)	**(-)**	5	(-)	(-)	2	**(7)**
	2. M. oreobates	(-)	(-)	(-)	(-)	(-)	(-)	**(-)**	(-)	(-)	(-)	2	**(2)**
15. Monarchidae	*Terpsiphone viridis*	(-)	(-)	(-)	(-)	(-)	(-)	**(-)**	1	(-)	2	(-)	**(3)**
16. Motacillidae	*1. Anthus cinnamomeus*	(-)	1	(-)	2	2	(-)	**(5)**	6	(-)	2	2	**(10)**
	2. Motacilla aguimp vidua	(-)	(-)	(-)	(-)	(-)	(-)	**(-)**	(-)	(-)	2	(-)	**(2)**
17. Muscicapidae	*1. Bradornis microrhynchus*	(-)	(-)	(-)	(-)	(-)	(-)	**(-)**	(-)	(-)	(-)	2	**(2)**
	2. Myrmecocichla aethiops cryptoleuca	(-)	(-)	4	7	(-)	(-)	**(11)**	5	6	36	(-)	**(47)**
18. Nectariniidae	*1. Nectarinia amethystina*	2	(-)	(-)	(-)	(-)	(-)	**(2)**	(-)	(-)	(-)	(-)	**(-)**
	2. N. venusta	2	2	2	(-)	(-)	2	**(8)**	(-)	(-)	(-)	5	**(5)**
19. Numididae	*Numida meleagris*	4	8	(-)	10	(-)	(-)	**(22)**	(-)	120	(-)	(-)	**(120)**
20. Oriolidae	*Oriolus larvatus rolleti*	(-)	2	2	(-)	2	(-)	**(6)**	(-)	(-)	(-)	2	**(2)**
21. Paridae	*Parus albiventris*	(-)	(-)	(-)	(-)	(-)	2	**(2)**	(-)	(-)	(-)	(-)	**(-)**
22. Passeridae	*1. Passer rufocinctus*	(-)	2	2	(-)	4	(-)	**(8)**	(-)	(-)	2	(-)	**(2)**
	2. P. domestica indicus	4	(-)	(-)	(-)	2	(-)	**(6)**	3	(-)	(-)	(-)	**(3)**
23. Phasianidae	*Francolinus hildebrandti*	(-)	(-)	(-)	(-)	(-)	(-)	**(-)**	(-)	(-)	2	(-)	**(2)**
24. Ploceidae	*1. Ploceus baglafecht*	(-)	(-)	3	(-)	(-)	(-)	**(3)**	2	2	4	1	**(9)**
	2. P. spekei	(-)	(-)	(-)	(-)	(-)	(-)	**(-)**	(-)	(-)	3	1	**(4)**
	3. Euplectes capensis crassirostirs	1	(-)	(-)	(-)	(-)	(-)	**(1)**	(-)	(-)	(-)	(-)	**(-)**
25. Podicipedidae	*Tachybaptus ruficollis capensis*	(-)	(-)	(-)	(-)	(-)	2	**(2)**	(-)	(-)	(-)	(-)	**(-)**
26. Pycnonotidae	*Pycnonotus barbatus*	(-)	4	2	(-)	(-)	4	**(10)**	6	(-)	(-)	5	**(11)**
27. Sagittariidae	*Sagittarius serpentarius*	(-)	(-)	(-)	(-)	(-)	(-)	**(-)**	(-)	2	2	(-)	**(4)**

Family	Bird Species	Number of birds within disturbed habitats							Number of birds within undisturbed habitats				
		T1	T3	T4	T5	T6	T8	Total birds	T2	T7	T9	T10	Total birds
28. Scopidae	*Scopus umbretta*	(-)	(-)	(-)	2	(-)	(-)	**(2)**	(-)	(-)	(-)	(-)	**(-)**
29. Struthionidae	*Struthio camelus*	(-)	(-)	(-)	(-)	(-)	(-)	**(-)**	(-)	3	(-)	(-)	**(3)**
30. Sturnidae	1. *Buphagus erythrorhynchus*	(-)	(-)	(-)	(-)	(-)	(-)	**(-)**	(-)	20	(-)	(-)	**(20)**
	2. *Onychognathus morio*	(-)	(-)	(-)	(-)	(-)	(-)	**(-)**	2	6	(-)	(-)	**(8)**
	3. *Lamprotornis superbus*	6	1	2	3	2	(-)	**(14)**	2	(-)	3	4	**(9)**
31. Sylviidae	1. *Cisticola chinianus*	(-)	(-)	2	4	(-)	(-)	**(6)**	(-)	(-)	1	(-)	**(1)**
	2. *C. galactotes*	(-)	(-)	(-)	2	(-)	(-)	**(2)**	(-)	(-)	2	6	**(8)**
	3. *Apalis flavida*	(-)	(-)	(-)	(-)	(-)	(-)	**(-)**	(-)	(-)	2	(-)	**(2)**
	4. *Camaroptera brachyura*	(-)	(-)	4	(-)	(-)	1	**(5)**	(-)	(-)	4	10	**(14)**
	5. *Sylvietta whytii*	(-)	(-)	(-)	(-)	(-)	(-)	**(-)**	(-)	(-)	(-)	2	**(2)**
32. Turdidae	1. *Cossypha heuglini*	(-)	(-)	2	(-)	(-)	(-)	**(2)**	(-)	(-)	(-)	(-)	**(-)**
	2. *Monticola saxatilis*	(-)	(-)	(-)	(-)	(-)	(-)	**(-)**	(-)	(-)	1	(-)	**(1)**
	3. *Oenanthe lugubris schalowi*	(-)	(-)	(-)	(-)	2	(-)	**(2)**	4	2	12	(-)	**(18)**
	4. *O. pleschanka*	(-)	(-)	(-)	(-)	(-)	(-)	**(-)**	(-)	1	6	(-)	**(7)**
33. Zosteropidae	*Zosterops abyssinicus*	(-)	(-)	(-)	(-)	(-)	4	**(4)**	2	2	(-)	(-)	**(4)**
Number of genera in each transect		**9**	**12**	**15**	**10**	**7**	**10**	**(26)**	**19**	**18**	**20**	**20**	**(41)**
Number of species in each transect		**11**	**12**	**16**	**13**	**8**	**11**	**(34)**	**23**	**26**	**25**	**25**	**(57)**
Number of birds present in each transect		**32**	**43**	**71**	**42**	**21**	**31**	**(240)**	**63**	**538**	**119**	**88**	**(728)**

Key : (-) Absent during study

Table 4.3: Bird species composition and their families in both disturbed and undisturbed habitats along ten transects within Hell's Gate National Park (May 2016).

Family	Bird Species	Number of birds within disturbed habitats							Number of birds within undisturbed habitats				
		T1	T3	T4	T5	T6	T8	Total birds	T2	T7	T9	T10	Total birds
1.Accipitridae	*1. Aquila verreauxii*	(-)	(-)	(-)	(-)	(-)	(-)	**(-)**	(-)	2	2	(-)	**(4)**
	2. Buteo augur	1	1	(-)	(-)	(-)	(-)	**(2)**	(-)	(-)	2	(-)	**(2)**
	3. Elanus caeruleus	(-)	(-)	(-)	(-)	(-)	(-)	**(-)**	1	(-)	(-)	(-)	**(1)**
	4. Gyps rueppellii	(-)	(-)	(-)	(-)	(-)	(-)	**(-)**	20	76	(-)	(-)	**(96)**
2.Alaudidae	*1. Calandrella cinerea*	(-)	(-)	(-)	(-)	(-)	(-)	**(-)**	(-)	2	(-)	5	**(7)**
	2. Mirafra hypermetra	(-)	(-)	(-)	(-)	(-)	(-)	**(-)**	(-)	(-)	4	(-)	**(4)**
3.Apodidae	*1. Apus aequatorialis*	(-)	(-)	(-)	(-)	(-)	(-)	**(-)**	>1300	>2700	(-)	(-)	**(>4000)**
	2. A. affinis	(-)	(-)	(-)	(-)	(-)	(-)	**(-)**	>2000	>4300	(-)	(-)	**(>6300)**
	3. A. caffer	(-)	(-)	(-)	(-)	(-)	(-)	**(-)**	>2600	>5200	(-)	(-)	**(>7800)**
	4. A. horus	(-)	(-)	(-)	(-)	(-)	(-)	**(-)**	>1000	>4340	(-)	(-)	**(>5340)**
	5. A. melba africanus	(-)	(-)	(-)	(-)	(-)	(-)	**(-)**	>1200	>4000	(-)	(-)	**(>5200)**
	6. A. niansae	(-)	(-)	(-)	(-)	(-)	(-)	**(-)**	>3000	>5400	(-)	(-)	**(>8400)**
4.Ardeidae	*Bubulcus ibis*	(-)	(-)	(-)	(-)	(-)	(-)	**(-)**	(-)	50	58	(-)	**(108)**
5.Coliidae	*Colius striatus*	1	(-)	8	(-)	(-)	(-)	**(9)**	(-)	(-)	(-)	(-)	**(-)**
6.Columbidae	*1. Columba guinea*	1	(-)	(-)	6	(-)	(-)	**(7)**	(-)	(-)	6	(-)	**(6)**
	2. Streptopelia capicola	4	(-)	2	(-)	(-)	(-)	**(6)**	8	4	4	(-)	**(16)**
	3. S. semitorquata	2	(-)	(-)	4	(-)	2	**(8)**	(-)	(-)	2	1	**(3)**
7.Cuculidae	*1. Chrysococcyx klaas*	2	(-)	(-)	(-)	(-)	(-)	**(2)**	2	(-)	(-)	(-)	**(2)**
	2. Cuculus solitaries	(-)	(-)	(-)	(-)	(-)	(-)	**(-)**	2	(-)	(-)	(-)	**(2)**
8.Dicruridae	*Dicrurus adsimilis*	2	1	(-)	(-)	1	(-)	**(4)**	8	2	2	2	**(14)**
9.Emberizidae	*Emberiza tahapisi*	(-)	(-)	(-)	(-)	(-)	(-)	**(-)**	4	(-)	8	(-)	**(12)**
10.Estrildidae	*1. Uraeginthus bengalus*	(-)	(-)	(-)	(-)	(-)	(-)	**(-)**	(-)	(-)	2	6	**(8)**
	2. U. ianthinogaster	(-)	(-)	4	(-)	2	(-)	**(6)**	(-)	(-)	9	2	**(1)**
11. Falconidae	*Falco biarmicus*	(-)	(-)	(-)	(-)	(-)	(-)	**(-)**	(-)	6	(-)	(-)	**(6)**
12. Fringillidae	*1. Serinus citrinelloides*	2	(-)	(-)	(-)	(-)	(-)	**(2)**	(-)	(-)	(-)	(-)	**(-)**
	2. S. reichenowi	(-)	2	(-)	(-)	(-)	(-)	**(2)**	(-)	(-)	(-)	(-)	**(-)**
	3. S. striolatus	4	6	(-)	(-)	(-)	2	**(12)**	3	(-)	3	4	**(10)**

Family	Bird Species	Number of birds within disturbed habitats							Number of birds within undisturbed habitats				
		T1	T3	T4	T5	T6	T8	Total birds	T2	T7	T9	T10	Total birds
	4. *S. sulphuratus sharpii*	(-)	(-)	(-)	(-)	(-)	(-)	**(-)**	2	(-)	(-)	(-)	**(2)**
13. Hirundinidae	1. *H. fuligula fusciventris*	(-)	15	(-)	(-)	(-)	(-)	**(15)**	15	(-)	8	5	**(28)**
	2. *Riparia riparia*	(-)	(-)	(-)	(-)	(-)	(-)	**(-)**	(-)	(-)	4	(-)	**(4)**
14. Laniidae	*Lanius collaris humeralis*	4	2	(-)	4	1	2	**(13)**	2	4	3	2	**(11)**
15.Malaconotidae	*Laniarius aethiopicus*	1	6	4	4	(-)	3	**(18)**	2	(-)	2	3	**(7)**
16. Meropidae	*Merops bullockoides*	2	(-)	(-)	(-)	(-)	(-)	**(2)**	4	(-)	6	4	**(14)**
17. Monarchidae	1. *Terpsiphone viridis*	(-)	(-)	(-)	(-)	(-)	(-)	**(-)**	2	(-)	(-)	(-)	**(2)**
	2. *Trochocercus nigromitratus*	(-)	(-)	(-)	(-)	(-)	(-)	**(-)**	(-)	(-)	2	(-)	**(2)**
18. Motacillidae	1. *Anthus cinnamomeus*	(-)	1	1	8	(-)	(-)	**(10)**	10	4	(-)	(-)	**(14)**
	2. *Motacilla aguimp vidua*	2	(-)	(-)	2	(-)	(-)	**(4)**	4	2	6	6	**(18)**
	3. *M. flava*	(-)	(-)	(-)	(-)	(-)	(-)	**(-)**	(-)	2	3	(-)	**(5)**
19. Muscicapidae	1. *Melaenornis fischer*	(-)	(-)	2	(-)	(-)	(-)	**(2)**	(-)	(-)	(-)	6	**(6)**
	2. *Bradornis microrhynchus*	(-)	(-)	(-)	(-)	(-)	(-)	**(-)**	3	3	3	7	**(16)**
	3. *Myrmecocichla aethiops cryptoleuca*	2	3	(-)	(-)	(-)	(-)	**(5)**	2	14	20	6	**(42)**
20. Nectariniidae	1. *Nectarinia hunter*	(-)	2	(-)	(-)	(-)	(-)	**(4)**	(-)	(-)	(-)	3	**(3)**
	2. *Nectarinia amethystina*	2	2	(-)	(-)	(-)	(-)	**(4)**	3	(-)	(-)	3	**(6)**
	3. *N. kilimensis*	2	(-)	(-)	(-)	(-)	(-)	**(2)**	(-)	(-)	(-)	(-)	**(-)**
	4. *N. venusta*	4	6	(-)	2	4	2	**(18)**	11	(-)	6	5	**(22)**
21. Numididae	*Numida meleagris*	6	(-)	8	20	(-)	(-)	**(34)**	(-)	(-)	8	(-)	**(8)**
22. Oriolidae	*Oriolus larvatus rolleti*	2	8	2	4	(-)	(-)	**(16)**	(-)	(-)	(-)	8	**(8)**
23. Paridae	*Parus albiventris*	(-)	(-)	(-)	(-)	(-)	(-)	**(-)**	(-)	(-)	(-)	2	**(2)**
24. Passeridae	1. *Passer domestica indicus*	(-)	2	1	2	2	(-)	**(7)**	2	(-)	(-)	3	**(5)**
	2. *P. rufocinctus*	2	(-)	(-)	(-)	3	(-)	**(5)**	3	5	8	6	**(22)**
25. Phasianidae	1. *Francolinus coqui*	5	(-)	(-)	(-)	(-)	(-)	**(5)**	(-)	(-)	(-)	(-)	**(-)**
	2. *Francolinus hildebrandti*	(-)	(-)	5	14	(-)	(-)	**(19)**	(-)	(-)	(-)	(-)	**(-)**
26. Platysteiridae	*Batis molitor*	(-)	(-)	(-)	(-)	(-)	2	**(2)**	(-)	(-)	(-)	3	**(3)**
27. Ploceidae	1. *Euplectes capensis crassirostirs*	(-)	2	(-)	(-)	(-)	(-)	**(2)**	(-)	(-)	3	(-)	**(3)**
	2. *P. baglafecht*	(-)	2	3	(-)	(-)	2	**(7)**	(-)	(-)	2	(-)	**(2)**

Family	Bird Species	Number of birds within disturbed habitats							Number of birds within undisturbed habitats				
		T1	T3	T4	T5	T6	T8	Total birds	T2	T7	T9	T10	Total birds
	3. P. spekei	(-)	(-)	(-)	(-)	(-)	(-)	**(-)**	(-)	(-)	(-)	3	**(3)**
28. Podicipedidae	*Tachybaptus ruficollis capensis*	(-)	(-)	(-)	(-)	(-)	1	**(1)**	(-)	(-)	(-)	(-)	**(-)**
29. Pycnonotidae	*Pycnonotus barbatus*	(-)	(-)	4	4	(-)	2	**(10)**	2	(-)	(-)	(-)	**(2)**
30. Sagittariidae	*Sagittarius serpentarius*	(-)	(-)	(-)	(-)	(-)	(-)	**(-)**	(-)	1	(-)	(-)	**(1)**
31. Scopidae	*Scopus umbretta*	(-)	(-)	(-)	(-)	(-)	1	**(1)**	(-)	(-)	(-)	(-)	**(-)**
32. Sturnidae	*1. Buphagus erythrorhynchus*	(-)	(-)	(-)	(-)	(-)	(-)	**(-)**	(-)	>1200	25	(-)	**(1225)**
	2. Lamprotornis superbus	2	2	2	(-)	2	(-)	**(8)**	2	2	8	(-)	**(12)**
	3. Onychognathus morio	(-)	(-)	(-)	(-)	(-)	(-)	**(-)**	(-)	2	(-)	(-)	**(2)**
33. Syliviidae	*1. Apalis flavida*	(-)	(-)	(-)	(-)	(-)	(-)	**(-)**	(-)	(-)	(-)	2	**(2)**
	2. Prinia subflava	(-)	(-)	(-)	(-)	(-)	(-)	**(-)**	(-)	(-)	2	8	**(10)**
	3. Camaroptera brachyura	(-)	4	2	(-)	2	(-)	**(8)**	(-)	(-)	2	16	**(18)**
	4. Cisticola chinianus-	2	(-)	(-)	(-)	(-)	(-)	**(2)**	(-)	(-)	3	(-)	**(3)**
	5. C. galactotes	2	(-)	2	(-)	(-)	(-)	**(4)**	2	1	(-)	4	**(7)**
	6. Eminia lepida	(-)	(-)	2	(-)	(-)	(-)	**(2)**	(-)	(-)	(-)	2	**(2)**
	7. Sylvietta whytii	(-)	(-)	(-)	(-)	(-)	(-)	**(-)**	(-)	(-)	(-)	6	**(6)**
34. Threskiornithidae	*Bostrychia hegedash brevirostris*	(-)	(-)	(-)	(-)	(-)	2	**(2)**	(-)	(-)	(-)	(-)	**(-)**
35. Timaliidae	*Turdoides sharpie*	(-)	(-)	(-)	(-)	(-)	(-)	**(-)**	(-)	(-)	5	(-)	**(5)**
36. Turdidae	*1. Cossypha heuglini*	(-)	(-)	4	(-)	(-)	(-)	**(4)**	(-)	(-)	2	3	**(5)**
	2. Oenanthe isabellina	(-)	(-)	(-)	(-)	(-)	(-)	**(-)**	4	(-)	(-)	(-)	**(4)**
	3. O. lugubris schalowi	(-)	(-)	(-)	(-)	2	(-)	**(2)**	9	7	11	3	**(30)**
	4. Oenanthe pleschanka	(-)	(-)	(-)	(-)	(-)	(-)	**(-)**	(-)	(-)	(-)	2	**(2)**
37. Zosteropidae	*Zosterops abyssinicus*	(-)	(-)	2	(-)	(-)	(-)	**(2)**	(-)	(-)	2	6	**(8)**
Number of genera in each transect		**19**	**15**	**18**	**12**	**8**	**11**	**(35)**	**24**	**19**	**32**	**28**	**(51)**
Number of species in each transect		**24**	**18**	**18**	**12**	**9**	**11**	**(44)**	**32**	**26**	**36**	**33**	**(67)**
Number of birds present in each transect		**59**	**67**	**58**	**74**	**19**	**21**	**(300)**	**132**	**1389**	**246**	**147**	**(1914)**

Key: (-) Absent during study

In February (2016), 22 families, 26 genera and 34 species were recorded in disturbed habitats while 30 families, 41 genera and 57 species were recorded in the undisturbed habitats (Table 4.2). In the month of May 2016, 28 families, 35 genera and 44 species were recorded in disturbed habitats while 32 families, 51 genera and 67 species were recorded in undisturbed habitats (Table 4.3).

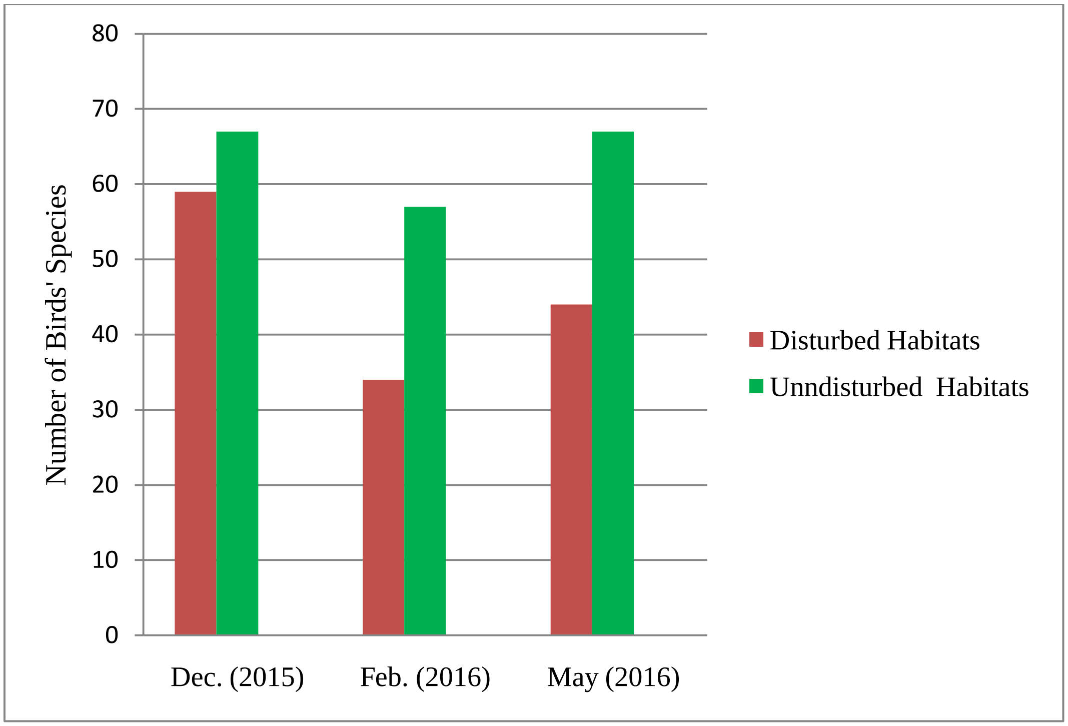

Figure 4.1. Number of birds' species present in disturbed and undisturbed habitats within Hell's National Park, Nakuru County, Kenya.

Species richness and total number of birds are less in disturbed compared to undisturbed sites. This may be attributed to Olkaria geothermal power production activities at certain stations. Low level of species richness and composition that were observed in disturbed habitats reflected to overall level of disturbances due to geothermal power plant such as high level of noise, H_2S emission, habitat loss, and fragmentation within study. Similar study on habitat loss and fragmentation by

(Fahrig, 1997), noise by (Aide and Isabel, 2011) and H_2S by (Martinez, & Alonso, 2014) have shown that they can significantly affect species distribution within a habitat. *Gyps Ruepelii* (Ruppell's Griffon Vulture) were not present in disturbed habitats only during the month of February and May (Table 4.4). This indicates that the nesting Ruppell's Griffon vultures at Hells' Gate National Park service other ecosystems.

The total number of birds and number of species were higher in the month of December 2015 and May 2016 than in February 2016. The month of February is drier with limited undergrowth and insects, which affects the availability of food and water within the park (Donald and Evans, 2006). There were more *Buphagus erythrorhynchus* at the study site in the month of December 2015 and May 206 due to a higher number of buffaloes (*Syncerus caffer*). During long rain season, buffaloes and other herbivores migrate from the surrounding habitats such as shores of Lake Naivasha and neighbouring ranches to the national park due to the growth of grass and other herbs. Ox-peckers graze mainly on the bodies of large mammals such as impala, buffaloes, and cattle. They feed on ecto-parasites such as ticks and insects infesting on wounds. They also feed on earwax, dandruff, flesh and blood of some wounds.

Plate 4.1: *Buphagus erythrorhynchus* on the *Syncerus caffer* in Hell's Gate National Park

There are some species that were recorded in disturbed habitats specifically transect 5 and 8 i.e. *Scopus umbretta* (Hamerkop), *Bostrychia hegedash brevirostris* (Hadada Ibis) and *Tachybaptus ruficollis capensis* (Little Grebe). *Scopus umbretta* feeds on aquatic invertebrates, which require wet land. *Bostrychia hegedash brevirostris* feeds on invertebrates in shallow water, wet grass, or forest clearings. While *Tachybaptus ruficollis capensis* is aquatic diving birds feeding on fish, aquatic worms, and other water invertebrates. *Tachybaptus ruficollis capensis* was only recorded at Transect 8 in the brine pond.

Transect 2 and 7 has the highest number of swifts, Ruppell's Griffon Vultures, Verreaux's Eagle *(Aquila verreauxii)*, Auger Buzzard *(Buteo auger)* Lanner Falcon *(Falco biarmicus).* This is due to proximity to the cliff face that offers ample supply of ledges preferred for nesting. The base of the cliff is heavily vegetated offering ample food for the large number of insectivores such *Oenanthe lugens schalowi, Myrmecocichla aethiops cryptoleuca,* and *Anthus Cinnamomeus.* The presence of top predators such as Ruppell's Griffon Vultures, Verreaux's Eagle, Auger Buzzard and Lanner Falcon and swifts make cliffs critical habitat for conservation to maintain sustainable ecology (Harper, 1991).

Plate 4.2. Location of Ruppell's Griffon Vultures' nesting site at the cliff within Hell's Gate National Park

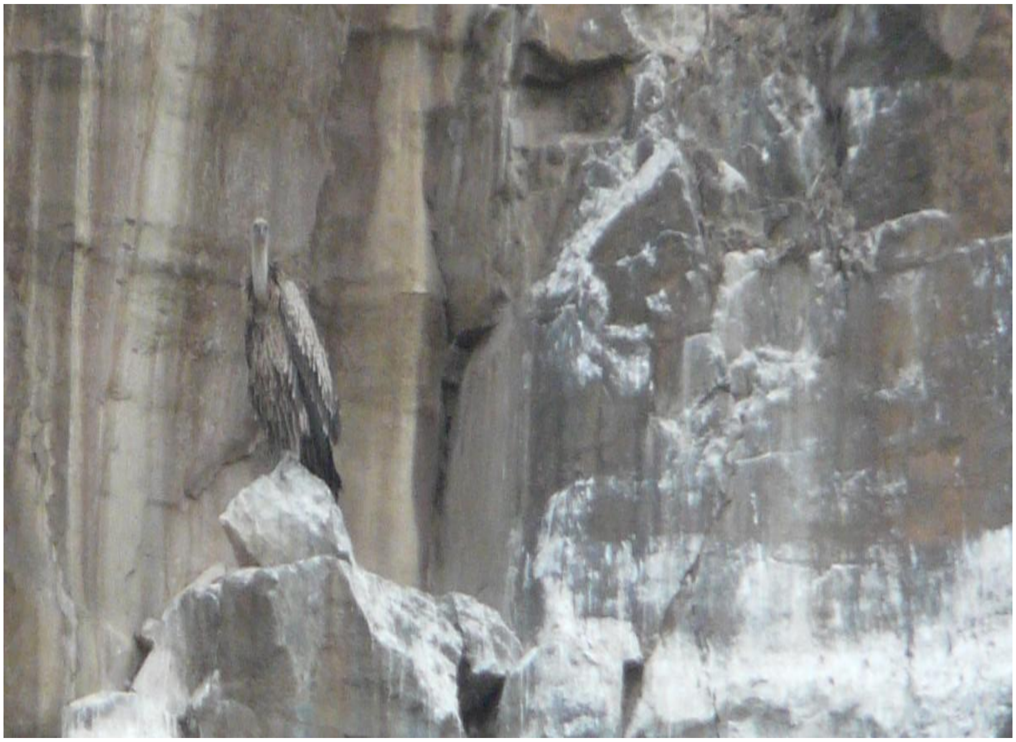

Plate 4.3: Ruppell's Griffon Vulture at the nest site at the cliff within Hell's Gate National Park

Higher numbers of *Nectarinia venusta* and *Nectarinia amethystina* at disturbed sites in is attributed to yellow flowered *Nicotiana glauca* and *Solanum incanum* at disturbed site. *Nicotiana glauca* was concentrated on cleared sites, along power lines, along steam pipes, around wells and roadsides. In the month of December, *Hirundo fuligula fusciventris* were more in areas where excavation and drilling was going on. This is due to high availability of disturbed insects. *Solanum incanum* was highly concentrated at cleared sites. *Nicotiana glauca* and *Solanum incanum* are used by ecologists in making conclusions for ecosystem disturbance. The two are invasive species and are associated with disturbed habitat succession.

Plate 4.4: ***Solanum incanum*** **(showing signs of Disturbance due to vegetation clearance within Hell's Gate Na tional Park).**

4.2 Guild Structures

Feeding guild approach is an important tool to study the relationship between disturbed and undisturbed habitats. Birds were studied for their feeding guilds under the impact of geothermal activities and exploration within Hells' Gate National Park during the month of December, February, and May, and their numbers were recorded in each transect. Five types of feeding guilds were identified in the study area: carnivores, graminivorous, insectivores, nectarivores and omnivore (table 4.4). The principle foods for carnivores are other birds, mammals and reptiles. Graminivorous feed on grains and seeds. Nectarivore feed mainly on plant nectar and omnivores feed on a variety of plants and animals.

Insectivore feed on insect/arthropods. Insectivores acquire food by sallying (from perch to flying insects) gleaning from leaves, gleaning from bark, collecting from ground and aerial (catching prey in air).

Table 4.4: Characteristic of Guild in Hell's Gate National Park

Family Name	**Generic Name**	**Common Name**	**Feeding Type**
1.Accipitridae	*Aquila verreauxii*	Verreaux's or Black Eagle	C
	Buteo augur	Augur Buzzard	C
	Elanus caeruleus	African Black-Shouldered Kite	C
	Gyps africanus	African White-Backed Vultures	C
	Gyps rueppellii	Ruppell's Griffon Vulture	C
	Hieraaetus spilogaster	African Hawk Eagle	*C*
	Polyboroides typus	African Harrier Hawk	C
	Necrosyrtes monachus	[x] Hooded Vulture	C
	Neophron percnopterus	[x] Nubian Vulture	C
	Gypaetus barbatus meridionalis	[x] Lammergeier	C
	Circus earuginosus	[x] Eurasian Marh Harrier	C
	Terthopiusecaudatus	[x] Bateleur	C
	Aquila rapax	[x] Tawny Eagle	C
	Aquila wahlbergi	[x] Wahlberg's Eagle	C
	Buteo buteo	[x] Common Bazzard	C
	Buteo rufinus	[x] Long-legged Buzzard	C
	Haeraaetus pennatus	[x] Booted Eagle	C
	Lophaeus pennatus	[x] Long-crested Eagle	C
	Melierax gaber	[x] Gaber Goshawk	C
	Haliaeetus vocifer	[x] African Fish Eagle	C
	Milvas migrans	[x] Black Kite	C
	Circus pygarus	[x] Montague's Harrier	C
	Circus macrourus	[x] Pillid Harrier	C
	Neophon percnopterus	[x] Egyptian Vulture	C
2.Alaudidae	*Calandrella cinerea*	Red-capped Lark	I
	Mirafra hypermetra	Red-Winged lark	I
	Mirafra afrcana	[x] Rufous-naped Lark	I
3.Apodidae	*Apus aequatorialis*	Mottled Swift	I
	Apus affinis	Little Swift	I
	Apus caffer	*White-Rumped Swift	I
	Apus horus	Horus Swift	I
	Apus melba africanus	*Alpine Swift	I
	Apus apus	[x] Eurasian Swift	I
	Apus niansae	Nyanza Swift	I
4.Ardeidae	*Bubulcus ibis*	Cattle Egret	O
5.Charadriidae	*Venellus coronatus*	Crowned Plover	I
	Charadrius tricollaris	[x] Three-banded Plover	I
	Venellus armatus	[x] Blacksmith Plover	I
6..Coliidae	*Colius striatus*	Speckled Mouse-bird	O
7.Columbidae	*Columba guinea*	Speckled Pigeon	G
	Streptopelia capicola	Ring-necked Dove	G
	Streptopelia lugens	Dusky Turtle Dove	*G*

	streptopelia semitorquata	Red-eyed Dove	G
	Streptopelia senegalensis	Laughing Dove	G
8.Corvidae	*Corvus albus*	Pied Crow	O
	Corvus capensis	[x] Cape Rook	O
	Corvus albicolis	[x] White necked Raven	O
9.Cuculidae	*Chrysococcyx klaas*	Klaas's Cuckoo	I
	Cuculus solitarius	Red- chested Cuckoo	I
	Centropus superciliosus	[x] White-browed coucal	I
10.Dicruridae	*Dicrurus adsimilis*	Common Drongo	I
11.Emberizidae	*Emberiza flaviventris kalaharica*	Golden-breasted Bunting	*G*
	Emberiza tahapisi	Cinnamon-breasted Rock Bunting	G
12.Estrildidae	*Uraeginthus bengalus*	Red-cheeked Cordon-bleu	G
	Uraeginthus ianthinogaster	Purple Grenadier	G
	Estrilda astrild	[x] Common Waxbill	G
	Estrilda rhodopyga	[x] Crimson-ramped waxbill	G
	Lagononosticta senegala	[x] Red-billed Firefinch	G
13.Falconidae	*Falco biarmicus*	Lanner Falcon	C
	Falco alopex	[x] Fox kestrel	C
	Falco cuvieri	[x] African Hobby	C
	Falco peregrinus	[x] Peregrine Falcon	C
	Falco rupicoloides	[x] White-eyed Kestrel	C
	Falco subbuteo	[x] Eurasian Hobby	C
14.Fringillidae	*Serinus citrinelloides*	African Citril	G
	Serinus reichenowi	Yellow-rumped Seedeater	G
	Serinus striolatus	Streaky Seedeater	G
	Serinus sulphuratus sharpii	Brimstone Canary	G
15.Hirundinidae	*Hirundo daurica emini*	Red-rumped Swallow	I
	Hirundo fuligula fusciventris	African Rock Martin	I
	Hirundo rustica	Barn Swallow	*I*
	Riparia riparia	Sand Martin	I
	Delcon urbica	[x] House Martin	I
	Hirundo griseopyga	[x] Grey-ramped Swallow	*I*
	Psalidoprocine albiceps	[x] White-headed Saw-wing	I
	Psalidoprocine holomelas	[x] Black Rough-wing	I
16.Laniidae	*Lanius cabanisi*	Long-tailed Fiscal	O
	Lanius collaris humeralis	Common Fiscal	O
	Lanius excubitoroides	Grey-Backed Fiscal	O
	Lanius collario	[x] Red-backed Shrike	O
17.Malaconotidae	*Laniarius aethiopicus*	Tropical Boubou	O
	Dryoscopus cubla	[x] Black-headed Puffback	O
	Nilaus afer	[x] Northern Brubru	O
	Tchagra australis	[x] Brown-headed Tchagra	O
	Tchagla senegala	[x] Black-headed Tchagra	O
18.Meropidae	*Merops bullockoides*	White-Fronted Bee-eater	I
	Merops oreobates	Cinnamon -chested Bee-eater	I
19.Monarchidae	*Terpsiphone viridis*	African Paradise Flycatcher	I
	Trochocercus nigromitratus	Dusky Crested Flycatcher	I
20.Motacillidae	*Anthus cinnamomeus*	Grassland pipit	I
	Motacilla aguimp vidua	African Pied Wagtail	I
	Motacilla flava	Yellow wagtail	I
	Anthus leucophrys	[x] Plain-backed Pipit	I
	Anthus novaesee landiae	[x] Richard's Pipit	I
	Motacilla capensis	[x] Cape Wagtail	I

	Motacilla cinerea	[x] Grey Wagtail	I
	Motacilla clara	[x] Mountain Wagtail	I
21.Muscicapidae	*Bradornis microrhynchus*	African Grey Flycatcher	I
	Melaenornis fischer	White-Eyed Slaty Flycatcher	I
	Myrmecocichla aethiops cryptoleuca	Northern Anteater Chat	I
	Muscicapa adusta	[x] Sported Flycatcher	I
22.Nectariniidae	*Nectarinia amethystina*	Amethyst Sunbird	N
	Nectarinia hunteri	Hunters Sunbird	N
	Nectarinia kilimensis	Bronze Sunbird	N
	Nectarinia venusta	Variable Sunbird	N
	Nectalinia senegalensis	[x] Scarlet-chested Sunbird	N
23.Numididae	*Numida meleagris*	Helmeted Guineafowl	O
24.Oriolidae	*Oriolus larvatus rolleti*	Black-headed Oriole	I
25.Paridae	*Parus albiventris*	White-bellied Tit	O
	Parus fringillinus	[x] Red-breasted Tit	O
26.Passeridae	*Passer domestica indicus*	House Sparrow	G
	Passer rufocinctus	Rufous Sparrow	G
	Plocepasser mohali	[x] White-browed Sparrow Weaver	G
	Passer griseus	[x] Grey-headed Sparrow	G
	Passer eminibey	[x] Chestnut Sparrow	G
27.Phasianidae	*Francolinus coqui*	Coqui Francolin	O
	Francolinus hildebrandti	Hildebrandt's Francolin	O
28.Picidae	*Dendropicos goertae*	African Grey Woodpecker	I
29.Platysteiridae	*Batis molitor*	Chin-spot Batis	I
30.Ploceidae	*Anaplectes rubriceps*	Red-headed Weaver	G
	Euplectes capensis crassirostirs	Yellow Bishop	G
	Ploceus baglafecht	Baglafecht weaver	G
	Ploceus cucullatus	Village or Black-headed Weaver	*G*
	ploceus spekei	Spekes Weaver	G
	Ploceus velatus	[x] Vitelline Masked Weaver	G
	quelea quelea	[x] Red-billed Quelea	G
	Ploceus rubiginosus	[x] Chestnut Weaver	G
31.Podicipedidae	*Tachybaptus ruficollis capensis*	Little Grebe	C
32.Prionopidae	*Prionops poliolophus*	Grey-crested Helmet-shrike	O
33.Pycnonotidae	*Pycnonotus barbatus*	Common Bulbul	O
34.Sagittariidae	*Sagittarius serpentarius*	Secretary Bird	C
35.Scopidae	*Scopus umbretta*	Hamerkop	C
36.Struthionidae	*Struthio camelus*	Common Ostrich	O
37.Sturnidae	*Buphagus erythrorhynchus*	Red-billed Oxpecker	I
	Lamprotornis purpuropterus	Ruppell's Long-tailed Starling	O
	Lamprotornis superbus	Superb starling	O
	Onychognathus morio	Red-winged Starling	O
	Creatorphora cinerea	[x] Wattled Starling	O
	Lamprtornis chalybaeus	[x] Blue-eared Glossy Starling	O
38.Syliviidae	*Prinia subflava melanorhyncha*	Tawny-flanked Prinia	I
	Apalis flavida	Yellow-breasted Apalis	I
	Camaroptera brachyura	Grey-backed Camaroptera	I
	Cisticola chinianus	Rattling Cisticola	I
	Cisticola erythrops sylvius	Red-faced Cisticola	I
	Cisticola galactotes	Winding Cisticola	I
	Eminia lepida	Grey-capped warbler	I
	Sylvietta whytii	Red-faced Crombec	I

	Spiloptila rubifrons	[x] Red-fronted Warbler	I
	Cisticola ayresii	[x] Wing-snapping Cisticola	I
	Cisticola robustus nuchalis	[x] Stout Cisticola	I
	Phyllolais pulchella	[x] Buff-billed Warbler	I
	Phylloscopus sibilatrix	[x] Wood Warbler	I
	Phylloscopus trochilus	Willow Warbler	I
	Phylloscopus umbrovirens	[x] Brown Woodland Warbler	I
	Sylvyetta brachyura	[x] Northern Crombec	I
39.Threskiornithidae	*Bostrychia hegedash brevirostris*	Hadada Ibis	C
40.Timaliidae	*Turdoides sharpei*	Black-lored Babbler	I
	Turdoides jardineii	-Arrow-marked Babbler	I
41.Turdidae	*Cossypha caffra iolaema*	*Cape Robin-Chat	O
	Cossypha heuglini	White-browed Robin-Chat	I
	Monticola saxatilis	Common Rock Thrush	O
	Oenanthe isabellina	Isabelline Wheatear	I
	Oenanthe lugubris schalowi	Schalow's Wheatear	I
	Oenanthe pleschanka	Pied Wheatear	I
	Motacila saxatilis	[x] Common Rock Thrush	I
	Oenanthe lugens	[x] Mourning Wheatear	I
	Oenanthe oenanthe	[x] Northern Wheatear	I
	Saxicola torquatus	[x] Common Stonechat	I
	Saxicola rubetra	[x] Whinchat	I
42.Zosteropidae	*Zosterops abyssinicus*	Abyssinian White-eye	I

Legend; **C**-carnivore, **G-** Graminivorous, **I**-Insectivore, **N-** Nectarivore, **O-** Omnivore,
*species not recorded at Hells Gate National Park prior to this study.
([x]) Species present in previous records from the national park but absent during this study.

During the month of December 2015, there were 669 insectivorous, 460 omnivores, 148 graminivorous, 128 carnivores and 40 nectarivores. In the month of February (2016), the park was dominated by insectivores (378 birds) and Omnivores (443 birds). The least number of birds was nectarivore (15) as recorded. In the month of May, the dominant feeding type was Insectivore birds (1604 birds) followed by Omnivore birds (268 birds). The least number was nectarivore (57 birds) in the park as shown in Table 4.5. In general, the dominant feeding type in Hell's Gate National Park in the three months was insectivores (2651 birds); followed by omnivores (1171 birds) and then graminivorous birds (425 birds). The lowest number recorded was of nectarivores (total 112 birds).

Table 4.5: Bird species based on feeding types recorded during December (2015), February 2016 and May 2016 within Hell's Gate National Park Kenya.

			Feeding Types					
Month	**Habitats**	**Transect No.**	**C**	**G**	**I**	**N**	**O**	**Total**
December 2015	Disturbed Habitat	T1	(-)	13	16	8	20	**57**
		T3	(-)	8	23	8	25	**64**
		T4	3	7	85	3	18	**116**
		T5	5	16	34	(-)	21	**76**
		T6	2	12	27	5	4	**50**
		T8	5	8	7	4	7	**31**
	Undisturbed Habitat	T2	15	14	53	8	16	**106**
		T7	90	6	116	(-)	290	**502**
		T9	5	12	231	(-)	34	**282**
		T10	3	52	77	4	25	**161**
February 2016	Disturbed Habitat	T1	(-)	8	4	4	16	**32**
		T3	(-)	4	15	2	22	**43**
		T4	(-)	9	48	2	12	**71**
		T5	2	5	15	(-)	20	**42**
		T6	(-)	11	8	(-)	2	**21**
		T8	2	8	12	2	7	**31**
	Undistubed Habitat	T2	8	13	29	(-)	13	**63**
		T7	88	6	114	(-)	330	**538**
		T9	2	17	92	(-)	8	**119**
		T10	(-)	29	41	5	13	**88**
May 2016	Disturbed Habitat	T1	1	15	16	8	19	**59**
		T3	1	14	32	10	10	**67**
		T4	(-)	10	17	(-)	31	**58**
		T5	(-)	12	14	2	46	**74**
		T6	(-)	7	5	4	3	**19**
		T8	4	6	2	2	7	**21**
	Undisturbed Habitat	T2	21	22	67	14	8	**132**
		T7	85	9	1237	(-)	58	**1389**
		T9	4	47	110	6	79	**246**
		T10	(-)	25	104	11	7	**147**
Total			**346**	**425**	**2651**	**112**	**1171**	**4705**
% Type			**9.6%**	**10.2%**	**45.7%**	**3.0%**	**31.5%**	**100%**
Mean± SE			**12.13 ± 4.79bc**	**13.47 ± 1.92bc**	**57.5 ± 12.1a**	**3.700 ± 0.72c**	**39.7 ± 12.8ab**	

F-Value (7.50), P-Value (0.0001)

Mean values denoted by similar letters are not significantly different using one-way ANOVA at 95%CI

Legend; **C**-Carnivore, **G**- Graminivorous, **I**-Insectivore, **N**- Nectarivore, **O**-Omnivore, When considering the total number of birds of different feeding type counted in the three months were subjected to a one-way ANOVA, the result showed that there was a significant difference (F = 30.02, P = 0.0001) in the number of birds. More insectivores were recorded than the other feeding types. The least recorded feeding type was nectarivores (mean 3.70 birds). From the results, it was observed that over that over 55.3% of birds at the park are of predatory nature, either insectivores or carnivores followed by omnivores (31.5%), graminivorous (10.2%) and nectarivores (3%).

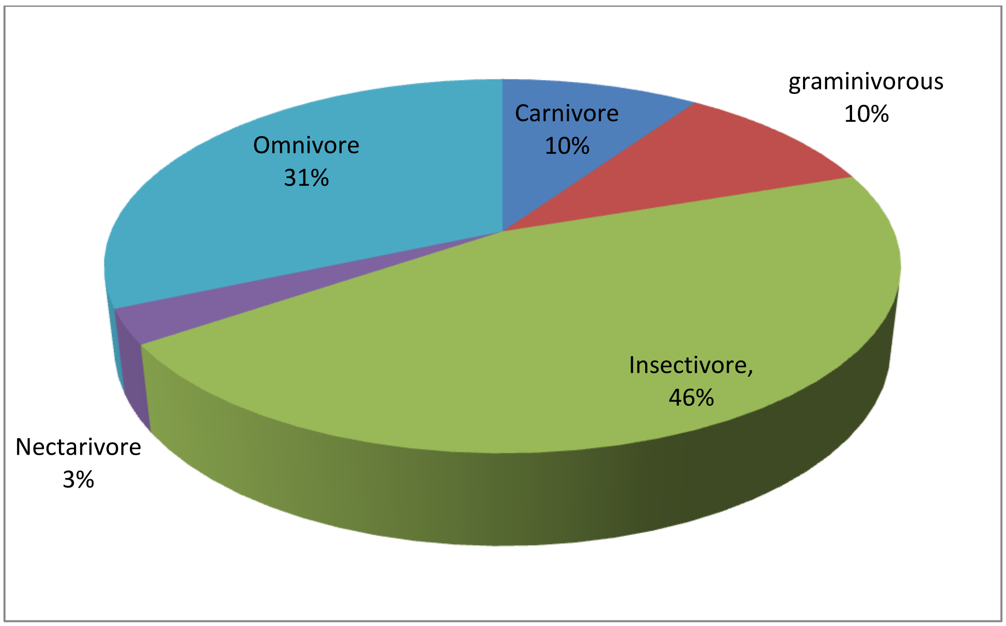

Figure 4.2 Mean percentage of bird feeding types for ten transects of Hell's Gate National Park

The high proportions of predators were recorded in the month of December 2015 (56%), February 2016 (54%), and May 2016 (55%). The largest number of predatory birds indicates that the national park is ecologically health. Transect 2 and 7 indicated the highest number of predatory birds this is due to the proximity to the cliff face that offer nesting site to most raptors.

4.3 Comparisons between feeding behaviour of the birds

A total number of birds with a particular feeding type in the ten transects were summed up and the results subjected to analysis of variance. Carnivorous species of birds showed a significant difference in the mean number of birds in transects (F=68.83, P=0.0001), transect seven (mean 87.0±1.50) was highest. Followed closely by transect 2 (mean 21.7±3.48). This was primarily influenced by the availability of nesting sites along the cliff face and food sources. This finding is consistent with the result of a study by (Virani and Harper, 2004) showing that the number of preditors increases in proportion to the number of prey. Prey species such as moles, snakes, swifts and rock hyrax are available along the cliff face. Studies have shown that rock hyrax (*Heterohyrax brucei)* Are prefered food for *Aquila verreauxii* and swifts are preferred by the *Falco biarmicus.*

Graminivorous showed the significant difference in the average number of birds in ten transects (F=4.38, P=0.003), transect 10 (mean 35.0±9.02) was the highest followed by transect 9 (mean 21.3±7.9). This is attributed to abundance of seed in the vegetation around the undisturbed habitats. There was a significant difference in the average number of insectivores (F=11.22, P=0.001), transect 7(mean 195.7±30.2) was the highest followed closely by transect 9 (mean 143.0±43.0). Further, Omnivores show a significant difference (F=6.20, P= 0.0001) with transect 7 (mean 211.7±76.9) recording highest number followed by transect 9 (mean 56.7±14.7). Nectarivores showed no significant difference (F=2.25, P=0.63). However, the number of nectarivores in transect 2 (mean 7.3±4.06) was higher than all other transects.

Table 4.6: Mean values of birds with specific feeding behaviour in ten selected transects within Hells Gate National Park (study area).

Transects / Feeding type	T1	T2	T3	T4	T5	T6	T7	T8	T9	T10	F-value	p-value
Carnivores	0.3±0.33c	21.7±3.48b	0.3±0.33c	1.0±1.00c	2.0±2.00c	0.3±0.33c	87.0±1.50a	3.7±0.82c	4.00±1.0c	1.0±1.0c	**68.83**	**0.0001**
Graminivorous	11.3±1.7b	21.7±3.48b	8.7±2.9b	9.3±1.2b	8.0±4.0b	10.7±0.9b	6.3±1.5b	7.33±0.7b	21.3±7.9ab	35.0±9.02a	**4.38**	**0.003**
Insectivores	12.7±4.4c	42.7±11.1c	23.3±5.0c	48.0±20.2c	23.7±6.4c	15.3±6.4c	195.7±30.2a	5.0±1.50c	143.0±43.0ab	65.3±10.5bc	**11.22**	**0.001**
Nectarivores	6.7±1.33a	6.7±2.4a	6.7±2.4a	1.7±0.9a	0.0±0.0a	3.3±1.8a	0.0±0.0a	2.7±0.7a	2.0±2.0a	6.7±2.2a	**2.25**	**0.63**
Omnivores	18.3±1.2b	14.0±1.2b	19.7±4.0b	26.3±7.8b	20.7±1.5b	3.7±1.2b	211.7±76.9a	7.0±0.0b	56.7±14.7b	18.7±4.1b	**6.2**	**0.0001**

Mean values denoted by similar letters in the same row are not significantly different at $P \leq 0.05$. Means separated using tukeys HSD

Transect 9 and 10 has a higher numbers of graminivorous and insectivores than transect 1, 3, 4, 5, 6 and 8; this can be attributed to the impacts of noise, chemical emission, habitat loss and fragmentation due to geothermal power production activities. Study by (Andrén, 1994) found that habitat fragmentation has a significant effect on distribution and density of birds within an ecosystem. (Fahrig, 1997), observed reduced survival and increased blood parasitism on nests in highly fragmented habitats. This strongly point out those geothermal power production activities has an effect on abundance and distribution of insects. However, nectarivores were highest in transect 1, 2 and 3 this is probably due high concentration of yellow flowered plants such as *Nicotiana glauca* and *Solanum incanum* and other herbs that are associated with disturbed habitat succession.

4.4 Relationship of bird density between disturbed and undisturbed site (December 2015, February, and May 2016)

The mean densities of each bird species for the three months were calculated and then subjected to a one-way ANOVA. Species with less than 10 observations in the entire period of study were excluded from this analysis. 14 out of 46 species that were analysed showed significantly lower in disturbed habitats and only one species showed a significant higher population in disturbed sites (Table 4.7).

Table 4.7: Standard error (±SE) and mean values of bird densities during December (2015) and February and May (2016) within Disturbed and Undisturbed transects at Hell's Gate National Park, Kenya.

Bird Species		Disturbed Transects	Undisturbed Transects			
		Savannah 1,3,4,5,6 & 8	Cliff Face T 2&7	Savannah T 9&10	F-Value	P-Value
1.	*Bradornis microrhynchus*	0.03±0.03b	1.20±1.20ab	2.50±2.50a	5.12	0.010*
2.	*Motacilla aguimp vidua*	0.10±0.08b	0.40±0.27ab	1.00±5.4a	3.73	0.032*
3.	*Nectarinia amethystina*	0.41±0.19a	0.30±0.30a	0.50±0.34a	0.10	0.907
4.	*Buteo augur*	0.10±0.06b	1.20±0.61a	0.20±0.20ab	5.31	0.008*
5.	*Ploceus baglafecht*	0.41±0.20a	0.80±0.53a	1.10±0.28a	1.35	0.269
6.	*Hirundo rustica*	0.00±0.00a	0.00±0.00ab	1.50±1.07a	4.02	0.025*
7.	*Oriolus larvatus rolleti*	0,60±0.59a	0.000±0.000a	1.310±0.375a	2.53	0.091
8.	*Bubulcus ibis*	0.00±0.00b	6.60±5.77b	36.00±8.33a	24.14	0.0001*
9.	*Emberiza tahapisi*	0.00±0.00b	1.30±0.94b	1.40±0.67a	4.13	0.022*
10.	*Pycnonotus burbatus*	1.14±0.38a	1.00±0.52a	1.50±0.67a	0.17	0.84
11.	*Dicrurus adsimilis*	1.90±0.42a	2.20±1.35a	1.30±0.52a	0.30	0.74
12.	*Lanius collaris*	1.03±0.27a	1.30±0.60a	0.90±0.41a	0.19	0.829
13.	*Francolinus coqui*	0.41±0.29a	0.00±0.00a	0.30±0.30a	0.38	0.686
14.	*Anthus cinnamomeus*	0.93±0.31a	2.40±1.78a	2.40±1.14a	1.23	0.302
15.	*Camaroptera brachyuran*	0.79±0.35b	0.00±0.00b	4.20±1.53a	8.03	0.001*
16.	*Numida meleagris*	2.03±1.09b	24.00±12.50a	1.30±0.67b	5.98	0.005*
17.	*Francolinus hilderbrandti*	0.69±0.39a	0.00±0.00a	0.20±0.20a	0.80	0.455
18.	*Passer domestica indicacus*	0.66±0.21a	0.70±0.71a	1.30±0.70a	0.60	0.55
19.	*Passer rufocinctus*	0.69±0.35b	0.60±0.40ab	2.30±0.47a	3.69	0.033*
20.	*Falco biarmicus*	0.00±0.00b	1.60±0.88a	0.20±0.20b	6.03	0.005
21.	*Oenanthe pleschanka*	0.07±0.07a	0.50±0.50a	0.80±0.80a	2.44	0.10
22.	*Uraeginthus ianthinogaster*	0.35±0.20b	0.00±0.00b	3.50±0.96a	16.92	0.0001*
23.	*Cisticola chinianus*	0.79±0.26a	0.00±0.00a	0.80±0.47a	1.56	0.222
24.	*Buphagus erythrorhynchus*	0.00±0.00b	30.00±15.30a	14.00±6.11ab	6.62	0.003*
25.	*Calandrella cinerea*	0.00±0.00b	0.20±0.20ab	1.20±0.92a	3.14	0.053

Bird Species		Disturbed Transects	Undisturbed Transects			
		Savanna 1,3,4,5,6 & 8	Cliff Face 2&7	Savanna 9&10	F-Value	P-Value
26.	*Uraegninthus bengalus*	0.21±0.21a	0.00±0.00a	1.00±0.45a	2.62	0.083
27.	*Streptopelia semitorquata*	0.69±0.29a	0.60±0.43a	0.90±0.48a	0.11	0.896
28.	*Sylvietta whytii*	0.14±0.10b	0.00±0.00b	0.80±0.33a	5.41	0.008*
29.	*Onychognathus morio*	0.00±0.00b	1.60±0.83a	0.20±0.20b	6.96	0.003*
30.	*Streptopelia capicola*	1.48±0.45a	2.40±0.98a	1.50±0.62a	0.54	0.586
31.	*Hirundo fuligula*	3.38±2.47a	1.50±1.50a	3.10±1.22a	0.12	0.891
32.	*Gyps rueppellii*	0.10±0.08b	43.70±28.20a	0.10±0.10b	4.85	0.012*
33.	*Riparia riparia*	0.31±0.28b	0.00±0.00b	2.90±1.64a	4.36	0.018*
34.	*Oenanthe lugubris schalowi*	0.21±0.21b	2.80±1.13a	3.30±1.08a	8.76	0.001*
35.	*Serinus striolatus*	0.66±0.23a	0.50±0.34a	2.00±0.84a	2.98	0.061
36.	*Mymecocichla aethiops cryptole*	1.28±0.60b	3.50±1.27ab	7.70±2.46a	7.23	0.002*
37.	*Lamprotornis superbus*	0.83±0.27a	0.80±0.44a	2.20±0.95a	2.21	0.121
38.	*Prinia subflava melanorhycha*	0.07±0.07b	0.00±0.00b	1.00±0.45a	7.57	0.001*
39.	*Laniarius aethiopicus*	1.93±0.46a	0.40±0.27a	2.40±0.95a	2.09	0.135
40.	*Nectarinia venusta*	1.55±0.40a	1.90±0.71a	1.80±0.55a	0.12	0.883
41.	*Parus albiventris*	0.28±.16a	0.00±0.00a	0.40±0.27a	0.71	0.498
42.	*Cossypha heuglini*	0.28±0.28a	0.00±0.00a	0.50±0.17a	0.45	0.640
43.	*Melaenornis fischeri*	0.14±0.14a	0.00±0.00a	0.60±0.31a	2.04	0.142
44.	*Merops bullockoides*	0.14±0.10b	1.50±0.73ab	2.00±1.07a	4.60	0.015*
45.	*Cisticola galactotes*	0.28±0.13a	0.00±0.00a	0.80±0.42a	2.65	0.082
46.	*Aquila verreauxii*	0.00±0.00b	0.55±0.39a	0.20±0.20ab	3.10	0.055

Mean values denoted by similar letters are not significantly different using one-way ANOVA at 95% CL. Means separated using tukeys HSD

The species that were less abundant in the disturbed area are *Bradornis microrhynchus, Motacilla aguimp vidua, Bubulcus ibis, Emberiza tahapisi, Camaroptera brachyura, Passer rufocinctus, Uraeginthus ianthinogaster, Calandrella cinerea, Sylvietta whytii, Oenanthe lugubris schalowi, Mymecocichla aethiops cryptole, Buphagus erythrorhynchus, Merops bullockoides,* and *Prinia subflava melanorhycha.*

Buteo augur, *Numida meleagris, Falco biarmicus*, *Onychognathus morio, Gyps rueppellii,* and *Aquila verreauxii* were more abundant at transects along the cliff-face. *Hirundo fuligula* showed higher densities at sites closer to geothermal power station.

The affected insectivores can be divided into (i) ground feeders (*Mymecocichla aethiops cryptole, Oenanthe lugubris schalowi, Motacilla aguimp vidua* and *Calandrella cinerea*), (ii) Foliage gleaners (*Camaroptera brachyura, Sylvietta whytii* and *Prinia subflava melanorhycha*), (iii) Aerial insectivores are *Bradornis microrhynchus* and *Merops bullockoides* and (iv) those that depend on other animals'(*Bubulcus ibis* and *Buphagus erythrorhynchu.*

The reduced number of ground insect feeders may be due to pollution-related changes in soil and the ground layer and noise. Emission of Sulphur (IV) Oxide and accumulation of heavy metals have an effect on ground layer vegetation and invertebrate fauna such as earthworms and snails (Eeva *et al.,* 2005). Eeva *et al.* (2002) also observed reduced population of ground feeders such as thrushes and flycatchers in polluted areas. This is attributed to reduced food abundance (invertebrates and insects) due to soil and air pollution. Foliage-gleaners may have suffered from the loss invertebrate food such as canopy living spiders. Spiders are sensitive to air pollution. Construction of roads, drilling of wells and laying of pipelines has affected the distribution of higher animals such as giraffes, buffaloes, Zebras, Gazelles and Eland. This has in turn affected the distribution of *Buphagus erythrorhynchus* and *Bubulcus ibis.* *Buphagus erythrorhynchus* depend on parasites on mammals' skin while *Bubulcus ibis* follows grazing animals taking advantage on disturbed insects. Over 70 dB of noise from the geothermal power station mask important biological communication. *Hirundo fuligula* was moderately abundant in the disturbed site, mostly in areas where excavation and drilling were going on due to high availability of disturbed insects.

The affected graminivorous within Hell's Gate National Park are *Emberiza tahapisi* and *Passer rufocinctus.* The decreased densities of these species may be due to lack of suitable food and habitats for breeding. According to (Eeva *et al*., 2002), air pollution can reduce the amount of suitable invertabrate food, and especially calcium rich food that is required by breeding females. The reduced population of graminivorous birds can also be attributed to reduction of important vegetation during construction of geothermal infrastructure (Fahrig, 1997).

4.5 Threats to bird species due to geothermal power station

Hydrogen sulphide, noise intensity, habitat modification and vegetation clearance was experienced in the study area due to geothermal power generation during the study period. The highest level of H_2S measured during the survey was 0.24ppm near Olkaria 1 (next to brine bond). Using wind speed and direction also recorded higher levels of H_2S concentration near overhead wells and power plants.

The variations in H_2S are due to proximity to overhead wells and power plant. This indicates that geothermal energy production is the primary source of H_2S.

Habitat modification in Hell's National Park is due to access road construction, extensive piping, well drilling, terracing, landscaping, construction of power lines and large brine pond at transect 8. Complete surface facilities for any geothermal plant i.e. power station, cooling tower, auxiliary building, and a sub-station**.**

Plate 4.5: Disturbed site for well drilling in Hell's Gate National Park

Continuous vegetation clearance is experienced along power lines, new construction areas (new access roads, wells and for installation of steam pipes). Primary sources of noise at Olkaria geothermal power station include turbines, generators, gas extraction units, condensers, cooling towers, pumps, steam ejectors, power transformers, exhaust air fans, air conditioners, circuit breakers, well drilling and vehicle traffic.

Table 4.8: Total average threats in all transects in Hell's Gate National Park during study period.

Transects	**T1**	**T2**	**T3**	**T4**	**T5**	**T6**	**T7**	**T8**	**T9**	**T10**	**F-Value**	**P-Value**
Hydrogen sulphide	0.036a	0.003a	0.024a	0.074a	0.009a	0.039a	0.003a	0.063a	0.001a	0.001a	**1.74**	**0.113**
Habitat modification	1a	0.04a	1.2a	1.4a	1a	2.6a	O.6a	2.25a	0a	0a	**1.64**	**0.139**
Vegetation clearing	0.400b	0.600b	0.600b	0.800b	0.800b	3.600a	0.000b	1.750ab	0.000b	0.00b	**5.64**	**0.001**
Noise Intensity (decibel)	63.80a	45.90b	56.40ab	53.80ab	55.20ab	64.80a	44.70b	49.25ab	41.00b	41.00b	**6.3**	**0.0001**

Mean values denoted by similar letters are not significantly different at 95% CI Means separated using tukeys HSD

Highest threats from hydrogen sulphide (H_2S) were experienced in transect four and eight. The lowest risk from H_2S was experienced in transect 9 and 10. The threat from habitat modification was experienced mainly in transect 6 and transect 8 and the least threat being in transects 9 and 10. The threat of noise was highest in transect 6 and 1 while transect 9 and 10 had lowest level of noise. In addition, transect 6 and 8 experienced highest threat of vegetation clearing (Table 4.8).

4.6 Correlation between the types of threats on species richness and number of birds

A Pearson moment correlation was conducted to establish the relationship between the number of birds and species richness in transect to a particular threat that was recorded in transects. The number of birds were not significantly related to the levels of H_2S, Vegetation clearance and habitat modification experienced in ten transects during the study period ($P<0.05$). Average noise level had a significant negative correlation with bird abundance ($r=-0.302$, $P=0.035$). The results of this study show a significant negative correlation between species richness and level of threats ($P < 0.05$) (table 4.9).

Table 4.9: Correlation between the types of threats on species richness and total number of birds during the study period

	species richness		**number of birds**	
Types of threats	**Pearson correlation coefficient (r)**	**p-Value**	**Pearson correlation coefficient (r)**	**p-Value**
H_2S	-0.368	0.005	-0.196	0.117
Habitat Modification	-0.369	0.009	-0.196	0.10
Vegetation cleared	-0.423	0.002	-0.238	0.620
Noise	-0.457	0.0001	-0.302	0.035

Correlation value is significant at 95% CI. Mean separated by tukeys HSD mean separation

A study carried out by (Aide and Isabel, 2011) revealed noise above 60dB significantly affect the species composition and abundance of birds. High levels of noise can cause physical damage of ears, stress, reduce reproduction success, and affect vocal communication in birds (Ortega, 2012). In addition, noises can mask warning calls or ability to hear predators. Aide and Isabel (2011) found that species with low-frequency calls avoid areas with traffic noises.

A study by (Martinez and Alonso, 2014) found a significant decrease in both birds' abundance and species richness in sites with as low as 0.1ppm of H_2S. Habitat loss and fragmentation reduces chances of breeding and increases predation and parasitism leading to decreased densities and species richness of birds. Andrén (1994), observed that habitat loss and fragmentation as an effect on distribution and population extinction.

4.7 Percentage vegetation covers during dry and wet seasons

Based on Braun-Blanguet Cover Abundance Scale, cover values were estimated. Vegetation covers of different plants during the dry and wet season in the study area were subjected to analysis of variance (One Way ANOVA).

Vegetation cover in the ten transects during the dry season was established to be significantly ($F = 4.05$, $P = 0.0001$) higher in transect T9 (mean 5.00 ± 0.00) and transect T7 (mean 5.00 ± 0.00). Followed by the percentage vegetative cover in transect T5 (3.75 ± 0.65). Transect T3 had the lowest percentage cover (mean 2.55 $\pm$ 0.28). The result also showed that there was a significant difference in the percentage cover of the different vegetation ($F = 3.57$, $P = 0.0001$) in transects during the wet season. The highest proportion cover was recorded in transect 9 (mean 5.00) (Table 4.9).

Table 4.10: Total number of plant species and their cover within 10 transects during February (dry) and May (wet) months, within Hell's Gate National Park, Nakuru County.

	Dry month (February 2016)		Wet month (May 2016)	
Transects	**Number of plant species**	**% vegetation cover (Mean ± SE)**	**Number of plant species**	**% vegetation cover (Mean ± SE)**
T1	49	2.72 ± 0.37a	63	2.33 ± 0.28a
T2	67	3.72 ± 0.28ab	83	3.61 ± 0.24ab
T3	74	2.55 ± 0.28a	76	2.53 ± 0.27a
T4	61	2.77 ± 0.29a	63	2.74 ± 0.28ab
T5	30	3.75 ± 0.65ab	25	3.57 ± 0.72ab
T6	33	2.75 ± 0.46a	36	2.57 ± 0.42a
T7	25	5.00 ± 0.00b	27	4.50 ± 0.50b
T8	41	3.15 ± 0.37ab	33	3.3 ±0.43ab
T9	25	5.00 ± 0.00b	25	5.00 ± 0.00c
T10	76	4.00 ± 0.22ab	76	4.00 ± 0.22bc
F-Value		**4.05**		**3.57**
P-Value		**0.0001**		**0.0001**

Mean values denoted by similar letters are not significantly different at 95% CI mean separated by tukeys HSD mean separation

4.8 Relationship between the vegetation cover during wet and dry seasons and number of birds

Pearson moment correlation was used to establish any relationship in the number of birds in transects to the percentage vegetation cover in dry and in the wet season. The result showed that there was no significant relationship in the number of birds to the percentage vegetation cover in the dry season ($r = 0.581$, $P = 0.078$). Similarly, there was no significant relationship between the number of birds in transects to the percentage vegetation cover in transects during the wet season.

Table 4.11: Mean values and standard error of associated number of birds and vegetation cover in ten transects during dry and wet months within Hell's Gate National Park

Transect numbers	Total no. of birds	vegetation cover % in dry month (Mean ± SE)	vegetation cover % in wet month (Mean ± SE)
T1	49.33 ± 8.69cd	2.72 ± 0.37	2.33 ± 0.28
T2	155 ± 17.6bc	3.72 ± 0.28	3.61 ± 0.24
T3	58.67 ± 7.97cd	2.55 ± 0.28	2.53 ± 0.27
T4	87.7 ± 16.7cd	2.77 ± 0.29	2.74 ± 0.28
T5	54.3 ± 10.9cd	3.75 ± 0.65	3.57 ± 0.72
T6	33.33 ± 8.41d	2.75 ± 0.46	2.57 ± 0.42
T7	506 ± 108a	5.00 ± 0.00	4.50 ± 0.50
T8	25.67 ± 2.91d	3.15 ± 0.37	3.3 ±0.43
T9	213.7 ± 47.4b	5.00 ± 0.00	5.00 ± 0.00
T10	125.0 ± 20.7bcd	4.00 ± 0.22	4.00 ± 0.22

Mean values denoted by similar letters are not significantly different at 95% CI. Mean separated by tukeys HSD mean separation

4.9 Global status of threatened species

Four globally threatened species were recorded in the study site. *Gyps rueppelli* were more abundant at the cliff-face which is now the only protected breeding site in Kenya. *Gyps africanus* was rare in the park where it was seen twice at transect 7 for the entire study period. *Sagittarius serpentarius* were seen ten times along grasslands. 12 *Prionops poliolophus* were recorded along the *Tarchonanthus comphoratus* shrubs. No evidence of *Neophron percnopterus, Necrosyrtes monachus,* and *Gypaetus barbatus* was recorded at the National Park.

Table 4.12: Summary of threatened species of birds within Hell's Gate National Park, Kenya during study period.

Globally threatened Bird Species (IUCN-2015)	Family	1971-1990	1991-2000	2000-2010	IUCN Red-List Category (2015)	Current Result (2015-16)
Gyps rueppelli	Accipitridae	R	R	R	CR	R
Gyps africanus	Accipitridae	R	R	R	CR	R
Necrosyrtes monachus	Accipitridae	NR	R	NR	CR	NR
Neophron percnopterus	Accipitridae	R	R	NR	EN	NR
Sagittarius serpentarius	Sagittariidae	R	R	R	VU	R
Ardeotis kori	Otididae	R	R	R	NT	R*
Gypaetus barbatus	Accipitridae	R	NR	NR	NT	NR
Terathopius ecaudatus	Accipitridae	R	R	R	NT	R*
Prionops poliolophus	Prionopidae	R	R	R	NT	R

Key:

R*- Species that has been recorded in the last one year but not during the present study period,
R- Bird species recorded during the study,
NR- Not recorded,
CR- Critically endangered,
EN-endangered,
VU-Vulnerable,
NT- Nearly threatened.

CHAPTER FIVE: CONCLUSION AND RECOMMENDATIONS

5.1 CONCLUSION

There were 99 species of birds belonging to 42 families recorded during this study. There is significant difference within the families and bird species composition. The disturbed sites have low frequency of birds than the undisturbed sites. Cliff's face was identified as one of the most important sites for Avifauna Conservation within this national park due to higher frequency and abundance of raptors and swifts.

Disturbed transects (T1, T3, T4, T5, T6, and T8) have high-level Hydrogen sulphide, noise intensity, habitat modification and vegetation clearance compared to (T2, T7, T9, and T10). Significant negative correlation between threats due to geothermal power generation with the total number of birds and species richness further indicated that geothermal energy activities are a threat to birds. 14 species that were analysed using one way ANOVA showed significant reduced densities in disturbed habitats.

Contaminated soils and ground layer negatively affect Hell's Gate ground feeders. Foliage-gleaners and aerial insectivores are suffering due to reduction of arthropods population and the impact of H_2S gas. More nectarivores birds are recorded in disturbed sites due to yellow flowering shrubs *Nicotiana glauca* and *Solanum incanum* growing in disturbed habitat.

5.2 RECOMMENDATIONS

- Intensive long-term avian monitoring programmes are required to study breeding success, density, feeding guilds and nest occupancy.

- Carry out an evaluation of the changes in vegetation cover due to geothermal power production activities and contaminated surface waters affect birds and other wildlife species.
- Restoration of suitable habitats for birds should be established to maintain bird species diversity for tourist attraction in this park.
- Seasonal monitoring of bird species need to be done at least once in a year.
- Studies are required on nesting success, survivorship, dispersal, predator ecology, and parasitism rates in relation to geothermal power production activities to maintain the status and to protect the suitable habitats in the park.

REFERENCES

Aide, M., & Isabel, M. (2011). Impacts of traffic noise on anuran and bird communities. *Urban Ecosyst, 35*(2), 30-47.

Alan, W. (2010). *Geothermal Energy Today*. Chelsea Clubhouse, Calfonia.

Alejo, A. (2000). *Generating Energies in Mount Apo: Cultural Politics in a Contested Environment.* Ateneo University Press, Quezon.

Andrén, H. (1994). Effects of Habitat Fragmentation on Birds and Mammals in Landscapes with DifferentProportions of Suitable Habitat. *JSTOR, 71*(3), 355-365.

Baldi, F. (1988). Mercury pollution in the soil and mosses around a geothermal plant. *Water, Air, and Soil Pollution, 38*(1-2), 111-119.

Bayer, P., Rybach, L., Blum, P., & Brauchler, R. (2013). Review on life cycle environmental effects of geothermal power generation. *Renewable and Sustainable Energy, 26*, 446–463.

Bennun, L., & Njoroge, P. (1999). *Important bird areas in Kenya.* Nature Kenya, Nairobi.

Bibby, C., Jones, M., & Marsden, S. (2000). *Expedition Field Techniques, Bird Survays.* BirdLife International, Cambridge.

BirdLife Inernational. (1998). *Endemic Bird Areas of the World: Priorities for Biodiversity Conservation.* BirdLife International, Cambridge, UK.

BirdLife International. (2015). *Global IUCN Red LIst Category*. Retrieved from BirdLife Internatinal: http://datazone.birdlife.org/species/results?cty=110&rlCR=Y&rec=N&vag=N&hdnAction=ADV_SEARCH

DiPippo, R. (2011). *Geothermal Power Plants: Principles, Applications, Case Studies and Environmental Impact.* Elsevier, Califonia.

Donald, P., & Evans, A. (2006). Habitat connectivity and matrix restoration: the wider implications of agri-environment schemes. *Journal of Applied Ecology, 43*, 209-218.

Eeva, T., Koivunen, V., & Hakkarainen, H. (2002). Population densities of forest birds in a heavy metal. *Avian Science , 2*(15), 1-15.

Eeva, T., Ryömä, M., & Riihimäki, J. (2005). pollution related changes in diets of two insectivorous passerines. *Oecologia 145*, 607-612.

Fahrig, L. (1997). Relative Effects of Habitat Loss and Fragmentation on Population Extinction. *The Journal of Wildlife Management, 61*(3), 603-610.

Hames, R., Rosenberg, K., Lowe, J., & Barker, S. (2002). Effect of forest fragmentation on tanager and thrush species in Eastern and Western North America. *Avian Biology, 25*, 85-91.

Harper, D. (1991). *Birds of Hell's Gate National Park.* University of Leicester Press, Leicester.

Kakkar, V., Nirmal, A., & Kumar, N. (2012). GEOTHERMAL ENERGY: NEW PROSPECTS. *International Journal of Advances in Engineering & Technology, 4*(2), 112.

Kihima, B. O. (2014). Unlocking the Kenyan Tourism Potential Through Park Branding Exercise. *Tourism Recreation Research, 39*(1), 51-64.

Knight, S. (1994). *Environmental Assessment of North East Olkaria Geothermal Power Project.* Geothermal Power Company, Nairobi.

Laynes, R., Pioquinto, W., & Caranto, J. (2005). Hazard Assessment and Mitigation Measures in Philippine Geothermal Fields. *Geothermics, 34*(1), 205-217.

Martinez, C., & Alonso, L. (2014). *Exposure and Effects of Oil Sands-Related Emissions on Wild Birds* (Doctoral dissertation, University of Calgary).

Matek, B. (2015). *2015 Annual U.S. & Global Geothermal Power Production Report.* Geothermal Energy Association, California.

Michael, M., Robert, S., & Logan, Y. (2007). *Environmental Science: Systems and Solutions.* Jones & Bartlett Learning, New York.

Ogola, P. F., Davidsdottir, B., & Fridleifsson, I. B. (2011). Lighting villages at the end of the line with geothermal energy in eastern Baringo. *Renewable & Sustainable Energy Reviews, 15*(8), 198.

Ortega, C. (2012). Effects of noise pollution on birds. *Ornithological Monographs, 74*(1), 6-22.

Pasvanoglu, S., Guner, A., & Gultekin, F. (2012). Environmental Problems at Nevsehir Geothermal Field. *Environmental Earth Science, 66*(4), 549-600.

Pimm, S. L., Jenkins, C. N., Abell, R., Brooks, T. M., Gittleman, J. L., Joppa, L. N., ... & Sexton, J. O. (2014). The biodiversity of species and their rates of extinction, distribution, and protection. *Science, 344*(6187), 1246752.

Prajapati, S. H., & Prajapati, R. P. (2013). Classified guilds in avian community with respect to food and feeding behaviour. *Ind. J. Sci. Res. and Tech*, *1*(2), 1-7.

Rapport, D., Lasley, B., Rolston, D., Nielsen, O., Qualset, C., & Damania, A. (2002). *Managing for Healthy Ecosystems.* CRC Press, Navada.

Ronald, D. (2012). *Geothermal Power Plants: Principles, Applications, Case Studies and Environmental Impact.* Butterworth-Heinemann, New York.

Siegel, J., & Nelder, C. (2008). *Investing in Renewable Energy: Making Money on Green Chip Stocks.* John Wiley & Sons, Newyork.

Smallie, J., & Virani, M. (2010). A preliminary assessment of the potential risks from electrical infrastructure to large birds in Kenya. *Scopus, 30*, 32–39.

Stober, I., & Bucher, K. (2013). *Geothermal Energy From Theoretical Models to Exploration and Development.* Springer Science & Business Media, Newyork.

Szymczyk, K., & Zalewski, K. (2002). Copper, Zinc, Lead and Cadmium Content in Liver and Muscles of Mallards (Anas Platyrhychnos) and Other Hunting Fowl Species in Warmia and Mazury in 1999-2000. *Polish Journal of Environmental Studies, 12*(3), 381-386.

Tit, K., Ghomshei, M., & Ellis, R. (2012). Geothermal energy as an indigenous alternative energy source in British Columbia. *Journal of Ecosystems and Management, 13*(2), 1-16.

Virani, M. Z., Monadjem, A., Thomsett, S., & Kendall, C. (2012). Seasonal variation in breeding Rüppell's Vultures Gyps rueppellii at Kwenia, southern Kenya and implications for conservation. *Bird Conservation International*, *22*(03), 260-269.

Virani, M., & Harper, D. (2004). A comparative study of the breeding behaviour of the Augur Buzzard,in two different land-use areas in southern Lake Naivasha, Kenya. *Ostrich 2004, 75(1&2): 11–19, 75*(2), 11-19.

Wetang'ula, G. N. (2004). *Assessment of geothermal wastewater disposal effects: case studies: Nesjavellir (Iceland) and Olkaria (Kenya) fields.* Oxford University Press, Nairobi .

Wiesmann, U. M., Kiteme, B., & Mwangi, Z. (2014). *Socio-economic atlas of Kenya: Depicting the national population census by county and sub-location*. Kenya National Bureau of Statistics, Nairobi.

Wright, T. M. (2013). Demolition of Native Rights and Self Determination: Act 55's Devastating Impact through the Development of Hawaii's Public Lands. *U. Haw. L. Rev., 35*, 297.

Zemedkun, M. T. (2012). Overview of geothermal resource exploration and development in the East African rift system. *short course VII on exploration for geothermal resources, organized by UNU-GTP, GDC and KenGen, at Lake Bogoria and Lake Naivasha, Kenya*.

Zimmerman, D., & Donald Turner, D. P. (2001). *Birds of Kenya and Northern Tanzania.* Bloomsbury, London.

APPENDICES

Appendix 1: Statistical Outputs

One-way ANOVA: Carnivore versus Transect

analysis of variance for trans 10

source	df	ss	ms	f-value	p-value
typ	9	19806.1	2200.68	368.83	0.000
error	20	119.3	5.97		
total	29	19925.5			

means

transect	n	mean	stdev	95% ci
t1	3	0.333	0.577	(-2.608, 3.275)
t10	3	1.00	1.73	(-1.94, 3.94)
t2	3	21.67	6.03	(18.72, 24.61)
t3	3	0.333	0.577	(-2.608, 3.275)
t4	3	1.00	1.73	(-1.94, 3.94)
t5	3	2.00	2.00	(-0.94, 4.94)
t6	3	0.333	0.577	(-2.608, 3.275)
t7	3	87.00	2.65	(84.06, 89.94)
t8	3	3.667	1.528	(0.725, 6.608)
t9	3	4.00	1.73	(1.06, 6.94)

pooled stdev = 2.44268

tukey pairwise comparisons

grouping information using the tukey method and 95% confidence

transect	n	mean	grouping
t7	3	87.00	a
t2	3	21.67	b
t9	3	4.00	c
t8	3	3.667	c
t5	3	2.00	c
t4	3	1.00	c
t10	3	1.00	c
t6	3	0.333	c
t3	3	0.333	c
t1	3	0.333	c

means that do not share a letter are significantly different.

one-way anova: granivore versus transect

analysis of variance for tran10

source	df	ss	ms	f-value	p-value
typ	9	2120	235.57	4.38	0.003
error	20	1075	53.77		
total	29	3195			

means

transect	n	mean	stdev	95% ci
t1	3	11.33	2.89	(2.50, 20.16)
t10	3	35.00	15.62	(26.17, 43.83)
t2	3	16.67	3.21	(7.84, 25.50)
t3	3	8.67	5.03	(-0.16, 17.50)
t4	3	9.33	2.08	(0.50, 18.16)
t5	3	8.00	7.00	(-0.83, 16.83)
t6	3	10.667	1.528	(1.836, 19.498)
t7	3	6.33	2.52	(-2.50, 15.16)
t8	3	7.333	1.155	(-1.498, 16.164)
t9	3	21.33	13.65	(12.50, 30.16)

pooled stdev = 7.33258

tukey pairwise comparisons

grouping information using the tukey method and 95% confidence

transect	n	mean	grouping
t10	3	35.00	a
t9	3	21.33	a b
t2	3	16.67	a b
t1	3	11.33	b
t6	3	10.667	b
t4	3	9.33	b
t3	3	8.67	b
t5	3	8.00	b
t8	3	7.333	b
t7	3	6.33	b

means that do not share a letter are significantly different.

one-way anova: insectivore versus transect

analysis of variance for tran10

source	df	ss	ms	f-value	p-value
typ	9	106885	11876	11.22	0.000
error	20	21175	1059		
total	29	128059			

means

transect	n	mean	stdev	95% ci
t1	3	12.67	7.57	(-26.52, 51.85)
t10	3	65.3	18.1	(26.1, 104.5)
t2	3	42.7	19.1	(3.5, 81.9)
t3	3	23.33	8.50	(-15.85, 62.52)
t4	3	48.0	35.0	(8.8, 87.2)
t5	3	23.67	11.02	(-15.52, 62.85)
t6	3	15.33	11.06	(-23.85, 54.52)
t7	3	195.7	52.3	(156.5, 234.9)
t8	3	5.00	2.65	(-34.19, 44.19)
t9	3	143.0	74.5	(103.8, 182.2)

pooled stdev = 32.5382

tukey pairwise comparisons

grouping information using the tukey method and 95% confidence

transect	n	mean	grouping
t7	3	195.7	a
t9	3	143.0	a b
t10	3	65.3	b c
t4	3	48.0	c
t2	3	42.7	c
t5	3	23.67	c
t3	3	23.33	c
t6	3	15.33	c
t1	3	12.67	c
t8	3	5.00	c

means that do not share a letter are significantly different.

one-way anova: nectarivore versus transect

analysis of variance for tran10

source	df	ss	ms	f-value	p-value
typ	9	225.6	25.07	2.25	0.063
error	20	222.7	11.13		
total	29	448.3			

means

transect	n	mean	stdev	95% ci
t1	3	6.67	2.31	(2.65, 10.69)
t10	3	6.67	3.79	(2.65, 10.69)
t2	3	7.33	7.02	(3.31, 11.35)
t3	3	6.67	4.16	(2.65, 10.69)
t4	3	1.667	1.528	(-2.352, 5.685)
t5	3	0.000000	0.000000	(-4.018451, 4.018451)
t6	3	3.33	3.06	(-0.69, 7.35)
t7	3	0.000000	0.000000	(-4.018451, 4.018451)
t8	3	2.667	1.155	(-1.352, 6.685)
t9	3	2.00	3.46	(-2.02, 6.02)

pooled stdev = 3.33667

tukey pairwise comparisons

grouping information using the tukey method and 95% confidence

transect	n	mean	grouping
t2	3	7.33	a
t3	3	6.67	a
t10	3	6.67	a
t1	3	6.67	a
t6	3	3.33	a
t8	3	2.667	a
t9	3	2.00	a
t4	3	1.667	a
t7	3	0.000000	a
t5	3	0.000000	a

means that do not share a letter are significantly different.

one-way anova: omnivore versus transect

analysis of variance for tran10

source	df	ss	ms	f-value	p-value
typ	9	104189	11577	6.20	0.000
error	20	37351	1868		
total	29	141541			

means

transect	n	mean	stdev	95% ci
t1	3	18.33	2.08	(-33.71, 70.38)
t10	3	18.67	7.02	(-33.38, 70.71)
t2	3	14.00	2.00	(-38.05, 66.05)
t3	3	19.67	6.81	(-32.38, 71.71)
t4	3	26.33	13.65	(-25.71, 78.38)
t5	3	20.67	2.52	(-31.38, 72.71)
t6	3	3.67	2.08	(-48.38, 55.71)
t7	3	211.7	133.1	(159.6, 263.7)
t8	3	7.000	0.000	(-45.046, 59.046)
t9	3	56.7	25.5	(4.6, 108.7)

pooled stdev = 43.2154

tukey pairwise comparisons

grouping information using the tukey method and 95% confidence

transect	n	mean	grouping
t7	3	211.7	a
t9	3	56.7	b
t4	3	26.33	b
t5	3	20.67	b
t3	3	19.67	b
t10	3	18.67	b
t1	3	18.33	b
t2	3	14.00	b
t8	3	7.000	b

t6	3	3.67	b

means that do not share a letter are significantly different.

one-way anova: total number of birds versus transect

source	df	ss	ms	f-value	p-value
typ	9	564335	62704	13.76	0.000
error	20	91155	4558		
total	29	655490			

means

transect	n	mean	stdev	95% ci
t1	3	49.33	15.04	(-31.97, 130.64)
t10	3	125.0	35.8	(43.7, 206.3)
t2	3	155.0	30.5	(73.7, 236.3)
t3	3	58.67	13.80	(-22.64, 139.97)
t4	3	87.7	28.9	(6.4, 169.0)
t5	3	54.3	18.9	(-27.0, 135.6)
t6	3	33.33	14.57	(-47.97, 114.64)
t7	3	506	187	(424, 587)
t8	3	25.67	5.03	(-55.64, 106.97)
t9	3	213.7	82.0	(132.4, 295.0)

pooled stdev = 67.5112

tukey pairwise comparisons

grouping information using the tukey method and 95% confidence

transect	n	mean	grouping
t7	3	506	a
t9	3	213.7	b
t2	3	155.0	b c
t10	3	125.0	b c d
t4	3	87.7	c d
t3	3	58.67	c d
t5	3	54.3	c d
t1	3	49.33	c d
t6	3	33.33	d
t8	3	25.67	d

means that do not share a letter are significantly different.

One-way ANOVA: Noise (dB) versus Transect

Analysis of Variance for Noise

Source	DF	SS	MS	F-Value	P-Value
Typ	9	3355	372.79	6.30	0.0001
Error	39	2306	59.14		
Total	48	5661			

Means

Transect	N	Mean	StDev	95% CI
T1	5	63.80	15.35	(56.84, 70.76)
T10	5	41.00	0.00	(34.04, 47.96)
T2	5	45.90	2.92	(38.94, 52.86)
T3	5	56.40	11.50	(49.44, 63.36)
T4	5	53.80	7.89	(46.84, 60.76)
T5	5	55.200	1.643	(48.244, 62.156)
T6	5	64.800	1.924	(57.844, 71.756)
T7	5	44.70	3.70	(37.74, 51.66)
T8	4	49.25	12.53	(41.47, 57.03)
T9	5	41.100	0.224	(34.144, 48.056)

Pooled StDev = 7.69007

Tukey Pairwise Comparisons

grouping information using the tukey method and 95% confidence

transect	n	mean	grouping
t6	5	64.800	a
t1	5	63.80	a
t3	5	56.40	a b
t5	5	55.200	a b
t4	5	53.80	a b
t8	4	49.25	a b
t2	5	45.90	b
t7	5	44.70	b
t9	5	41.100	b
t10	5	41.00	b

means that do not share a letter are significantly different

One-way ANOVA: Hydrogen Sulphide versus Transect

analysis of variance for hydrogen sulphide

source	df	ss	ms	f-value	p-value
typ	9	0.03157	0.003508	1.74	0.113
error	39	0.07875	0.002019		
total	48	0.11032			

means

transect	n	mean	stdev	95% ci
t1	5	0.0362	0.0458	(-0.0044, 0.0768)
t10	5	0.001000	0.000000	(-0.039647, 0.041647)
t2	5	0.002600	0.000548	(-0.038047, 0.043247)
t3	5	0.0244	0.0331	(-0.0162, 0.0650)
t4	5	0.0744	0.0725	(0.0338, 0.1150)
t5	5	0.009000	0.000000	(-0.031647, 0.049647)
t6	5	0.0392	0.0283	(-0.0014, 0.0798)
t7	5	0.002800	0.000447	(-0.037847, 0.043447)
t8	4	0.0630	0.1180	(0.0176, 0.1084)
t9	5	0.001200	0.000447	(-0.039447, 0.041847)

pooled stdev = 0.0449349

tukey pairwise comparisons

grouping information using the tukey method and 95% confidence

transect	n	mean	grouping
t4	5	0.0744	a
t8	4	0.0630	a
t6	5	0.0392	a
t1	5	0.0362	a
t3	5	0.0244	a
t5	5	0.009000	a
t7	5	0.002800	a
t2	5	0.002600	a
t9	5	0.001200	a
t10	5	0.001000	a

means that do not share a letter are significantly different

One-way ANOVA: Habitat Modification versus Transect

Analysis of Variance For Habitat Modification

source	df	ss	ms	f-value	p-value
typ	9	32.63	3.626	1.64	0.139
error	39	86.35	2.214		
total	48	118.98			

means

transect	n	mean	stdev	95% ci
t1	5	1.000	1.732	(-0.346, 2.346)
t10	5	0.000000	0.000000	(-1.345995, 1.345995)
t2	5	0.400	0.894	(-0.946, 1.746)
t3	5	1.200	1.789	(-0.146, 2.546)
t4	5	1.400	1.342	(0.054, 2.746)
t5	5	1.000	1.732	(-0.346, 2.346)
t6	5	2.60	2.51	(1.25, 3.95)
t7	5	0.600	0.548	(-0.746, 1.946)
t8	4	2.25	2.06	(0.75, 3.75)
t9	5	0.000000	0.000000	(-1.345995, 1.345995)

pooled stdev = 1.48799

Tukey Pairwise Comparisons

Grouping Information Using the Tukey Method and 95% Confidence

Transect	N	Mean	Grouping
t6	5	2.60	a
t8	4	2.25	a
t4	5	1.400	a
t3	5	1.200	a
t5	5	1.000	a
t1	5	1.000	a
t7	5	0.600	a
t2	5	0.400	a
t9	5	0.000000	a
t10	5	0.000000	a

Means that do not share a letter are significantly different.

One-way ANOVA: Vegetation clearing versus Transect

Analysis of Variance for Vegetation clearing

source	df	ss	ms	f-value	p-value
typ	9	53.54	5.949	5.64	0.000
error	39	41.15	1.055		
total	48	94.69			

means

transect	n	mean	stdev	95% ci
t1	5	0.400	0.548	(-0.529, 1.329)
t10	5	0.000000	0.000000	(-0.929174, 0.929174)
t2	5	0.600	1.342	(-0.329, 1.529)
t3	5	0.600	0.894	(-0.329, 1.529)
t4	5	0.800	1.095	(-0.129, 1.729)
t5	5	0.800	0.837	(-0.129, 1.729)
t6	5	3.600	2.074	(2.671, 4.529)
t7	5	0.000000	0.000000	(-0.929174, 0.929174)
t8	4	1.750	1.258	(0.711, 2.789)
t9	5	0.000000	0.000000	(-0.929174, 0.929174)

pooled stdev = 1.02719

tukey pairwise comparisons

Grouping information using the tukey method and 95% confidence transect n mean grouping

transect	n	mean	grouping
t6	5	3.600	a
t8	4	1.750	a b
t5	5	0.800	b
t4	5	0.800	b
t3	5	0.600	b
t2	5	0.600	b
t1	5	0.400	b
t9	5	0.000000	b
t7	5	0.000000	b
t10	5	0.000000	b

means that do not share a letter are significantly different.

Correlation: Total No.of birds, Noise (dB)

Pearson correlation of Total No.of birds and Noise (dB) = -0.302
P-Value = 0.035

Correlation: Total No.of birds, Hydrogen Sulphide

Pearson correlation of Total No.of birds and Hydrogen Sulphide = -0.196
P-Value = 0.177

Correlation: Total No.of birds, Habitat Modification

Pearson correlation of Total No.of birds and Habitat Modification = -0.127
P-Value = 0.383

Correlation: Vegetation clearing, Total No.of birds

Pearson correlation of Vegetation clearing and Total No.of birds = -0.238
P-Value = 0.10

Correlation: Number of species, Noise (dB)

Pearson correlation of Number of species and Noise (dB) = -0.457
P-Value = 0.001

Correlation: Number of species, Hydrogen Sulphide
Pearson correlation of Number of species and Hydrogen Sulphide = -0.368
P-Value = 0.009

Correlation: Number of species, Habitat Modification
Pearson correlation of Number of species and Habitat Modification = -0.369
P-Value = 0.009

Correlation: Number of species, Vegetation clearing
Pearson correlation of Number of species and Vegetation clearing = -0.423
P-Value = 0.002