Avian impact of South Africa's first concentrating solar power tower facility in the Northern Cape

by

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DECLARATION

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SUMMARY

Through its commitment to a greener economy that is less dependent on nonrenewable energy resources, South Africa's Integrated Resource Plan aims to diversify the energy system by including energy resource alternatives such as concentrating solar power (CSP).

All CSP facilities harvest solar thermal energy by utilising reflectors that focus energy to a receiver where the energy is concentrated and eventually converted into electricity via a conventional thermoelectric power cycle. Four main types of CSP technologies exist in today's global market of which central receivers, also known as CSP towers, are one of the dominant types.

Recent studies suggest that the potential impacts of utility-scale CSP tower facilities on avian populations may be substantial given that these impacts are driven by factors such as project location, footprint size and technology. It is anticipated that these factors mainly impact avifauna by altering the demography of avian communities and by exposing birds to singeing and collision risk. However, given the novelty of tower CSP and the global shortfall of publicised data on avian impacts, conclusive investigations into the avian impact of these facilities have yet to be established. Further rigorous investigation of these factors is therefore encouraged.

This study was the first to investigate the impact of a solar power tower facility in South Africa, seeing that it was conducted on the only operational CSP tower facility in southern Africa. The study aimed to evaluate the impact of the Khi Solar One CSP tower facility on avifauna of the area with special attention to biodiversity dynamics and avian mortalities and injuries.

Industry best practice guidelines and peer-reviewed literature were used as the point of departure from which the fieldwork methodology was developed. Data on avian mortality and injury were gathered over four seasons by conducting weekly monitoring and identifying patterns of avian use by means of vantage point surveys and parallel-line transects that were conducted inside and outside the facility footprint. Data collected during the field surveys were analysed to determine a suitable risk analysis model for this kind of development and to determine whether and to what extent the development had caused a change in avian behaviour.

The findings demonstrate that concerns about the impacts of CSP towers on bird populations are not completely unsubstantiated, even though some results remain inconclusive. Avian species diversity, abundance and density per unit area were found to be higher in the neighbouring untransformed habitat than within the facility footprint. Data suggest that certain shrubland/woodland species favoured the CSP facility, however, they did not represent an

unaffected population by default. In contrast, generalist and open country/grassland species were not adversely affected by impacts caused by the CSP tower facility. The presence of constructed water bodies and structures within the transformed habitat also appeared to have an indirect impact as in this otherwise rural habitat, they lure a diversity of aquatic and other species that favour a more urban habitat. Breeding observations indicated that reproductive activity within the transformed habitat was lower than within the untransformed habitat.

A total of 324 avian impact detections were recorded during the monitoring year, involving 34 identified species. Of the total avian impact detections, 61% of injuries/mortalities were found to be caused impact trauma and 14% by singeing related trauma. Most collisions were recorded in the solar field with trending evidence of impact occurring on the lower quarter of the heliostats' reflective surfaces. Singeing data displayed a significant increase in detections during the summer months and revealed that most recorded detections were of aerial feeding migratory birds. A clear correlation was found between the peak singeing detection months and the positioning of heliostats into the standby position during this period.

It was difficult to make a meaningful assessment of the overall avian fatality at CSP tower facilities and to formulate accurate hypotheses regarding the risk of avian mortality among these facilities and other sources of solar electricity generation. Still, data suggested that fatalities per area may be a more suitable metric for estimating cumulative impacts among CSP tower facilities since the efficiency of this technology is continuing to improve and change in design and operation over time.

Ultimately, this study offers several findings and recommendations that may contribute to the compilation of a mitigation framework that will ensure that the industry develops in a sustainable manner in South Africa.

OPSOMMING

In die strewe na 'n omgewingsvriendelike (groener) ekonomie, is dit van kritiese belang, vir Suid-Afrika, om minder afhanklik te wees van fossielbrandstowwe of, anders genoem, nie-hernubare energiebronne. Suid-Afrika se Geïntegreerde Hulpbronplan maak dit dan ook moontlik vir rolspelers, op hierdie gebied, om betrokke te raak in die voorsienning van hernubare energie vir die land. Sonverwarmingstelsels of te wel "concentrating solar power" (CSP) is een voorbeeld van so 'n alternatiewe wyse van kragopwekking.

'n CSP-aanleg produseer termiese sonkrag deur gebruik te maak van spieëls wat die sonstrale gefokus weerkaats na 'n ontvanger, waar die energie gekonsentreer word. Hier word die termiese energie dan omgesit in elektriese energie deur 'n konvensionele termo-elektriese energiesirkel. Daar is vier basiese wyses (tegnologieë) waardeur bogenoemde bereik kan word, met CSP-torings as een van die mees prominente.

Daar moet egter ook, wat hernubare- energieopwekking, betref, deurgaaans bepaal word wat die invloed van hierdie tipe ontwikkeling op die omgewing is. So toon verskeie studies byvoorbeeld aan, dat voëls tipiese slagoffers van die tipe ontwikkelings is, met die ligging, omvang asook die tipe aanleg (tegnologie) wat bepalend is tot in 'n hoe groot mate die impak is.

Aanlegte kan 'n invloed uitoefen deur habitatversteuring, verskroeiing en dan ook deur fisiese botsings met hierdie nuwe, vreemde objekte in die voëls se natuurlike hou areas. Siende dat CSP-torings onlangse ontwikkelings is, is daar plaaslik sowel as internasionaal, beperkte inligting wat spesifiek, oor hierdie potensiële impak op voëlbevolkings, handel. Dit het dus dringend noodsaaklik geword om hierdie veld in diepte te ondersoek.

Hierdie navorsing is die eerste van hierdie aard in Suid-Afrika en is onderneem op die enigste operasionele CSP-toringaanleg in suidelike Afrika. Die navorsing is gedoen om te bepaal wat die impak, van die Khi Solar One CSP Tower op die verskillende voëlbevolkings in die gebied het, werklik is. Spesifieke aandag is geskenk aan die invloed op biodiversiteit, verskroeiing (solar flux) en botsings tussen voëls en objekte in die CSP aanleg.

Riglyne daar gestel deur die industrie, sowel as reeds toepaslik nagevorste inligting in die verband, is as vertrekpunt gebruik in die ontwikkeling van 'n model vir die veldwerk. Die versameling van data, van geaffekteerde voëls, het oor vier seisoene geskied. Weeklikse monitering en identifisering is gedoen op die terrein van die aanleg self, sowel as op die aangrensende areas. Hierdie aksie het op 'n bepaalde wyse geskied en is daar seker gemaak dat die gebied deeglik gefynkam word deur vanuit verskillende hoeke, met oorkruisaksies die

gebied te deursoek. Data is bestudeer om gebruik te kan word om 'n risiko-analisemodel, vir hierdie tipe ontwikkeling, daar te stel. Hieruit kon bepaal word watter invloed en in hoe 'n groot mate, die voëls se gedrag, indien enigsins, verander of beïnvloed is.

Die resultate toon wel aan dat CSP-torings 'n invloed op die verskillende voëlbevolkings het, maar kan dit nie sonder meer as ingrypend beskou word nie. Baie interessant, wel, is die waarneming wat gemaak is dat die spesie-diversiteit, -getalle en -digtheid, van die verskillende voëlbevolkings, hoër is in die aangrensende gebiede as op die aanleg self. Tog is daar ook bewyse dat sommige spesies, veral die wat normaalweg in bos- en woudagtige habitatte voorkom, in 'n redelike mate na die CSP-toringarea gelok word. Hierdie spesies verteenwoordig egter nie 'n ongeaffekteerde groep nie, en word, in 'n beduidend kleiner mate, deur die aanleg benadeel. Verdampingsdamme en ander bronne van water, binne die aanleg, het ook 'n indirekte invloed op veral akwatiese-voëls, deurdat hulle na die bronne aangetrek word. Ook spesies wat daarvoor bekend is dat hul in beboude gebiede aangepas het, is ook geredelik deur die aanleg gelok. Tog ook hier, herhaal die tendens, dat die voëls steeds die gebiede, aangrensend tot die aanleg, as broeiplek, verkies het.

Gedurende die tydperk van monitering (12 maande) is 324, beseerde of noodlottig beseerde voëls gevind, verteenwoordigend van 34 spesies. Daar kon bepaal word dat 61% van die beseerde of noodlottig beseerde voëls, in botsing was met strukture op die aanleg, terwyl 14% deur skroeiing beseer of gedood is. Verder is vasgestel dat die meerderheid van die botsings van die voëls met strukture, plaasgevind het in die heliostat-gebied, met die meerderheid botsings in die onderste kwart van die heliostats. Data vir voëls deur skroeiing gedood of beseer, toon dat dit veral migrende, lugjagters (aerial feeders) is wat hier ten prooi val, veral gedurende die somermaande. Wanneer die heliostats in die bystandposisie geposisioneer is, is die ongevalle dienooreenkomstig kleiner.

Dit is moeilik om 'n sinvolle assessering in die algemeen, wat beserings en sterftes van voëls, spesifiek vir CSP-toringaanlegte, asook ander vorme van opwekking, te maak en om te bepaal wat die werklike risiko vir voëlspesies is. Nogtans het data getoon dat sterftes per ‘n spesifieke gestandardiseerde area 'n meer geskikte wyse kan wees vir die beraming van die kumulatiewe impak onder CSP-toringfasiliteite.

Hierdie studie bied verskeie bevindings en aanbevelings wat kan bydra tot die daarstel van 'n versagtingsraamwerk. Dit sal verseker dat die bedryf op 'n sensitiewe en volhoubare wyse verder in Suid-Afrika ontwikkel.

BIOGRAPHICAL SKETCH

Hendrik Petrus van Heerden was born and raised in Upington and matriculated from Upington High School in 2003. He enrolled at the University of Stellenbosch in 2005 and obtained a Bachelor of Science in Conservation Ecology in 2009. Hendrik's career started in 2010 as an Environmental Consultant from where he pursued his dream of working in the renewable energy industry. His involvement in this sector dates back to 2012 and he currently works as an Environmental and Social Advisor at Scatec Solar, in Cape Town.

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PREFACE

This thesis is presented as a compilation of five chapters. Each chapter is introduced separately and is written according to the style of a typical journal article. None of the chapters have been submitted for publication yet.

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CHAPTER 1: INTRODUCTION

South Africa is committed to a greener economy that is less dependent on coal resources for the generation of electricity. Since the launch of South Africa's Renewable Energy Independent Power Producer Procurement Programme (REIPPPP) in August 2011, large-scale solar thermal power facilities, for example concentrating solar power (CSP) facilities and other solar power generation facilities, have been developed at a rapid rate. Currently, the avifaunal impacts of central receiving CSP technology in particular are poorly understood, posing a challenge for comprehensive analysis of the environmental impacts associated with central receiving CSP facilities.

This chapter aims to describe the process followed to initiate an investigation into the adverse avifaunal impacts associated with central receiving CSP facilities.

1.1 Background

1.1.1 Solar energy and South Africa

The Climate Change Performance Index is an instrument designed to enhance transparency in international climate politics and to determine a country's progress in fulfilling its Paris Agreement commitment to combat climate change (Burck et al., 2017). According to Burck et al., South Africa was ranked amongst the poorest performers in 48th place, with Sweden the best performer in 4th place and Saudi Arabia the poorest in 60th place. No countries were considered as doing enough to prevent climate change to occupy the first, second and third positions, and these were left open in the report. South Africa's low rating can be attributed to its reliance on fossil fuels, particularly coal as the primary energy generation source, which affects the country's performance in terms of emission levels and energy generation efficiency. South Africa's low rating due to fossil fuel reliance emphasises the substantial role that renewable energy will be required to play in diversifying the country's future power generation mix (Burk et al., 2017; Rudman et al., 2017).

Due to its location on the continent, with its diverse geography, coastline and climate, South Africa has an abundance of wind and solar resources (DOE, 2015b; Rudman et al., 2017). The South African climate is considered ideal for solar energy generation, given the abundant solar resources. The annual direct normal irradiance values are in excess of 2 900 kWh/m^2 (Figure 1.1) in the Nama-Karoo and Savanna biomes in the north-western parts of the country. These areas are also characterised by large, relatively topographically flat expanses that fulfil the requirements for the construction of solar power generation facilities (Rudman et al., 2017).

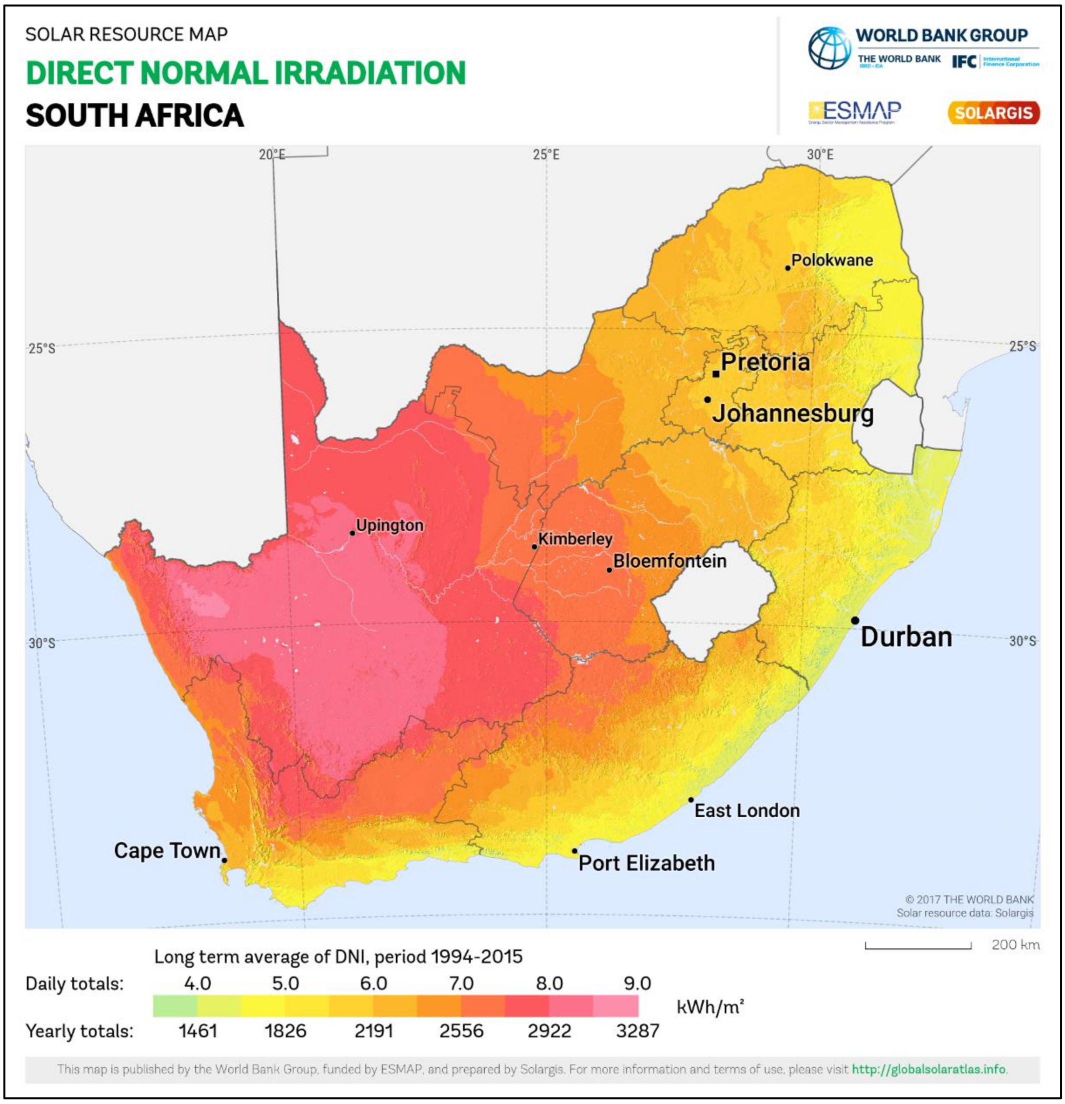

Figure 1.1 Annual direct normal irradiance for South Africa
Source: World Bank (2017)

The publication of the South African White Paper on Renewable Energy (Department of Minerals and Energy, 2003) stimulated renewable energy development in South Africa. To actualise this development, the DOE’s Strategic Plan 2015–2020 explicates the government’s vision to ensure that 30% of South Africa’s energy is derived from renewable energy resources (DOE, 2015b).

The Integrated Resource Plan (IRP), first released in 2010 and promulgated in March 2011, is a subset of the Integrated Energy Plan that aims to set out the energy resources and capacities that will be utilised and related infrastructure that will be constructed in the country between 2010 and 2030 (DOE, 2011). The IRP of 2010 and the IRP Update of 2013 include greater allocation of renewable energy generation capacity in the country by 2030 (DOE, 2015b). The capacity allocations in the 2010 IRP and the IRP Update include 1 200 MW and

3 300 MW respectively for CSP, 8 400 MW and 9 770 MW for photovoltaic (PV) energy and 9 200 MW and 4 360 MW for wind power (Table 1.1).

Table 1.1 Total energy generation capacity allocated to the major renewable energy technologies in the IRP 2010 and the draft IRP Update where an increase in solar power technologies can be observed. The column on the far right represents the total capacities awarded to projects in rounds 1-5 of the REIPPPP.

Technology	IRP 2010 (MW)	IRP Update (MW)	Total allocated in REIPPPP (MW)
Wind	9 200	4 360	3 357
PV	8 400	9 770	2 292
CSP	1 200	3 300	600

Source: DOE (2015a)

The REIPPPP was launched by the DOE in 2011 with the objective to initiate the implementation programme for renewable energy capacity stipulated in the IRP. According to the DOE (2016), the REIPPPP can be lauded as the first successful renewable energy programme in South Africa that initiated significant development of renewable energy generation through independent power producers, subsequently increasing energy diversification and reducing the carbon footprint. The REIPPPP has concluded five bidding rounds between 2011 and 2019, which allocated a total amount of 600 MW to CSP, 2 292 MW to PV energy and 3 357 to wind energy (Table 1.2).

Table 1.2 Total energy generation capacity allocated to the major renewable energy technologies per REIPPPP bid window

Technology	Bid window 1 (MW)	Bid window 2 (MW)	Bid window 3 (MW)	Bid window 3.5 (MW)	Bid window 4 (MW)	Total allocated (MW)
Wind	649	559	787	-	1 362	3 357
PV	627	417	435	-	813	2 292
CSP	150	50	200	200	-	600

Source: DOE (2015a)

1.1.2 Overview of utility-scale solar power developments

Large-scale solar power developments (solar power facilities) are divided into two types of technologies, namely PV and CSP. The location and size of these solar power facilities are determined by the availability of solar resources and the intended use of the produced electricity (Rudman et al., 2017).

Utility-scale solar power developments or systems are generally defined as ground-mounted facilities that exceed 1 MW in production capacity and that are directly tied to the transmission grid. The majority of these facilities found in the industry can generate several hundreds of MW and cover several hundreds of hectares in footprint size (Walston et al., 2015).

CSP facilities, also known as solar thermal electricity systems, harvest solar thermal energy that is then converted into electricity via a conventional thermoelectric power cycle. All CSP facilities utilise reflectors to reflect and concentrate sunlight onto a receiver that absorbs the solar energy and heats a flowing liquid such as water, molten salt, or synthetic oil. The reflectors are mostly made of specially designed glass mirrors that have a highly reflectivity index to ensure that the liquid absorbs the highest levels of thermal energy during the heat exchanging process. The heated liquid may be pumped to a storage tank or pumped directly to heat exchangers in the power block to generate steam. Electricity is generated by spinning a steam turbine/generator.One of the major benefits of CSP is that it has the ability to store energy and retrieve it later to produce electricity in periods of poor sunlight or during late afternoons into the night (Walston et al., 2015; Rudman et al., 2017).

Four main types of CSP technologies exist globally: parabolic dish concentrator systems, known as dish Stirling systems, linear Fresnel systems, parabolic troughs and central receivers, generally referred to as power towers (Everett, 2012). Parabolic troughs and power towers are presently the dominant technological types in the global CSP industry and are also the only two CSP technology types supported by the REIPPPP in South Africa (Rudman et al., 2017). Power towers, as a more recent technology (when compared to older parabolic trough technology), arguably presents a research gap for the investigation of avian impacts (Rudman et al., 2017).

1.2 Solar power developments and the environment

Although considered as ‘renewable’ and ‘green’ energy, the generation and transmission of electricity by utility-scale solar energy facilities also have a number of environmental impacts. The environmental impacts of solar power developments include degradation of habitats, reduction of resource availability and transformation of habitats, which can affect biodiversity (Hernandez et al., 2014). During a comprehensive review and analysis of the environmental impacts of CSP developments in South Africa, Rudman et al. (2017) classified the environmental impacts of solar power facilities as beneficial (e.g. reduction in carbon emissions) or adverse (e.g. wildlife mortality). Rudman et al. assert that avian mortality can be considered as one of the direct adverse impacts that is likely to be the most controversial in impact assessment reports in South Africa. This statement is largely based on the fact that avian mortalities related to utility-scale solar energy developments (power tower CSP facilities in particular) have drawn a substantial amount of negative publicity globally (Ho, 2016). Some media statements even suggest that birds are killed by concentrated solar light, known as solar flux, at a rate of one bird every two minutes. This is concerning considering that these numbers appear to be inflated and based on misinformation when compared with information obtained from prior published scientific studies (Ho, 2016). Therefore, one can argue that given its immaturity, rapid expansion rate and future development prospects, the South African solar power industry is likely to attract similar negative attention due to misinformed sources. This provides both a challenge and an opportunity for the analysis of the direct and indirect avian impacts of CSP developments in South Africa.

1.3 Potential impacts of concentrating solar power facilities

Recent studies suggest that the potential impacts of utility-scale solar energy facilities on avian populations may be substantial, seeing that these developments transform large surface areas in geographical regions of high species endemism (Lovich & Ennen, 2011). More specifically, it is generally accepted that CSP facilities have the potential to impact avian communities directly and indirectly as a result of the project itself and that this impact can be observed within the project footprint (Lovich & Ennen, 2011; Walston et al., 2015; Smith & Dwyer, 2016). The nature and extent of direct and indirect impacts on avian demography are related to three project-specific factors, which are location, footprint size and technology (Lovich & Ennen, 2011).

Indirect environmental impacts may potentially alter bird communities through habitat degradation, increased surface water runoff, water depletion, dust deposition, noise and/or visual impacts (Lovich & Ennen, 2011; Walston et al., 2015; Smith & Dwyer, 2016). The potential direct avian impact of CSP towers are mainly because of exposure to concentrated solar flux around the power tower receiver and collision risk imposed by the large reflective surfaces of heliostats (Kagan et al., 2014). The region of solar flux around the power tower may expose birds passing through it to shock and damage to feathers and soft tissue (McCrary et al., 1986; Hernandez et al., 2014). In addition, CSP technologies involve the utilisation of waste water evaporation ponds that may increase avian collision risk with infrastructure and alter avian demography by luring birds to these water bodies. This impact may be exacerbated by the fact that these facilities are usually located in arid biomes with low water resource availability (McCrary et al., 1986; Kagan et al., 2014).

The first study outside the United States of America that focussed on the impact of a parabolic trough CSP facility on birds and other animals in the Northern Cape, South Africa, found that recorded mortalities associated with parabolic trough CSP facilities were low in comparison with similar studies on CSP tower facilities and that the facility itself had a low impact on bird populations (Jeal et al., 2017). However, given the global shortfall of published data regarding the avian impact of CSP facilities, conclusive estimates of avian trauma associated with solar energy facilities cannot be established and further investigation of these factors is therefore encouraged (Smith & Dwyer, 2016).

1.4 Problem statement

Relative to other renewable energies (e.g. wind), the impacts of CSP tower facilities on avian communities are not well understood, both globally and locally (Smith & Dwyer, 2016; Jeal et al., 2017). This necessitates further investigation of and research into the effects that CSP towers may have on bird communities given that CSP tower technologies in South Africa are understandably limited, which is reflected in the limited publications available.

This study was the first to investigate the impact of a solar power tower facility in the South Africa. The study aimed to evaluate the impact of the Khi Solar One CSP tower facility on avifauna of the area with special attention to biodiversity dynamics and avian mortalities and injuries. This study is relevant to conservation given that the data collected and the conclusions reached will allow developers and policymakers to make informed management decisions with regard to environmental risk mitigation (specifically linked to avifaunal impacts) during the planning, design, construction and operation of these facilities going forward.

1.5 Research aim and objectives

The aim of this study was to identify and investigate the adverse impacts of the Khi Solar One CSP tower facility on avifauna.

The objectives of the project were as follows:

- To identify patterns of avian utilisation at the facility: On- and offsite surveys were conducted by assessing the patterns of avian use to document and compare on- and offsite avian demography.
- To investigate collision risks: Risks were investigated by monitoring and identifying avian mortality and injury associated with facility structure collisions.
- To investigate solar flux risks: Risks from solar flux were investigated by monitoring and identifying avian mortality and injury associated with solar flux generated at the facility.

- To provide a mitigation framework for the management of and response to avian risks: The ultimate objective was to improve knowledge of the impacts of CSP tower facilities and to establish which mitigation measures were warranted to ensure that the industry developed in a sustainable manner in South Africa.

1.6 Research method

The objectives and limitations of this research subject provided guidance to the following approach to answer the research questions:

- Literature review: Because this type of utility-scale solar energy development is new and poorly researched in South Africa, the literature review consisted of the review of existing reports on similar utility-scale solar energy developments as well as relevant literature on similar local and international developments to obtain a better understanding of the Khi Solar One facility.
- Fieldwork: The Birdlife South Africa guidelines (Jenkins et al., 2015) were used as a basis from which the study methodology was developed, which aimed to investigate and gather data on avian solar flux and infrastructure collision incidents, to identify patterns of avian use by means of vantage point surveys and to conduct parallel-line transects inside and outside the facility footprint.
- Data analysis: Data that were collected during the field surveys were analysed to identify and assess the impacts associated with the CSP development observed during the study. The data were also analysed to determine a suitable collision risk analysis model for this kind of development. The data were further analysed to compare and explain avian behaviour inside and outside the facility footprint to determine whether and to what extent the development had caused a change in avian behaviour.
- Recommendations: Recommendations were put forward for mitigation measures to limit the identified existing avian impacts and potential future impacts as well as for future studies.
- Conclusion: A conclusion regarding the key findings was reached.

1.7 Assumptions

This research study was subject to the following underlying assumptions and limitations:

- The distribution of biomes and vegetation types was according to the vegetation map on the South African National Biodiversity Institute's Biodiversity Geographic

Information System website (http://bgis.sanbi.org/SpacialDataset) and the Mucina & Rutherford (2006) vegetation map of South Africa, Lesotho and Swaziland.

- The accuracy of GPS waypoints taken in the field would be within a 10-m radius.
- Rare species occurred in the study area. However, recording of these species might not occur even if the species did occur in the area.

1.8 Significance and contribution

The academic significance of this work lies in the focus on the avian impact of this specific CSP technology, which is relevant in its field considering the substantial amount of data that was gathered on a weekly basis over four seasons on the study site. The topic of this study is also highly relevant because no peer-reviewed academic literature could be found on the relevant energy technology (i.e. CSP tower) within the study area.

The practical significance lies in the methodology used to investigate the research problem and to provide a breakdown of the extent and significance of avian impacts from CSP tower developments in the local arena. This will possibly allow all role players in the industry to comprehend the significance of avian impacts, which will allow them to make better informed management and policy decisions towards mitigation during the planning, placement, design and operation of these facilities.

1.9 Chapter overview

Chapter 1: General introduction

The context and background of the thesis are introduced by defining the problem statement and research objectives, followed by the research methodology, assumptions, and significance and contribution of the study.

Chapter 2: Literature review

Because this type of technological development is new and avifaunal impact is poorly understood in South Africa, the literature review includes reports on similar projects abroad to gain an extensive understanding of the technology and the impacts thereof in other parts of the world.

Chapter 3: Initial investigation into the indirect impact on bird communities of the Khi Solar One CSP tower facility in the Northern Cape, South Africa

This chapter presents an initial investigation into the indirect impact on bird communities of the Khi Solar One CSP tower facility in the Northern Cape, South Africa, by identifying patterns of avian utilisation at the facility, which will shed more light on species richness and abundance at the facility footprint.

Chapter 4: Initial investigation into the direct impact on bird communities of the Khi Solar One CSP tower facility in the Northern Cape, South Africa

This chapter presents an initial investigation into the direct avian impact of the Khi Solar One CSP tower facility in the Northern Cape, South Africa, by investigating bird injury and mortality caused by facility structure collisions and solar flux generated at the facility.

Chapter 5: General findings, conclusion and recommendations

This chapter presents the findings regarding the direct and indirect avian impacts of the establishment and operation of the Khi Solar One CSP tower facility. The key findings of this study are consolidated by means of a general conclusion.

CHAPTER 2: LITERATURE REVIEW

The nature and extent of avian population and community impacts caused by utility-scale solar power facilities are generally associated with three facility-specific factors, namely technology type, size and location. This is because avian abundance and activity are influenced by habitat availability and the distribution of other physical features in the environment. It is, therefore, anticipated that the impacts of a utility-scale CSP tower facility on birds are ultimately influenced by the location of such a facility in relation to avian habitats, such as migration routes, wetlands and riparian vegetation, as well as the transformation or preservation of habitats within arrays.

The aim of this chapter is to provide a comprehensive literature review regarding vegetation dynamics and avian endemism of the study area, factors influencing bird presence and behaviour, and the avian impacts of CSP tower facilities. The study site is also introduced.

2.1 Study site and area

2.1.1 About the Khi Solar One facility

Khi Solar One is a utility-scale CSP tower facility that is located about 18 km southwest of Upington and that falls within the Kai !Garib Local Municipality in the Northern Cape Province of South Africa. The facility, which commenced with construction in mid-2012 and became operational in December 2016, has a generating capacity of 50 MW and is also the first solar power tower facility in Africa. The development was awarded preferred bidder status during the first bidding window of South Africa's REIPPPP (DOE, 2015a). Abengoa holds a majority share of 51% in the facility, the Industrial Development Corporation holds 29% and the Khi Community Trust holds 20% (Renewables Now, 2016).

The facility covers roughly 320 ha and claims to prevent the emission of approximately 183 000 tons of CO_2 per year by supplying around 45 000 households with clean electricity when compared to coal-burning power stations (Abengoa, 2016). The solar tower, the most conspicuous item of infrastructure in central receiver technology, comprises a cylindrical slip-form casted concrete tower, standing roughly 215 m tall. The solar tower's function is twofold, since it operates as both a central receiver and a natural draft condenser (NDC). The latter implies that solar-generated steam originating from the turbine exhaust condensates through dry cooling and is applied in the facility's internal steam cycle, which greatly improves water consumption. The top-mounted central receiver comprises two water-to-steam heat exchangers, each with its cavities facing in an eastern and western direction, respectively, and a central southern-facing super heater, which turns saturated steam from the two flanking heat exchangers into super-heated steam (Figure 2.1 and Figure 2.2).

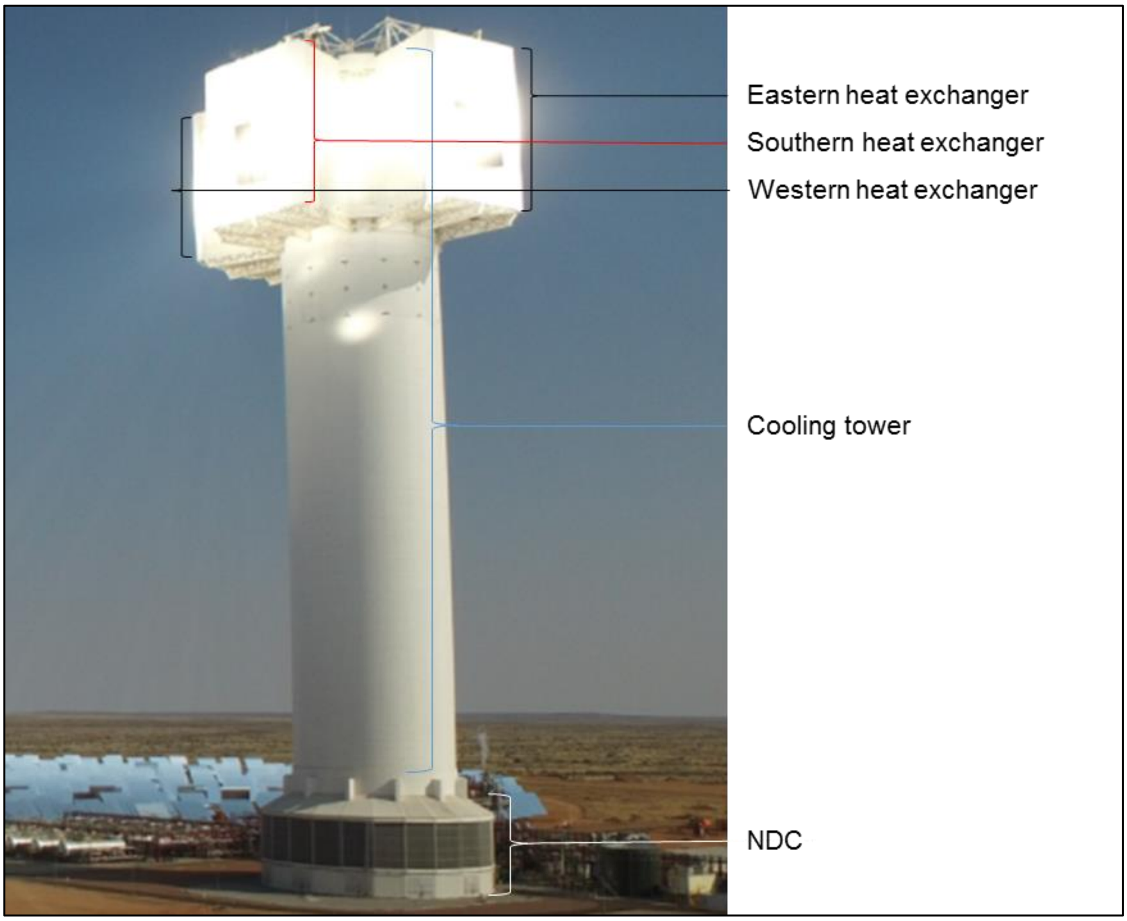

Figure 2.1 Solar tower infrastructure of the Khi Solar One facility

Photo credit: CMI Energy

Each heat exchanger (i.e. cavity) receives its energy from an array of heliostats that are grouped in accordance with each cavity in footprint areas known as the eastern, southern and western solar fields. The three solar fields combined span an area of 300 ha and house more than 4 000 heliostats (Figure 2.2).

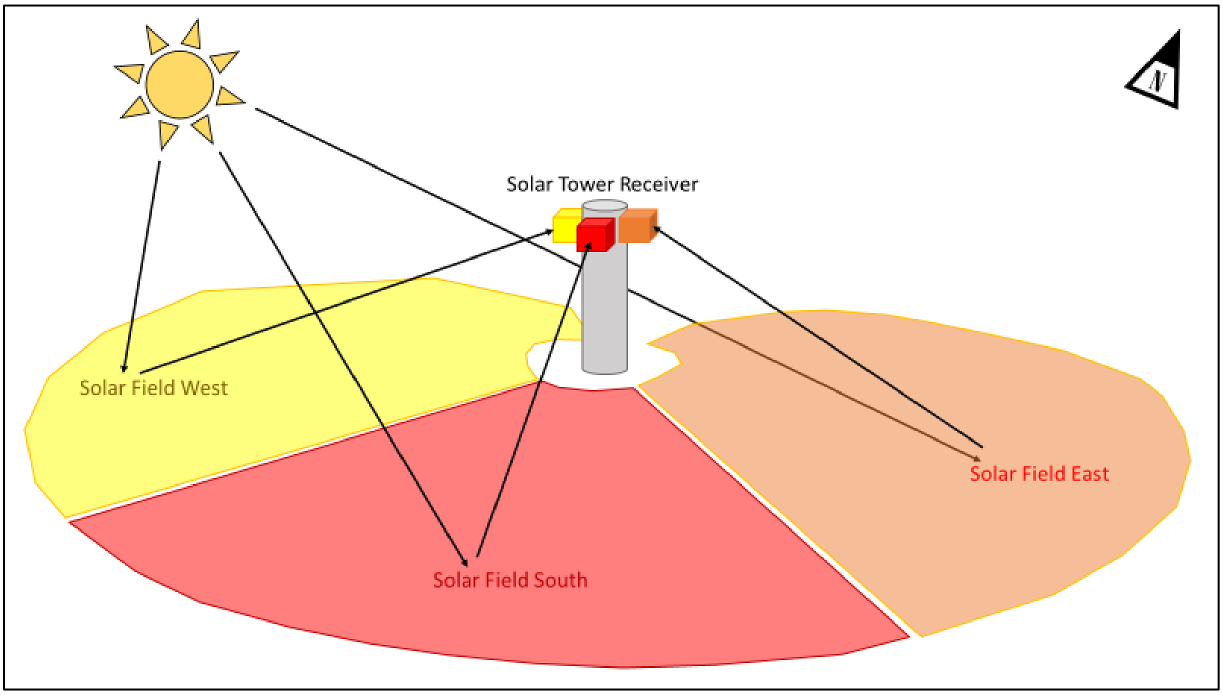

Figure 2.2 A simplified orientational illustration of the Khi Solar One solar tower receiver in relation to the eastern, southern and western solar fields

Image credit: HP van Heerden

The reflective surface of each heliostat contains 21 mirror facets that span an area of roughly 144 m^2, mounted on a single 6-m-tall metal tube pedestal (Figure 2.3).

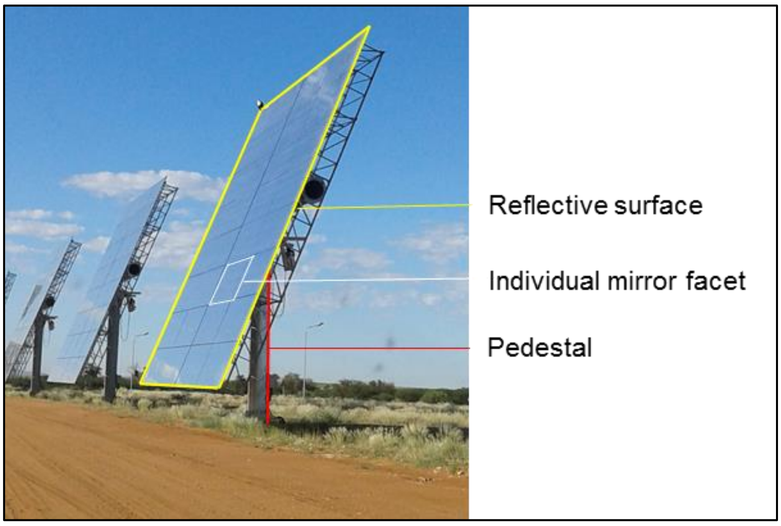

Figure 2.3 Separate main components of a heliostat of the Khi Solar One facility

Photo credit: HP van Heerden

The solar receiver tower is located at the facility footprint area known as the power block that also houses associated infrastructure such as the steam accumulator vessels, steam turbine, control building, electrical substation and water treatment system (Figure 2.4).

As part of the water treatment system, waste water ponds collect steam cycle blowdown (i.e. power station discharge) as well as all the waste water streams generated. Water is neutralised and conveyed at ambient temperature to the onsite dual-lined surface evaporation ponds for dewatering (Figure 2.4). These ponds are designed so that residual solids will not require removal for the duration of the facility's operating life.

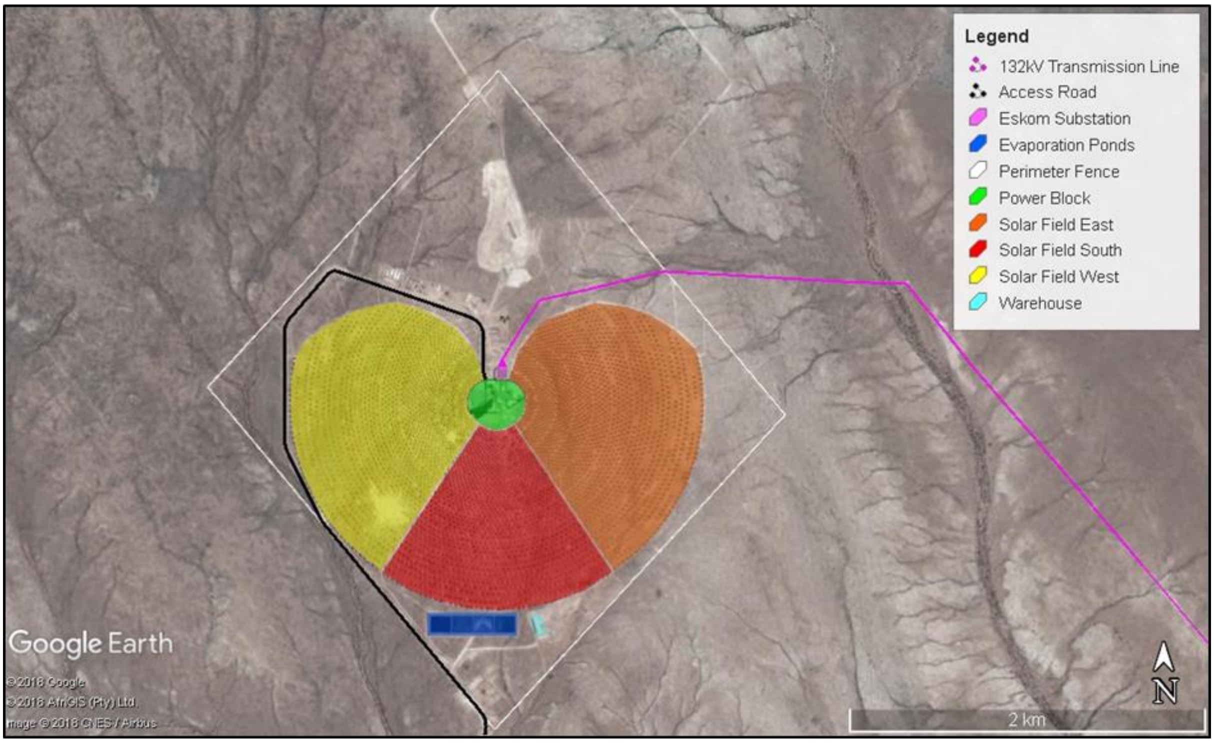

Figure 2.4 Satellite image of Khi Solar One with footprint areas of the facility

Photo credit: Google Earth

While the waste constituents in the liquid waste stream are not classified as hazardous, the ponds are nevertheless designed in accordance with strict international and local requirements and incorporate 1.5 mm high-density polyethylene liners with a leachate (leak detection system) to prevent ground contamination.

2.1.2 Vegetation types of the study area

The study area is situated in the Nama-Karoo biome and consists of two dominant vegetation types, namely Bushmanland Arid Grassland (NKb 3) and Kalahari Karroid Shrubland (NKb 5) (Mucina & Rutherford, 2006; Figure 2.4). Mean annual rainfall in these vegetation types varies between 100 mm and 520 mm (South African National Biodiversity Institute, n.d.). The town of Upington, which is situated near Khi Solar One, has a mean annual rainfall of around 150 mm (Dean & Milton, 1999). The only vegetation type listed as endangered is the Lower Gariep Alluvial Vegetation (AZa 3), occurring 7-9 km southeast of the study area, along the Orange River (Mucina & Rutherford, 2006).

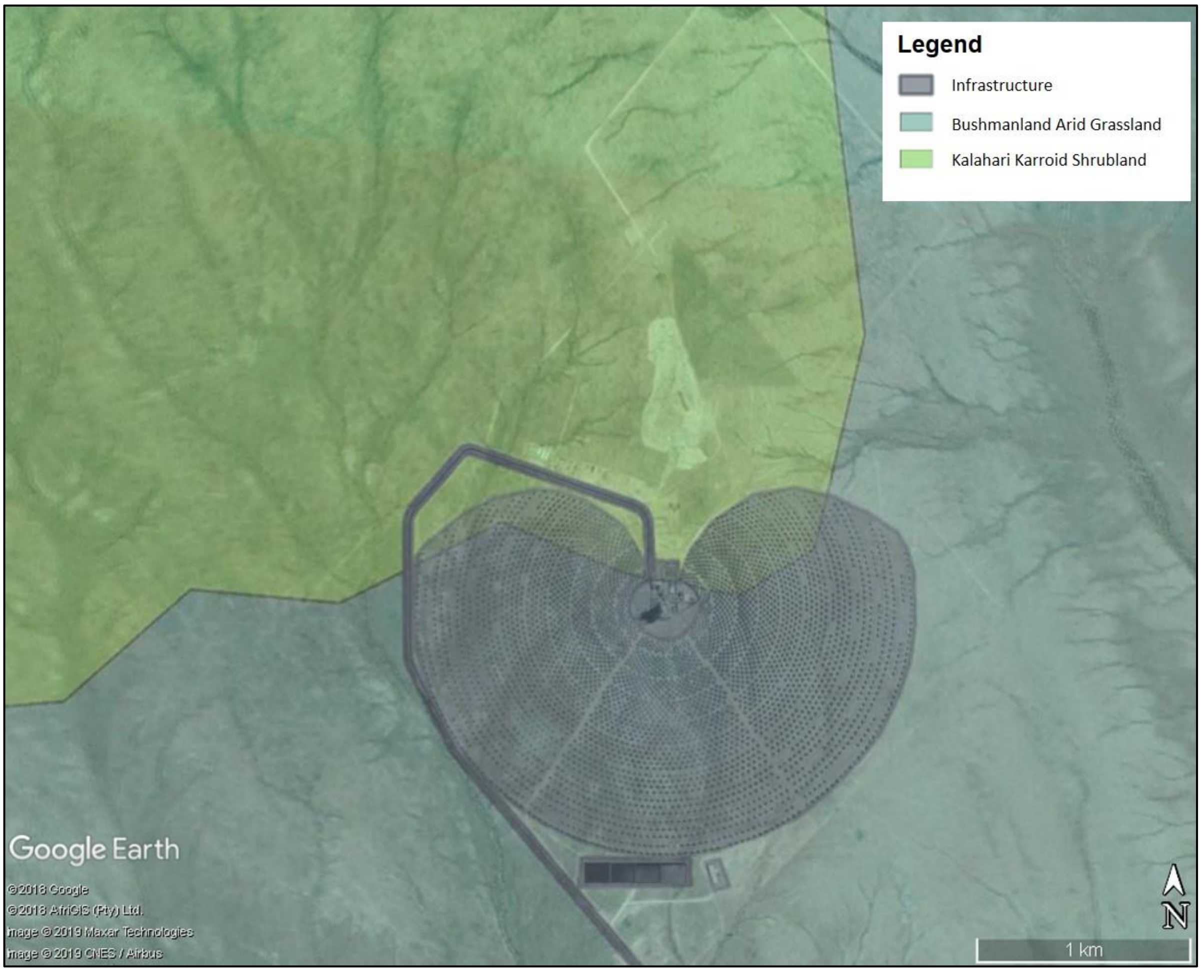

Figure 2.5 Study area displaying the study site and vegetation types
Source: Mucina and Rutherford (2006); photo credit: Google Earth

The Bushmanland Arid Grassland landscape comprises widespread or fragmented plains on a gentle, sloping plateau. Vegetation density fluctuates annually from high to relatively sparse densities, comprising mostly grass species of the genera *Stipagrostis*, *Enneapogon*, *Eragrostis* and *Schmidtia*. Shrubs occur at variable density, dominated by *Acacia mellifera*, *Rhigozum trichotomum* and *Boscia foetida* subspecies *foetida.* Dwarf karroid shrubs, especially of the genera *Pentzia*, *Aptosimum*, *Pteronia* and *Salsola* (Mucina & Rutherford, 2006), are also common.

Bushmanland Arid Grassland vegetation is currently classified as least threatened; however, a target of 21% has been earmarked for conservation, of which a small portion falls within the Augrabies National Park. Very little of this vegetation type has been transformed in general; however, extensive areas may be in various states of degradation due to grazing pressure (Mucina & Rutherford, 2006).

The Bushmanland Arid Grassland merges to some extent with fragments of the Kalahari Karroid Shrubland within the study area. Kalahari Karroid Shrubland typically occurs along gravelly scraps of intermittent rivers or narrow belts on calcrete outcrops. This vegetation type is characterised by a low karroid shrub layer with grasses and shrubs that are more related to the Savannah biome (i.e. Kalahari Duneveld). Tall shrubs and small trees are dominated by *Acacia mellifera*, *Rhigozum trichotomum*, *Parkinsonia africana*, *Boscia albitrunca* and *Boscia foetida* subspecies *foetida*. The lower shrub layer is typically populated with genera that include *Hermannia*, *Aptosimum*, *Leucospharea* and *Monechma.* Grass layer composition varies but consists predominantly of *Stipagrostis*, *Enneapogon*, *Eragrostis* and *Schmidtia* genera (Mucina & Rutherford, 2006).

Kalahari Karroid Shrubland is also considered as least threatened and holds a conservation target of 21% overall. Currently, only a small fraction is protected in the Augrabies National Park. Belts of this vegetation type have in the past been negatively impacted by road infrastructure, which has resulted in the introduction of several alien invasive species (Mucina & Rutherford, 2006).

2.1.3 Avian endemism, diversity and Red Data species occurring in the study area

A desktop study of avian diversity and respective conservation status was done by utilising a variety of field guides, leading to the conclusion that 196 avifauna species potentially occur in the study area, as summarised in Appendix A. Initial analysis, based on distribution ranges and habitat requirements, identified six species of special concern that were likely to occur within the study area (Table 2.1).

Table 2.1 Avifaunal species of special concern likely to occur in the study area

Common name	Scientific name	Regional status
Kori bustard	*Ardeotis kori*	NT
Lanner falcon	*Falco biarmicus*	VU
Ludwig's bustard	*Neotis ludwigii*	EN
Sociable weaver	*Philetairus socius*	NT
Martial eagle	*Polemaetus bellicosus*	EN
Secretarybird	*Sagittarius serpentarius*	VU
Sclater's lark	*Spizocorys sclateri*	NT

NT = near threatened; VU = vulnerable; EN = endangered

Source: Taylor et al. (2015)

Kori bustard (*Ardeotis kori*)

The Kori bustard inhabits Nama Karoo swarf shrublands and occasionally western grasslands where clumps of trees on tree-lined watercourses provide shade and shelter as well as open, fairly dry savannas within the 100-600 mm rainfall zone (Allan, 1997).

The regional population of this species has been undergoing a steady decline over 47 years and is faced by multiple threats, although habitat destruction seems to be the primary impact (Anderson, 2000; Taylor et al., 2015). Habitat destruction by means of changes in land use and habitat quality, for example through establishment of agricultural fields, overgrazing or bush encroachment, may lead to a decline in food resources, causing localised extinction (Allan, 1997; Anderson, 2000; Young et al., 2003). However, this species is occasionally recorded in transformed habitats such as fire-breaks, airstrips, field pastures and burnt areas (Taylor et al., 2015).

Secondary impacts such as collisions with overhead powerlines may be underestimated, and birds are also known to be killed by entanglement in fences (Van Rooyen, 2000; Taylor et al., 2015). The potential effect of climate change has not been fully investigated; however, initial work suggests that clutches are smaller and fewer during dry years (Osborne, 1998).

Lanner falcon (*Falco biarmicus*)

The lanner falcon favours open grassland, cleared woodlands and agricultural areas (Taylor et al., 2015). Cliffs are utilised for nesting and roosting sites; however, this species also uses alternative structures such as trees and human-made structures, for example buildings and quarries (Jenkins, 1998).

The primary impact on this species is the transformation of habitat within the Grassland biome by means of human activities such as urbanisation, establishment of agricultural land and afforestation that lower prey and foraging opportunities (Barnes & Jenkins, 2000). Collisions with powerlines are also known to occur (Taylor et al., 2015).

Ludwig's bustard (*Neotis ludwigii*)

Ludwig's bustard inhabits flat, open, semiarid shrublands of the Nama Karoo, Succulent Karoo and Namib (Allan, 1994). Habitat tolerance depends on rainfall, allowing the species also to occur in the western grasslands of the Free State and Eastern Cape provinces, the southern Kalahari and cultivated pastures (Allan, 1994).

The regional population of Ludwig's bustard is projected to decline by > 50% over the next 30 years (Taylor et al., 2015). Primary impacts on this species are mortalities originating from collisions with powerlines and telephone lines, and hunting (Taylor et al., 2015).

Sociable weaver (*Philetairus socius*)

The sociable weaver populates arid regions of the North West, western Free State and Northern Cape provinces (Taylor et al., 2015). The range of this species may have expanded due to the construction of artificial nest supports, for example telephone poles, electricity pylons, railway pylons and wind pumps (Taylor et al., 2015). The species is known to drink from artificial water sources such as boreholes, which may be beneficial to the sustainability and extend the range of the sociable weaver (Taylor et al., 2015). At the same time, land transformation by clearing of indigenous nesting trees for agricultural land has reduced population numbers in some areas (Taylor et al., 2015).

Martial eagle (*Polemaetus bellicosus*)

Martial eagles occur in a diverse range of habitats, yet they seem to prefer arid and mesic savanna, forest edges and open shrubland (Simmons, 2005). Habitats that offer adequate tall trees and pylons (e.g. electricity pylons and wind pumps) for nesting and perching will be inhabited by this species given that it is known to nest on human-made structures and in alien trees (Tarboton & Allan, 1984; Machange et al., 2005). The ability to nest on such structures therefore may increase population densities in naturally treeless parts of the Kalahari, Karoo and Namaqualand (Machange et al., 2005).

It is believed that this species has been undergoing a continuous population decline of > 20% over a period of two generations (Taylor et al., 2015). Small-stock farming is earmarked as the primary cause of population decline due to direct impacts such as shooting and trapping and indirect impacts such as poisoning and drowning in sheer-walled farm dams (Barnes, 2000b). Nest site disturbance and electrocution on electricity pylons are also known contributors (Taylor et al., 2015). Another indirect impact is caused by overgrazing, which influences the distribution, abundance and accessibility of prey (Machange et al., 2005).

Secretarybird (*Sagittarius serpentarius*)

The secretarybird prefers open grassland, open savanna and shrub with mean ground cover shorter than 500 mm and adequate scattered trees for nest sites (Boshoff & Allan, 1997; Dean & Simmons, 2005). The species is known to be solitary or to occur in pairs while groups of up to 50 have been documented at waterholes in arid areas (Herhold & Anderson, 2006). Usual nesting occurs on top of isolated flat-crowned trees (particularly *vachellia* species), and in the absence of indigenous thorny trees, alien pines or wattles may be utilised (Tarboton, 2011). Barnes (2000a) suggests that these adaptive traits indicate that the secretarybird may have the potential to exploit marginal conditions and therefore recover from population declines.

The species has undergone a population size reduction of > 30% over the past 10 years, and its causes may be ongoing (Taylor et al., 2015). This reduction is due to indirect impacts such as habitat transformation and agricultural and urban development (Barnes 2000a; Hofmeyr et al., 2014). Direct impacts are caused by powerline collisions, and there is a risk that wind farms may negatively impact this species in the future due to collisions (Taylor et al., 2015).

Sclater's lark (*Spizocorys sclateri*)

Sclater's lark is a scarce semidesert specialist, restricted to western South Africa and Namibia (Taylor et al., 2015). This species occurs on arid to semiarid stony plains with scattered shrubs and grass tuffs on shale soils (Taylor et al., 2015). These birds are often found in areas with impeded drainage and extensive bare patches of quartz gravel that are devoid of vegetation (Keith et al., 1992; Dean, 1997; Lloyd, 2005). Water is consumed frequently from natural and artificial watering points, and nests are normally constructed within 1 km from a water source (Lloyd, 2005). This species is poorly represented in formally protected areas; however, it persists on farms since it likely benefits from stock watering points (Loyd, 2005).

2.2 Factors influencing avifauna presence and behaviour

Like all other living organisms, birds require certain conditions and resources to survive and propagate. Bird distribution is ultimately influenced by the availability of the resources that they require to fulfil their needs (Hockey, 2003). Human activity alters environments directly and indirectly, which causes changes in the factors determining birds' ability to utilise those habitats and subsequently causes a change in bird species composition in the areas in question (Hockey, 2003).

Human intervention such as deforestation, land degradation and transformation, invasions of exotic flora and fauna, and other types of habitat destruction can have a negative effect on species diversity and abundance since habitats can become unsuitable for species. For example, deforestation will cause a direct decline or total disappearance of avian forest specialists in the same way that wetland deterioration will cause the habitat to become unsuitable for wetland birds (e.g. aquatic birds and waders). The subsequent transformed areas become more suitable for generalist species (e.g. starlings) and human commensals (e.g. sparrows) (Hockey, 2003).

A contradictory effect of human intervention is situations where such interference does not have a negative impact on bird species. For example, human migration westwards into southern Africa has resulted in an increase in human-made structures that form suitable breeding environments for birds such as the southern grey-headed sparrow (*Passer diffuses*). In addition, southern grey-headed sparrow movements appear to be closely linked to the lesser honeyguide (*Indicator minor*), which is a nest parasite of the southern grey-headed sparrow (Hockey, 2003). Dam and artificial wetland construction for irrigation and livestock watering also increases the range of water-dependant bird species such as Burchell's sandgrouse (*Pterocles burchelli*) and Sclater's lark (*Spizocorys sclateri*) (Hockey, 2003).

While factors influencing avian diversity might be well documented, ongoing debate remains as to which of the factors influencing avian diversity are more important in determining the presence or absence of bird species in a specific area. The latter statement can be supported by a study conducted by DeGraaf et al. (1991) on forest and rangeland birds that concluded that food, water and shelter were the primary factors influencing bird diversity and abundance. Secondary factors identified were nesting sites, song posts and perch sites. The authors elaborate by stating that proximate factors such as vegetation structure provide indications of ultimate factors such as food availability (De Graaf et al., 1991).

An opposing view suggests that birds are rather 'programmed' to select suitable habitats by identifying patterns and features that are not immediately required for survival (Lack, 1933). This argument is based on the assumption that species are limited in their range of distribution by one of three factors, i.e. suitable climatic conditions, sufficient food supply and safe nesting areas (Lack, 1933). The study therefore suggests that birds do not adapt to a specific area but rather select the area because of their ability to identify potential satisfactory ultimate factors by means of the visible proximate factors.

2.2.1 Food availability

Studies have been conducted to determine whether food availability influences the distribution of birds. Johnson and Sherry (2001) found that food availability did impact the distribution of birds; however, the study did not take vegetation structure into account during the site selection process to determine whether birds were able to track variations in food availability among habitats.

However, vegetation structure was taken into consideration in a similar study by De Walt et al. (2003) that manged to demonstrate a correlation between frugivorous bird species and the availability of food in tropical forest areas. The authors also found that insectivorous bird species distribution might be determined by food availability to some degree, although the effect might not be as reflective given the wide distribution of insect communities within habitats. However, food availability cannot be considered a definitive indicator of species distribution given that this cannot be applied as a general rule to all bird species. For example, food availability may not be a definite indicator of granivorous bird distribution in savanna or grassland biomes due to the abundance of seed-bearing grasses in these biomes (De Walt et al., 2003).

Conversely, small and large raptor species are more constrained in their distribution by food availability in the form of prey species (Casey & Hein, 1994). In general, raptor species tend to be greater specialists in relation to species of other guilds, and their foraging requirements are much more refined, considering that raptors need perches from which to hunt as well as open areas in which to hunt, with the exception that some owl and eagle species such as the crowned eagle (*Stephanoaetus coronatus*) hunt in forest areas (Casey & Hein, 1994; Taylor et al., 2015).

2.2.2 Water availability

The need for water varies among bird species. Granivorous birds such as Sclater's lark (*Spizocorys sclateri*) and the sandgrouse species are restricted in their distribution due to their dependence on a daily supply of water (Hockey, 2003). However, several bird species occurring in the arid areas of southern Africa are not dependent on a regular supply of water (Maclean, 1993).

2.2.3 Nesting sites

Avian species are diverse selectors of nesting sites. This results in all vegetation layers of a specific habitat being available for nesting, depending on the specific nesting requirements of a species (Maclean, 1993). For example, species such as the jackal buzzard (*Buteo rufofuscus*), the peregrine falcon (*Falco peregrinus*) and the cliff swallow (*Hirundo spilodera*) require rocky ledges, cliffs or high human-made structures in areas where ledges or cliffs are absent in the natural landscape (Maclean, 1993). Species that solely nest in trees also occur, such as the fork-tailed drongo (*Dicrurus adsirnilis*), the pied babbler (*Turdoides bicolor*) and the bateleur (*Terathopius ecaudatus*) (Maclean, 1993).

Shrub-nesting birds should be categorised separately from trees nesters as species such as the pririt batis (*Batis pririt*), the long-billed crombec (*Sylvietta rufescens*) and the yellow-bellied eremomelas (*Eremomela icteropygialis*) solely nest in the shrub layer of a habitat (Maclean, 1993). The grass layer of a habitat can also be divided according to species that nest in grass just above the ground, for example the desert cisticola (*Cisticola aridulus*), the white-winged widowbird (*Euplectes albonotatus*) and the Kalahari robin (*Cercotrichas paena*) (Maclean, 1993). The last group of birds categorised according to their nesting habits are species such as the pink-billed lark (*Spizocorys conirostris*), the lark-like bunting (*Emberiza impetuans*) and the kori bustard (*Ardeotis kori*) that are categorised as ground-nesting birds (Maclean, 1993).

2.2.4 Competition

Competition is defined as the process by which species or individuals within species compete for resources. The result of competition is that certain individuals or species in a habitat become deprived of those resources due to their inability to compete with more efficient and/or aggressive competitors (Begon et al., 1996). Overall, competition can be subdivided into direct, indirect, interspecific and intraspecific competition.

Competition can influence bird presence and behaviour directly or indirectly. Direct competition occurs when individuals physically interact with one another to gain access to a resource (e.g. birds jostling for song perches). Indirect competition occurs when an individual's use of a certain resource leads to the inability of other individuals to utilise that resource. An example would be more effective predatory birds hunting prey to such an extent that reduced numbers of prey are available for less effective predatory birds (Begon et al., 1996).

Interspecific competition is defined as competition amongst different species (Begon et al., 1996). This phenomenon is relevant to bird species when species compete for the same or similar resources such as food, nesting sites and song and hunting perches. Interspecific competition results in a reduction in fecundity, survivorship and growth due to the interference of individuals of another species (Begon et al., 1996). This kind of competition is most noticeable in bird species that belong to the same guild or those that utilise the same resources in a habitat, be it nesting, breeding or feeding (Begon et al., 1996). Eventually, this kind of competition leads to the regulation of individual numbers of species occurring in a specific ecosystem (Begon et al., 1996). Moreover, in habitats where contested resources are limited, interspecific competition is more pronounced and can ultimately lead to the complete exclusion of one or more of the weaker competing bird species (Begon et al., 1996). Intraspecific competition deals with instances of competition amongst individuals of the same species

(Begon et al., 1996). This type of competition does not lead to the exclusion of the species from the area; however, it does have a profound effect on the number of individuals of the species in an ecosystem (Begon et al., 1996).

Finally, competition in general has a much more profound effect on specialist bird species in comparison to generalist species (Maesetas et al., 2003). This is because generalists are more resilient to environmental pressures given that they are more adaptable than specialists who, as their name suggests, are much more specific in their resource requirements such as food type, method of feeding and nesting area for breeding (Maesetas et al., 2003). For example, the introduction of pied crows (*Corvus albus*) to an otherwise crow-free environment may reduce the survival and success of the small bird community around them (Madden, 2013) and reduce the success of raptor species breeding nearby (Simmons & Barnard, 2011).

2.2.5 Predation

According to Begon et al. (1996), predation is defined as the killing and resulting consumption of an organism (i.e. prey) by another organism (i.e. predator). The primary effect of predation is the reduction of prey population size by the predatory weeding out of older and weaker individuals, therefore reducing intraspecific competition within the prey population (Begon et al., 1996). However, predation can contribute to other effects on prey populations, depending on the condition under which predation takes place. Prey populations, in theory, will not be completely depleted by predators due to the reduction in predator numbers when prey populations decrease in number (Begon et al., 1996).

Nonetheless, human interference in system processes may cause prey populations to decrease below the critical level required by that population to regenerate and ultimately lead to local extinctions of those species (Keyser, 2002). Human interference factors or impacts that can increase the intensity or effect of predation are habitat fragmentation, introduction of predators (domestic or wild) and destruction of suitable nesting habitats (Keyser, 2002; Maesetas et al., 2003).

2.2.6 Vegetation structure

De Walt et al. (2003) argue that although the role of vegetation structure in shaping bird communities is not entirely clear, vegetation does provide important resources for nesting, foraging and protection for a diverse number of taxa. This supports a much earlier study conducted in 1961 by MacArthur and MacArthur that found a definite positive correlation between vertical height diversity of vegetation and the number of avian species in North American forest areas. Dean (2000) also concluded that an increase in taller, woody vegetation resulted in an increase in avian species richness, compared to the surrounding shrubland in the Karoo semidesert areas of South Africa.

Even so, separate studies conducted in desert scrub and forest areas found no positive correlation between foliage height diversity and avian species diversity (Tomoff, 1974; Willson, 1974). Furthermore, Willson did not find any positive correlation between spatial heterogeneity and avian species diversity, and these findings appear to indicate that bird species diversity is more dependent on factors other than spatial heterogeneity. One can, however, not dismiss the possibility that the studies conducted by Tomoff and Willson were affected by variables that were not taken into account by the researchers.

A study conducted by Flather et al. (1992) found that species diversity could not be accounted for by vertical habitat structure alone and concluded that spatial heterogeneity needed to be considered to predict avian species diversity effectively. Whitford (1997) suggested that bird species diversity essentially increased with an increasing degree of desertification.

Some studies appear to oppose the school of thought that avian diversity is enhanced by vertical structural diversity. A study of avian demography in reforested grasslands suggested that the reforestation of these systems caused a rapid decline not only in grassland bird species but also in the total number of avian species in the afforested area (Naddra & Nyberg, 2001). Locally, Hudson and Bouwman (2007) studied how different land-use types affected bird communities in the Kalahari, and their findings indicated a distinct correlation between an increase in vegetation structural diversity and avian species diversity in savanna biomes.

2.3 Avian impacts of concentrating solar power tower facilities

Human impact on ecosystems have increased the number of sources that cause wildlife mortality (Loss et al., 2015). Subsequently, avian communities are experiencing rapid population declines as a result of multiple anthropogenic impacts (Loss et al., 2015).

Amongst other impacts, climate change and habitat loss mainly cause avian mortality through indirect intermediate mechanisms (Loss et al., 2015; Smith & Dwyer, 2016). For example, a study by Feely and Terborgh (2008) on the direct versus indirect effects of habitat reduction on the loss of avian species from tropical forest fragments, found that habitat loss indirectly impact avian persistence through changes in the abundance and/or composition of other species groups which in turn drive changes in the biotic environment. Yet, their research findings also concluded that habitat loss may also directly drive the loss of avian species through reductions in population size and an associated increase in the risk of local extinction (Feely & Terborgh, 2008).

If compared with indirect impacts, direct avian mortality sources are mostly characterized by visual observation of root cause and effect. This is because the majority of these direct mortality sources can be attributed to collisions with man made structures (i.e. building windows and wind turbines), poisoning and predation by domestic cats (Loss et al., 2015). Yet, several publications note that numerous additional sources of direct avian impact mortality have not been studied sufficiently, which include collision and singeing trauma at solar power tower facilities (Kagan et al., 2014; Loss et al., 2015; Walston et al., 2015; Smith & Dwyer, 2016).

CSP tower facilities, like all other utility-scale solar power facilities of all ranges of technology types, tend to transform and occupy large surface areas to harvest energy from the sun (Walston et al., 2015; Rudman et al., 2017). Therefore, the construction, operation and decommissioning of CSP tower facilities signify a strong human land-use impact on the environment that has the potential to affect avian communities and individuals in a number of direct and indirect ways (Walston et al., 2015; Rudman et al., 2017).

2.3.1 Indirect impacts

The development footprint size of any utility-scale solar power facility logically stands as a direct measure of the extent of habitat transformation caused by human activity (Walston et al., 2015). One can therefore expect that a facility with a larger development footprint will have a greater overall impact on avifauna than a project with a smaller footprint (Walston et al., 2015). In some instances, the development of CSP facilities has resulted in the complete removal of vegetation from the development footprint (Lovic & Ennen, 2011). Vegetation removal by itself tends to destroy, degrade and/or fragment habitats or otherwise displace birds from large areas of their natural habitat, especially species with restricted ranges and specific habitat requirements (Lovic & Ennen, 2011).

However, it is important to consider that the utilisation of different facility components may indirectly influence the types and magnitude of impacts on birds (Walston et al., 2015). An example of such an indirect impact is facilities that deploy wet-cooling technologies that consume more water than their dry-cooling counterparts (i.e. Khi Solar One's NDC). This may significantly increase water demand and alter the availability of water sources to sustain water-dependant avian populations in a particular habitat (Lovic & Ennen, 2011; Hernandez et al., 2014).

Facilities such as Khi Solar One that utilise evaporation ponds for waste water disposal may also provide an artificial habitat by luring birds to these water bodies, especially considering that these facilities are normally found in arid biomes with low water resource availability (McCrary et al., 1986; Kagan et al., 2014). This may increase avian collision risk with facility components and/or change bird community structures by attracting species of birds or animals that were not previously recorded in the area (McCrary et al., 1986; Kagan et al., 2014; Smith & Dwyer, 2016). Other perceived indirect impacts associated with CSP facilities are the use of structural components for nesting and roosting sites, noise pollution (e.g. behavioural changes), the effects of altered surface water and groundwater on habitat condition, and light pollution attracting insects, which in turn lures foraging insectivorous avian species to the facility (Lovich & Ennen, 2011; Hernandez et al., 2014).

In contrast, although based on utility-scale PV facilities, it is worth mentioning that recent reports in Europe have found empirical evidence indicating that PV facilities enable the formation of working synergies amid climate protection and nature conservation (Peschel, 2010; Parker & McQueen, 2013). For instance, brown sites such as landfills and defunct agricultural lands were converted into biotopes of a higher value compared to their original state, resulting in the luring of novel avian species benefitting from the artificial provision of otherwise scarce resources such as nesting sites, shade and perches (Peschel, 2010; Parker & McQueen, 2013; DeVault et al., 2014).

2.3.2 Direct impacts

Direct impacts occur as a result of land transformation at a facility and are observable within the development footprint (Walston et al., 2015). Although several types of direct impacts such as habitat fragmentation and habitat destruction exist, direct solar energy-related bird fatality impact factors have been identified by several reports, which has drawn a significant amount of attention and negative publicity (McCrary et al., 1986; Hernandez et al., 2014; Kagan et al., 2014; Ho, 2016). Certain press releases suggest that birds are being killed by solar energy-related bird impact factors at a rate of one bird every two minutes, which amounts to 28 000 birds annually (Peck, 2014; Ho, 2016). These reported numbers appear to be exaggerated and misleading, given that these reports are based on anecdotal observations (Ho, 2016).

In addition to collision and solar flux risks, some researchers hypothesise that polarised light (derived from the solar flux generated around the tower) has the potential to attract invertebrates to the tower, with insects being burnt when entering the solar flux. This is thought to attract insectivorous avifauna to facilities, thereby increasing the risk to birds and amplifying mortality rates, potentially causing an ecological ‘mega-trap’ around a solar tower and exposing an entire food chain to injury or death (Kagan et al., 2014). To further anticipate direct impacts that might be inflicted by Khi Solar One, it was worth studying avian mortality studies at other CSP tower facilities on a global scale, which is summarised in Table 2.2.

Table 2.2 Summary of avian mortality findings at CSP tower facilities

Facility	MW	Solar towers	Tower height (m)	Area (ha)	Survey (months)	Total deaths	Singeing	Collision trauma	Average deaths per month
ISEGS (USA)	337	3	130	1 457	12	2 500	1 146	1 352	208
CDSEP (USA)	110	1	200	660	1	115	115	-	115
Gemasolar (Spain)	20	1	140	200	14	0	-	-	0
Solar One (USA)	10	1	86	40	10	70	13	57	7
SEDC (Israel)	6	1	60	8	48	0	0	-	0

Source: McCrary et al. (1986), Ho (2016) and West Inc. (2015).

Solar One (Daggett, California)

During 40 weeks of study from May 1982 to June 1983 on Solar One, a 10-MW direct-steam pilot project that is located in California's Mojave Desert, McCrary et al. (1986) recorded 57 collision fatalities and 13 singeing fatalities (Table 2.2). Aerial foragers such as swallows and swifts were found to be more susceptible to injury due to their foraging behaviour (McCrary et al., 1986). It is worth noting that singeing incidents were attributed to birds' being burned while flying through the standby focal point above the tower and not while the heliostats were focused on the central receiver of the tower (McCrary et al., 1986). McCrary et al. also found that most of the collision incidences were recorded at the reflective surfaces (i.e. mirrors) of the heliostats and not at other components of the heliostats or the solar tower. Considering the number of avian fatalities during the study, the impact of the facility on avifauna was determined to be minimal with a mortality rate of 1.9–2.2 birds per week, which was only 0.6–0.7% of the local population (McCrary et al., 1986).

Ivanpah Solar Electric Generating System (Ivanpah, California)

Detailed avian and bat monitoring surveys were conducted from 21 October 2014 to 20 October 2015 at the ISEGS, located in California, which consists of three CSP tower facilities spanning 1 457 ha with a combined net capacity of 377 MW (West Inc., 2015). Data collected during the surveys were used in conjunction with a fatality estimator model to estimate 2 500 avian fatalities from known causes (i.e. singeing and collision). Of the known causes, 54% were collision incidents and 45.8% were singeing incidents (Table 2.2) (West Inc., 2015).

Crescent Dunes Solar Energy Project (Tonapah, Nevada)

The CDSEP, located in Nevada, operates at a capacity of 110 MW, and 114 avian fatalities were recorded in January 2015 (Table 2.2) (Ho, 2016). Mortality was mainly caused by birds' flying through the solar flux when 3 000 heliostats were aimed at standby points above the tower receiver (Ho, 2016).

Solar Energy Development Centre (Negev Desert, Southern Israel)

Contrary to the findings above, the 6 MW SEDC in Israel reported no avian singeing in four years of operation while following United States Fish and Wildlife Service protocols (Table 2.2) (Ho, 2016).

Gemasolar Thermosolar Plant (Gemasolar) (Andalusia, Spain)

The Gemasolar facility, which has a capacity of 20 MW and is located in Spain, is situated in an area with a high avian population, and during a 14-month study by the Department of Zoology, University of Granada, no avian fatalities were recorded in the vicinity of the tower (Table 2.2) (Ho, 2016).

2.4 Conclusion

The literature included in this chapter serves to provide the necessary context and background for the study site and area, to provide the background of the factors that influence avifauna presence and behaviour within a habitat, and to provide an introduction to the recognised and hypothesised avian impacts of CSP tower facilities.

International media reports of multiple avian deaths caused by solar flux and impact trauma through collisions at CSP tower facilities appear to be misleading and inflated. A review of dated and recent avian mortality studies at several CSP tower facilities around the world was performed, which brought some context to the argument seeing that on average, only 66 deaths occurred per month (Table 2.2). However, given the variability in findings of previous studies and seeing that no literature on the impact of CSP tower facilities in southern Africa was available, it was deemed crucial to investigate how Khi Solar One's technology type, size and location influenced the avian population composition and dynamics.

It is also evident that CSP facilities may potentially offer benefits through an increase in habitat availability due to the increase in food and water resources (e.g. evaporation ponds) and nesting sites (e.g. facility components). These beneficial spinoffs may potentially offset some of the negative impacts of habitat loss. Therefore, by understanding how avian communities are affected, one can grasp the full impact of this type of facility.

CHAPTER 3: INITIAL INVESTIGATION INTO THE INDIRECT IMPACT ON BIRD COMMUNITIES OF THE KHI SOLAR ONE CSP TOWER FACILITY IN THE NORTHERN CAPE, SOUTH AFRICA

Although regarded as “green” and “renewable” energy, the generation of electricity from utility-scale solar energy facilities also precipitate a number of avian impacts. Impacts caused by utility-scale solar energy facilities can range from habitat degradation and reduction of resource availability to transformation of habitats, which may affect avian biodiversity (Hernandez et al., 2014). Yet, only a limited amount of studies have investigated the potential for indirect impacts on avian biodiversity dynamics resulting from the habitat transformation and degradation.

This chapter presents the results of an investigation into the impact on avian biodiversity dynamics of a utility-scale power tower CSP facility in the Northern Cape, South Africa. In the study, a comparison was made between the abundance and composition of avian communities inside the CSP facility’s solar field and adjacent rangelands. Avian species diversity, abundance and density per unit area were found to be higher in the neighbouring untransformed habitat than within the facility footprint. Survey observations and gathered abundance and density data suggest that certain shrubland/woodland species favoured the CSP facility, however, overall, they did not represent an unaffected population by default. In contrast, generalist and open country/grassland species were not adversely affected by impacts caused by the CSP tower facility. The presence of man-made structures such as water bodies within the transformed habitat appeared to be luring a diversity of aquatic species and species that favour an urban habitat. As for avian use and behaviour, the majority of recorded avian species in the facility and reference survey areas fly at an average height of approximately 6 m, while the average minimum height is 5 m and the average maximum height is 17 m. Breeding observations indicated that breeding activity within the transformed habitat was lower than within the untransformed habitat.

3.1 Introduction

3.1.1 Known indirect impacts of utility-scale solar energy facilities on birds

Lovich and Ennen (2011) suggest that the potential impacts of utility-scale solar energy facilities on avian populations may be substantial, since these developments may transform large surface areas in geographical regions of high species endemism. Habitat loss indirectly impacts avian persistence through changes in the abundance and/or composition of other species groups which in turn drive changes in the biotic environment (Feely & Terborgh, 2008). The nature and extent of indirect impacts on avian demography are related to three project-specific factors, which are location, footprint size and technology (Lovich & Ennen, 2011).

For example, utility-scale solar energy facilities located in arid biomes that utilise evaporation ponds and/or water reservoirs, may create artificial habitats by luring birds to these water bodies (McCrary et al., 1986; Kagan et al., 2014). This may change bird community structures by attracting novel bird species that were not previously recorded in the area (McCrary et al., 1986; Kagan et al., 2014; Smith & Dwyer, 2016).

The development footprint of any utility-scale solar power facility stands as a direct measure of the extent of habitat transformation caused by human activity (Walston et al., 2015). Vegetation removal by itself tends to destroy, degrade and/or fragment habitats or otherwise displace birds from large areas of their natural habitat, especially species with restricted ranges and specific habitat requirements (Lovic & Ennen, 2011). Utility-scale solar power facilities can also disrupt habitat hydrology by increase in stormwater surface runoff or water extraction, which may impact both avian habitat and food availability (Hernandez et al. 2014).

DeVault et al. (2014) demonstrated in a study on five different utility-scale solar PV facilities across the United States, that avian species diversity was lower at each of the facilities when compared to their adjacent grasslands. In contrast, avian densities at these facilities was more than double when compared to the adjacent grasslands. The facility infrastructure associated with the technology type, therefore provided certain habitat novelties such as shade, perches and nesting sites which increased avian use at these facilities (Devault et al., 2014; Smith & Dwyer, 2016).

The first study on the impact of a parabolic trough CSP facility on birds and other animals in a South African context was conducted at the ACWA Power SolAfrica Bokpoort CSP facility, which is located approximately 90 km southwest of Khi Solar One and effectively shares the same biome and vegetation types as the latter (Jeal et al., 2017). Although a trough CSP facility, the facility also comprises a number of infrastructure components similar to those found at Khi Solar One, given that evaporation ponds are also utilised (Jeal et al., 2017). The study concluded that avian communities were significantly affected by changes in demography within the solar fields where vegetation had been stripped, which demonstrated the effect of habitat loss on birds (Jeal et al., 2017).

3.1.2 Understanding the mechanisms that underlie the indirect effects of utility-scale solar energy on birds

Comparative to other renewable energies, the impacts of CSP tower facilities on avian communities are both globally and locally not well understood (Smith & Dwyer, 2016; Jeal et al., 2017). This necessitates further investigation of and research into the effects that CSP towers may have on bird communities given that CSP tower technologies in South Africa are understandably limited, which is reflected in the limited publications available.

3.2 Methodology and data analysis to investigate patterns of avian use

3.2.1 Study Site and Area

The study site was subdivided into two survey areas: The Khi Solar One facility footprint was represented by the facility's solar field, power block, evaporation ponds and warehouse and represented a transformed habitat (Figure 3.1). The neighbouring untransformed habitat constituted the reference site (Figure 3.1), based on information from an Environmental Impact Assessment indicating that the physical environmental conditions were similar to the facility footprint prior to construction (Savannah, 2010).

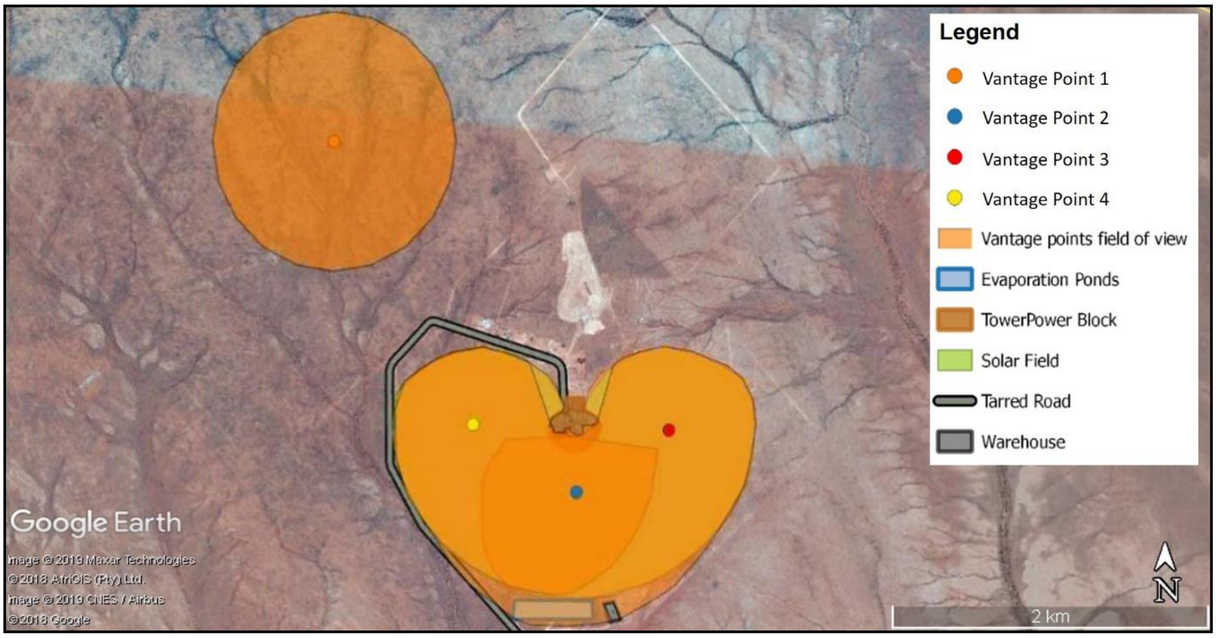

Figure 3.1 Locations of the vantage point surveys within the study area
(Darker shades indicate overlaps of field of view)

Photo credit: Google Earth

3.2.2 Survey Design

Avian community surveys were conducted in the dry season (i.e. winter) from 8 to 13 July 2015 and in the wet season (i.e. summer) from 2 to 6 April 2016.

3.2.3 Field methodology

3.2.3.1 Vantage point surveys

Avian community surveys were conducted using vantage point surveys during the dry and wet seasons. One vantage point survey was conducted in the reference site outside the facility footprint (Figure 3.1; Legend: Vantage Point 1). One vantage point survey was deemed adequate for this site seeing that visibility (line of sight) was not impeded by vegetation or geomorpholocilal charaterisics of the terrain. However, because visibility was impeded by CSP infrastructure within the development footprint, three vantage point surveys were conducted inside the facility footprint (Figure 3.1; Legends: Vantage Point 2; Vantage Point 3 & Vantage Point 4). The approximate radius of each of the vantage point surveys was 800 m, although this varied according to topography.

Survey equipment utilised for vantage point surveys included Zeiss Conquest 15x56 binoculars; Sightmark SM21031K 6-100x100 Spotting Scope; Garmin Montana 600 GPS; Tascam DR-100MKII sound recorder with ME66/K6 Microphone; Samsung Galaxy 4 Tablet with preloaded field data sheets; and waterproof notebook and pencil.

Each of the vantage points was surveyed for 12 hours, from 06:00 to 18:00 each day, 5 days per season. The following data were recorded at each site: date of survey; location (co-ordinates of vantage point); species recorded; number of each species recorded; species behaviour; and species flight height.

3.2.3.2 Parallel-line transects

Avian breeding surveys were conducted using 10 transects of 100 m in parallel 10-m intervals, thus covering a total area of 1 ha. The aim of these surveys was to investigate any evidence of nesting and breeding birds inside and outside the facility footprint. The position of these transect blocks are given in Figure 3.2.

The following data were recorded at each site: date of survey; location (co-ordinates of the transects; nests recorded (including species); paired birds recorded (including species); eggs, hatchlings and fledglings recorded (including species); and courtship or other breeding behaviour.

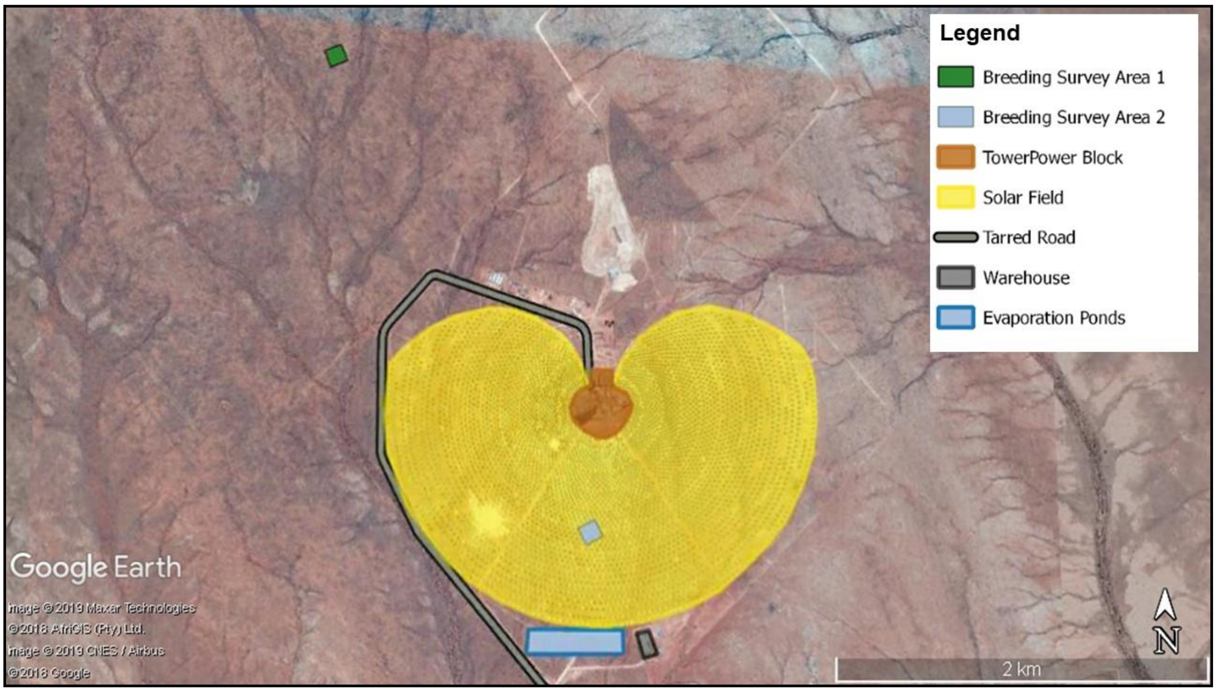

Figure 3.2 Locations of the transect surveys within the study area

Photo credit: Google Earth

3.2.3.3 Survey and data collection protocols

Vantage point and transect surveys were carried out according to standard procedures, and possible biases caused by different observers, detectability, time of day, bird song activity and/or weather conditions were considered (Bibby et al., 2000). All detected birds seen and heard were counted and identified with Zeiss Conquest 15 x 56 binoculars. Surveys were conducted from the early morning from just befor dawn until the late afternoon until just before dusk, when birds were most active and noticeable, ranging from around 06:00 to 18:00 (Bibby et al., 2000). Surveys were not conducted on days when weather conditions might have affected avian activity such as thunder storms, sand storms.

3.2.4 Data analysis

All birds heard or seen at each vantage point survey up to 800 m from the observer were recorded to document species occurrence and to estimate abundance. The total number of birds observed was used to calculate species richness and abundance (West Inc., 2015). Results for species composition (number of species recorded) and avian abundance (number of observations) were presented by survey area (West Inc., 2015). One vantage point survey was conducted for the reference site and three for the solar energy facility. For the purpose of comparison, the solar energy facility data were subsequently normalised by using the mean for the three sites rounded to the nearest integer. Mean avian use (number of birds per survey) was presented to standardise data among survey areas to account for unequal number of visits per survey area.

Avifauna data were subsequently analysed by calculating the average height per species (quantitative) when compared between the minimum and maximum recorded flight height and evidence of breeding in the facility footprint and reference site (i.e. untransformed habitat). Data were furthermore analysed to determine patterns of avian land use between the facility footprint and the reference site.

3.3 Results

3.3.1 Dry and wet season survey results

A total of 57 recognisable avian species and a total of 2 380 individual avian observations were recorded during the avian demograpy during the 2015–2016 monitoring year. Table 3.1 lists these species and the number of individuals observed within the facility footprint and reference site survey areas by dry (i.e. winter) and wet (i.e. summer) season and habitat preference. Table 3.2 summarises avian species diversity and abundance within the facility footprint and reference site survey areas according to their habitat distribution and preference.

Table 3.1 Avian dry and wet season survey results for species diversity and abundance within the reference site and facility footprint grouped according to their habitat dependencies

Common name	Biological name	Conservation status		Winter				Summer			
				Reference site	Facility footprint			Reference site	Facility footprint		
		Regional	Global	Vantage point 1	Vantage point 2	Vantage point 3	Vantage point 4	Vantage point 1	Vantage point 2	Vantage point 3	Vantage point 4
Guild – aquatic species											
Egyptian goose	*Alopochen aegyptiaca*	–	LC	0	1	0	0	0	5	2	0
Cape teal	*Anas capensis*	–	LC	0	5	0	0	0	12	0	0
Guild – generalist species											
Acacia pied barbet	*Tricholaema leucomelas*	–	LC	0	1	1	0	1	0	2	0
Bokmakierie	*Telophorus zeylonus*	LC	LC	2	0	0	0	2	0	0	0
Cape glossy starling	*Lamprotornis nitens*	–	LC	11	1	4	1	12	2	7	3
Cape turtle dove	*Streptopelia capicola*	–	–	10	11	13	9	14	16	18	13
Cape wagtail	*Motacilla capensis*	–	LC	1	0	0	0	1	1	0	0
Familiar chat	*Cercomela familiaris*	–	LC	6	5	3	4	7	9	6	8
Laughing dove	*Streptopelia senegalensis*	–	LC	6	7	7	9	12	13	12	19
Pied crow	*Corvus albus*	–	LC	3	3	2	3	2	2	1	3
Southern (common) fiscal	*Lanius collaris*	–	LC	1	0	0	0	1	0	1	0
Spotted eagle owl	*Bubo africanus*	–	LC	0	0	0	0	0	0	0	0

Red-billed quelea	*Quelea quelea*	–	–	44	32	43	28	68	45	32	37
				Guild – open country/grassland species							
African pipit	*Anthus cinnamomeus*	–	LC	0	0	0	0	1	0	0	0
Ant-eating chat	*Myrmecocichla formicivora*	–	LC	3	3	1	3	9	5	6	3
Crowned lapwing	*Vanellus coronatus*	–	LC	1	0	0	0	2	0	0	0
Desert cisticola	*Cisticola aridulus*	–	LC	3	1	0	1	5	2	1	0
Grey-backed sparrow-lark	*Eremopterix verticalis*	LC	LC	6	2	3	2	10	4	6	2
Lanner falcon	*Falco biarmicus*	VU	LC	0	0	0	0	0	1	2	1
Northern black korhaan	*Afrotis afraoides*	LC	LC	2	0	0	0	3	0	0	0
Red-capped lark	*Calandrella cinerea*	–	LC	4	2	1	0	4	3	0	2
Spike-heeled lark	*Chersomanes albofasciata*	–	LC	3	0	5	1	4	5	7	3
Zitting cisticola	*Cisticola juncidis*	–	LC	3	0	0	0	4	1	0	0
Common quail	*Coturnix coturnix*	–	LC	2	0	0	0	2	1	0	0
Zebra finch	*Taeniopygia guttata*	–	LC	2	0	1	1	3	1	4	0
Blacksmith lapwing	*Vanellus armatus*	–	LC	1	0	2	0	1	1	3	0
White-throated swallow	*Hirundo albigularis*	–	–	0	0	0	0	13	12	14	17
Red-headed finch	*Amadina erythrocephala*	–	LC	14	18	19	12	16	21	23	19
				Guild – shrubland/woodland species							
African red-eyed bulbul	*Pycnonotus nigricans*	–	LC	6	3	4	3	8	5	3	6
Ashy tit	*Parus cinerascens*	–	LC	0	0	0	0	1	0	0	0
Chestnut-vented tit-babbler	*Sylvia subcaerulea*	–	–	1	0	0	0	3	0	0	1
Dusky sunbird	*Cinnyris fuscus*	LC	LC	2	0	0	0	3	0	0	0
Fawn-coloured lark	*Calendulauda africanoides*	LC	LC	8	2	2	1	12	4	3	3
Grey-backed cisticola	*Cisticola subruficapilla*	–	LC	3	0	0	0	4	1	0	0

Hadeda ibis	*Bostrychia hagedash*	–	LC	3	0	0	2	2	1	1	2
Kalahari scrub robin	*Erythropygia paena*	–	LC	8	2	0	1	9	4	0	2
Karoo korhaan	*Eupodotis vigorsii*	NT	LC	2	0	0	0	2	0	0	0
Lark-like bunting	*Emberiza impetuani*	LC	LC	8	10	15	148	10	12	18	17
Layard's tit-babbler	*Sylvia layardi*	LC	LC	0	0	0	0	2	0	0	0
Long-billed crombec	*Sylvietta rufescens*	–	LC	0	0	0	0	1	0	0	0
Namaqua dove	*Oena capensis*	–	LC	5	2	1	4	5	3	2	7
Namaqua sandgrouse	*Pterocles namaqua*	LC	LC	9	5	3	6	11	5	3	9
Pale chanting goshawk	*Melierax canorus*	–	LC	0	0	0	0	1	0	0	0
Pririt batis	*Batis pririt*	–	LC	3	0	0	0	4	0	1	0
Red-crested korhaan	*Lophotis ruficrista*	LC	LC	1	0	0	0	1	0	0	0
Red-eyed dove	*Streptopelia semitorquata*	–	LC	1	2	0	1	2	4	2	1
Sabota lark	*Calendulauda sabota*	LC	LC	8	2	1	1	9	3	3	2
Sociable weaver	*Philetairus socius*	–	NT	32	44	76	32	48	68	92	44
White-backed mousebird	*Colius colius*	–	LC	12	0	3	0	16	0	2	1
White-browed sparrow-weaver	*Plocepasser mahali*	–	LC	11	9	6	16	16	13	9	18
Scaly-feathered finch	*Sporopipes squamifrons*	LC	LC	5	3	3	1	2	5	2	7
Olive thrush	*Turdus olivaceus*	LC	LC	1	0	0	0	1	1	1	1
Southern masked weaver	*Ploceus velatus*	–	LC	7	1	5	2	6	3	9	4
Shaft-tailed whydah	*Vidua regia*	–	NT	6	3	7	4	7	6	9	5
Guild – human commensal species											
House sparrow	*Passer domesticus*	–	LC	4	3	6	4	3	7	11	8
Rock dove	*Columba livia*	–	LC	1	4	8	3	1	6	12	7
African rock pigeon	*Columba guinea*	–	LC	12	4	12	2	12	6	14	3

Total	287	191	257	305	399	319	344	278
Total per season *	**287**		**251***		**399**		**314***	

The Regional status and Global status columns denote the latest local and global species classification according to their conservation threat category (Taylor et al., 2015; IUCN, 2019).

LC = least concern; NT = near threatened; VU = vulnerable (Taylor et al., 2015; IUCN, 2019).

* Represents mean values calculated among the overlapping three vantage point surveys within the facility footprint (Vantage Point 2, Vantage Point 3 and Vantage Point 4).

Table 3.2 Avian species diversity and abundance within the reference site and facility footprint grouped according to their habitat dependencies

Guild	**Species diversity**			**Avian abundance**		
	Reference site	Facility footprint	Total	Reference site	Facility footprint	Total
Shrubland/woodland species	26	19	26	328	288*	616
Open country/grassland species	14	12	15	121	83*	204
Generalist species	10	9	10	204	146*	350
Human commensal species	3	3	3	33	40*	73
Aquatic species	0	2	2	0	8*	8
Total	**53**	**45**	**56**	**686**	**565***	**1 251**

* Represents mean values calculated among the overlapping three vantage point surveys within the facility footprint (Vantage Point 2, Vantage Point 3 and Vantage Point 4).

3.3.2 Species diversity

The recoded data from Table 3.1 are displayed in Figure 3.3 according to species diversity in relation to each survey site and season. During the winter survey, a total of 49 avian species were recorded (Table 3.1; Figure 3.3). No species of conservation importance was recorded during the winter survey. The summer survey yielded a total of 57 avian species (Table 3.1; Figure 3.3). The only species of conservation importance was recorded during the summer survey and was identified as the lanner falcon (*Falco biarmus*), which is classified as vulnerable (Taylor et al., 2015).

The total annual findings suggest overall higher species diversity in the reference site given that 53 species were recorded as opposed to 45 species in the facility footprint (Table 3.2; Figure 3.3). Species diversity remained higher during the winter and summer seasons at the reference site with 46 species recorded in winter and 53 in summer. In contrast, findings from the facility footprint yielded 30 species in winter and 45 species in summer (Table 3.1; Figure 3.3).

Both survey areas yielded higher diversity numbers in the summer as opposed to the winter season (Figure 3.3). Notably, larger terrestrial bird species, such as the korhaan species, were absent in the facility footprint survey site (Table 3.1).

Species diversity distribution according to habitat dependency showed that shrubland/woodland species comprised the highest species diversity (n = 26 species) with a higher species diversity count of 26 species in the reference site opposed to a total of 19 recordings in the facility footprint (Table 3.1; Table 3.2). Open country/grassland species had the second highest species diversity overall (n = 15 species) with a higher diversity count of 14 species in the reference site and a slightly lower value of 12 species in the facility footprint (Table 3.1; Table 3.2). Generalist avian species distribution was found to be almost uniform across both survey areas given that 10 different species were recorded in the reference site and 9 species in the facility footprint, with a total diversity value of 10 species (Table 3.1; Table 3.2). Avian species whose habitat dependency is associated with urban areas (i.e. human commencal species) were uniformly distributed across both survey areas with a total of three species across the survey areas, implying three species per site (Table 3.1; Table 3.2). In contrast, no aquatic species were recorded in the reference site opposed to two species in the facility footprint (Table 3.1; Table 3.2).

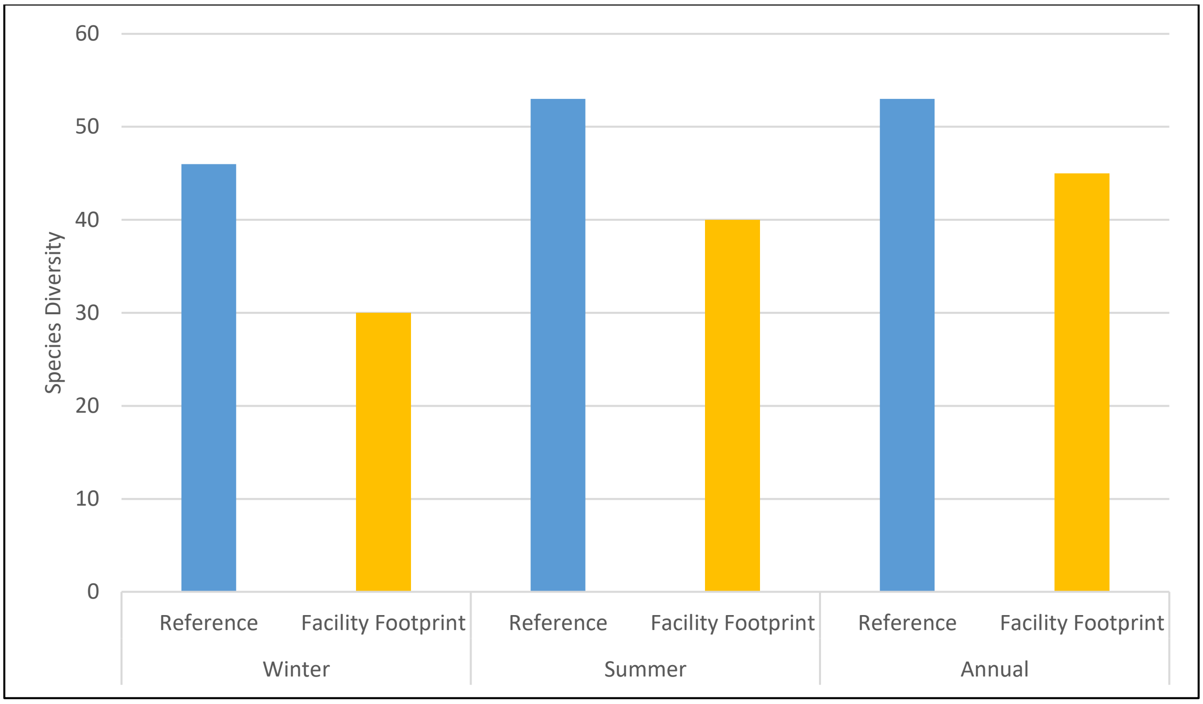

Figure 3.3 Number of avian species recorded at the survey areas during the dry (i.e. winter) and wet (i.e. summer) seasons

3.3.3 Avian abundance and density

Recoded survey data from Table 3.1 are summarised in Table 3.2 and displayed in Figure 3.4 according to species abundance in relation to each survey site and season. A comparison of species density among the survey areas is calculated per hectare and illustrated in Table 3.3.

During the winter survey, a total number of 287 individual birds were recorded in the reference site and a lower mean value of 251 birds was recorded in the facility footprint (Table 3.1; Figure 3.4). The summer survey yielded higher values for both survey areas given that a total number of 399 individual birds were recorded in the reference site and a slightly lower mean total of 314 birds were recorded in the facility footprint (Table 3.1; Figure 3.4).

Total annual findings suggest overall higher avian abundance in the reference site given that 686 individuals were recorded opposed to a mean number of 565 individual recordings in the facility footprint (Table 3.1; Table 3.2; Figure 3.4).

Avian abundance and use, according to their habitat dependency, indicated that shrubland/woodland species denoted the highest abundance (n = 616 individuals) with higher avian abundance documented in the reference site (n = 328 individuals) opposed to the facility footprint (n = 288 individuals) (Table 3.1; Table 3.2). Open country/grassland species illustrated the second highest avian abundance overall (n = 204 individuals) and a higher avian abundance of 121 individuals documented in the reference site opposed to the facility footprint with 83 individuals (Table 3.1; Table 3.2). Generalist avian species distribution was also found to be slightly higher in the reference site (n = 204 individuals) compared to the facility footprint with a mean of 146 individuals (Table 3.1; Table 3.2). In contrast, avian species that are known to be associated with urban areas yielded to some extent higher abundance values in the facility footprint (n = 40 individuals) in relation to the reference site (n = 33 individuals) (Table 3.1; Table 3.2). In addition, avian abundance for aquatic species yielded higher abundance in the facility footprint (n = 8 individuals) opposed to the reference site that did not produce any individuals (Table 3.1; Table 3.2).

Total avian density was on average 0.41 birds per hectare higher in the reference site when compared with the facility footprint (Table 3.3). The winter surveys suggested that avian density was on average 0.13 birds per hectare higher in the facility footprint (n = 1.32 birds per hectare) in relation to the reference site (n = 1.19 birds per hectare) (Table 3.3). Contrasting findings were documented for the summer surveys given that on average 0.54 birds per hectare more were recorded in the reference site (n = 2.12 birds per hectare) compared with the facility footprint (n = 1.58 birds per hectare) (Table 3.3).

Red-billed quelea (*Quela qualea*), which have a general habitat preference, had the highest density of birds per hectare in the reference site (n = 0.51 birds per hectare) (Table 3.3). Shrubland/woodland habitat preference species identified as the sociable weaver (*Philetairus socius*) produced the highest density of birds per hectare for the facility footprint (n = 50 birds per hectare) (Table 3.3). Overall, shrubland/woodland habitat-dependant species comprised on average the highest density of birds found in the reference site (n = 1.69 birds per hectare) and the facility footprint (n = 1.37 birds per hectare) (Table 3.3). Aquatic habitat-dependent species represented the lowest density of birds per hectare for both survey areas given that 0.01 birds per hectare were found on average in the reference site and 0.03 birds per hectare were found in the facility footprint (Table 3.3).

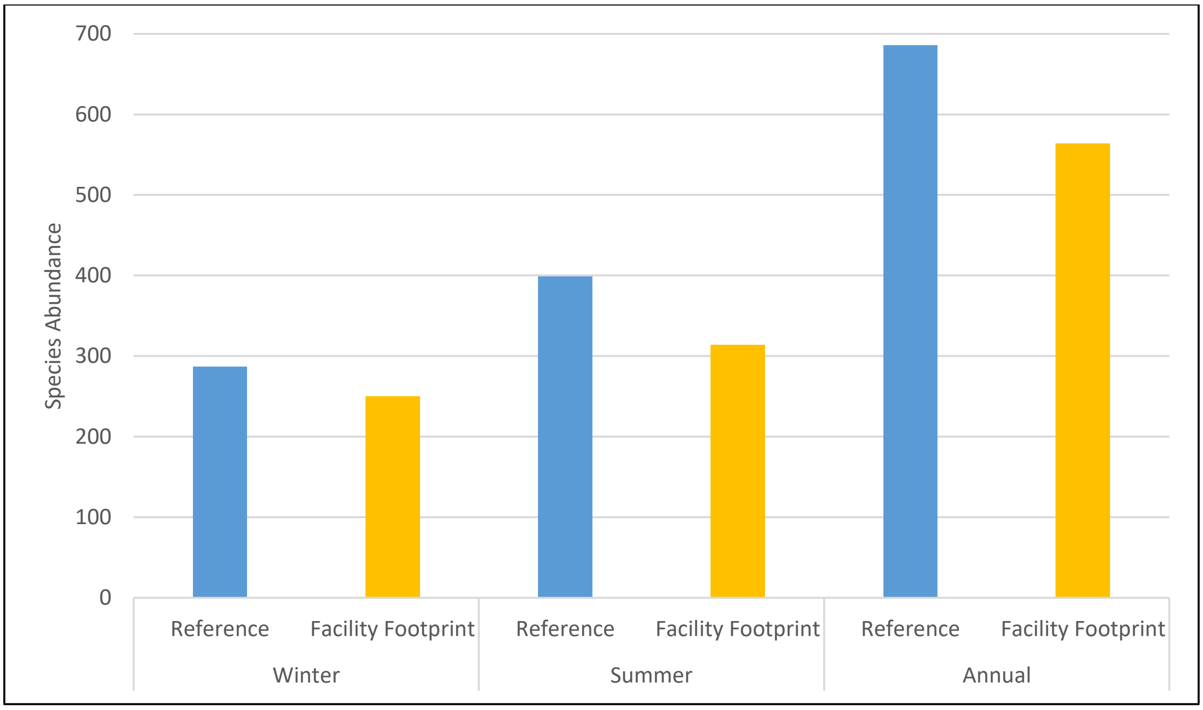

Figure 3.4 Avian species abundance recorded at the survey areas during the dry (i.e. winter) and wet (i.e. summer) seasons

Table 3.3 Dry and wet season avian use survey results with species density within the reference site and facility footprint grouped according to their habitat dependencies

		Winter		Summer		Total	
Common name	**Biological name**	**Reference**	**Facility footprint**	**Reference**	**Facility footprint**	**Reference**	**Facility footprint**
		Birds per ha	Birds per ha	Birds per ha	Birds per ha	Birds per ha	Birds per ha
		Guild – aquatic species					
Egyptian goose	*Alopochen aegyptiaca*	0.00	0.00	0.00	0.01	0.00	0.01
Cape teal	*Anas capensis*	0.01	0.00	0.00	0.02	0.01	0.02
		Guild – generalist species					
Acacia pied barbet	*Tricholaema leucomelas*	0.00	0.00	0.01	0.00	0.01	0.00
Bokmakierie	*Telophorus zeylonus*	0.00	0.01	0.01	0.00	0.01	0.01
Cape glossy starling	*Lamprotornis nitens*	0.01	0.05	0.06	0.02	0.07	0.07
Cape turtle dove	*Streptopelia capicola*	0.05	0.05	0.07	0.08	0.12	0.13
Cape wagtail	*Motacilla capensis*	0.00	0.00	0.01	0.00	0.01	0.00
Familiar chat	*Cercomela familiaris*	0.02	0.03	0.04	0.04	0.06	0.07
Laughing dove	*Streptopelia senegalensis*	0.04	0.03	0.06	0.07	0.10	0.10
Pied crow	*Corvus albus*	0.01	0.01	0.01	0.01	0.02	0.02
Southern (common) fiscal	*Lanius collaris*	0.00	0.00	0.01	0.00	0.01	0.00
Spotted eagle-owl	*Bubo africanus*	0.00	0.00	0.00	0.00	0.00	0.00
Red-billed quelea	*Quelea quelea*	0.17	0.22	0.34	0.19	0.51	0.41
		Guild – open country/grassland species					
African pipit	*Anthus cinnamomeus*	0.00	0.00	0.01	0.00	0.01	0.00

Ant-eating chat	*Myrmecocichla formicivora*	0.01	0.01	0.05	0.02	0.06	0.03
Crowned lapwing	*Vanellus coronatus*	0.00	0.00	0.01	0.00	0.01	0.00
Desert cisticola	*Cisticola aridulus*	0.00	0.01	0.03	0.01	0.03	0.02
Grey-backed sparrow-lark	*Eremopterix verticalis*	0.01	0.03	0.05	0.02	0.06	0.05
Lanner falcon	*Falco biarmicus*	0.00	0.00	0.00	0.01	0.00	0.01
Northern black korhaan	*Afrotis afraoides*	0.00	0.01	0.02	0.00	0.02	0.01
Red-capped lark	*Calandrella cinerea*	0.00	0.02	0.02	0.01	0.02	0.03
Spike-heeled lark	*Chersomanes albofasciata*	0.01	0.01	0.02	0.03	0.03	0.04
Zitting cisticola	*Cisticola juncidis*	0.00	0.01	0.02	0.00	0.02	0.01
Common quail	*Coturnix coturnix*	0.00	0.01	0.01	0.00	0.01	0.01
Zebra finch	*Taeniopygia guttata*	0.00	0.01	0.02	0.01	0.02	0.02
Blacksmith lapwing	*Vanellus armatus*	0.00	0.00	0.01	0.01	0.01	0.01
White-throated swallow	*Hirundo albigularis*	0.00	0.00	0.07	0.07	0.07	0.07
Red-headed finch	*Amadina erythrocephala*	0.08	0.07	0.08	0.11	0.16	0.18
Guild – shrubland/woodland species							
African red-eyed bulbul	*Pycnonotus nigricans*	0.02	0.03	0.04	0.02	0.06	0.05
Ashy tit	*Parus cinerascens*	0.00	0.00	0.01	0.00	0.01	0.00
Chestnut-vented tit-babbler	*Sylvia subcaerulea*	0.00	0.00	0.02	0.00	0.02	0.00
Dusky sunbird	*Cinnyris fuscus*	0.00	0.01	0.02	0.00	0.02	0.01
Fawn-coloured lark	*Calendulauda africanoides*	0.01	0.04	0.06	0.02	0.07	0.06
Grey-backed cisticola	*Cisticola subruficapilla*	0.00	0.01	0.02	0.00	0.02	0.01
Hadeda ibis	*Bostrychia hagedash*	0.00	0.01	0.01	0.01	0.01	0.02
Kalahari scrub robin	*Erythropygia paena*	0.00	0.04	0.05	0.01	0.05	0.05
Karoo korhaan	*Eupodotis vigorsii*	0.00	0.01	0.01	0.00	0.01	0.01

Lark-like bunting	*Emberiza impetuani*	0.29	0.04	0.05	0.08	0.34	0.12
Layard's tit-babbler	*Sylvia layardi*	0.00	0.00	0.01	0.00	0.01	0.00
Long-billed crombec	*Sylvietta rufescens*	0.00	0.00	0.01	0.00	0.01	0.00
Namaqua dove	*Oena capensis*	0.01	0.02	0.03	0.02	0.04	0.04
Namaqua sandgrouse	*Pterocles namaqua*	0.02	0.04	0.06	0.03	0.08	0.07
Pale chanting goshawk	*Melierax canorus*	0.00	0.00	0.01	0.00	0.01	0.00
Pririt batis	*Batis pririt*	0.00	0.01	0.02	0.00	0.02	0.01
Red-crested korhaan	*Lophotis ruficrista*	0.00	0.00	0.01	0.00	0.01	0.00
Red-eyed dove	*Streptopelia semitorquata*	0.00	0.00	0.01	0.01	0.01	0.01
Sabota lark	*Calendulauda sabota*	0.01	0.04	0.05	0.01	0.06	0.05
Sociable weaver	*Philetairus socius*	0.25	0.16	0.24	0.34	0.49	0.50
White-backed mousebird	*Colius colius*	0.00	0.06	0.08	0.01	0.08	0.07
White-browed sparrow-weaver	*Plocepasser mahali*	0.05	0.05	0.08	0.07	0.13	0.12
Scaly-feathered finch	*Sporopipes squamifrons*	0.01	0.02	0.01	0.02	0.02	0.04
Olive thrush	*Turdus olivaceus*	0.00	0.00	0.01	0.01	0.01	0.01
Southern masked weaver	*Ploceus velatus*	0.01	0.03	0.03	0.03	0.04	0.06
Shaft-tailed whydah	*Vidua regia*	0.02	0.03	0.04	0.03	0.06	0.06
Guild – human commencal species							
House sparrow	*Passer domesticus*	0.02	0.02	0.02	0.04	0.04	0.06
Rock dove	*Columba livia*	0.02	0.00	0.01	0.04	0.03	0.04
African rock pigeon	*Columba guinea*	0.03	0.06	0.06	0.04	0.09	0.10
Total		**1.19**	**1.32**	**2.12**	**1.58**	**3.31**	**2.90**

3.3.4 Avian flight height

Table 3.4 provides the average avian flight height data rounded to the nearest one decimal, recorded during the vantage point surveys in each of the survey areas. It was, however, found that the average values were biased by a few outlier species such as the Egyptian goose (*Alopochen aegyptiaca*), the Karoo korhaan (*Eupodotis vigorsii*), the northern black korhaan (*Afrotis afraoides*), the pale chanting goshawk (*Melierax canorus*), the pied crow (*Corvus albus*) and the red-crested korhaan (*Lophotis ruficrista*). These are relatively uncommon species that fly very high, such as the pale chanting goshawk and the pied crow, or species that fly up to a significant height when flushed, only to settle a short distance away, such as the korhaan species (Hudson, 2017). If these species are removed from the dataset, the average flight height decreases considerably (Table 3.4). The data thus suggest that most avian species recorded in the survey areas fly at an average height of 6 m while the average minimum flight height is 5 m and the average maximum height is 17 m (Table 3.4). Regardless of the exclusion or inclusion of outlier species, it is worth noticing that the vast majority of species show an average flight height of below 10 m (Table 3.4).

Table 3.4 Minimum, maximum and average flight heights according to data collected during the vantage point surveys

Common name	**Biological name**	**Flight height in metres**		
		Minimum	Maximum	Average
Acacia pied barbet	*Tricholaema leucomelas*	1	5	3
African pipit	*Anthus cinnamomeus*	0	20	4
African red-eyed bulbul	*Pycnonotus nigricans*	0.5	10	3
African rock pigeon	*Columba guinea*	6	19	15
Ant-eating chat	*Myrmecocichla formicivora*	0	15	3
Ashy tit	*Parus cinerascens*	2	10	3
Blacksmith lapwing	*Vanellus armatus*	0	10	5
Bokmakierie	*Telophorus zeylonus*	1	15	3
Cape glossy starling	*Lamprotornis nitens*	0	20	4
Cape teal	*Anas capensis*	0.5	30	18
Cape turtle dove	*Streptopelia capicola*	0	15	3
Cape wagtail	*Motacilla capensis*	0	10	4
Chestnut-vented tit-babbler	*Sylvia subcaerulea*	2	10	4
Common quail	*Coturnix coturnix*	0	9	5
Crowned lapwing	*Vanellus coronatus*	0	15	3
Desert cisticola	*Cisticola aridulus*	0	10	3
Dusky sunbird	*Cinnyris fuscus*	0	10	3

Egyptian goose*	*Alopochen aegyptiaca*	0	40	20
Familiar chat	*Cercomela familiaris*	0	15	5
Fawn-coloured lark	*Calendulauda africanoides*	0	10	4
Grey-backed cisticola	*Cisticola subruficapilla*	1	10	4
Grey-backed sparrow-lark	*Eremopterix verticalis*	0	15	4
Hadeda ibis	*Bostrychia hagedash*	20	40	30
House sparrow	*Passer domesticus*	0	10	3
Kalahari scrub robin	*Erythropygia paena*	0	10	4
Karoo korhaan*	*Eupodotis vigorsii*	0	60	30
Lanner falcon	*Falco biarmicus*	20	80	40
Lark-like bunting	*Emberiza impetuani*	1	9	3
Laughing dove	*Streptopelia senegalensis*	0	10	3
Layard's tit-babbler	*Sylvia layardi*	2	10	3
Long-billed crombec	*Sylvietta rufescens*	3	10	4
Namaqua dove	*Oena capensis*	0	10	4
Namaqua sandgrouse	*Pterocles namaqua*	0	50	3
Northern black korhaan*	*Afrotis afraoides*	20	40	30
Olive thrush	*Turdus olivaceus*	0	12	4
Pale chanting goshawk*	*Melierax canorus*	20	40	30
Pied crow*	*Corvus albus*	11	60	18
Pririt batis	*Batis pririt*	1	10	4
Red-billed quelea	*Quelea quelea*	1	6	4
Red-capped lark	*Calandrella cinerea*	0	10	3
Red-crested korhaan*	*Lophotis ruficrista*	0	40	30
Red-eyed dove	*Streptopelia semitorquata*	0	30	4
Red-headed finch	*Amadina erythrocephala*	1	10	3
Rock dove	*Columba livia*	6	12	8
Sabota lark	*Calendulauda sabota*	0	15	4
Scaly-feathered finch	*Sporopipes squamifrons*	2	5	3
Shaft-tailed whydah	*Vidua regia*	2	11	3
Sociable weaver	*Philetairus socius*	0	10	4
Southern (common) fiscal	*Lanius collaris*	1	10	3
Southern masked weaver	*Ploceus velatus*	1	12	3
Spike-heeled lark	*Chersomanes albofasciata*	0	15	3
White-backed mousebird	*Colius colius*	0	10	4
White-browed sparrow-weaver	*Plocepasser mahali*	0	10	3
White-throated swallow	*Hirundo albigularis*	30	120	45
Zebra finch	*Taeniopygia guttata*	2	8	4

Zitting cisticola	*Cisticola juncidis*	0	10	4
Average flight height of species		5	20	8
Average flight height of species with rare outliers species excluded		5	17	6

* Represents outlier avian species.

3.3.5 Breeding behaviour

Breeding behaviour data collected during the breeding season (wet season surveys) were augmented with data obtained during the mortality investigations (Chapter 4). A spatial summary of breeding activity is provided in Figure 3.5 and Figure 3.6, which indicates that breeding activity inside the facility footprint area is greatly reduced in comparison with the reference site and the surrounding undeveloped landscape. This is based on findings suggesting that no signs of breeding activities were evident in Breeding Survey Area 2, which was located within the facility footprint (Figure 3.5).

In contrast, four sociable weaver (*Philetairus socius*) nests and one northern black korhaan (*Afrotis afraoides*) breeding pairs were located outside the undeveloped areas adjacent to the facility footprint boundary (Figure 3.5; Figure 3.6). In addition, Breeding Survey Area 1, which was located within the reference site, produced two Namaqua sandgrouse (*Pterocles Namaqua*) breeding pairs, one laughing dove nest (*Streptopelia senegalensis*), one ashy tit (*Parus cinerascens*) nest, one Namaqua dove (*Oena capensis*) nest and one southern common fiscal (*Lanius collaris*) nest (Figure 3.5; Figure 3.6).

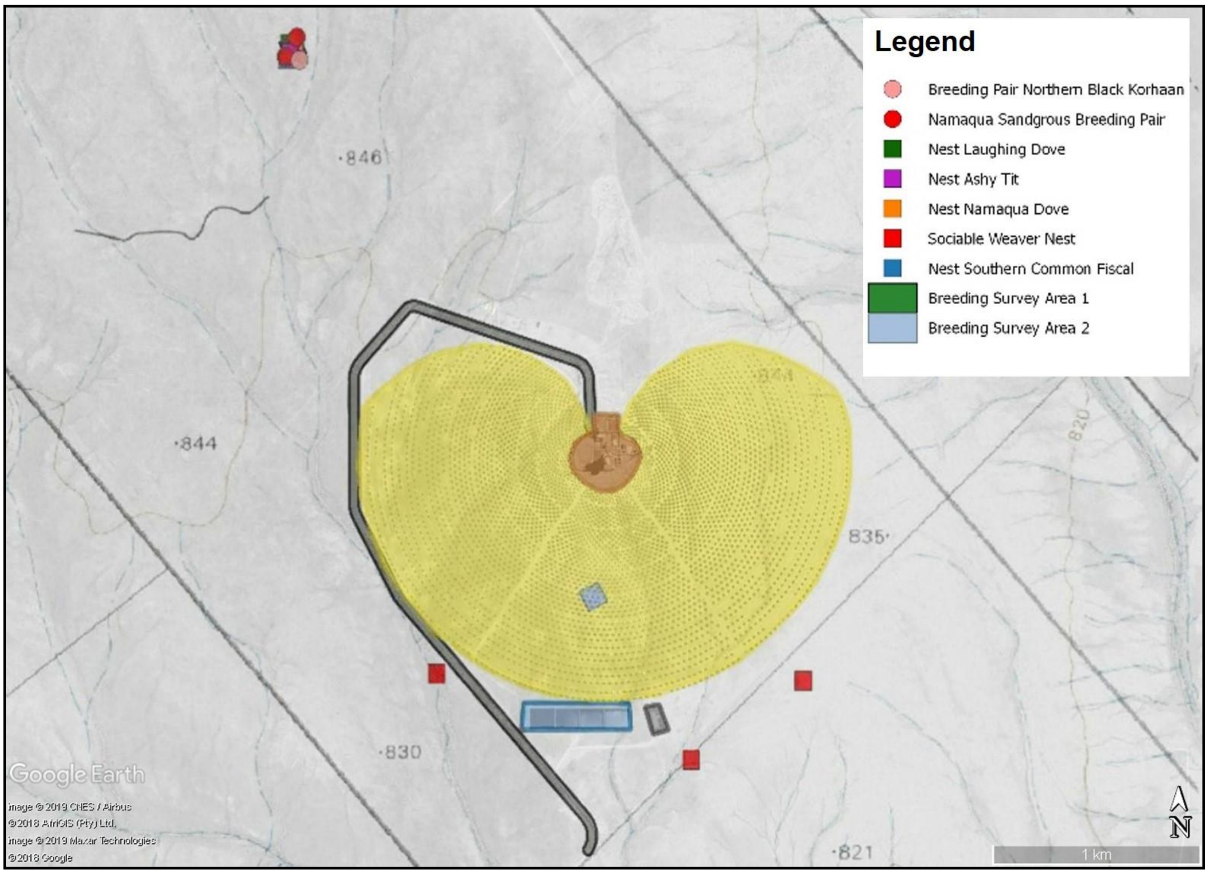

Figure 3.5 Recorded breeding activity within the survey areas

Photo credit: Google Earth

Figure 3.6 Enlarged view of Breeding Survey Area 1 in the reference site

Photo credit: Google Earth

3.4 Discussion

Overall, avian species diversity, abundance and density per unit area were found to be higher in neighbouring untransformed habitat (i.e. reference site) than within the facility footprint, providing evidence that the solar facility is impacting avifauna to some extent.

3.4.1 Structural changes in avian communities

Visser et al. (2016), who conducted a similar study on the indirect impacts of a utility-scale PV solar energy facility on birds in the Northern Cape, also noted differences in bird assemblages between the facility and an adjacent untransformed reference habitat. In the current study, survey data findings suggested that shrubland/woodland species were the most affected since they were well represented in the untransformed habitat in comparison with the transformed habitat. Where woody and shrubby vegetation is impacted in transformed habitat, certain species are therefore inevitably affected. Certain studies have found that shrubland/woodland species are specialists with narrow habitat ranges, given that they have specific habitat needs

(Schlossberg & King, 2008, 2009). In addition, shrubland species tend to either be absent or scarce in smaller habitat patches in general; additionally, they also experience lower nesting success or avoid nesting near edges of habitats (King et al., 2009). Most interestingly and contrarily to the latter, survey observations and gathered abundance and density data in the current study suggest that certain shrubland/woodland species such as the sociable weaver (*Philetairus socius*) and the southern masked weaver (*Ploceus velatus*) favour the CSP facility (Table 3.1; Table 3.3). These species together with the lark-like bunting (*Emberiza impetuani*) were found to embark on a local migration through the solar field to the evaporation ponds and then back to their feeding areas each day in the late morning and/or early afternoon (personal observation). Overall, these findings suggest that although shrubland/woodland birds are detected in close proximity to the CSP tower facility, they do not automatically represent an unaffected population. Further expansion of CSP tower facilities may have cumulative impacts on such bird populations considering that some of the shrubland/woodland species detected within the study area such as the Karoo korhaan (*Eupodotis vigorsii*) are considered near threatened (Table 3.1).

In contrast to the above the findings suggest that generalist and open country/grassland species are not adversely affected by impacts caused by the CSP tower facility (Table 3.1; Table 3.2; Table 3.3). This may be due to the abilities of these species to utilise both open and shrubland areas that are supplemented by the transformed habitat that is dominated by short grassland and low diversity of shrubs and trees (Dean, 2000; Hockey et al., 2005). Arguably, open country/grassland species might benefit from CSP tower developments, which in this case comprise a large grassy-vegetated solar field, given that the loss of open grassland habitat within the Savannah biome has become a conservation concern. This is because bush encroachment has resulted in the general increase in woody vegetated biomes at the expense of grassland and savannas across South Africa, which is driven by land-use change and increased atmospheric CO_2 levels (Wigley et al., 2009, 2010; O'Connor & Chamane, 2012; Visser et al., 2016).

The presence of water (i.e. evaporation ponds) and human-made structures (e.g. heliostats) within the transformed habitat appears to be luring a diversity of aquatic species and some species that favour an urban habitat (i.e. human commencial species). This is supported by higher species abundance and density values of these species for the facility footprint in relation to the reference site (Table 3.1; Table 3.3).

3.4.2 Avian use and behaviour

The majority of recorded avian species in the facility and reference survey areas fly at an average height of approximately 6 m, while the average minimum height is 5 m and the average maximum height is 17 m (Table 3.4). It is worth noticing that the vast majority of avian species show an average flight height of below 10 m. This is likely due to the natural vegetation structure being low shrubland and grassland with scattered trees, providing food, nesting and protection against predation; thus, flight occurs at very low altitudes.

Initial breeding observations indicated that breeding activity within the transformed habitat was lower than within the untransformed habitat. This may be because of the increased human activity, decreased habitat diversity and the fact that nesting is actively discouraged through the removal of nests in the infrastructure of the facility footprint to manage potential fire hazards. These findings therefore cannot support the claim that some tree-nesting bird species such as the sociable weaver (*Philetairus socius*) that are known to nest on human-made structures such as electricity pylons might utilise the various raised structural components such as the heliostats for nesting and roosting (Lovich & Ennen, 2011; Hernandez et al., 2014).

Although no vegetation and invertebrate studies were conducted at the study site, a variety of Coleoptera, Orthoptera, Lepidoptera, Isoptera, Scorpionses and Solifugae species that may provide a food source for terrestrial, aquatic and aerial avian feeders in the area were observed throughout the study period. Simultaneously, raptors such as the pale chanting goshawk (*Melierax canorus*) and the lanner falcon (*Falco biarmicus*) were observed scoping the corridors among the heliostats of the CSP tower facility and surrounds in search of prey. This suggests that some birds of prey have the capability to adapt to the development of CSP facilities through alteration of their preying strategy (Visser, 2016).

3.5 Conclusion

Previous studies on CSP tower facilities in the United States of America indicated that these kinds of developments had negative impacts on species abundance, density and diversity of avian communities in the area (DeVault et al., 2014; West Inc., 2015). To some extent these findings are consistent with this study, since avian species diversity, abundance and density per unit area were found to be higher in the neighbouring untransformed habitat (i.e. reference site) than in the transformed habitat (i.e. facility footprint). However, the findings indicated that open country/grassland and generalist avian species were most abundant within the facility footprint because they used the transformed habitat more extensively than other species.

However, data findings from the untransformed habitat and transformed habitat do not vary greatly in comparison, which suggest that the transformed habitat is accessable to most avian species (Visser, 2016). Significant environmental factors such as vegetation quality and habitat availability are most likely the dominant factors influencing species' occurrence and their relative density within the facility footprint (Visser, 2016).

In conclusion, further investigation into resource exploitation among bird species and adequate pre- and postconstruction avian monitoring may improve our understanding of species-landscape relationships (Lima & Zollner, 1996; Fox et al., 2006).

CHAPTER 4: INITIAL INVESTIGATION INTO THE DIRECT IMPACT ON BIRD COMMUNITIES OF THE KHI SOLAR ONE CSP TOWER FACILITY IN THE NORTHERN CAPE, SOUTH AFRICA

Avian collisons have been quantified for South African wind energy facilities, but less consideration has been given to other renewable energy sectors such as utility-scale solar developments. A research gap was therefore identified for the investigation of the direct impacts of concentrating solar power tower technologies on bird communities.

This chapter presents the results of an investigation into the direct impact on bird communities of a utility-scale power tower CSP facility in the Northern Cape, South Africa. In the study, bird injury and mortality caused by facility structure collisions and solar flux generated at the facility were investigated. Throughout the monitoring year, a total of 324 avian impact detections were recorded involving 34 identified species. Avian detections were highest in the summer season, followed by the winter season. Of the total avian impact detections, 61% of injuries/mortalities were found to be caused impact trauma and 14% by singeing related trauma. Most collisions were recorded in the solar field with trending evidence of impact occurring on the lower quarter of the heliostats' reflective surfaces. Singeing data displayed a significant increase in detections during the summer months and revealed that most recorded detections were aerial feeding migratory birds. A clear correlation was found between the peak singeing detection months and the positioning of heliostats into the standby position during this period.

Meaningful assessment of the overall avian fatality at CSP tower facilities was challenging, as was the formulation of accurate hypotheses regarding the risk of avian mortality among these facilities and other sources of solar electricity generation. This is due to existing literature providing inconsistent and sparse avian fatality data, as standardisation is lacking in relation to data collection methods, reporting units and bias correction at utility-scale solar energy facilities in general. Still, data analysis suggested that fatalities per area may be a more suitable metric for estimating cumulative impacts among CSP tower facilities, since the efficiency of this technology is continuing to improve and change in design and operation over time.

4.1 Introduction

4.1.1 Known direct impacts of utility-scale power tower energy facilities

A comprehensive analysis of the potential environmental impacts of utility-scale solar developments in South Africa asserted that avian mortality can be considered as one of the key direct adverse impacts of these facilities, and is likely to be the most controversial impact (Rudman et al. 2017). However, avian impacts of CSP power tower facilities are largely unknown, especially when compared to other renewable energies (Smith & Dwyer, 2016; Jeal et al., 2017).

A limited amount of peer-reviewed literature containing empirical data is available on studies that have investigated solar energy-related bird mortality impact factors at CSP tower facilities (Ho, 2016). It appears that two types of direct solar energy-related bird mortality impact factors have been identified in the CSP tower industry:

The first is collision-related mortality risk resulting from birds colliding with facility structures. The large reflective surfaces of heliostats may pose a high collision risk when in a vertical position as they may create an illusion of continuity of the surrounding landscape (McCrary et al., 1986; Hernandez et al., 2014; Kagan et al., 2014). Supporting evidence was found from two separate studies conducted at different occasions at non-related CSP power tower facilities in California. During a 40-week investigation from May 1982 to June 1983 on Solar One, a 10 MW direct-steam pilot project that is located in California's Mojave Desert, McCrary et al. (1986) recorded 70 avian fatalities. Just over 80% of fatalities were related to collision trauma which enabled them to determine that most of the collision incidences were recorded at the reflective surfaces of the heliostats and not at other components of the heliostats or the solar tower (McCrary et al., 1986). Detailed avian monitoring surveys were also conducted from 21 October 2014 to 20 October 2015 at the Ivanpah Solar Electric Generating System, which consists of three CSP tower facilities spanning 1 457 ha with a combined net capacity of 377 MW (West inc., 2015). Researchers found that 2 500 avian fatalities were derived from known causes, using a fatality estimator model (West Inc., 2015) Of the known causes, 52% were collision incidents (West Inc., 2015).

The second is solar flux-related mortality risk resulting from singeing when birds are exposed to concentrated sunlight, referred to as solar flux (McCrary et al., 1986; Hernandez et al., 2014; Kagan et al., 2014). Solar flux originates from sunlight that is reflected from heliostats and is radiated (concentrated) at the central receiver of the tower where solar flux is converted into thermal energy (heat) once the energy is absorbed by the heat exchanger of the central receiver (Desmond, 2014). This heat exchange process may expose birds to the risk of being singed and killed as temperatures of up to 800 °C can be reached (McCrary et al., 1986; Hernandez et al., 2014; Kagan et al., 2014). In addition, the preprogrammed standby position of the heliostats is usually focused above the top of the tower, causing the solar flux to be radiated at a point in mid-air above the tower (Kagan et al., 2014; Smallwood, 2014). The concentrated solar flux does not emit thermal energy, given that atmospheric air for all practical purposes does not absorb solar flux (Desmond, 2014). However, should the solar flux strike an object such as a passing bird, it will cause singeing since the energy is then converted into thermal energy (Desmond, 2014; Kagan et al., 2014; Smallwood, 2014). Birds' passing through an area of solar flux may result in direct mortality through singeing of flight feathers, resulting in the loss of flight ability and leading to impact with other objects or impairment of flight capability, thus reducing the ability to forage or avoid predators, resulting in starvation or predation of individuals (McCrary et al., 1986; Hernandez et al., 2014; Kagan et al., 2014).

In comparison with other man-made structures, all types of CSP facility infrastructure may cause avian mortality or trauma through collision-related impact, yet, solar flux-related mortality or trauma remain exclusive to power tower facilities (Smith & Dwyer, 2016).

Given the global shortfall of published data regarding the impacts of CSP tower facilities on avian communities, conclusive understanding of avian mortality and trauma associated with solar energy facilities has thus far not been established and further research of these impacts has therefore been encouraged (Smith & Dwyer, 2016). This study therefore aimed to evaluate the direct impact of the Khi Solar One CSP tower facility on avifauna of the area with special attention to avian trauma and mortalities.

4.2 Field methodology to investigate mortalities and injuries

4.2.1 Study site and area

The study site was the Khi Solar One development near Upington, South Africa, which was defined as the facility and occupied a facility area. The facility area was defined as the industrial zoned area of Khi Solar One, which spans roughly 615 ha in total. The study area comprised the development footprint of the facility. The development footprint was divided into sampling areas that encompassed 100% of the development footprint.

4.2.2 Survey design

4.2.2.1.1 Sampling areas

Table 4.1 provides the sampling areas monitored within the Khi Solar One facility area (i.e. study site) as well as the calculated surface area in hectares and the percentage of the study site occupied by these areas. Overall, approximately 58% of the facility area was monitored.

Table 4.1 Sampling areas within the Khi Solar One facility area (i.e. study site)

Sampling area	Facility components included	Hectares searched	Percentage of facility area
Power block	See Figure 3.2	7.5	1.22
Solar field	Heliostat segments, solar field roads and open areas	300	48.78
Evaporation ponds	Ponds, embankments, open areas and fence	6.5	1.06
Perimeter fence	Fence and maintenance road	9	1.46
Warehouse	Inside and outside warehouse	1	0.16
Substation and Powerline	Substation and powerline	19	3.09
Access roads	External and internal roads	11	1.79
Total		**354**	**57.56**

The remaining 42% of the study site was excluded from the study since the area did not contain any CSP or associated infrastructure and did not form part of the operational activities of the facility. The sampling areas were consistent from season to season and covered the entire study area (Khi Solar One development footprint and associated infrastructure) (Figure 2.2), thus eliminating the need to extrapolate data from sectional surveys. The sample areas are described in more detail below.

Power block (Figure 2.2; Figure 3.2)

The power block area of roughly 7.5 ha comprised 1.24% of the study site (Table 4.1). The relatively small surface area allowed monitoring to be conducted mainly by walkthrough surveys, which improved observer mobility and visual observation as the area hosted a great deal of hardware components and concealed areas.

Monitoring was conducted around the control building and parking area, the electrical building and transformer area, the laydown area (which was stripped of vegetation and used during construction), the solar tower area (which included the Natural Draft Condencer and solar tower), the steam accumulator vessels (which consisted of 19 storage vessels), the steam turbine hall and diesel boilers, and the water treatment plant and the chemical store (which consisted of the water treatment plant, four water storage tanks, pipe and cable racks and the chemical store). All the subareas of the power block zone excluding the laydown area contained urban infrastructure such as service roads, storm-water drains and open areas layered with imported gravel.

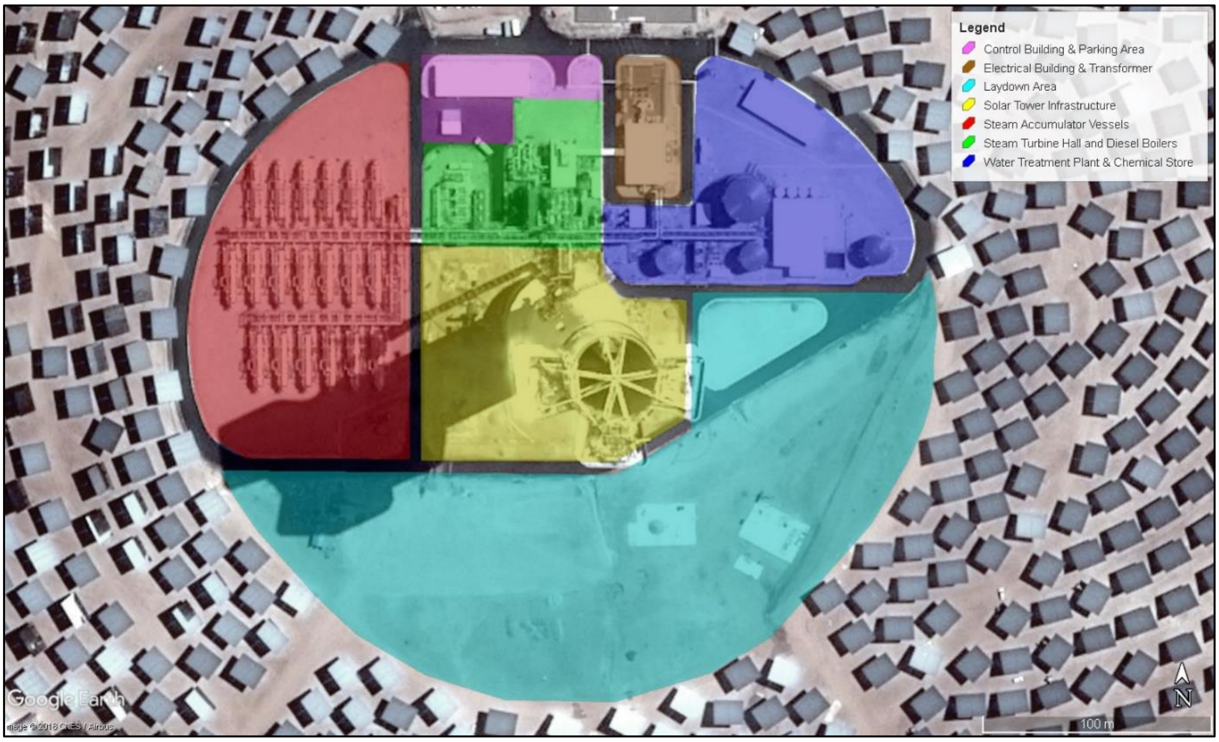

Figure 4.1 Satellite image of power block with related subareas

Photo credit: Google Earth

Solar field (Figure 2.2)

The eastern, southern and western solar fields encompassed a total area of roughly 300 ha and therefore comprised nearly 50% of the study site (Table 4.1). Bird carcass and/or injury searches entailed the monitoring of all components of the solar field infrastructure, including all the heliostats, 135 km of maintenance roads and the graminoid vegetated open areas amongst the infrastructure. Surveying such a vast area was made possible by utilising an all-terrain vehicle (ATV), given that it provided a 360° field of observer view, could transport equipment and made it possible to cover the entire sampling area whilst maintaining a slow traveling speed of around 15 km/h for observation purposes. Each round trip lasted one working day per week.

Evaporation ponds (Figure 2.2)

The four evaporation ponds and their associated infrastructure occupied an area of roughly 6.5 ha and therefore comprised 1.08% of the study site (Table 4.1). The pond embankments with sparse graminoid cover and open areas together with the enclosed perimeter fence were monitored by walkthrough surveys or by ATV.

Perimeter fence (Figure 2.2)

The perimeter fence and associated maintenance road covered an area of roughly 9 ha and therefore represented 1.49% of the study site (Table 4.1). This linear area of 9 km was surveyed using the ATV.

Warehouse (Figure 2.2)

The inside and outside areas of the warehouse roughly spanned 1 ha, which represented 0.17% of the study site (Table 4.1). This small surface area was monitored by walkthrough surveys.

Substation and powerline (Figure 2.2)

The 132-kV monopole powerline and Eskom substation site comprised roughly 20 ha, which represented 3.31% of the study site (Table 4.1). The powerline servitude area and substation were monitored with the ATV as the linear infrastructure totalled a distance of 6.5 km.

Access roads (Figure 2.2)

Internal and external access roads combined represented an area of 11 ha, which represented 1.79% of the study site. Access roads were not systematically surveyed since they were utilised daily by surveyors and operational and maintenance personnel.

4.2.2.1.2 Monitoring frequency and timing

Standardised monitoring occurred at each sampling area at weekly intervals (seven days) through the 2016–2017 spring, summer, autumn and winter seasons and commenced on 9 June 2016 and finished on 8 June 2017.

4.2.2.1.3 Survey and data collection protocols

All mortalities and injuries were recorded as incidents and the specimens collected, which included the following data as summarised in Table 4.1:

Table 4.2 Data collected for each recorded avian incident

Collected data	Description
Date	Date when incident was recorded
Time	Time when incident was recorded
Sample number	Sampling number or ID was assigned to each incident
Sampled by	Name of person who recorded incident
Incidental/systematic	Incidental recording is defined as an accidental recoding
Sample area	E.g. evaporation ponds
Facility feature	Project feature where sample was located, e.g. heliostat
Species	Scientific name of species
Common name	Common name of species
Gender	Gender, if possible to identify
Foraging zone	E.g. terrestrial, aquatic or air
Likely cause of death/injury	E.g. solar flux, predation or impact trauma
MCI	Impact trauma that involved a mirror collision
Supporting observations	Any additional observations deemed important
Estimated time of death/injury	Determined by condition of remains
GPS coordinates	Position where incident was recorded
Photographic evidence	Date-stamped photos were taken of each incident

Feather spots were recorded as incidents when they met the following criteria (Smallwood, 2007):

- At least two or more primary flight feathers.
- Five or more tail feathers.
- Ten or more feathers of any type concentrated in an area of 1 m^2 or smaller, without any body part or significant amounts of flesh or skin.

Each carcass and feather spot were examined and photographed for evidence of singeing or collision. Singeing detections involving carcasses as opposed to feather spots were assigned a solar flux injury grade based on Kagan et al. (2014):

- Grade 1 – curling of less than 50% of flight feathers
- Grade 2 – curling of 50% or more of flight feathers
- Grade 3 – curling and visible charring of contour feathers

Collision incidents were supported by evidence of physical trauma or from evidence gathered from the scene where the specimen was found. With each recorded incident situated close to a heliostat, the reflective surface was examined for bird-strike imprints/smudge marks on the reflective surfaces of mirror facets, which led to the development of the Mirror Collision Index (MCI). This index was developed to identify and record the locations on reflective surfaces where avian collisions occurred to detect any possible trend in collisions. Mirror facets (Figure 2.3) were categorised by creating a matrix of designated rows and columns. Columns were labelled A to D and rows 1 to 8 to assign an alphanumeric code to each heliostat mirror, as indicated in Figure 4.2.

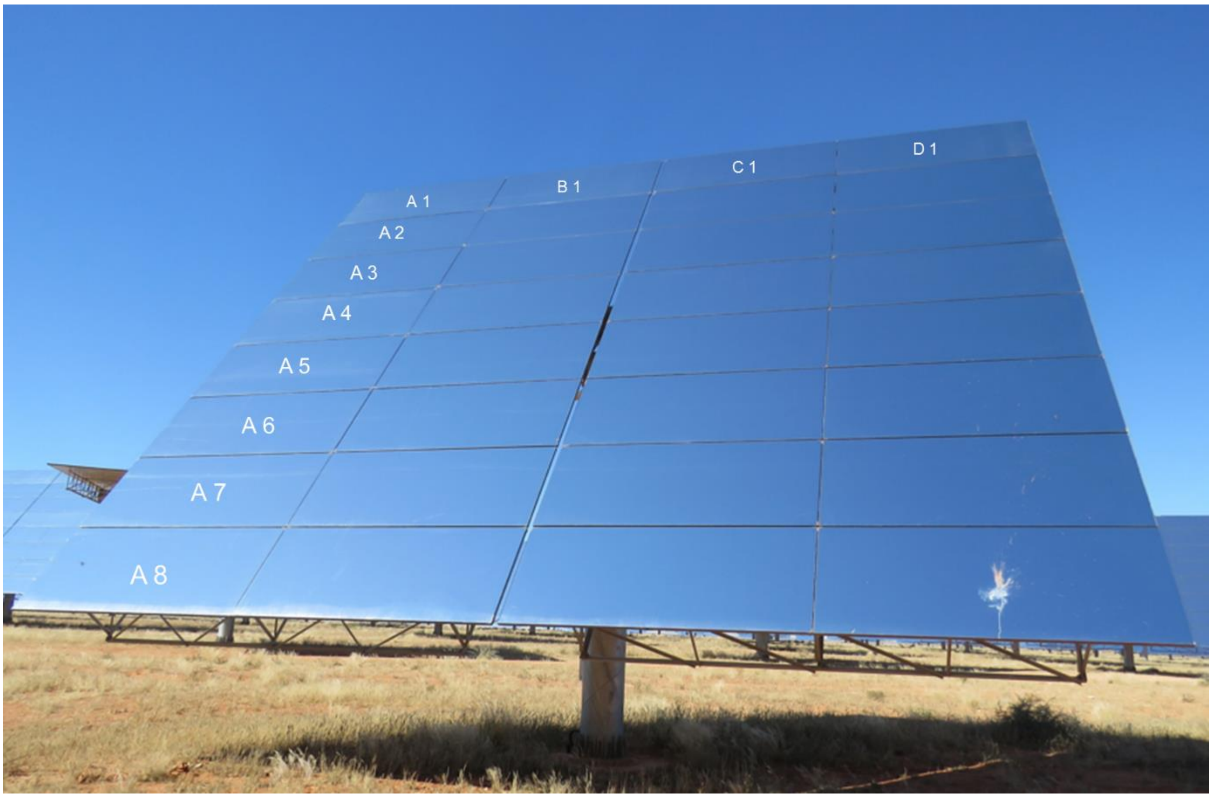

Figure 4.2 Nomenclature for mirrors facets of heliostats used in the MCI. In this picture, a bird strike imprint can be seen on D8.

Photo credit: HP van Heerden

The examination criteria for predation incidents involved signs of decapitation, missing body parts with associated haemorrhage and/or lacerations of skin and pectoral muscles. If there was no clear evidence of collision, singeing or predation, the cause of injury or fatality was recorded as unknown.

4.2.2.2 Incidental reporting

Some incidents were recorded outside sample areas or within sample areas though not during systematic monitoring events by the facility's operational and maintenance personnel. These detections were reported in accordance with the fauna management procedure of the facility and were documented as incidentalrecordings.

4.2.3 Data analysis

4.2.3.1 Scavenger removal trials

To determine the rate speciments are removed by scavengers, four scavenger removal trials were conducted. These occured from 26 December 2016 to 30 January 2017, 18 August 2017 to 11 September 2017, 20 November 2017 to 3 December 2017 and 29 January 2018 to 12 February 2018.

The carcass removal trails were scheduled for weekly inspection, to coincide with the standardised weekly searches for incidents. Separate trials were conducted in the unvegetated power block area and the vegetated area of the heliostat fields. Study areas were approximately 1-2 ha in size and clearly delineated before the removal studies started. To obtain a standardised sample size, 19 carcasses were placed in the power block and 17 were placed in the solar field. These consisted of 10 small carcasses (sparrows), 17 medium-sized carcasses (doves or pigeons) and 9 large carcasses (guineafowl).

Each carcass was marked on the beak or claws with an indelible and easily visible substance to make sure that the study included only those carcasses placed for the trial. A camera trap was inconspicuously placed adjacent to each carcass to record information on scavenger species and time.

To determine the extent of scavenger activity, marked carcasses were randomly distributed (planted) within the delineated study areas for one week at a time (seven days). Carcasses were checked for removal daily, and on the seventh day, remaining carcasses were recovered. Only the placed carcasses that had been completely removed were recorded, given that feather spots, wings and/or other remains were recorded for the monitoring programme and did not constitute birds that might have been missed due to scavenging.

Statistical analysis

Determination of t_{mean} (mean of the time that a carcass remained before removal by scavengers):

$$t_{mean} = \sum_{i=1}^{S} t/(S - S_c)$$

Where:

t_{mean} is the mean time that a carcass remained before removal by scavengers

t is the duration of the study

S is the total number of carcasses placed in the trial

S_c is the number of right censored observations

Based on carcass persistence data from the cumulative trials, models were constructed and compared for the datasets. Models were compared for relative explanatory power using the corrected Akaike information criterion (AIC) score (Akaike, 1973), as suggested by Huso (2011). The AIC provides a relative measure of model fit and parsimony among a selection of candidate models. The model with the lowest AIC score is typically chosen as the best-fit model relative to other models tested; however, any model within two AIC points of the best model is considered strongly supported (Burnham & Anderson, 2004). The chosen models predicted the persistence of carcasses for the nominal search intervals.

4.2.3.2 Searcher efficiency trials

Three searcher efficiency trials were conducted in order to determine the searcher accuracy in spotting carcasses. Trials were conducted between 23 June and 29 July 2017 on both observers; thus, three trials were conducted per individual to achieve a representative average of their carcass spotting efficciency. Carcasses were placed at various vegetation heights and densities amongst the infrastructure and open areas in the solar field since groundcover in this area represented vegetation cover similar to that of the remaining sample areas. No trials were conducted in the power block since detection probability was assumed to be 100% due to ease of observation in unvegetated groundcover.

Study areas were approximately 1-2 ha in size and clearly delineated before the commencement of the study. To achieve a significant sample size, 15 carcasses were placed in the solar field. These comprised 8 small carcasses (sparrows), 5 medium-sized carcasses (doves or pigeons) and 2 large carcasses (guineafowl). Each carcass was marked on the beak or claws with an indelible and easily visible substance to make sure that the study included only these carcasses. To determine searcher efficiency, marked carcasses were placed randomly within the delineated study areas without the knowledge of the observer and the observer was then allowed in the area to search for the carcasses.

Statistical analysis

Searcher efficiency (ρ) is determined by the equation

$$\rho = \frac{C_o}{C_a}$$

Where:

P is the searcher efficiency

C_o is the observed carcasses

C_a is the available carcasses

4.2.3.3 Fatality estimator

Multiple underlying variables make estimation of every fatality rate a complex task seeing that carcasses may persevere for variable amounts of time due to local environmental conditions or scavenger activity, leading to carcass degradation over time (West 2015). In addition, carcasses and feather spots are also detected with variable levels of accuracy due to carcass characteristics and ground cover (e.g. vegetated areas underneath heliostats versus cleared areas around towers) (West, 2015).

Therefore, it is generally inappropriate to draw conclusions based on the raw number of fatalities alone, and for this study, the Huso estimator was used to correct for detection and scavenging bias given that the estimator had been demonstrated to perform well under a variety of conditions (West, 2015). The Huso model was primarily developed for contextual fatality estimation for postconstruction fatality studies at wind energy facilities; however, the Huso estimator is suitable for other sources of anthropogenic avian mortality, including powerlines and utility-scale solar energy facilities (Huso, 2011).

Statistical analysis

Fatality estimation for a given site may be expressed as

$$F = \frac{C}{rp}$$

Where:

F is the total number of fatalities

C is the number fatalities detected

r is the probability that a carcass is unscavenged and can be found at the end of the search interval

p is the probability of detecting a carcass

The bias correction factors *r* and *p* were estimated by covariates that might have influenced the detectability and persistence of each carcass, such as carcass size, presence of vegetation and stage of decay or scavenging.

4.3 Results

4.3.1 Summary of avian impact detections

Throughout the 2016–2017 monitoring year, a total of 324 avian impact detections (including injured bird and incidental detections) were recorded involving 34 identified species (Table 4.3). Avian detections were highest in the 2016/2017 summer season (121 total detections; 37%), followed by the 2016 winter season (89 total detections; 27%) and the 2016 spring season (73 detections; 23%) and lowest in the 2017 autumn season (41 detections; 13%) (Figure 4.3).

Overall, the most frequently detected species were the red-billed quela (*Quela quela*) (109 detections; 34%), the lark-like bunting (*Emberiza impetuani*) (69 detections; 21%), the white-rumped swift (*Apus caffer*) (37 detections; 11%) and the red-headed finch (*Amadina erythrocephala*) (15 detections; 5%) (Figure 4.3).

None of the frequently detected species were classified as threatened or near threatened according to *The IUCN Red List of Threatened Species* (IUCN, 2019) and/or *The Eskom Red Data Book of Birds of South Africa, Lesotho and Swaziland* (Taylor et al., 2015). Nonetheless, two affected species that were classified as vulnerable were identified as the lanner falcon (*Falco biarmicus*) (1 detection) and the great white pelican (*Pelecanus onocrotalus*) (1 detection) (Taylor et al., 2015; Figure 4.3).

The frequency of affected bird species in relation to each location is summarised in Table 4.4 and illustrated in Figure 4.3.

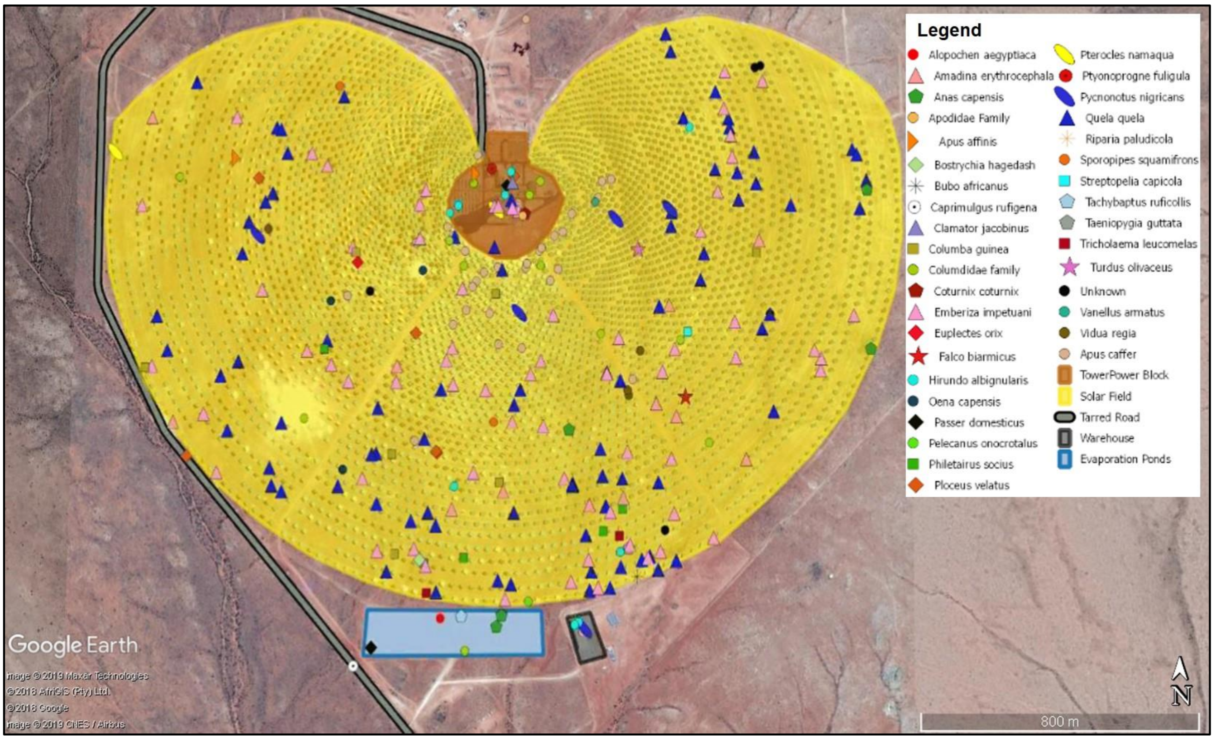

Figure 4.3 Locations of avian detections within the sample areas

Photo credit: Google Earth

Of the 324 detections, 285 were located within the solar field, which represented 88% of the total recorded detections and 71% (27 species) of the total identified species. Dominant species detected in the solar field were the red-billed quela (*Quela quela*) (109 detections), the lark-like bunting (*Emberiza impetuani*) (65 detections), the white-rumped swift (*Apus caffer*) (30 detections) and the red-headed finch (*Amadina erythrocephala*) (15 detections). Seasonal detections in the solar field varied throughout the monitoring period, and detections were highest in the 2016/2017 summer season (109 detections), followed by the 2016 winter season (74 detections) and the 2016 spring season (67 detections) and lowest in the 2017 autumn season (35 detections) (Table 4.4).

The power block yielded the second highest number of detections, which represented only 8% (26 detections) of the total recorded detections and 26% (10 species) of the total confirmed species (Table 4.4). Temporal detections in the power block varied to some extent throughout the monitoring season, and detections were found to be the highest in the 2016 winter and spring seasons (9 detections each) followed by the 2016/2017 summer season (6 detections) and slightly lower in the 2017 autumn season (2 detections) (Table 4.4).

The evaporation ponds yielded the third highest number of detections, which represented merely 2.5% (8 detections) of the total recorded detections and 8% (3 species) of the total confirmed species (Table 4.4). Temporal detections at the evaporation ponds varied slightly throughout the monitoring season with the only recoded detections in the 2016 winter season (4 detections), the 2017 autumn season (3 detections) and the 2016 spring season (1 detection) (Table 4.4). No detections were recorded during the 2016/2017 summer season (Table 4.4).

The lowest number of detections was recorded at the warehouse, which represents 1.5% (5 detections) of the total recorded detections (Table 4.4). Nonetheless, species diversity was slightly higher than at the evaporation ponds and represents 11% (3 species) of the total confirmed species (Table 4.4). Temporal detections at the warehouse were fairly constant throughout the monitoring season with single detections throughout the 2016–2017 monitoring year. The only exception was in the 2016/2017 summer season when 3 detections were documented (Table 4.4). The remaining sampling areas, namely the access road, perimeter fence, and substation and powerline, did not produce any detections throughout the 2016–2017 monitoring period.

Table 4.3 Number of avian mortalities and injuries by species, conservation status and season (2016–2017)

(Complete incident register with recorded data included in Appendix B)

Common name	Biological name	Conservation Status		Winter		Spring		Summer		Autumn		Total	
		Regional	Global	Fatalities	Injuries	Fatalities	Injuries	Fatalities	Injuries	Fatalities	Injuries	Fatalities	Injuries
Egyptian goose	*Alopochen aegyptiaca*	–	LC	0	0	0	0	0	0	1	0	1	0
Red-headed finch	*Amadina erythrocephala*	–	LC	8	0	6	0	1	0	0	0	15	0
Cape teal	*Anas capensis*	–	LC	5	0	0	0	0	0	0	0	5	0
Swift family	*Apodidae Family*	–	–	1	0	0	0	0	0	0	0	1	0
Little swift	*Apus affinis*	–	LC	0	0	3	0	0	0	0	0	3	0
White-rumped swift	*Apus caffer*	–	LC	1	0	0	0	31	1	4	0	36	1
Hadeda ibis	*Bostrychia hagedash*	–	LC	0	0	0	0	1	0	0	0	1	0
Spotted eagle owl	*Bubo africanus*	–	LC	1	0	0	0	0	0	0	0	1	0
Rufous-cheeked nightjar	*Caprimulgus rufigena*	–	LC	0	0	0	0	0	0	1	0	1	0
Jacobin cuckoo	*Clamator jacobinus*	–	LC	0	0	0	0	1	0	0	0	1	0
Rock pigeon	*Columba guinea*	–	LC	4	0	2	0	1	0	1	0	8	0
Columdidae family	*Columbidae Family*	–	–	9	0	4	0	0	0	0	0	13	0
Common quail	*Coturnix coturnix*	–	LC	1	0	0	0	0	0	0	0	1	0
Lark-like bunting	*Emberiza impetuani*	LC	LC	31	0	4	0	29	1	4	0	68	1
Red bishop	*Euplectes orix*	–	LC	0	0	0	0	1	0	0	0	1	0
Lanner falcon	*Falco biarmicus*	VU	LC	0	0	0	0	0	0	0	1	0	1
White-throated swallow	*Hirundo albignularis*	–	–	1	0	6	0	3	0	0	0	10	0
Namaqua dove	*Oena capensis*	–	LC	1	0	2	0	0	0	1	0	4	0
House sparrow	*Passer domesticus*	–	LC	1	0	0	0	0	0	0	0	1	0
Passeridae family	*Passeridae Family*	–	–	1	0	0	0	0	0	0	0	1	0

Great white pelican	*Pelecanus onocrotalus*	VU	LC	0	0	0	0	1	0	0	0	1	0
Sociable weaver	*Philetairus socius*	-	LC	0	0	0	0	2	0	3	0	5	0
Ploceidae family	*Ploceidae Family*	–	–	1	0	0	0	0	0	0	0	1	0
Southern masked weaver	*Ploceus velatus*	–	LC	1	0	1	0	1	0	2	0	5	0
Namaqua sandgrouse	*Pterocles namaqua*	LC	LC	2	0	0	0	0	0	0	0	2	0
Rock martin	*Ptyonoprogne fuligula*	–	LC	0	0	0	0	0	0	1	0	1	0
African red-eyed bulbul	*Pycnonotus nigricans*	-	LC	5	0	0	0	0	0	0	0	5	0
Red-billed quela	*Quela quela*	–	–	8	0	39	0	43	0	19	0	109	0
Brown-throated martin	*Riparia paludicola*	–	LC	0	0	1	0	0	0	0	0	1	0
Scaly-feathered finch	*Sporopipes squamifrons*	LC	LC	1	0	0	0	1	0	0	0	2	0
Cape turtle dove	*Steptopelia capicola*	–	–	0	0	2	0	0	0	0	0	2	0
Laughing dove	*Spilopelia senegalensis*	–	LC	0	0	2	0	0	0	0	0	2	0
Little grebe	*Tachybaptus ruficollis*	–	LC	0	0	0	0	0	0	2	0	2	0
Timor zebra finch	*Taeniopygia guttata*	–	LC	1	0	0	0	0	0	0	0	1	0
Acacia pied barbet	*Tricholaema leucomelas*	–	LC	1	0	0	0	0	0	1	0	2	0
Olive thrush	*Turdus olivaceus*	LC	LC	1	0	0	0	0	0	0	0	1	0
Blacksmith plover	*Vanellus armatus*	–	LC	1	0	0	0	0	0	0	0	1	0
Shaft-tailed whydah	*Vidua regia*	-	LC	1	0	0	0	0	0	0	0	1	0
Unknown sample/feather spot	Unknown sample	–	–	1	0	1	0	3	0	0	0	5	0
Total				**89**	**0**	**73**	**0**	**119**	**2**	**40**	**1**	**321**	**3**

The Regional status and Global status columns denote the latest global IUCN species classification according to their conservation threat category.

LC = least concern; VU = vulnerable.

Table 4.4 Number of avian detections by species in relation to study area and season (2016–2017)

(Complete incident register with recorded data included in Appendix B)

Common name	Species	Winter				Spring				Summer				Autumn				Total			
		EP	PB	SF	WH	EP	PB	SF	WH	EP	PB	SF	WH	EP	PB	SF	WH	EP	PB	SF	WH
Egyptian goose	*Alopochen aegyptiaca*													1				1	0	0	0
Red-headed finch	*Amadina erythrocephala*			8				6				1						0	0	15	0
Cape teal	*Anas capensis*	3		2														3	0	2	0
Swift family	*Apodidae Family*		1															0	1	0	0
Little swift	*Apus affinis*						2	1										0	2	1	0
White-rumped swift	*Apus caffer*		1								5	27				3	1	0	6	30	1
Hadeda ibis	*Bostrychia hagedash*							1										0	0	1	0
Spotted eagle owl	*Bubo africanus*			1														0	0	1	0
Rufous-cheeked nightjar	*Caprimulgus rufigena*															1		0	0	1	0
Jacobin cuckoo	*Clamator jacobinus*						1											0	1	0	0
Rock pigeon	*Columba guinea*			4				2				1				1		0	0	8	0
Columdidae family	*Columbidae Family*	1	2	6			2	2										1	4	8	0
Common quail	*Coturnix coturnix*		1															0	1	0	0
Lark-like bunting	*Emberiza impetuani*		2	29			2	2				30				4		0	4	65	0
Red bishop	*Euplectes orix*											1						0	0	1	0
Lanner falcon	*Falco biarmicus*															1		0	0	1	0
White-throated swallow	*Hirundo albignularis*			1			2	4			1		2					0	3	5	2
Namaqua dove	*Oena capensis*			1				2								1		0	0	4	0
House sparrow	*Passer domesticus*		1															0	1	0	0
Passeridae family	*Passeridae Family*					1												1	0	0	0
Great white pelican	*Pelecanus onocrotalus*											1						0	0	1	0
Sociable weaver	*Philetairus socius*							2								3		0	0	5	0
Ploceidae family	*Ploceidae Family*			1														0	0	1	0
Southern masked weaver	*Ploceus velatus*			1				1				1			1	1		0	1	4	0

Namaqua sandgrouse	*Pterocles namaqua*		1	1														0	1	1	0
Rock martin	*Ptyonoprogne fuligula*														1			0	1	0	0
African redeyed bulbul	*Pycnonotus nigricans*			4	1													0	0	4	1
Red-billed quela	*Quela quela*			8				39				43				19		0	0	109	0
Brown-throated martin	*Riparia paludicola*								1									0	0	0	1
Scaly-feathered finch	*Sporopipes squamifrons*			1								1						0	0	2	0
Cape turtle dove	*Steptopelia capicola*							2										0	0	2	0
Laughing dove	*Spilopelia senegalensis*							2										0	0	2	0
Little grebe	*Tachybaptus ruficollis*													2				2	0	0	0
Timor zebra finch	*Taeniopygia guttata*			1														0	0	1	0
Acacia pied barbet	*Tricholaema leucomelas*			1												1		0	0	2	0
Olive thrush	*Turdus olivaceus*			1														0	0	1	0
Blacksmith plover	*Vanellus armatus*			1														0	0	1	0
Shaft-tailed whydah	*Vidua regia*			1														0	0	1	0
Unknown sample/feather spot	Unknown sample			1			0	1				3						0	0	5	0
Total		**4**	**9**	**74**	**1**	**1**	**9**	**67**	**1**	**0**	**6**	**109**	**2**	**3**	**2**	**35**	**1**	**8**	**26**	**285**	**5**

EP = evaporation ponds; PB = power block; SF = solar field; WH = warehouse.

4.3.2 Cause of fatality or injury

The following section outlines the number of detections with evidence of impact trauma, predation, solar flux (singeing) or unknown causes, the number for which cause of fatality or injury is known or unknown and the temporal distributions of detections. Table 4.5 displays the number of detections by species, cause and season, and Figure 4.4 shows the distribution of detections by cause throughout the 2016–2017 monitoring season.

4.3.2.1 Impact trauma (collision)

Avian collision with mirrors yielded the most recordings given that 198 detections (61%) were documented during the 2016–2017 monitoring year. These detections represented 53% (18 species) of the total number of species detected, of which three were identified as dominant in terms of detected occurrences (Table 4.5; Figure 4.4).

Dominant species were the red-billed quela (*Quela quela*) (98 detections; 49%), the lark-like bunting (*Emberiza impetuani*) (65 detections; 33%) and the red-headed finch (*Amadina erythrocephala*) (13 detections; 7%) (Table 4.5). None of the frequently detected species were classified as threatened or near threatened (Taylor et al., 2015; IUCN, 2019).

Impact trauma detections varied slightly across seasons in the 2016–2017 monitoring period. Detections were highest in the 2016/17 summer season (57 detections), followed by the 2016 winter season (56 detections), the 2016 spring season (54 detections) and the 2017 autumn (31 detections) (Table 4.5, Figure 4.4). Hundred and ninety-six detections (99%) were recorded in the solar field, and the remaining 2 detections (1%) were recorded in the power block (Table 4.6).

4.3.2.2 Predation

Predation accounted for the lowest amount of detections given that only 21 detections (6%) were documented during the 2016–2017 monitoring year. The diversity of species affected by predation was found to be 27% (9 species) (Table 4.5; Figure 4.4).

None of the detected species were classified as threatened (Taylor et al., 2015; IUCN, 2019). Temporal predation detections varied slightly throughout the 2016–2017 monitoring season. Detections were highest in the 2016 winter season (9 detections), followed by the 2016/2017 summer season (8 detections) and the 2016 spring season (4 detections), with no detections in the 2017 autumn season (Table 4.5; Figure 4.4). Twenty detections (95%) were recorded in the solar field and 1 (5%) at the evaporation ponds (Table 4.6).

4.3.2.3 Solar flux (singeing)

Singeing mortalities and injuries generated the third most recordings given that 44 detections (14%) were documented during the 2016–2017 monitoring year. The total number of species affected by solar flux was found to be 12% (4 species) of which 1 species showed dominance in terms of recorded detections (Table 4.5; Figure 4.4). The dominant species was identified as the white-rumped Swift (*Apus caffer*) which comprised 80% (35 detections) of singeing detections (Table 4.5). None of the detected species were classified as threatened or near threatened (Taylor et al., 2015; IUCN, 2019). However, the lanner falcon (*Falco biarmicus*) (1 detection) that was injured by feather singeing was classified as vulnerable (Taylor et al., 2015; IUCN, 2019; Table 4.3; Table 4.5).

Singeing detections varied significantly throughout the 2016–2017 monitoring season. Detections were highest in the 2016/2017 summer season given that 70% (31 detections) of the total detections were documented in January and February 2017. Only 1 detection was documented in December 2016, which provided a total of 32 detections for the 2016/2017 summer season. Fewer detections were recorded in the 2016 spring season (5 detections), the 2017 autumn season (4 detections) and the 2017 winter season (3 detections) (Table 4.5; Figure 4.4). Thirty-two detections (73%) were recorded in the solar field, and the remaining 12 detections (27%) were recorded in the power block (Table 4.6).

4.3.2.4 Unknown causes

Birds for which no cause of mortality or injury could be determined yielded the second most recordings with 61 detections (19%) documented during the 2016–2017 monitoring year. The diversity of species affected by unknown trauma was found to be highest at 74% (25 species) (Table 4.5; Figure 4.4).

Species with the highest detection frequency were the lark-like bunting (*Emberiza impetuani*) (12 detections; 20%), the red-billed quela (*Quela quela*) (7 detections; 11%) and the white-throated swallow (*Hirundo albignularis*) (5 detections; 8%) (Table 4.5). None of the three most frequently detected species was classified as threatened or near threatened (Taylor et al., 2015; IUCN, 2019). Nonetheless, one documented species was classified as near threatened, namely the great white pelican (*Pelecanus onocrotalus*) (1 detection) (Taylor et al., 2015; IUCN, 2019; Table 4.3; Table 4.5).

Trauma detections with unknown cause varied throughout the 2016–2017 monitoring season. Detections were highest in the 2016/2017 summer season (23 detections), followed by the 2016 winter season (21 detections), the 2016 spring season (11 detections) and the 2017 autumn season (6 detections) (Table 4.5; Figure 4.4). Thirty-seven detections (61%) were recorded in the solar field, 12 detections (20%) in the power block, 7 detections (11%) at the evaporation ponds and 5 detections (8%) in the warehouse (Table 4.6).

Table 4.5 Number of avian mortality and injury detections by cause and by season (2016–2017)

(Complete incident register with recorded data included in Appendix B)

		Winter				**Spring**				**Summer**				**Autumn**				**Total**			
Common name	**Biological name**	Impact	Predation	Flux	Unknown	Impact	Predation	Flux	Unknown	Impact	Predation	Flux	Unknown	Impact	Predation	Flux	Unknown	Impact	Predation	Flux	Unknown
Egyptian goose	*Alopochen aegyptiaca*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	1
Red-headed finch	*Amadina erythrocephala*	6	1	0	1	6	0	0	0	1	0	0	0	0	0	0	0	13	1	0	1
Cape teal	*Anas capensis*	2	0	0	3	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	3
Swift family	*Apodidae Family*	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0
Little swift	*Apus affinis*	0	0	0	0	0	0	3	0	0	0	0	0	0	0	0	0	0	0	3	0
White-rumped swift	*Apus caffer*	0	0	1	0	0	0	0	0	0	0	31	1	0	0	3	1	0	0	35	2
Hadeda ibis	*Bostrychia hagedash*	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	1
Spotted eagle owl	*Bubo africanus*	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
Rufous-cheeked nightjar	*Caprimulgus rufigena*	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	1	0	0	0
Jacobin cuckoo	*Clamator jacobinus*	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	1
Rock pigeon	*Columba guinea*	3	1	0	0	1	1	0	0	0	0	0	1	1	0	0	0	5	2	0	1
Columdidae family	*Columbidae Family*	1	3	1	4	1	1	0	2	0	0	0	0	0	0	0	0	2	4	1	6
Common quail	*Coturnix coturnix*	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
Lark-like bunting	*Emberiza impetuani*	29	1	0	1	2	0	0	2	19	2	0	9	4	0	0	0	54	3	0	12
Red bishop	*Euplectes orix*	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	1	0	0	0
Lanner falcon	*Falco biarmicus*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	1	0
White-throated swallow	*Hirundo albignularis*	1	0	0	0	1	0	2	3	0	0	1	2	0	0	0	0	2	0	3	5
Namaqua dove	*Oena capensis*	0	0	0	1	2	0	0	0	0	0	0	0	1	0	0	0	3	0	0	1
House sparrow	*Passer domesticus*	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
Passeridae family	*Passeridae Family*	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
Great white pelican	*Pelecanus onocrotalus*	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	1

Sociable weaver	*Philetairus socius*	0	0	0	0	0	0	0	0	1	0	0	1	3	0	0	0	4	0	0	1
Ploceidae family	*Ploceidae Family*	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
Southern masked weaver	*Ploceus velatus*	1	0	0	0	1	0	0	0	0	1	0	0	1	0	0	1	3	1	0	1
Namaqua sandgrouse	*Pterocles namaqua*	0	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	1
Rock martin	*Ptyonoprogne fuligula*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	1
African red-eyed bulbul	*Pycnonotus nigricans*	3	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	3	1	0	1
Red-billed quela	*Quela quela*	6	0	0	2	38	1	0	0	35	3	0	5	19	0	0	0	98	4	0	7
Brown-throated martin	*Riparia paludicola*	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	1
Scaly-feathered finch	*Sporopipes squamifrons*	1	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	1	0	0	1
Cape turtle dove	*Steptopelia capicola*	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	1	1	0	0
Laughing dove	*Spilopelia senegalensis*	0	0	0	0	1	0	0	1	0	0	0	0	0	0	0	0	1	0	0	1
Little grebe	*Tachybaptus ruficollis*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	2
Timor zebra finch	*Taeniopygia guttata*	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0
Acacia pied barbet	*Tricholaema leucomelas*	1	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	2	0	0	0
Olive thrush	*Turdus olivaceus*	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0
Blacksmith plover	*Vanellus armatus*	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
Shaft-tailed whydah	*Vidua regia*	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0
Unknown sample	Feather spot	0	0	0	1	0	0	0	1	0	2	0	1	0	0	0	0	0	2	0	3
Total		**56**	**9**	**3**	**21**	**54**	**4**	**5**	**11**	**57**	**8**	**32**	**23**	**31**	**0**	**4**	**6**	**198**	**21**	**44**	**61**

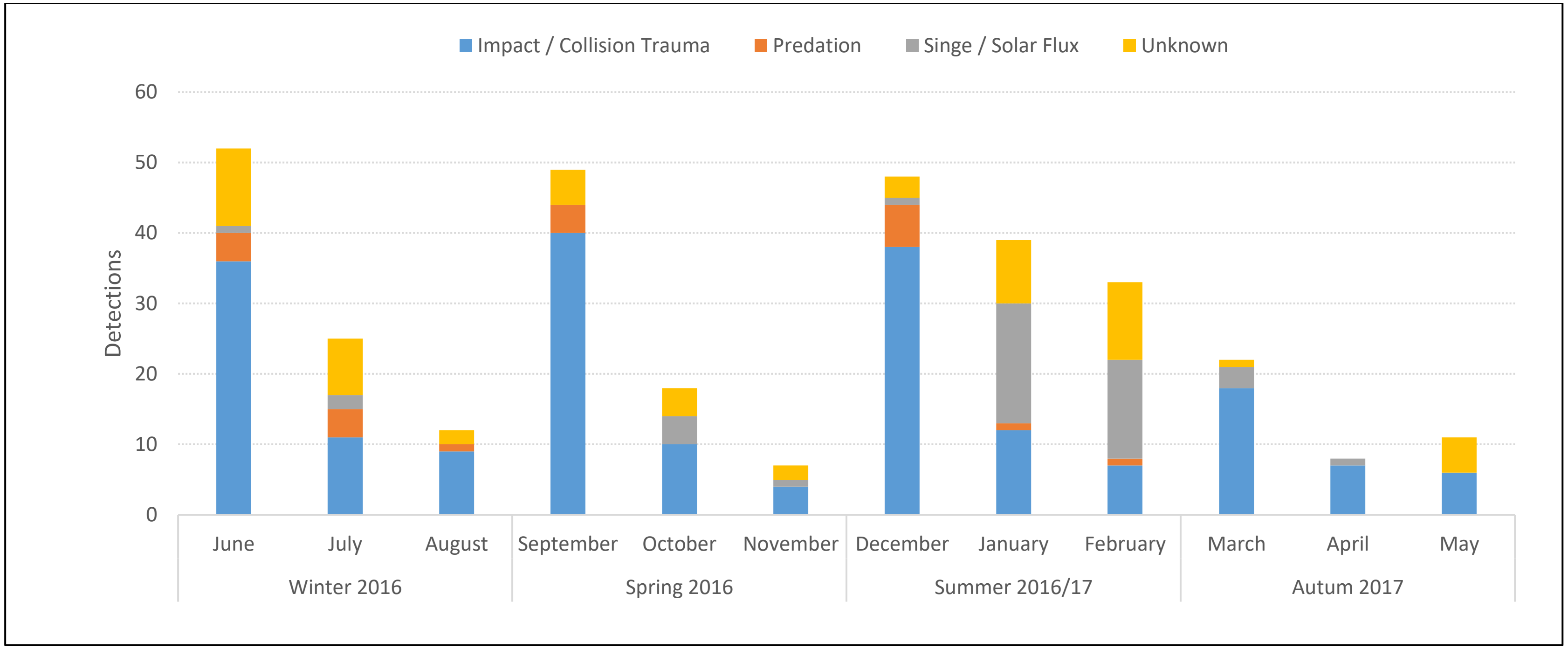

Figure 4.4 Avian mortalities and injuries by cause and by season (2016–2017)
(Complete incident register with recorded data included in Appendix B)

Table 4.6 Number of avian detections by cause of fatality or injury in relation to study area (complete incident register with recorded data included in Appendix B)

Fatality/injury	Study area			
	EP	**PB**	**SF**	**WH**
Impact	0	2	196	0
Predation	1	0	20	0
Flux	0	12	32	0
Unknown	7	12	37	5
Total	**8**	**26**	**285**	**5**

EP = evaporation ponds; PB = power block; SF = solar field; WH = warehouse.

4.3.3 Mirror Collision Index

This section defines the number of incidents, trend patterns and avian species associated with impact trauma (mirror collisions) with heliostats. Bird-strike imprints/smudge marks on the reflective surfaces of mirror facets were recorded and categorised by formulating the Mirror Collision Index (MCI) (Figure 4.2).

Table 4.7 and Figure 4.5 display the number of impact detections in relation to their positions on the heliostat as documented throughout the 2016–2017 monitoring season using the MCI. A total number of 136 mirror collision detections were documented with MCI positions, which represented 69% of the total number of impact trauma detections. The MCI documented a trend that indicated that 96% of all the mirror collisions occurred on the bottom two rows of the heliostat mirrors, ranging from A7 to D7 and A8 to D8 (Table 4.7; Figure 4.5).

All the species that were documented from A7 to D7 and A8 to D8 are summarised in Table 4.8. Dominant species from A7 to D7 and A8 to D8 are the red-billed quela (*Quela quela*) (81 detections; 62%) and the lark-like bunting (*Emberiza impetuani*) (27 detections; 21%) (Figure 4.8).

Table 4.7 Mirror collisions (impact trauma) in relation to their locations on the heliostat using the MCI

	A	B	C	D	Total
1				1	1
2					0
3					0
4					0
5		1		1	2
6	1	1		1	3
7	4	5	3	5	17
8	27	25	22	39	113
Total	32	32	25	47	**136**

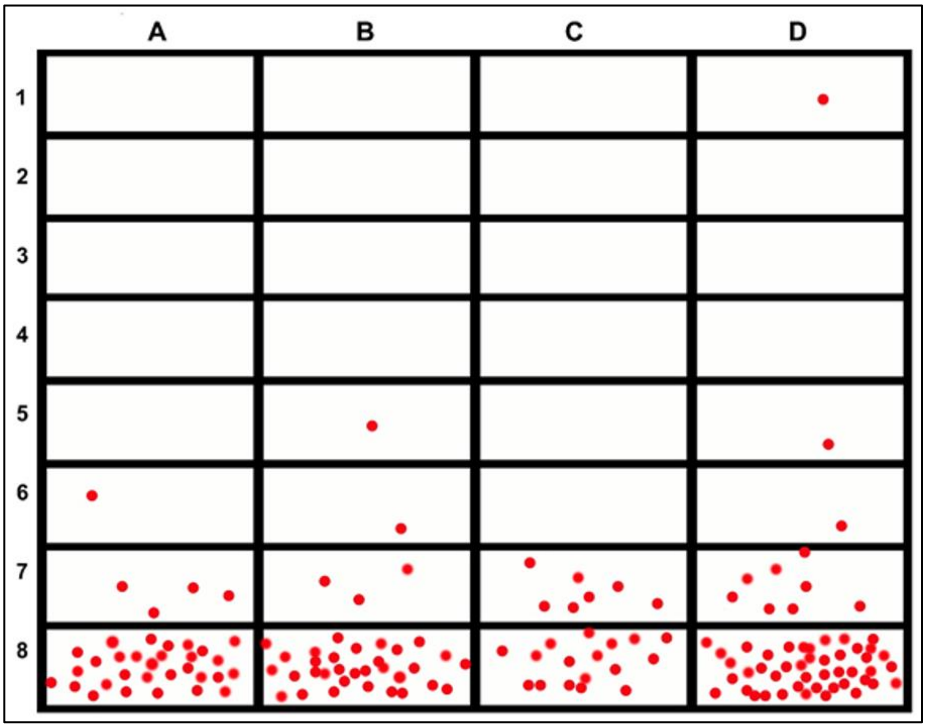

Figure 4.5 Mirror collisions (impact trauma) with their positions plotted according to the MCI

Image credit: Adrian Hudson

Table 4.8 Affected avian species that were documented with the MCI from A7 to D7 and A8 to D8

Common name	Species	MCI								Total
		A7	A8	B7	B8	C7	C8	D7	D8	
Red-billed quela	*Quela quela*	3	21	2	17	2	10	3	23	81
Lark-like bunting	*Emberiza impetuani*	1	4	1	3	0	8	1	9	27
Red-headed finch	*Amadina erythrocephala*	0	0	1	1	1	1	0	4	8
Rock pigeon	*Columba guinea*	0	1	0	1	0	0	1	1	4
Namaqua dove	*Oena capensis*	0	1	0	0	0	0	0	0	1
Southern masked weaver	*Ploceus velatus*	0	0	0	1	0	0	0	0	1
Acacia pied barbet	*Tricholaema leucomelas*	0	0	0	0	0	0	0	1	1
Columdidae family	*Ploceidae Family*	0	0	0	0	0	1	0	0	1
White-throated swallow	*Hirundo albignularis*	0	0	0	1	0	0	0	0	1
Sociable weaver	*Philetairus socius*	0	0	0	1	0	0	0	0	1
Cape turtle dove	*Steptopelia capicola*	0	0	0	0	0	1	0	0	1
Laughing dove	*Spilopelia senegalensis*	0	0	1	0	0	0	0	0	1
Timor zebra finch	*Taeniopygia guttata*	0	0	0	0	0	0	0	1	1
Shaft-tailed whydah	*Vidua regia*	0	0	0	0	0	1	0	0	1

4.3.4 Fatality estimation

4.3.4.1 Scavenger removal trials

A total of 36 carcass persistence trials were conducted from December 2016 to February 2018. Carcass variety comprised 10 small birds, 17 medium-sized birds and 9 large birds, distributed randomly throughout the power block and solar field. Species diversity amongst the carcasses was represented by 10 species. Small carcasses included the lark-like bunting (*Emberiza impetuani*; n = 4), the red-eyed bulbul (*Pycnonotus bnigricans*; n = 2), the red-billed quela (*Quelea quelea*; n = 2) and the white-throated swallow (*Hirundu albignularis*; n = 2). Medium-sized carcasses comprised the Cape turtle dove (*Steptopelia capicola*; n = 8), the rock pigeon (*Columba guinea*; n = 7), the common quail (*Coturnix coturnix*; n = 1) and the blacksmith plover (*Vanellus armatus*; n = 1). Large carcasses included the helmeted guineafowl (*Numida meleagris*; n = 8) and the cape teal duck (*Anas capensis*; n = 1).

Camera traps were placed at each carcass, and only one malfunction was detected associated with a medium-sized carcass that was placed in the solar field on 23 August 2017 (Table 4.9). The camera traps recorded the remaining 35 trials successfully, which implies that the removal time could be determined via photographic evidence for all the samples that were scavenged within the 7-day trial period (Table 4.9). It was found that 4 out of 10 small carcasses, 6 out of 10 medium-sized carcasses and 5 out of 9 large carcasses were removed within the 7-day trial period, which provided a total of 41 (7%) scavenged species (n = $\frac{15}{36}$) (Table 4.9).

Photographic evidence from the camera traps allowed for the detection of 10 scavengers, which included the pied crow (*Corvus albus*; n = 5), the Cape fox (*Vulpes chama*; n = 3), the yellow mongoose (*Cynictis penicillata*; n = 1) and the striped polecat (*Ictonyx striatus*; n = 1); (Table 4.10). Based on the summarised findings in Table 3.10, overall, 68.6% of carcasses were still detectable after 7 days given that in 11 out of the 35 trials that were successfully recorded by camera trap, carcasses were scavenged between 0 and 5 days.

The total number of days for all scavenged species were calculated with the camera trap time recordings of all 35 camera trials, which provided a value of 196 days. This implies that the mean day average for carcass removal was 5.6 days per carcass ($\frac{196 \text{ Days}}{35 \text{ Trials}}$) (Table 4.9).

In addition, based on the carcass persistence data from the cumulative trials (Table 4.9), t_{mean} was found to be approximately 20.9 days when corrected using the corrected AIC score where:

$$t_{mean} = \sum_{i=1}^{S} t/(S - S_c)$$

t = 7 days

S = 36 carcasses

S_c = 24 carcasses lasted 7 days

Table 4.9 Results from scavenger removal trials using motion-triggered scouting cameras

Trial start date	Time	Area	Size	Scavenged	Scavenger spp.	Trial end date	Time	Duration (days)
16/12/26	18:00	PB	S	1	Pied crow	16/12/30	12:00	3.5
16/12/26	18:23	PB	S	0		17/01/04		7
16/12/26	18:47	PB	S	0		17/01/04		7
16/12/30	8:25	SF	S	0		17/01/04		7
17/01/16	8:30	PB	S	0		17/01/23		7
17/01/16	9:00	PB	S	0		17/01/23		7
17/09/11	10:00	SF	S	1	Striped polecat	17/09/11	19:16	0
17/09/11	10:10	SF	S	1	Pied crow	17/09/16	11:27	4
17/09/11	10:20	SF	S	1	Cape fox	17/09/12	23:15	1.5
17/09/11	10:30	SF	S	0		17/09/18		7
Subtotal			10	4/10				51
17/01/23	10:00	PB	M	0		17/01/30		7
17/01/23	10:25	PB	M	0		17/01/30		7
17/01/23	11:20	PB	M	0		17/01/30		7
17/08/23	10:30	SF	M	1	*	17/08/30	*	*
17/08/23	10:50	SF	M	0		17/08/30		7
17/09/04	10:00	SF	M	0		17/09/11		7
17/09/04	10:10	SF	M	0		17/09/11		7
17/09/04	10:25	SF	M	1	Unknown	17/09/05	13:03	1
17/09/04	10:30	SF	M	1	Unknown	17/09/05	14:15	1
17/09/04	10:45	SF	M	0		17/09/11		7
17/11/20	14:44	PB	M	0		17/12/02		7
17/11/20	14:45	PB	M	1	Pied crow	17/11/28	5:08	7
17/11/20	14:50	PB	M	1	Pied crow	17/12/03	17:37	7
18/01/29	8:30	PB	M	0		18/02/05		7
18/01/29	8:40	PB	M	1	Pied crow	18/02/05	16:57	7
18/02/05	13:20	PB	M	0		18/02/12		7
18/02/05	13:43	PB	M	0		18/02/12		7
Subtotal			17	6/10				100

16/12/30	17:16	SF	L	1	Unknown	17/01/03	23:45	3
17/08/18	14:00	SF	L	1	Yellow mongoose	17/08/23	16:19	5
17/08/18	14:05	SF	L	1	Cape fox	17/08/23	20:57	5
17/08/18	14:10	SF	L	1	Cape fox	17/08/18	18:59	0
17/08/18	14:15	SF	L	1	Unknown	17/08/22	6:30	4
17/11/20	14:00	PB	L	0		17/11/27		7
17/11/20	14:10	PB	L	0		17/11/27		7
17/11/20	14:30	PB	L	0		17/11/27		7
17/11/20	14:40	PB	L	0		17/11/27		7
Subtotal			9	5/9				45
Total			36	15/36				196
Mean								**5.6**

*Camera trap malfunction – no data recorded.

PB = power block; SF = solar field.

4.3.4.2 Searcher efficiency trials

In total, 92 carcasses were placed for searcher efficiency trials, of which 75 were found to be available for observation. Carcass loss was attributed to scavenger removal activities, given that carcass samples were placed between one and two days prior to each trial event.

Based on the searcher efficiency data from the cumulative trials (Table 4.11), searchers were able to detect 87% of the trial carcasses, where:

$$\rho = \frac{C_o}{C_a}$$

C_o = 65 observed carcasses

C_a = 75 available carcasses

Searcher efficiency was influenced by carcass size since detection rate was found to be the lowest with small carcasses (Trial 1, ρ = 61%; Trial 2, ρ = 100%; Trial 3, ρ = 87%) (Table 4.11). Medium-sized carcass detection rate was the highest and most consistent given that it was found that ρ = 100% for all three trials. Large carcass detection rate was found to be second highest given that one carcass was not detected during the first trial (Trial 1, ρ = 75%; Trial 2, ρ = 100%; Trial 3, ρ = 100%) (Table 4.11).

Table 4.10 Results from human searcher efficiency values for size and overall average

Trial no	Area	Size	Placed	Available	Observed	Searcher efficiency (*ρ*)
	SF	S	18	18	11	11/18 (61%)
1	SF	M	10	7	7	7/7 (100%)
	SF	L	4	4	3	3/4 (75%)
Subtotal			32	29	21	21/29 (72%)
	SF	S	16	6	6	6/6 (100%)
2	SF	M	10	9	9	9/9 (100%)
	SF	L	4	4	4	4/4 (100%)
Subtotal			30	19	19	19/19 (100%)
	SF	S	16	15	13	13/15 (87%)
3	SF	M	10	8	8	8/8 (100%)
	SF	L	4	4	4	4/4 (100%)
Subtotal			30	27	25	25/27 (93%)
Total			92	75	65	65/75
ρ_{mean}						**87%**

4.3.4.3 Fatality estimator

The probability for a carcass to be unscavenged and available during a search interval ranged from 68.8% to 100% as the analysed data and results from Section 4.3.4.1 suggest. The former probability value was derived from the data in Table 4.10, which indicated that in 24 out of the 35 successful carcass camera trails, carcasses remained 7 days or longer without being scavenged. This probability is represented by r_x. The latter value was formulated using the corrected AIC score, which indicated that the approximate mean time for a carcass to remain unscavenged and available was 20.9 days. The fact that standardised monitoring searchers were conducted every 7 days would therefore indicate that scavenger removal did not have a significant effect on the data collected, and thus a 100% probability was obtained, presented as r_y.

Fatality estimation was therefore formulated separately for each probability value (r_x = 68.8%; r_y = 100%) for a carcass to be unscavenged and available where:

$$F_x = C/r_x p$$

F_x = total number of fatalities by incorporating a probability value of 68.8%

C = total number avian mortality and injury detections

r_x = 68.8% (probability of unscavenged and available carcass at the end of the search interval)

p = 87% (probability of detecting a carcass) and

$$F_y = C/r_y\,p$$

F_y = total number of fatalities by incorporating a probability value of 100%

C = total number of avian mortality and injury detections

r_y = 100% (probability of unscavenged and available carcass at the end of the search interval)

p = 87% (probability of detecting a carcass)

Probability values for the annual number of birds affected by the Khi Solar One CSP facility are summarised in Table 4.12. During the 2016–2017 monitoring year, there were an estimated total of 543 fatalities based on r_x = 68.8% and p = 87%. Regarding cause of fatality, 332 (61%) were caused by collision trauma, 74 (14%) were caused by solar flux, 70 (13%) were caused by an undetermined/unknown cause and 35 (6%) were caused by predation (Table 4.12). Summer yielded the highest results with 201 mortalities, winter 149 mortalities, spring 124 mortalities and autumn the lowest with 69 mortalities (Table 4.12).

Alternatively, the 2016–2017 monitoring year produced an estimated total of 372 avian fatalities based on r_y = 100% and p = 87%. Collision trauma caused an estimated number of 228 (61%) avian mortalities, 51 (14%) were caused by solar flux, 70 (19%) were caused by an undetermined/unknown cause and 24 (6%) were caused by predation (Table 4.12). Summer yielded the highest results with 138 mortalities, winter 102 mortalities, spring 85 mortalities and autumn the lowest with 47 mortalities (Table 4.12).

Table 4.11 Annual avian fatality and injury estimates in relation to cause, detections (***C***) and 2016–2017 season (with r_x = 68.8% and r_y = 100% carcass availability)

Season	Impact/collision trauma			Predation			Singeing/solar flux			Unknown cause			*C* Total	F_x Total	F_y Total
	C	F_x	F_y	*C*	F_x	F_y	*C*	F_x	F_y	*C*	F_x	F_y			
Winter	56	94	64	9	15	10	3	5	3	21	35	24	89	149	102
Spring	54	90	62	4	7	5	5	8	6	11	18	13	74	124	85
Summer	57	96	66	8	13	9	32	54	37	23	39	26	120	201	138
Autumn	31	52	36	0	0	0	4	7	5	6	10	7	41	69	47
Total	**198**	**332**	**228**	**21**	**35**	**24**	**44**	**74**	**51**	**61**	**70**	**70**	**324**	**543**	**372**

4.4 Discussion

4.4.1 Avian mortalities and injuries

4.4.1.1 Impact trauma (collision) and its *i*mportant association with the Mirror Collision Index

Of the 324 avian detections documented during the 2016–2017 monitoring year, 198 injuries/mortalities were found to be caused by collisions and showed signs of impact trauma. The vast majority of these collisions were recorded in the solar field, and evidence of the collisions was found on the reflective surfaces of the heliostats. This implies that collision comprised 61% of the total number of mortalities (Table 4.5; Figure 4.4). This cause of avian mortality and injury was widespread throughout the solar field and comprised 99% of total collision detections (Table 4.6).

These collision-related findings in relation to their locality could be expected since collision hazards to birds are the greatest among solar fields at CSP and PV facilities (Walston et al., 2015). The probable root cause of the high collision hazard at PV facilities in particular is hypothesised to be the probability that migratory birds are lured by the 'lake effect' (Kagan et al., 2014). The lake effect is described as the phenomenon whereby migrating birds perceive the reflective surfaces of PV panels in particular as bodies of water due to their reflective characteristics, resulting in avian collision with these structures as they attempt to land on the PV panels. The lake effect hypothesis is, however, highly unlikely to be worthy of consideration as a root cause of the high impact trauma detections at Khi Solar One. Firstly, the mirrors (i.e. heliostats) at Khi Solar One are individual panels that appear from as above in a stippling-pattern during normal operation in a semidesert background (Figure 4.6). Contrary to heliostats, PV panels are generally positioned in long banks of adjacent panels, providing a more continuous, aquatic appearance (Kagan et al., 2014). In addition, mirror collision findings at Khi Solar One indicate that dominant avian species (red-billed quela, n = 98; lark-like bunting, n = 65; red-headed finch, n = 13) that contribute to 89% of all heliostat collision-related injuries/mortalities are classified as resident and not migratory species (Table 4.5). This stands as contradictory evidence to the lake effect hypothesis.

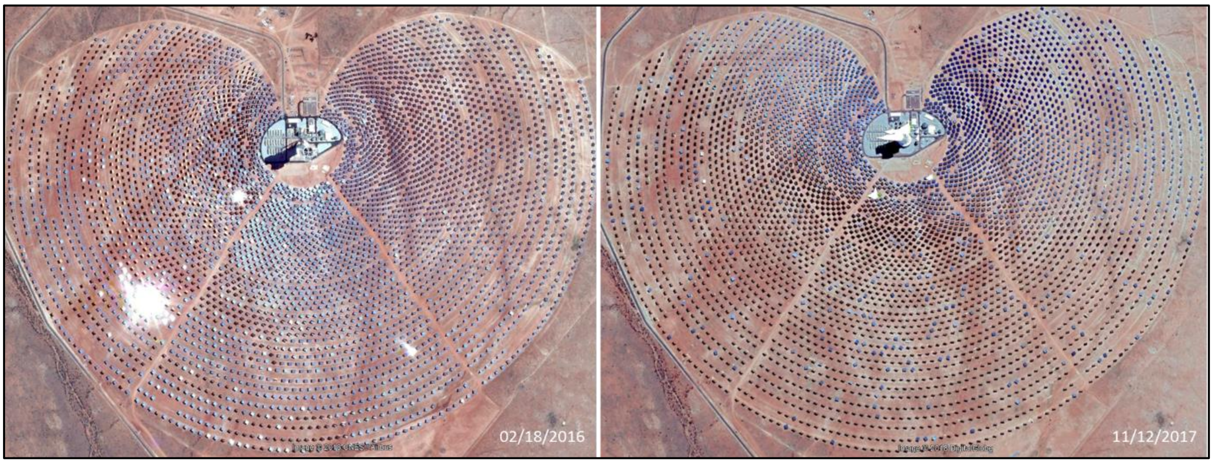

Figure 4.6 Khi Solar One Solar heliostats seen via satellite during two different timelines.

The left-hand image was photographed on 18 February 2016 and the right-hand image on 12 November 2017.

Photos credit: Google Earth

During the study, it was noticed that the heliostats were programmed to move into a 90° vertical position (i.e. washing position) from dusk till dawn. From an avian collision risk point of view, this can be considered as a highly probable root cause of avian mirror collision given that vertically positioned heliostats create an illusion of a continuous landscape (Figure 4.7), which can be considered as a well-established hazard for birds (Kagan et al., 2014).

Figure 4.7 Khi Solar One heliostats positioned in a 90° vertical position during dusk. Note the illusion of the continuous surrounding landscape except for the heliostat to the far right, which is breaking the illusive pattern by being positioned in an operational position.

Photo Credit: HP van Heerden

This root cause finding is further supported by MCI findings that identified a trend of avian collision with the reflective surfaces (mirrors) of the heliostats. Ninety six percent of all the mirror collisions occurred on the bottom two rows of the heliostat mirrors (Table 4.7; Figure 4.5). By measuring the vertical height of these two rows, A7–D7 and A8–D8 (Figure 4.2), when a heliostat was orientated in the washing position, it was found that the lower two rows spanned a height of approximately 0.6 m to 3.2 m. Avian flight height data that were collected during the Khi Solar One vantage point surveys (Table 3.4) revealed that the vertical height of rows A7–D7 and A8–D8 corresponded with the average flight height of the dominant MCI species, namely the red-billed quela (*Quela quela*) and the lark-like bunting (*Emberiza impetuani*). These species were found to be most susceptible to mirror collisions between the bottom two rows of the heliostats (Table 4.7; Figure 4.5).

These findings therefore suggest that the 90° vertical position (i.e. washing position) and the timing thereof (dust till dawn) are not ideal and probably the root cause of the high number of collisions recorded in the solar field given that the majority of avian species are on the wing before sunrise and will most probably collide with the reflective surfaces of the heliostats during this period.

4.4.1.2 Solar flux (singeing)

The findings clearly demonstrate that a significant increase in solar flux-related detections occurred during the summer months of January and February, seeing that 70% of all solar flux-related injuries/mortalities were recorded during this particular period (Table 4.5; Figure 4.4). Further data analysis for this peak time in singeing detections revealed that most recorded detections were migratory birds such as the white-rumped swift (*Apus caffer*) (Taylor et al., 2015) (Table 4.5). It stands to reason that the increase in solar flux-related injuries/mortalities was the result of the fact that migratory avian species, which are aerial feeders with a higher flight height than resident species, were present at the time (Table 4.4).

It is also noteworthy that a clear correlation exists between the peak singeing detection months (January and February) and the positioning of heliostats into the standby position during this period. At this time, the facility was subjected to low production due to technical reasons, which resulted in the heliostats' being frequently orientated into the standby position, resulting in solar flux being radiated above the tower in mid-air, creating a 'halo effect' due to the concentrated solar radiation. The avian risk and resulting direct impact of birds flying into mid-air concentrated solar flux have been widely documented and investigated (McCrary et al., 1986; Hernandez et al., 2014; Kagan et al., 2014; Ho, 2015). It is therefore highly likely that the high injury/mortality rate during January and February 2017 can be attributed to an increase in migratory high-flying aerial feeders such as the white-rumped swift (*Apus caffer*) with the combined effect of concentrating solar flux above the power tower during this time.

4.4.1.3 Predation

Predation was found to be the least significant cause of avian mortality and/or injury given that it constituted 6% of the total number of injuries/mortalities (Table 4.5; Figure 4.4). From mapping, it would appear that predation occurred over most of the facility; however, it is worth noting that 95% of all injuries/mortalities were recorded in the solar field (Table 4.6). This seems logical since the solar field comprised nearly 50% of the study site; however, observations at other utility-scale solar power facilities suggest that predation is likely linked to panel-related nonfatal impact trauma (Kagan et al., 2014). This is supported by the numerous sightings of birds of prey species in the solar field such as the rock kestrel (*Falco rupicolus*), the pale chanting goshawk (*Melierax canorus*) and the lanner falcon (*Falco biarmicus*) (Taylor et al., 2015). Rock kestrels and pale chanting goshawks were found perching on a variety of infrastructure such as street lights, monopoles and heliostats. Pied crows took residence in the solar field and were observed nesting, foraging or feeding on bird carcasses on a frequent basis.

4.4.1.4 Unknown causes

Detections for which the root cause of mortality or injury could not be determined yielded the second most recordings: 61 detections (19%) of which the majority (61%) were recorded in the solar field (Table 4.6).

It is worth noting that although the cause of mortality was considered unknown, 36 of the 37 detections recorded in the solar field were found in close proximity to heliostats (Appendix B). Furthermore, 19 of these 37 detections were identified as species that were predominantly affected by mirror impact trauma (Table 4.5), namely the lark-like bunting (*Emberiza impetuani*) (n = 10), the red-billed quela (*Quela quela*) (n = 7), the red-headed finch (*Amadina erythrocephala*) (n = 1) and the sociable weaver (*Philetairus socius*) (n = 1) (Appendix A). Findings at other solar power facilities support the assertion of nonfatal collisions through evidence of predation mortalities among aquatic habitat-dependent species (Kagan et al., 2014). In this instance, one can argue that these detections were due to nonfatal impact that led to starvation due to the inability to feed because of injury. Natural causes not related to the Khi Solar One facility such as inter- or intraspecific competition, age, disease and poisoning can be considered as part of the cause of mortality or injury (Begon et al., 1996).

4.4.2 Annual fatality estimates

The review of existing literature provided inconsistent and sparse avian fatality data given that standardisation was lacking in relation to data collection methods, reporting units and bias correction at utility-scale solar energy facilities in general (Table 4.13; Walston et al., 2015). As a result, it was difficult to make a meaningful assessment of the overall avian fatality at CSP tower facilities and to formulate accurate hypotheses regarding the risk of avian mortality among these facilities and other sources of solar electricity generation. Among CSP tower facilities alone, fatalities per area may be a more suitable metric for estimating cumulative impacts since the efficiency of CSP tower technology is continuing to improve and change in design and operation over time is thus inevitable (Walston et al., 2015).

The data summarised in Table 4.13 were derived from studies that dated back as early as 1986 (McCrary, et al.) and were as recent as 2016 (West Inc., 2015). The reviewed data clearly illustrated variation in area surveyed, survey time span and the presence of avian fatality and injury estimates in the findings (Table 4.13).

Nevertheless, should one consider fatalities per area (detection per hectare). It is interesting to note that the most recent studies that incorporated fatality and injury estimates were in the same order of magnitude; i.e. 1.72 and 1.53 detections per hectare (ISEGS and KHI S1). Whether this finding can be attributed to mere chance or to the fact that the survey period of both studies spanned four seasons (12 months) cannot be determined further, as inconsistent and sparse avian fatality data are available. In addition, other notable observations in the examination of these studies are the variations in avian mortalities in relation to singeing (solar flux); data suggests that mortalities are higher at facilities that contain shorter towers (Table 3.4). The reason for this observation might be the flight height of birds with the majority of avian species not flying at 200 m and beyond. It is therefore possible that higher power towers might reduce the risk for singeing mortalities.

Therefore, similar to other studies, it is worth considering that to fully understand the risk of avian mortality posed by CSP tower facilities, fatality estimates need to be calculated through standardised protocols to account for potential biases and yield meaningful comparisons through estimates (Erickson et al., 2005; Sovacool, 2009).

Apart from technology type, footprint size and operational procedures, one needs to consider that similar to wind energy facilities, avian fatality risk might be affected by a solar power facility's geographic setting in relation to seasonal variances in avian activity and abundance, avian migration patterns, avian daytime versus night-time activity and weather patterns (Harvey & Associates, 2015).

Table 4.12 Comparison of available avian fatality data at CSP tower facilities

Facility	MW	Tower height (m)	Area (ha)	Study area	Survey (months)	Total deaths	Singeing	Collision trauma	Detections per ha
ISEGS	337	130	1 457	29%	12	2 500 ∅	1 146 ∅	1 352 ∅	1.72
CDSEP	110	200	660	-	1	115	115	-	0.174
KHI S1	50	205	354	100%	12	543 ∅	74 ∅	332 ∅	1.53
Gemasolar	20	140	200	-	14	0	-	-	-
Solar One	10	86	40	100%	10	70	13	57	7
SEDC	6	60	8	-	48	0	0	-	-

Source: McCrary et al. (1986), Ho (2016) and West Inc. (2015).

∅ represents values derived from annual avian fatality and injury estimates.

Khi Solar One value is derived from a 68.8% probability for carcass availability as documented in Figure 3.12.

Study area resembles the percentage of development footprint surface area surveyed.

4.5 Conclusion

The findings presented in this chapter demonstrate that concerns in relation to direct impacts of CSP towers on bird populations are not completely unsubstantiated, even though some results remain inconclusive. Rigorous monitoring confirmed a definite link between collision impact trauma and solar energy-related infrastructure, in particular heliostats and the preprogrammed positioning thereof. In addition, mid-air concentrated solar flux emitted above the tower by the preprogrammed standby positioning of heliostats was also demonstrated to have a profound effect on high-flying avian species.

Therefore, CSP tower technology in South Africa can be associated with two general types of direct avian impacts, which are mirror collision related and solar flux related. This emphasises that this particular utility-scale solar technology, like many other industrial developments, has the potential to directly impact birds in a number of ways.

The results of the direct impacts on birds therefore suggest that onsite mitigation measures should be implemented under an adaptive management framework that will allow further assessment of their effectiveness. Shortcomings in data analysis could be due to a general lack in standardisation of data collection in the utility-scale solar power industry. Standardized methodology is essential to make avian impact comparisons among projects and across industries that will allow the compilation of appropriate mitigation protocols to lessen adverse effects on species of concern and their habitats (Walston et al., 2015). These overall findings are further investigated in Chapter 5 where onsite mitigation measures for the Khi Solar One Facility are identified.

CHAPTER 5: CONCLUSION

This study offers a number of findings and recommendations from the investigation of the avian impact of South Africa's first CSP tower facility situated in the Northern Cape. This chapter provides a summary of the key findings, final conclusions and recommendations for current and future CSP tower facilities.

5.1 Summary of impact findings and conclusions

5.1.1 Indirect impacts

The results of studies on CSP tower facilities in the United States of America suggest that this technology has negative impacts on the species abundance, density and diversity of avian communities (DeVault et al., 2014; West Inc., 2015). The findings of this study are consistent with these trends since avian species diversity, abundance and density per unit area were found to be higher in the untransformed habitat (i.e. reference site) than in the transformed habitat (i.e. facility footprint). However, the findings indicated that open country/grassland and generalist avian species were more abundant in the facility footprint and therefore used the transformed habitat more extensively than other species.

Nevertheless, considering the comparable data variables between the two survey areas, the impacts may be considered as minor since the transformed habitat is penetrable to most avian species (Visser, 2016). Significant environmental factors such as vegetation quality and habitat availability are most likely the dominant factors influencing species' presence and their relative density within the facility footprint (Visser, 2016).

It is difficult to predict the effects of vegetation quality and habitat availability given that a knowledge gap exists between the behavioural flexibility and the habitat requirements of most avian species (Barrios & Rodriquez, 2004; Fox et al., 2006; Madsen & Boertmann, 2008). Further investigation into resource exploitation among bird species and integration of adequate pre- and postconstruction avian monitoring may improve our understanding of species-landscape relationships (Lima & Zollner, 1996; Fox et al., 2006).

5.1.2 Direct impacts

The general lack of standardisation of data collection in the utility-scale solar power industry causes shortcomings in data analysis. It is therefore vital to ensure that methodology is standardised to allow avian impact comparisons among projects and across industries to be made. This will ensure the compilation of appropriate mitigation protocols to lessen adverse effects on species of concern and their habitats (Walston et al., 2015).

The findings presented in Chapter 4 demonstrate that concerns in relation to direct impacts of CSP towers on bird populations are not unsupported, even though some results remain inconclusive. Through rigorous monitoring, the existence of a definite link between collision impact trauma and solar energy-related infrastructure, in particular heliostats and the positioning thereof, was established. In addition, mid-air concentrated solar flux emitted above the power tower by the preprogrammed standby positioning of heliostats was also demonstrated to have a profound effect on high-flying avian species.

CSP tower technology in South Africa can thus be associated with two general types of direct avian impacts, namely mirror collision related and solar flux related. Onsite mitigation measures should be implemented under an adaptive management framework that will allow further assessment of their effectiveness.

5.2 Important associations and recommendations

5.2.1 Mitigation measures

5.2.1.1 Conventional mitigation measures

To mitigate avian trauma in general, numerous measures have been recommended to deter birds from CSP tower facilities (Ho, 2016). These measures include acoustic, tactile, visual and chemosensory deterrents (Walston et al., 2015).

Acoustic deterrents produce either predatory or painful sounds that birds tend to evade (Walston et al., 2015). However, a known flaw in this type of system is unlikely long-term effectiveness given that avian species become habituated to sound, which decreases this deterrent’s effectiveness over time (Dooling, 2002).

Visual deterrents that involve intense light, colours and decoys have been recommended and implemented in the wind energy sector, with limited reports on failure or success (Walston et al., 2015). However, structures such as meteorological and communication towers have been shown to reduce bird collisions with a steady-burn lighting regime (Gehring et al., 2009).

Tactile deterrents create pain or discomfort with the aim of encouraging aversion (Schakner & Blumstein, 2013). Currently, literature on the success of tactile deterrents for flying animals in general is lacking, but avian perch deterrents have largely been found to be ineffective (Duarte et al., 2011; Walston et al., 2015), whereas deterrents such as electric shock devices have been found to be partially effective for nuisance avian species (Seamans & Blackwell, 2014). In the case of CSP tower facilities, tactile deterrents are not envisaged as a suitable mitigation measure given that the majority of birds at Khi Solar One were affected in flight and not when perching or nesting.

Chemosensory deterrents refer to measures that rely on chemicals or scents that are irritating to birds (Walston et al., 2015). In general, conditioned smell or taste aversion methods to reduce wildlife conflicts with humans have produced noncomparable results in terrestrial ecosystems (Shivik et al., 2003). Therefore, additional research is required to determine the effectiveness of chemosensory deterrents at CSP tower facilities (Walston et al., 2015).

5.2.1.2 Mirror collision mitigation

A number of important factors regarding collisions at Khi Solar One were documented during this study:

- Collision trauma is predominantly limited to the solar field where gregarious granivores appear to be most likely to collide with the mirrors (heliostats).
- This can be attributed to the illusion of the continuous surrounding landscape that is created by the heliostats when in the 90° washing position.
- Impacts on the heliostats correlate with the average avian flight height of birds in the study area.
- It appears that impact occurs in the early morning (dusk) and late afternoon (dawn) at the time when the heliostats are programmed to position themselves into the 90° washing position.

These factors allow one to conclude that collisions can be addressed should the illusion of a continuous surrounding landscape created by heliostats when in the 90° washing position be eliminated. Alternatively, heliostats need to be made more visible to birds.

Following conventional methods of making reflective surfaces more visible may cause a predicament. The assumption is that the alteration of mirrors by reflective paint or adhesives may cause a reduction in the reflectiveness of the heliostats, making them more visible to birds. However, any reflective alteration will reduce the reflective area of each mirror and may result in a loss of productivity of the facility.

The most obvious method for reducing mirror collisions would therefore be to avoid using the 90° washing position as a rest or starting position during the early morning and late afternoon when birds are most active. The continuous landscape illusion can also be eliminated by reprogramming the heliostats to position themselves slightly off the 90° vertical angle washing position, as illustrated below in Figure 5.1.

Figure 5.1 Khi Solar One heliostats positioned in a 90° vertical position at dawn (left).
Note the illusion of the continuous surrounding landscape. In contrast, heliostats increase in visibility when positioned at an angle of < 90° (right).

Photos credit: Adrian Hudson

5.2.1.3 Solar flux mitigation

Solar flux trauma is arguably more difficult to mitigate than mirror collision trauma. Nevertheless, a number of important factors were determined during the study at Khi Solar One, especially when solar flux findings are compared with the findings of studies of other CSP tower facilities. These factors can be summarised as follows:

- Solar flux trauma at a facility is inversely proportional to solar tower height.
- Solar flux trauma is directly proportional to the existence and intensity of concentrated flux above the solar tower when the heliostats are in the standby position.
- It is unlikely for birds to fly into concentrating flux around a solar tower's heat exchanger due to the visual and tactile cues emanating from these structures.
- Solar flux trauma is directly proportional to the presence of migratory avian species that are aerial feeders.
- The design of the solar tower appears to affect the number of solar flux-related avian mortalities and/or injuries.

The abovementioned factors allow one to conclude that the reduction of mid-air solar flux emitted above the solar tower at Khi Solar One should reduce the risk of avian singeing. This is supported by reports which suggest that solar flux energy levels from 4 kW/m^2 to 50 kW/m^2 could be considered as safe irradiance levels for birds (Kraemer, 2015). Damage to the feathers and keratin structure can occur at expected exposure durations when irradiance levels rise beyond the 4 kW/m^2 to 50 kW/m^2 threshold (Ho, 2016). Based on this finding, the most practical and feasible method of reducing solar flux trauma would be to reduce the concentrating energy level of solar flux in mid-air when heliostats are in the standby position

(Ho, 2016). This could be achieved by scattering the concentrated flux (i.e. aim points) and choosing suitable standby aiming tactics to minimise both solar flux and heliostat slew time (Ho, 2016).

Both the Crescent Dunes Solar Energy Project and the Invanpah Solar Electric Generating System have implemented mitigation strategies to disperse the aim points of heliostats when in the standby position (Ho, 2016). The former project reportedly has had success with this mitigation procedure (Kraemer, 2015). A second option would be to place the heliostats in a horizontal position that is known as the 'safe position' when solar energy is not concentrated on the solar tower's heat exchanger.

5.3 Recommendations for future research

A number of fascinating combinations of methods and scopes could be considered for future research in this context. Based on the initial investigation, the following recommendations are made:

- It is important to investigate how avian impact methodology can be standardised across the emerging solar industry to ensure that avian impact comparisons among projects and across industries can be made. This will ensure the compilation of appropriate mitigation protocols to lessen adverse effects on species of concern and their habitats.
- With the proposed mirror collision and solar flux mitigation measures implemented, a further four-season study should be conducted to determine the efficiency of these mitigation measures.
- Further investigation into resource exploitation among bird species and implementation of adequate pre- and postconstruction avian monitoring may improve our understanding of species-landscape relationships.

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APPENDICES

A. AVIAN SPECIES KNOWN TO OCCUR IN THE STUDY AREAS

Table A.1 Represents a list of Avian Species known to occur in the Study Area.

The **Regional Status** and **Global Status** columns denotes the latest global IUCN species classification according to their conservation threat category. Standardised abbreviations followed: Extinct (EX); Critically Endangered (CR); Endangered (E); Vulnerable (VU); Near Threatened (NT); Least Concern (LC) and (-) Unknown/Not Assessed (Maclean 1993; Sinclair et al. 2002; Hockey et al 2005; Taylor et al. 2015; IUCN 2019).

Common Name	**Biological name**	**Regional Status**	**Global Status**
Little Grebe	*Tachybaptus ruficollis*	-	LC
White-breasted Cormorant	*Phalacrocorax lucidus*	-	-
Reed Cormorant	*Phalacrocorax africanus*	-	-
Crowned Cormorant	*Phalacrocorax coronatus*	NT	NT
Great Cormorant	*Phalacrocorax carbo*	-	LC
African Darter	*Anhinga rufa*	-	LC
Grey Heron	*Ardea cinerea*	-	LC
Black-headed Heron	*Ardea melanocephala*	-	LC
Little Egret	*Egretta garzetta*	-	LC
Western Cattle Egret	*Bubulcus ibis*	-	LC
White Stork	*Ciconia ciconia*	-	LC
Black Stork	*Ciconia nigra*	VU	LC
Abdim's Stork	*Ciconia abdimii*	NT	LC
Hamerkop	*Scopus umbretta*	-	LC
Hadeda Ibis	*Bostrychia hagedash*	-	LC
Egyptian Goose	*Alopochen aegyptiaca*	-	LC
South African Shelduck	*Tadorna cana*	LC	LC
African Comb Duck	*Sarkidiornis melanotos*	-	LC
Southern Pochard	*Netta erythrophthalma*	-	LC
African Black Duck	*Anas sparsa*	LC	LC
Cape Shoveler	*Anas smithii*	NT	NT

Common Name	Biological name	Regional Status	Global Status
Cape Teal	*Anas capensis*	-	LC
Red-billed Teal	*Anas erythrorhyncha*	-	LC
White-backed Vulture	*Gyps africanus*	CR	CR
Lappet-faced Vulture	*Torgos tracheliotos*	EN	EN
Bateleur	*Terathopius ecaudatus*	EN	NT
African Fish Eagle	*Haliaeetus vocifer*	-	LC
Black-chested Snake Eagle	*Circaetus pectoralis*	-	LC
Verreauxs' Eagle	*Aquila verreauxii*	VU	LC
Martial Eagle	*Polemaetus bellicosus*	EN	VU
Booted Eagle	*Hieraaetus pennatus*	-	LC
Jackal Buzzard	*Buteo rufofuscus*	LC	LC
Common (Steppe) Buzzard	*Buteo buteo*	-	LC
African Harrier-Hawk	*Polyboroides typus*	-	LC
Black Harrier	*Circus maurus*	EN	VU
Black Kite	*Milvus migrans*	-	LC
Black-shouldered Kite	*Elanus caeruleus*	-	LC
Pale Chanting Goshawk	*Melierax canorus*	-	LC
Yellow-billed Kite	*Milvus aegyptius*	-	-
Pygmy Falcon	*Polihierax semitorquatus*	-	LC
Shikra	*Accipiter badius*	-	LC
Gabar Goshawk	*Melierax gabar*	-	LC
Peregrine Falcon	*Falco peregrinus*	LC	LC
Lanner Falcon	*Falco biarmicus*	VU	LC
Red-necked Falcon	*Falco chicquera*	-	NT
Rock Kestrel	*Falco rupicolus*	-	-
Greater Kestrel	*Falco rupicoloides*	-	LC
Lesser Kestrel	*Falco naumanni*	LC	LC
Helmeted Guineafowl	*Numida meleagris*	-	LC
Common Quail	*Coturnix coturnix*	-	LC
Red-knobbed coot	*Fulica cristata*	-	LC
Secretarybird	*Sagittarius serpentarius*	VU	VU
Kori Bustard	*Ardeotis kori*	NT	NT
Ludwig's Bustard	*Neotis ludwigii*	EN	EN
Karoo Korhaan	*Eupodotis vigorsii*	NT	LC
Red-crested Korhaan	*Lophotis ruficrista*	LC	LC
Northern Black Korhaan	*Afrotis afraoides*	LC	LC

Common Name	**Biological name**	**Regional Status**	**Global Status**
Pied Avocet	*Recurvirostra avosetta*	-	LC
Black-winged Stilt	*Himantopus himantopus*	-	LC
Common Ringed Plover	*Charadrius hiaticula*	-	LC
Kittlitz's Plover	*Charadrius pecuarius*	-	LC
Three-banded Plover	*Charadrius tricollaris*	-	LC
Crowned Lapwing	*Vanellus coronatus*	-	LC
Blacksmith Lapwing	*Vanellus armatus*	-	LC
Ruff	*Philomachus pugnax*	-	LC
Common Sandpiper	*Actitis hypoleucos*	-	LC
Wood Sandpiper	*Tringa glareola*	-	LC
Common Redshank	*Tringa totanus*	-	LC
Marsh Sandpiper	*Tringa stagnatilis*	-	LC
Eurasian Curlew	*Numenius arquata*	NT	NT
Spotted Thick-knee	*Burhinus capensis*	-	LC
Burchell's Courser	*Cursorius rufus*	VU	LC
Double-banded Courser	*Rhinoptilus africanus*	-	-
White-winged Tern	*Chlidonias leucopterus*	-	LC
Namaqua Sandgrouse	*Pterocles namaqua*	LC	LC
Burchell's Sandgrouse	*Pterocles burchelli*	-	LC
Rock Dove	*Columba livia*	-	LC
Speckled Pigeon	*Columba guinea*	-	LC
Red-eyed Dove	*Streptopelia semitorquata*	-	LC
African Mourning Dove	*Streptopelia decipiens*	-	-
Cape Turtle Dove	*Streptopelia capicola*	-	LC
Laughing Dove	*Streptopelia senegalensis*	-	LC
Namaqua Dove	*Oena capensis*	-	LC
Diederik Cuckoo	*Chrysococcyx caprius*	-	LC
Western Barn Owl	*Tyto alba*	-	LC
Spotted Eagle-Owl	*Bubo africanus*	-	LC
Verreaux's Eagle-Owl	*Bubo lacteus*	-	LC
Southern White-faced Owl	*Ptilopsis granti*	-	LC
Pearl-spotted Owlet	*Glaucidium perlatum*	-	LC
Rufous-cheeked Nightjar	*Caprimulgus rufigena*	-	LC
Common Swift	*Apus apus*	-	LC
Bradfield's Swift	*Apus bradfieldi*	-	LC
Alpine Swift	*Tachymarptis melba*	-	LC

Common Name	Biological name	Regional Status	Global Status
White-rumped Swift	*Apus caffer*	-	LC
Little Swift	*Apus affinis*	-	LC
African Palm Swift	*Cypsiurus parvus*	-	LC
White-backed Mousebird	*Colius colius*	-	LC
Red-faced Mousebird	*Urocolius indicus*	-	LC
Pied Kingfisher	*Ceryle rudis*	-	LC
Giant Kingfisher	*Megaceryle maxima*	-	LC
Malachite Kingfisher	*Alcedo cristata*	-	-
European Bee-eater	*Merops apiaster*	-	LC
Swallow-tailed Bee-eater	*Merops hirundineus*	-	LC
African Hoopoe	*Upupa africana*	-	-
Common Scimitarbill	*Rhinopomastus cyanomelas*	-	LC
Acacia Pied Barbet	*Tricholaema leucomelas*	-	LC
Bennett's Woodpecker	*Campethera bennettii*	-	LC
Golden-tailed Woodpecker	*Campethera abingoni*	-	LC
Cardinal Woodpecker	*Dendropicos fuscescens*	-	LC
Monotonous Lark	*Mirafra passerina*	LC	LC
Eastern clapper Lark	*Mirafra fasciolata*	-	LC
Fawn-coloured Lark	*Calendulauda africanoides*	LC	LC
Sabota Lark	*Calendulauda sabota*	LC	LC
Red-capped Lark	*Calandrella cinerea*	-	LC
Karoo Long-billed Lark	*Certhilauda subcoronata*	LC	LC
Pink-billed Lark	*Spizocorys conirostris*	-	LC
Sclater's Lark	*Spizocorys sclateri*	NT	NT
Stark's Lark	*Spizocorys starki*	-	LC
Spike-heeled Lark	*Chersomanes albofasciata*	-	LC
Grey-backed Sparrow-lark	*Eremopterix verticalis*	LC	LC
Greater Striped Swallow	*Cecropis cucullata*	-	LC
Barn Swallow	*Hirundo rustica*	-	LC
Pearl-breasted Swallow	*Hirundo dimidiata*	-	LC
Rock Martin	*Hirundo fuligula*	-	-
Brown-throated Martin	*Riparia paludicola*	-	LC
Fork-tailed Drongo	*Dicrurus adsimilis*	-	LC
Cape Crow	*Corvus capensis*	-	LC
Pied crow	*Corvus albus*	-	LC
Ashy Tit	*Parus cinerascens*	-	LC

Common Name	**Biological name**	**Regional Status**	**Global Status**
African Red-eyed Bulbul	*Pycnonotus nigricans*	-	LC
Karoo Thrush	*Turdus smithi*	LC	LC
Short-toed Rock Thrush	*Monticola brevipes*	-	LC
Mountain Wheatear	*Oenanthe monticola*	-	LC
Familiar Chat	*Cercomela familiaris*	-	LC
Tractrac Chat	*Cercomela tractrac*	-	LC
Sickle-winged Chat	*Cercomela sinuata*	-	LC
Karoo Chat	*Cercomela schlegelii*	-	LC
Capped Wheatear	*Oenanthe pileata*	-	LC
Ant-eating Chat	*Myrmecocichla formicivora*	-	LC
Cape Robin-Chat	*Cossypha caffra*	-	LC
Karoo Scrub Robin	*Erythropygia coryphoeus*	LC	-
Kalahari Scrub Robin	*Erythropygia paena*	-	LC
Willow Warbler	*Phylloscopus trochilus*	-	LC
Cape Penduline-Tit	*Anthoscopus minutus*	-	LC
Yellow-bellied Eremomela	*Eremomela icteropygialis*	-	LC
African Reed Warbler	*Acrocephalus baeticatus*	-	-
Lesser Swamp Warbler	*Acrocephalus gracilirostris*	-	LC
Chestnut-vented Tit-Babbler	*Sylvia subcaerulea*	-	-
Layard's Tit-Babbler	*Sylvia layardi*	LC	LC
Long-billed crombec	*Sylvietta rufescens*	-	LC
Fairy Flycatcher	*Stenostira scita*	-	LC
Zitting Cisticola	*Cisticola juncidis*	-	LC
Desert Cisticola	*Cisticola aridulus*	-	LC
Grey-backed Cisticola	*Cisticola subruficapilla*	-	LC
Levaillant's Cisticola	*Cisticola tinniens*	-	LC
Black-chested Prinia	*Prinia flavicans*	-	LC
Karoo Prinia	*Prinia maculosa*	LC	LC
Namaqua Warbler	*Phragmacia substriata*	LC	LC
Spotted flycatcher	*Muscicapa striata*	-	LC
Marico flycatcher	*Bradornis mariquensis*	-	LC
Chat Flycatcher	*Bradornis infuscatus*	-	LC
Cape White-eye	*Zosterops virens*	LC	LC
Pririt Batis	*Batis pririt*	-	LC
African Pied Wagtail	*Motacilla aguimp*	-	LC
Cape Wagtail	*Motacilla capensis*	-	LC

Common Name	Biological name	Regional Status	Global Status
Long-billed Pipit	*Anthus similis*	-	LC
African Pipit	*Anthus cinnamomeus*	-	LC
Lesser Grey Shrike	*Lanius minor*	-	LC
Southern (Common) Fiscal	*Lanius collaris*	-	LC
Red-backed Shrike	*Lanius collurio*	-	LC
Crimson-breasted Shrike	*Laniarius atrococcineus*	LC	LC
Bokmakierie	*Telophorus zeylonus*	LC	LC
Brubru	*Nilaus afer*	-	LC
Cape Glossy Starling	*Lamprotornis nitens*	-	LC
Pale-winged Starling	*Onychognathus nabouroup*	-	LC
Wattled Starling	*Creatophora cinerea*	-	LC
Dusky Sunbird	*Cinnyris fuscus*	LC	LC
Southern Double-collared Sunbird	*Cinnyris chalybeus*	LC	LC
House Sparrow	*Passer domesticus*	-	LC
Cape Sparrow	*Passer melanurus*	LC	LC
Southern Grey-headed Sparrow	*Passer diffusus*	-	LC
White-browed Sparrow-Weaver	*Plocepasser mahali*	-	LC
Sociable Weaver	*Philetairus socius*	-	LC
Southern Masked Weaver	*Ploceus velatus*	-	LC
Red-billed Quelea	*Quelea quelea*	-	LC
Southern Red Bishop	*Euplectes orix*	-	LC
Pin-tailed Whydah	*Vidua macroura*	-	LC
Scaly-feathered Finch	*Sporopipes squamifrons*	LC	LC
Red-headed Finch	*Amadina erythrocephala*	-	LC
Black-throated Canary	*Crithagra atrogularis*	-	LC
Yellow Canary	*Crithagra flaviventris*	-	LC
Black-headed Canary	*Serinus alario*	LC	LC
White-throated Canary	*Crithagra albogularis*	LC	LC
Cape Bunting	*Emberiza capensis*	LC	LC
Cinnamon-breasted Bunting	*Emberiza tahapisi*	-	LC
Lark-like Bunting	*Emberiza impetuani*	LC	LC

B. AVIAN INCIDENT REGISTER

Table B.1 Comprehensive Avian Incident Register of avian mortalities and injuries recorded during the avian mortality surveys conducted from June 2016 – June 2017 at the Khi Solar One facility in the Northern Cape, South Africa.

									Likely cause of death / Injury								
Date	**Time**	**Sample number**	**Surveying**	**Area**	**Project feature where sample was located**	**Species**	**Common name**	**Foraging Zone**	Solar Flux	Impact Trauma	Predation Trauma	Un determined	MCI	Supporting / Additional observations	**Mortality / Injury**	**Estimated time before discovery**	**GPS Coordinates**
09 June 2016	09:00	KHI01	Systematic	Power Block	NDC	*Pterocles namaqua*	Namaqua Sandgrouse	Terrestrial				X		Possible collision	M	Day	28°32.235"S 21°04.649"E
10 June 2016	08:20	KHI02	Systematic	SF-S	HS-2050037	*Bubo africanus*	Spotted Eagle Owl	Terrestrial				X		Remains in poor state located at base of HS	M	Month	28°32.810"S 21°04.904"E
10 June 2016	11:03	KHI03	Systematic	SF-E	HS-30119008	*Vanellus armatus*	Blacksmith Plover	Terrestrial				X			M	Week	28°32.222"S 21°04.827"E
10 June 2016	11:46	KHI04	Systematic	SF-W	HS-1013016	*Oena capensis*	Namaqua Dove	Terrestrial				X			M	Week	28°32.331"S 21°04.519"E
10 June 2016	13:30	KHI05	Systematic	SF-W	SF Road	*Columdidae Family*	Columdidae Family	Terrestrial				X			M	Month	28° 32.431"S 21° 4.838"E

10 June 2016	13:25	KHI06	Systematic	SF-W	HS-103724	*Pycnonotus nigricans*	Redeyed Bulbul	Terrestrial	X		ND	HS Mirror collision	M	Minutes	28° 32.275"S 21° 4.222"E
10 June 2016	16:00	KHI07	Systematic	SF-S	HS-1045019	*Columdidae Family*	Columdidae Family	Terrestrial	X		ND	HS Mirror collision - "Splat spot" on HS mirror	M	Month	28° 32.182"S 21° 4.080"E
10 June 2016	16:57	KHI08	Systematic	SF-S	HS-2033011	*Emberiza impetuani*	Lark-like bunting	Terrestrial	X		ND	HS Mirror collision - "Splat spot" on HS mirror	M	Day	28° 32.576"S 21° 4.736"E
10 June 2016	17:07	KHI09	Systematic	SF-S	HS-2032014	*Sporopipes squamifrons*	Scalyfeathered Finch	Terrestrial	X		ND	HS Mirror collision - "Splat spot" on HS mirror	M	Hours	28° 32.570"S 21° 4.648"E
11 June 2016	09:40	KHI10	Systematic	SF-S	HS-2031015	*Emberiza impetuani*	Lark-like bunting	Terrestrial	X		ND	HS Mirror collision - "Splat spot" on HS mirror. Predation secondary event.	M	Hours	28°32.827"S 21°04.835"E
11 June 2016	09:40	KHI11	Systematic	SF-S	HS-2031015	*Emberiza impetuani*	Lark-like bunting	Terrestrial	X		ND	HS Mirror collision - "Splat spot" on HS mirror. Predation secondary event.	M	Hours	28°32.570"S 21°04.681"E
11 June 2016	10:35	KHI12	Systematic	SF-S	HS-2029007	*Emberiza impetuani*	Lark-like bunting	Terrestrial	X		ND	HS Mirror collision - "Splat spot" on HS mirror. Head fracture.	M	Hours	28°32.511"S 21°04.575"E
11 June 2016	10:50	KHI13	Systematic	SF-S	HS-2026004	*Emberiza impetuani*	Lark-like bunting	Terrestrial	X		ND	HS Mirror collision - "Splat spot" on HS mirror	M	Hours	28°32.473"S 21°04.563"E
11 June 2016	11:07	KHI14	Systematic	SF-S	HS-2025015	*Emberiza impetuani*	Lark-like bunting	Terrestrial	X		D8	Most propable collision due to position of carcass with HS	M	Hours	28°32.474"S 21°04.731"E
11 June 2016	11:21	KHI15	Systematic	SF-S	HS-2023005	*Emberiza impetuani*	Lark-like bunting	Terrestrial	X		ND	Most propable collision due to position of carcass with HS	M	Day	28°32.453"S 21°04.573"E

11 June 2016	11:37	KHI16	Systematic	SF-S	HS-2017015	*Emberiza impetuani*	Lark-like bunting	Terrestrial	X		ND	Most propable collision due to position of carcass with HS	M	Hours	28°32.402"S 21°04.753"E
11 June 2016	12:00	KHI17	Systematic	SF-S	HS-2015007	*Pycnonotus nigricans*	Redeyed Bulbul	Terrestrial	X		ND	HS Mirror collision - "Splat spot" on HS mirror	M	Day	28°32.398"S 21°04.692"E
11 June 2016	13:26	KHI18	Systematic	SF-S	HS-2011002	*Emberiza impetuani*	Lark-like bunting	Terrestrial	X		ND	HS Mirror collision - "Splat spot" on HS mirror	M	Day	28°32.360"S 21°04.590"E
14 June 2016	09:10	KHI19	Systematic	SF-S	HS-2050033	*Emberiza impetuani*	Lark-like bunting	Terrestrial	X		ND	HS Mirror collision - "Splat spot" on HS mirror	M	Day	28°32.827"S 21°04.835"E
14 June 2016	09:20	KHI20	Systematic	SF-S	HS-2050045	*Emberiza impetuani*	Lark-like bunting	Terrestrial	X		ND	Possible collision, "no splat spot" recorded	M	Day	28°32.750"S 21°05.039"E
14 June 2016	09:40	KHI21	Systematic	SF-S	HS-2049036	*Emberiza impetuani*	Lark-like bunting	Terrestrial	X		ND	Possible collision, "no splat spot" recorded	M	Day	28°32.781"S 21°04.923"E
14 June 2016	11:00	KHI22	Systematic	SF-S	HS-2035022	*Anas capensis*	Cape Teal	Water	X		ND	Possible collision, "no splat spot" recorded	M	Day	28°32.582"S 21°04.782"E
15 June 2016	09:20	KHI23	Systematic	SF-E	HS-3046013	*Emberiza impetuani*	Lark-like bunting	Terrestrial	X		D8	HS Mirror collision - "Splat spot" on HS mirror	M	Day	28°32.489"S 21°05.230"E
15 June 2016	09:20	KHI24	Systematic	SF-E	HS-3046013	*Emberiza impetuani*	Lark-like bunting	Terrestrial	X		D8	HS Mirror collision - "Splat spot" on HS mirror	M	Day	28°32.470"S 21°05.231"E
15 June 2016	10:55	KHI25	Systematic	SF-E	HS-3041001	*Emberiza impetuani*	Lark-like bunting	Terrestrial	X		ND	HS Mirror collision - "Splat spot" on HS mirror	M	Day	28°32.637"S 21°04.941"E

15 June 2016	11:45	KHI26	Systematic	SF-E	HS-3032023	*Emberiza impetuani*	Lark-like bunting	Terrestrial	X			ND	HS Mirror collision - "Splat spot" on HS mirror	M	Day	28°32.205"S 21°05.047"E
16 June 2016	16:00	KHI27	Systematic	Power Block	Drain at wet cooler	*Columdidae Family*	Columdidae Family	Terrestrial			X		Solar Flux not probable cause. No signs of burned feathers.	M	Month	28°32'12.59" S 21° 4'42.19"E
20 June 2016	13:15	KHI28	Systematic	SF-W	HS-1048015	*Amadina erythrocephala*	Red-headed finch	Terrestrial	X			ND	HS Mirror collision - "Splat spot" on HS mirror	M	Day	28°32.086"S 21°04.014"E
20 June 2016	13:55	KHI29	Systematic	SF-W	HS-1041011	*Emberiza impetuani*	Lark-like bunting	Terrestrial	X			ND	HS Mirror collision - "Splat spot" on HS mirror	M	Day	28°32.086"S 21°04.181"E
20 June 2016	14:35	KHI30	Systematic	SF-W	HS-1034013	*Emberiza impetuani*	Lark-like bunting	Terrestrial	X			ND	HS Mirror collision - "Splat spot" on HS mirror	M	Day	28° 32.227"S 21° 4.013"E
20 June 2016	14:45	KHI31	Systematic	SF-W	HS-1034035	*Emberiza impetuani*	Lark-like bunting	Terrestrial	X			ND	Possible collision, "no splat spot" recorded	M	Day	28° 32.557"S 21° 4.132"E
20 June 2016	15:10	KHI32	Systematic	SF-W	HS-1031017	*Emberiza impetuani*	Lark-like bunting	Terrestrial	X			ND	HS Mirror collision - "Splat spot" on HS mirror	M	Day	28°32.164"S 21°04.345"E
21 June 2016	10:20	KHI33	Incidental	Power Block	Demi water tank	*Columdidae Family*	Columdidae Family	To be determined			X		Decomposed. Solar Flux not probable cause. No signs of burned feathers.	M	Months	28°32.211"S 21°04.709"E
21 June 2016	10:45	KHI34	Incidental	Power Block	NDC	*Emberiza impetuani*	Lark-like bunting	Terrestrial	X			ND	Possible collision, "no splat spot" recorded	M	Hours	28°32.237"S 21°04.689"E
22 June 2016	10:35	KHI35	Systematic	SF - E	HS - 3036004	*Emberiza impetuani*	Lark-like bunting	Terrestrial		X			Possible collision, "no splat spot" recorded	M	Day	28° 32.491"S 21° 4.948"E

22 June 2016	11:00	KHI36	Systematic	SF - E	HS - 3035007	*Columdidae Family*	Columdidae Family	Terrestrial		X			Hawk had dove remains in talons as it flew off. "No splat spot" recorded on heliostats were incident was recorded	M	Hours	28°32.441"S 21°04.986"E
22 June 2016	11:40	KHI37	Systematic	SF - E	HS - 3028003	*Quela quela*	Redbilled Quela	Terrestrial	X			ND	Possible collision, "no splat spot" recorded	M	Day	28°32.458"S 21°04.908"E
22 June 2016	12:35	KHI38	Systematic	SF - E	HS - 3016013	*Pycnonotus nigricans*	Redeyed bulbul	Terrestrial	X			ND	HS Mirror collision - "Splat spot" on HS mirror	M	Day	28°32.249"S 21°04.864"E
22 June 2016	15:30	KHI39	Incidental	Power Block	South of turbine building	*Passer domesticus*	House sparrow	Terrestrial			X			M	Months	28° 32.196"S 21° 4.668"E
23 June 2016	10:52	KHI40	Systematic	SF - S	HS - 2049028	*Emberiza impetuani*	Lark-like bunting	Terrestrial	X			ND	HS Mirror collision - "Splat spot" on HS mirror	M	Day	28°32.818"S 21°04.787"E
23 June 2016	11:30	KHI41	Systematic	SF - S	HS - 2040024	*Emberiza impetuani*	Lark-like bunting	Terrestrial	X			ND	Possible collision, "no splat spot" recorded	M	Day	28°32.658"S 21°04.774"E
23 June 2016	11:45	KHI42	Systematic	SF - S	HS - 2031025	*Emberiza impetuani*	Lark-like bunting	Terrestrial	X			ND	Possible collision, "no splat spot" recorded	M	Day	28°32.494"S 21°04.849"E
23 June 2016	15:30	KHI43	Incidental	Evapo ration ponds	Evaporatrion pond 1	*Anas capensis*	Cape teal juvenile	Water			X		Juvenile chick	M	Months	28°32.887"S 21°04.656"E
23 June 2016	15:40	KHI44	Incidental	Evapo ration ponds	Evaporatrion pond 1	*Anas capensis*	Cape teal juvenile	Water			X		Juvenile chick	M	Months	28° 32.870"S 21° 04.665"E
28 June 2016	12:40	KHI45	Systematic	SF - S	HS - 2031002	*Emberiza impetuani*	Lark-like bunting	Terrestrial	X			ND	HS Mirror collision - "Splat spot" on HS mirror	M	Day	28° 32.507"S 21° 4.474"E

28 June 2016	12:23	KHI46	Systematic	SF - S	HS - 2030001	*Amadina erythrocephala*	Red-headed finch	Terrestrial	X			ND	HS Mirror collision - "Splat spot" on HS mirror	M	Day	28° 32.482"S 21° 04.475"E
28 June 2016	13:03	KHI47	Systematic	SF - S	HS - 2030701	*Columdidae Family*	Columdidae Family	Terrestrial		X				M	Day	28°32.324"S 21°04.592"E
29 June 2016	12:00	KHI48	Systematic	SF-W	HS - 1025280	*Unknown-remains in poor state*	Unknown-remains in poor state	Undetermined			X		Possible predation	M	Day	28°32.364"S 21°04.425"E
30 June 2016	11:20	KHI49	Systematic	SF-E	HS - 3048024	*Emberiza impetuani*	Lark-like bunting	Terrestrial	X			ND	Possible collision, "no splat spot" recorded	M	Day	28°32.402"S 21°05.290"E
30 June 2016	11:05	KHI50	Systematic	SF-E	HS - 3050023	*Anas capensis*	Cape Teal	Water	X			ND	HS Mirror collision - "Splat spot" on HS mirror	M	Day	28°32.455"S 21°05.320"E
30 June 2016	11:45	KHI51	Systematic	SF-E	HS - 3038020	*Amadina erythrocephala*	Red-headed finch	Terrestrial		X			Possible collision, "no splat spot" recorded	M	Day	28°32.283"S 21°05.121"E
07 July 2016	10:47	KHI52	Systematic	SF-E	HS - 3048030	*Vidua regia*	Shaft-tailed Whydah	Terrestrial	X			C8	HS Mirror collision - "Splat spot" on HS mirror	M	Day	28°32.203"S 21°05.315"E
07 July 2016	12:05	KHI53	Systematic	SF-E	HS - 3047005	*Amadina erythrocephala*	Red-headed finch	Terrestrial	X			D1	HS Mirror collision - "Splat spot" on HS mirror	M	Day	28°32.628"S 21°05.097"E
07 July 2016	15:55	KHI54	Systematic	SF-E	HS - 3030008	*Amadina erythrocephala*	Red-headed finch	Terrestrial	X			B8	HS Mirror collision - "Splat spot" on HS mirror	M	Day	28°32.386"S 21°04.960"E
07 July 2016	16:54	KHI55	Systematic	SF-E	HS - 3020003	*Turdus olivaceus*	Kurrichane Thrush	Terrestrial		X			Scattered remains	M	Week	28°32.298"S 21°04.904"E

08 July 2016	09:55	KHI56	Systematic	SF - S	HS - 2048030	*Emberiza impetuani*	Lark-like bunting	Terrestrial	X			C8	HS Mirror collision - "Splat spot" on HS mirror	M	Hours	28°32.784"S 21°04.818"E
11 July 2016	12:00	KHI57	Incidental	SF - S	HS - 2050016	*Tricholaema leucomelas*	Acacia pied barbet	Terrestrial	X			B5	HS Mirror collision - "Splat spot" on HS mirror	M	Hours	28° 32.835"S 21° 4.532"E
12 July 2016	12:05	KHI58	Systematic	SF - S	HS - 2034030	*Quela quela*	Redbilled Quela	Terrestrial	X			B7	HS Mirror collision - "Splat spot" on HS mirror	M	Hours	28°32.528"S 21°04.888"E
12 July 2016	12:05	KHI59	Systematic	SF - S	HS - 2034030	*Quela quela*	Redbilled Quela	Terrestrial	X			B7	HS Mirror collision - "Splat spot" on HS mirror	M	Hours	28° 32.520"S 21° 4.886"E
13 July 2016	14:05	KHI60	Systematic	Evapo ration ponds	Evaporatrion pond 4	*Passeridae Family*	Passeridae Family	Terrestrial			X			M	Week	28°32.919"S 21°04.436"E
13 July 2016	14:42	KHI61	Systematic	Evapo ration ponds	Evaporatrion pond 2	*Columbidae Family*	Columdidae Family	Terrestrial		X			Scattered remains	M	Week	28° 32.924"S 21° 04.601"E
25 July 2016	11:50	KHI62	Systematic	SF - E	HS - 3038019	*Columba guinea*	Rock Pigeon	Terrestrial	X			D8	HS Mirror collision - "Splat spot" on HS mirror. Predation secondary event.	M	Hours	28°32.303"S 21°05.116"E
25 July 2016	13:35	KHI63	Systematic	SF - S	HS - 2044036	*Quela quela*	Redbilled Quela	Terrestrial			X		Decapitated, poor remains	M	Days	28°32.664"S 21°04.941"E
25 July 2016	14:25	KHI64	Systematic	SF - S	HS - 2040017	*Columba guinea*	Rock Pigeon	Terrestrial	X			D7	HS Mirror collision - "Splat spot" on HS mirror. Predation secondary event.	M	Hours	28°32.664"S 21°04.659"E
25 July 2016	14:41	KHI65	Systematic	SF - S	SF Road	*Columba guinea*	Rock Pigeon	Terrestrial		X			Predation, scattered remains	M	Hours	28°32.620"S 21°04.468"E

25 July 2016	16:00	KHI66	Systematic	SF - S	SF Road	*Columbidae Family*	Domestic pigeon	Terrestrial				X		Secondary predation, scattered remains	M	Days	28°32.323"S 21°04.730"E
25 July 2016	16:15	KHI67	Systematic	SF - W	SF Road	*Columbidae Family*	Domestic pigeon	Terrestrial	X					Grade1 Flux Injury	M	Days	28°32.284"S 21°04.566"E
26 July 2016	09:15	KHI68	Incidental	Ware house	Inside warehouse	*Pycnonotus nigricans*	Redeyed bulbul	Terrestrial				X			M	Days	28° 32.890'S 21° 4.811'E
26 July 2016	14:31	KHI69	Systematic	SF - W	HS - 1037018	*Ploceidae Family*	Ploceidae Family	Terrestrial				X			M	Days	28° 32.184'S 21° 04.222'E
26 July 2016	16:05	KHI70	Incidental	Power Block	Underneath East cavity, next to NDC	*Apodidae Family*	Swift Family	Air	X					Grade 2 Flux Injury	M	Days	28° 32.244'S 21° 4.697'E
27 July 2016	08:50	KHI71	Systematic	Power Block	Underneath East cavity, next to NDC	*Coturnix coturnix*	Common Quail	Terrestrial				X		No physical injuries noted	M	Hours	28° 32.241'S 21° 4.701'E
27 July 2016	10:11	KHI72	Systematic	Power Block	Underneath West cavity, next to NDC	*Emberiza impetuani*	Lark-like bunting	Terrestrial		X			NA		M	Days	28° 32.229'S 21° 04.653'E
28 July 2016	08:15	KHI73	Incidental	SF - W	HS - 1050004	*Pterocles namaqua*	Namaqua Sandgrouse	Terrestrial			X			Predation. Pied Crow observed	M	Days	28° 32.142'S 21° 3.963'E
28 July 2016	13:35	KHI74	Systematic	SF - E	HS - 3028006	*Quela quela*	Redbilled Quela	Terrestrial				X		No physical injuries noted. Possible HS collision	M	Days	28° 32.388'S 21° 04.942'E
29 July 2016	10:32	KHI75	Systematic	SF - S	HS - 2041018	*Amadina erythrocephala*	Redheaded finch	Terrestrial				X		Static position towards HS suggests collision / impact trauma however no "splat spot" evident	M	Days	28°32.678"S 21°04.666"E

29 July 2016	12:30	KHI76	Systematic	SF - S	HS - 2009006 / HS - 2010005	*Columba guinea*	Rock Pigeon	Terrestrial	X			D5	"Side way collision" with HS-2009006 situated left from a located feather spot near HS-201005. Secondary predation.	M	Days	28°32.368"S 21°04.650"E
04 August 2016	12:35	KHI 77	Systematic	SF - W	HS - 1038028	*Emberiza impetuani*	Lark-like bunting	Terrestrial	X			C8	HS Mirror collision - "Splat spot" on HS mirror	M	Days	28° 32.362'S 21° 04.232'E
09 August 2016	16:07	KHI 78	Systematic	SF - E	SF Road	*Pycnonotus nigricans*	Redeyed bulbul	Terrestrial		X			Predation	M	Days	28°32.233"S 21°04.961"E
10 August 2016	09:21	KHI 79	Systematic	SF - S	HS - 2048034	*Taeniopygia guttata*	Zebra finch	Terrestrial	X			D8	Evident "Splat spot".	M	Hours	28°32.766"S 21°04.889"E
10 August 2016	10:50	KHI 80	Systematic	SF - S	HS - 2026014	*Emberiza impetuani*	Lark-like bunting	Terrestrial			X		Specimen's deformed body strongly suggests collision / impact trauma	M	Days	28°32.495"S 21°04.713"E
12 August 2016	10:40	KHI 81	Systematic	SF - W	HS - 1050015	*Amadina erythrocephala*	Red-headed finch	Terrestrial	X			ND	Heliostat in stow position due to high wind could not observe "splat spot" on mirrors	M	Days	28° 32.569"S 21° 4.078"E
12 August 2016	10:52	KHI 82	Systematic	SF - W	HS - 1048028	*Quela quela*	Redbilled Quela	Terrestrial	X			ND	Heliostat in stow position due to high wind could not observe "splat spot" on mirrors	M	Days	28°32.457"S 21°04.065"E
12 August 2016	11:45	KHI 83	Systematic	SF - W	HS - 1034031	*Quela quela*	Redbilled Quela	Terrestrial	X			ND	Heliostat in stow position due to high wind could not observe "splat spot" on mirrors	M	Days	28°32.442"S 21°04.350"E
17 August 2016	15:15	KHI 84	Systematic	Evaporation ponds	Evaporation pond 1	*Anas capensis*	Cape teal juvenile	Water			X		Juvenile chick	M	Days	28°32.869"S 21°04.665"E
23 August 2016	10:40	KHI 85	Systematic	SF - E	HS - 3031029	*Hirundo albignularis*	Whitethroated Swallow	Air	X			ND	Unable observe "splat spot" on mirrors due to angle of operational heliostat	M	Days	28°32.102"S 21°04.996"E

24 August 2016	12:00	KHI 86	Systematic	SF - S	HS - 2044032	*Amadina erythrocephala*	Red-headed finch	Terrestrial	X		B7	HS Mirror collision - "Splat spot" on HS mirror	M	Days	28°32.688"S 21°04.879"E
24 August 2016	13:00	KHI 87	Systematic	SF - S	HS - 2024001	*Ploceus velatus*	Southern Masked-Weaver	Terrestrial	X		B8	HS Mirror collision - "Splat spot" on HS mirror	M	Days	28°32.430"S 21°04.508"E
25 August 2016	11:45	KHI 88	Systematic	SF - W	HS - 1048024	*Quela quela*	Redbilled Quela	Terrestrial	X		A8	HS Mirror collision - "Splat spot" on HS mirror	M	Days	28°32.403"S 21°04.045"E
02 September 2016	14:14	KHI 89	Systematic	SF - W	HS - 1050021	*Columba guinea*	Rock Pigeon	Terrestrial	X		A8	HS Mirror collision - "Splat spot" on HS mirror. Secondary predation	M	Days	28°32.484"S 21°04.026"E
07 September 2016	13:20	KHI 90	Systematic	SF - S	HS - 2048033	*Hirundo albignularis*	Whitethroated Swallow	Air		X		Possible collision, "no splat spot" recorded	M	Days	28°32.772"S 21°04.874"E
07 September 2016	13:20	KHI 91	Systematic	SF - S	HS - 2048033	*Hirundo albignularis*	Whitethroated Swallow	Air		X		Possible collision, "no splat spot" recorded	M	Days	28°32.772"S 21°04.874"E
07 September 2016	14:00	KHI 92	Systematic	SF - S	HS - 2041013	*Hirundo albignularis*	Whitethroated Swallow	Air	X		B8	HS Mirror collision - "Splat spot" on HS mirror	M	Days	28°32.670"S 21°04.579"E
07 September 2016	14:15	KHI 93	Systematic	SF - S	HS - 2038009	*Ploceus velatus*	Southern Masked-Weaver	Terrestrial	X		B6	HS Mirror collision - "Splat spot" on HS mirror	M	Days	28°32.616"S 21°04.546"E
07 September 2016	14:25	KHI 94	Systematic	SF - S	HS - 2035016	*Quela quela*	Redbilled Quela	Terrestrial	X		A8	HS Mirror collision - "Splat spot" on HS mirror	M	Days	28°32.543"S 21°04.684"E
08 September 2016	14:35	KHI 95	Systematic	SF - W	HS - 1039017	*Quela quela*	Redbilled Quela	Terrestrial	X		C8	HS Mirror collision - "Splat spot" on HS mirror	M	Days	28°32.304"S 21°04.195"E

08 September 2016	14:45	KHI 96	Systematic	SF - W	HS - 1038021	*Quela quela*	Redbilled Quela	Terrestrial	X		C8	HS Mirror collision - "Splat spot" on HS mirror	M	Days	28°32.254"S 21°04.206"E
08 September 2016	15:00	KHI 97	Systematic	SF - W	HS - 1036024	*Quela quela*	Redbilled Quela	Terrestrial	X		D8	HS Mirror collision - "Splat spot" on HS mirror	M	Days	28°32.265"S 21°04.241"E
08 September 2016	15:15	KHI 98	Systematic	SF - W	HS - 1036021	*Quela quela*	Redbilled Quela	Terrestrial	X		B8	HS Mirror collision - "Splat spot" on HS mirror	M	Days	28°32.222"S 21°04.235"E
08 September 2016	15:15	KHI 99	Systematic	SF - W	HS - 1036021	*Quela quela*	Redbilled Quela	Terrestrial	X		B8	HS Mirror collision - "Splat spot" on HS mirror	M	Days	28°32.222"S 21°04.235"E
08 September 2016	15:15	KHI 100	Systematic	SF - W	HS - 1036021	*Quela quela*	Redbilled Quela	Terrestrial	X		B8	HS Mirror collision - "Splat spot" on HS mirror	M	Days	28°32.222"S 21°04.235"E
08 September 2016	15:35	KHI 101	Systematic	SF - W	HS - 1035021	*Quela quela*	Redbilled Quela	Terrestrial	X		D8	HS Mirror collision - "Splat spot" on HS mirror	M	Days	28°32.208"S 21°04.248"E
08 September 2016	15:35	KHI 102	Systematic	SF - W	HS - 1035021	*Quela quela*	Redbilled Quela	Terrestrial	X		D8	HS Mirror collision - "Splat spot" on HS mirror	M	Days	28°32.208"S 21°04.248"E
08 September 2016	15:35	KHI 103	Systematic	SF - W	HS - 1035021	*Quela quela*	Redbilled Quela	Terrestrial	X		D8	HS Mirror collision - "Splat spot" on HS mirror	M	Days	28°32.208"S 21°04.248"E
09 September 2016	10:35	KHI 104	Incidental	Power Block	Between accumolator 6 and 5	*Columdidae Family*	Columdidae Family	Terrestrial		X		Juvenile chick	M	Days	28°32.192"S 21°04.608"E
13 September 2016	16:10	KHI 105	Incidental	SF - W	HS - 1015008	*Hirundo albignularis*	Whitethroated Swallow	Air		X		Undetermined, secondary predation, no visible “splat spot”.	M	Days	28°32.239"S 21°04.566"E

13 September 2016	14:18	KHI 106	Systematic	SF - W	HS - 1031015	*Emberiza impetuani*	Lark-like bunting	Terrestrial	X		A7	HS Mirror collision - "Splat spot" on HS mirror	M	Days	28°32.144"S 21°04.317"E
13 September 2016	09:00	KHI 107	Systematic	SF - W	HS - 1041044	*Columdidae Family*	Columdidae Family	Terrestrial		X		Predation, scattered remains. No "splat spot"	M	Days	28°32.564"S 21°04.311"E
21 September 2016	11:10	KHI 108	Systematic	SF - S	HS - 2050032	*Quela quela*	Redbilled Quela	Terrestrial	X		D7	HS Mirror collision - "Splat spot" on HS mirror	M	Days	28°32.831"S 21°04.820"E
21 September 2016	11:20	KHI 109	Systematic	SF - S	HS - 2049022	*Quela quela*	Redbilled Quela	Terrestrial	X		A7	HS Mirror collision - "Splat spot" on HS mirror	M	Days	28°32.822"S 21°04.681"E
21 September 2016	11:20	KHI 110	Systematic	SF - S	HS - 2049022	*Quela quela*	Redbilled Quela	Terrestrial	X		ND	Possible collision, "no splat spot" recorded	M	Days	28°32.822"S 21°04.681"E
21 September 2016	11:35	KHI 111	Systematic	SF - S	HS - 2049033	*Quela quela*	Redbilled Quela	Terrestrial	X		B8	HS Mirror collision - "Splat spot" on HS mirror	M	Days	28°32.795"S 21°04.875"E
21 September 2016	11:40	KHI 112	Systematic	SF - S	HS - 2049036	*Quela quela*	Redbilled Quela	Terrestrial	X		B8	HS Mirror collision - "Splat spot" on HS mirror	M	Days	28°32.778"S 21°04.926"E
21 September 2016	12:20	KHI 113	Systematic	SF - S	HS - 2044030	*Quela quela*	Redbilled Quela	Terrestrial	X		B8	HS Mirror collision - "Splat spot" on HS mirror	M	Days	28°32.701"S 21°04.848"E
21 September 2016	12:20	KHI 114	Systematic	SF - S	HS - 2044030	*Quela quela*	Redbilled Quela	Terrestrial	X		B8	HS Mirror collision - "Splat spot" on HS mirror	M	Days	28°32.701"S 21°04.848"E
21 September 2016	12:20	KHI 115	Systematic	SF - S	HS - 2044030	*Quela quela*	Redbilled Quela	Terrestrial	X		B8	HS Mirror collision - "Splat spot" on HS mirror	M	Days	28°32.701"S 21°04.848"E

21 September 2016	12:20	KHI 116	Systematic	SF - S	HS - 2044030	*Quela quela*	Redbilled Quela	Terrestrial	X		A8	HS Mirror collision - "Splat spot" on HS mirror	M	Days	28°32.701"S 21°04.848"E
21 September 2016	12:30	KHI 117	Systematic	SF - S	HS - 2043021	*Spilopelia senegalensis*	Laughing Dove	Terrestrial	X		B7	HS Mirror collision - "Splat spot" on HS mirror	M	Days	28°32.711"S 21°04.685"E
21 September 2016	13:00	KHI 118	Systematic	SF - E	HS - 3040002	*Amadina erythrocephala*	Red-headed finch	Terrestrial	X		C8	HS Mirror collision - "Splat spot" on HS mirror	M	Days	28°32.561"S 21°04.973"E
22 September 2016	12:10	KHI 119	Systematic	SF - W	HS - 1048046	*Quela quela*	Redbilled Quela	Terrestrial	X		D8	HS Mirror collision - "Splat spot" on HS mirror. Numerous other splat spots recorded on mirror	M	Days	28°32.678"S 21°04.273"E
22 September 2016	12:15	KHI 120	Systematic	SF - W	HS - 1048045	*Quela quela*	Redbilled Quela	Terrestrial	X		C7	HS Mirror collision - "Splat spot" on HS mirror	M	Days	28°32.669"S 21°04.255"E
22 September 2016	12:15	KHI 121	Systematic	SF - W	HS - 1048045	*Quela quela*	Redbilled Quela	Terrestrial	X		A7	HS Mirror collision - "Splat spot" on HS mirror	M	Days	28°32.669"S 21°04.255"E
22 September 2016	14:10	KHI 122	Systematic	SF - W	HS - 1031032	*Oena capensis*	Namaqua Dove	Terrestrial	X		D6	HS Mirror collision - "Splat spot" on HS mirror	M	Days	28°32.379"S 21°04.355"E
29 September 2016	09:00	KHI 123	Systematic	SF - E	HS - 3049006	*Quela quela*	Redbilled Quela	Terrestrial	X		C8	HS Mirror collision - "Splat spot" on HS mirror. Numerous other splat spots recorded on mirror	M	Days	28°32.571"S 21°04.271"E
29 September 2016	09:30	KHI 124	Systematic	SF - E	HS - 3045013	*Quela quela*	Redbilled Quela	Terrestrial	X		D8	HS Mirror collision - "Splat spot" on HS mirror. Numerous other splat spots recorded on mirror	M	Days	28°32.497"S 21°04.161"E
29 September 2016	10:20	KHI 125	Systematic	SF - E	HS - 3037002	*Amadina erythrocephala*	Red-headed finch	Terrestrial	X		D8	HS Mirror collision - "Splat spot" on HS mirror	M	Days	28°32.541"S 21°04.937"E

29 September 2016	10:20	KHI 126	Systematic	SF - E	HS - 3037002	*Amadina erythrocephala*	Red-headed finch	Terrestrial	X			D8	HS Mirror collision - "Splat spot" on HS mirror	M	Days	28°32.541"S 21°04.937"E
29 September 2016	10:20	KHI 127	Systematic	SF - E	HS - 3037002	*Amadina erythrocephala*	Red-headed finch	Terrestrial	X			D8	HS Mirror collision - "Splat spot" on HS mirror	M	Days	28°32.541"S 21°04.937"E
29 September 2016	10:20	KHI 128	Systematic	SF - E	HS - 3037002	*Amadina erythrocephala*	Red-headed finch	Terrestrial	X			C7	HS Mirror collision - "Splat spot" on HS mirror	M	Days	28°32.541"S 21°04.937"E
29 September 2016	10:45	KHI 129	Systematic	SF - E	HS - 3034008	*Steptopelia capicola*	Cape turtle dove	Terrestrial	X			C8	HS Mirror collision - "Splat spot" on HS mirror	M	Days	28°32.428"S 21°04.993"E
30 September 2016	14:53	KHI 130	Systematic	SF - S	HS - 2004004	*Quela quela*	Redbilled Quela	Terrestrial	X			C8	HS Mirror collision - "Splat spot" on HS mirror	M	Hours	28°32.330"S 21°04.661"E
30 September 2016	15:03	KHI 131	Systematic	SF - S	HS - 2004002	*Columba guinea*	Rock Pigeon	Terrestrial		X			Decapitation	M	Days	28°32.323"S 21°04.612"E
30 September 2016	15:15	KHI 132	Systematic	SF - S	HS - 2016004	*Oena capensis*	Namaqua Dove	Terrestrial	X			A7	HS Mirror collision - "Splat spot" on HS mirror	M	Hours	28°32.398"S 21°04.603"E
30 September 2016	15:26	KHI 133	Systematic	SF - W	HS - 1017003	*Columdidae Family*	Columdidae Family	Terrestrial	X			C8	HS Mirror collision - "Splat spot" on HS mirror	M	Hours	28°32.076"S 21°04.543"E
30 September 2016	15:51	KHI 134	Systematic	SF - W	Outer edge of SF rd.	*Quela quela*	Redbilled Quela	Terrestrial		X			Decapitation	M	Hours	28°32.588"S 21°04.191"E
30 September 2016	16:59	KHI 135	Systematic	SF - W	HS - 1035043	*Spilopelia senegalensis*	Laughing Dove	Terrestrial			X		No physical injuries	M	Hours	28°32.501"S 21°04.402"E

30 September 2016	17:09	KHI 136	Systematic	SF - W	HS - 1034033	*Steptopelia capicola*	Cape turtle dove	Terrestrial			X		Predated body	M	Hours	28°32.465"S 21°04.379"E
30 September 2016	17:19	KHI 137	Systematic	SF - W	HS - 1034027	*Quela quela*	Redbilled Quela	Terrestrial		X		D8	HS Mirror collision - "Splat spot" on HS mirror	M	Hours	28°32.383"S 21°04.307"E
05 October 2016	11:00	KHI 138	Systematic	SF - W	HS - 1038023	*Quela quela*	Redbilled Quela	Terrestrial		X		D8	HS Mirror collision - "Splat spot" on HS mirror	M	Days	28°32.377"S 21°04.237"E
13 October 2016	12:15	KHI 139	Systematic	SF - E	HS - 3042032	*Apus affinis*	Little swift	Air	X				Grade 2 Flux Injury, 2ndry predation	M	Days	28°32.152"S 21°04.187"E
13 October 2016	12:30	KHI 140	Systematic	SF - E	HS - 3042036	*Quela quela*	Redbilled Quela	Terrestrial		X		C8	HS Mirror collision - "Splat spot" on HS mirror	M	Hours	28° 32.083"S 21° 5.165"E
13 October 2016	12:30	KHI 141	Systematic	SF - E	HS - 3042036	*Quela quela*	Redbilled Quela	Terrestrial		X		D8	HS Mirror collision - "Splat spot" on HS mirror	M	Hours	28° 32.083"S 21° 5.165"E
14 October 2016	09:32	KHI 142	Systematic	SF - S	HS - 2048001	*Quela quela*	Redbilled Quela	Terrestrial		X		D8	HS Mirror collision - "Splat spot" on HS mirror	M	Hours	28° 32.712"S 21° 4.312"E
14 October 2016	10:11	KHI 143	Systematic	SF - S	HS - 2038006	*Quela quela*	Redbilled Quela	Terrestrial		X		A8	HS Mirror collision - "Splat spot" on HS mirror	M	Days	28°32.599"S 21°04.495"E
19 October 2016	10:00	KHI 144	Systematic	SF - S	HS - 2048013	*Quela quela*	Redbilled Quela	Terrestrial		X		A8	HS Mirror collision - "Splat spot" on HS mirror	M	Days	28°32.785"S 21°04.512"E
19 October 2016	12:00	KHI 145	Systematic	SF - E	HS - 3036043	*Quela quela*	Redbilled Quela	Terrestrial		X		C8	HS Mirror collision - "Splat spot" on HS mirror	M	Days	28° 31.980"S 21° 4.962"E

24 October 2016	09:37	KHI 146	Incidental	Top of tower	NE catwalk	*Apus affinis*	Little swift	Air	X				Grade 3 Flux Injury	M	Hours	28° 32.219"S 21° 4.676"E
24 October 2016	19:00	KHI 147	Incidental	Power Block	North of tower next to control building	*Hirundo albignularis*	Whitethroated Swallow	Air	X				Grade 1 Flux Injury, carcass was removed by predators. No ID sample	M	Hours	28° 32.174"S 21° 4.675"E
25 October 2016	13:10	KHI 148	Incidental	Power Block	North west of tower near vacuum pumps	*Emberiza impetuani*	Lark-like bunting	Terrestrial			X		Secondary predation, head is missing	M	Days	28° 32.229"S 21° 4.646"E
26 October 2016	09:50	KHI 149	Systematic	Ware house	North access gate of the warehouse	*Riparia paludicola*	Brown-throated martin	Air			X		Remains in poor state located inside warehouse	M	Days	28° 32.877"S 21° 4.795"E
26 October 2016	10:L53	KHI 150	Systematic	SF - W	HS - 1047045	*Quela quela*	Redbilled Quela	Terrestrial		X		D8	HS Mirror collision - "Splat spot" on HS mirror. 3 additional "splat spots" recorded	M	Days	28° 32.641"S 21° 4.251"E
26 October 2016	11:08	KHI 151	Systematic	SF - W	HS - 1043021	*Quela quela*	Redbilled Quela	Terrestrial		X		A8	HS Mirror collision - "Splat spot" on HS mirror	M	Days	28° 32.475"S 21° 4.192"E
26 October 2016	11:08	KHI 152	Systematic	SF - W	HS - 1043021	*Quela quela*	Redbilled Quela	Terrestrial		X		A8	HS Mirror collision - "Splat spot" on HS mirror	M	Days	28° 32.475"S 21° 4.192"E
26 October 2016	15:40	KHI 153	Systematic	SF - S	HS - 2048038	Unknown-remains in poor state	Unknown-remains in poor state	Terrestrial			X		Secondary predation	M	Days	28° 32.738"S 21° 4.953"E
27 October 2016	11:00	KHI 154	Incidental	Power Block	Accumulator 6	*Apus affinis*	Little swift	Air	X				Grade 3 Flux Injury	M	Days	28° 32.177"S 21° 4.619"E
27 October 2016	11:49	KHI 155	Incidental	Power Block	Inside NDC	*Emberiza impetuani*	Lark-like bunting	Terrestrial			X			M	Week	28° 32.232"S 21° 4.678"E

03 November 2016	09:00	KHI 156	Systematic	SF-S	HS - 2047014	*Bostrychia hagedash*	Hadeda ibis	Terrestrial			X		Undetermined, secondary predation, no visible “splat spot”.	M	Days	28° 32.784"S 21° 4.519"E
03 November 2016	09:25	KHI 157	Systematic	SF-S	HS - 2046009	*Emberiza impetuani*	Lark-like bunting	Terrestrial		X		C8	HS Mirror collision - "Splat spot" on HS mirror	M	Days	28° 32.770"S 21° 4.444"E
03 November 2016	10:25	KHI 158	Systematic	SF-S	HS - 204329	*Amadina erythrocephala*	Red-headed finch	Terrestrial		X		ND	HS Mirror collision - "Splat spot" on HS mirror	M	Days	28° 32.699"S 21° 4.819"E
03 November 2016	10:25	KHI 159	Systematic	SF-S	HS - 204329	*Quela quela*	Redbilled Quela	Terrestrial		X		ND	HS Mirror collision - "Splat spot" on HS mirror	M	Days	28° 32.699"S 21° 4.819"E
11 November 2016	09:15	KHI 160	Systematic	Power Block	Next to water treatment plant	*Columdidae Family*	Columdidae Family	Terrestrial			X			M	Days	28° 32.189"S 21° 4.728"E
13 November 2016	09:00	KHI 161	Systematic	SF-W	HS - 1017020	*Quela quela*	Redbilled Quela	Terrestrial		X		D8	HS Mirror collision - "Splat spot" on HS mirror	M	Days	28° 32.294"S 21° 4.467"E
22 November 2016	10:30	KHI 162	Incidental	Power Block	At the top of eastern cavity	*Hirundo albignularis*	Whitethroated Swallow	Air	X				Grade 3 Flux Injury.	M	Days	28° 32.211"S 21° 4.665"E
02 December 2016	08:30	KHI 163	Systematic	Power Block	West of accumulators	*Hirundo albignularis*	Whitethroated Swallow	Air	X				Grade 3 Flux Injury.	M	Hours	28° 32.228"S 21° 4.581"E
07 December 2016	09:10	KHI 164	Systematic	SF-S	HS - 2048034	*Emberiza impetuani*	Lark-like bunting	Terrestrial		X		C8	HS Mirror collision - "Splat spot" on HS mirror	M	Days	28° 32.761"S 21° 4.891"E
27 December 2016	10:38	KHI 165	Systematic	SF - W	HS - 3047040	*Quela quela*	Redbilled Quela	Terrestrial		X		D8	HS Mirror collision - "Splat spot" on HS mirror	M	Week	28° 32.138"S 21° 5.289"E

27 December 2016	10:45	KHI 166	Systematic	SF - W	HS - 3047030	*Quela quela*	Redbilled Quela	Terrestrial		X			Predated body	M	Week	28° 32.146"S 21° 5.297"E
27 December 2016	10:51	KHI 167	Systematic	SF - W	HS - 3047034	*Quela quela*	Redbilled Quela	Terrestrial	X			B8	HS Mirror collision - "Splat spot" on HS mirror	M	Week	28° 32.232"S 21° 5.302"E
27 December 2016	11:04	KHI 168	Systematic	SF - W	HS - 3046012	*Emberiza impetuani*	Lark-like bunting	Terrestrial			X		Undetermined, secondary predation, no visible “splat spot”.	M	Week	28° 32.457"S 21° 5.219"E
27 December 2016	11:10	KHI 169	Systematic	SF - W	HS - 3046007	*Quela quela*	Redbilled Quela	Terrestrial		X			Predated body	M	Week	28° 32.553"S 21° 5.146"E
27 December 2016	11:23	KHI 170	Systematic	SF - W	HS - 3043032	*Emberiza impetuani*	Lark-like bunting	Terrestrial	X			B8	HS Mirror collision - "Splat spot" on HS mirror	M	Week	28° 32.198"S 21° 5.213"E
27 December 2016	11:30	KHI 171	Systematic	SF - W	HS - 3042042	Unknown-remains in poor state	Unknown-remains in poor state	Terrestrial		X			Predated body	M	Week	28° 32.003"S 21° 5.124"E
27 December 2016	11:39	KHI 172	Systematic	SF - W	Between SF roads	Unknown-remains in poor state	Unknown-remains in poor state	Terrestrial		X			Predated body	M	Week	28° 32.006"S 21° 5.114"E
27 December 2016	11:57	KHI 173	Systematic	SF - W	HS - 3041027	*Quela quela*	Redbilled Quela	Terrestrial	X			B8	HS Mirror collision - "Splat spot" on HS mirror	M	Week	28° 32.227"S 21° 5.178"E
27 December 2016	12:00	KHI 174	Systematic	SF - W	HS - 3041040	*Emberiza impetuani*	Lark-like bunting	Terrestrial			X		Secondary insect predation (ants).	M	Week	28° 32.028"S 21° 5.128"E
27 December 2016	12:05	KHI 175	Systematic	SF - W	HS - 3041043	*Quela quela*	Redbilled Quela	Terrestrial	X			A8	HS Mirror collision - "Splat spot" on HS mirror	M	Days	28° 32.400"S 21° 5.140"E

27 December 2016	12:08	KHI 176	Systematic	SF - W	HS - 3041043	Unknown-remains in poor state	Unknown-remains in poor state	Terrestrial		X		Undetermined, secondary predation, no visible "splat spot".	M	Week	28° 32.400"S 21° 5.140"E
27 December 2016	12:15	KHI 177	Systematic	SF - W	HS - 3041044	*Quela quela*	Redbilled Quela	Terrestrial	X		D8	HS Mirror collision - "Splat spot" on HS mirror	M	Week	28° 32.423"S 21° 5.126"E
27 December 2016	12:21	KHI 178	Systematic	SF - W	HS - 3040048	*Emberiza impetuani*	Lark-like bunting	Terrestrial	X		D8	HS Mirror collision - "Splat spot" on HS mirror	M	Week	28° 32.469"S 21° 5.079"E
27 December 2016	12:31	KHI 179	Systematic	SF - W	HS - 3040933	*Emberiza impetuani*	Lark-like bunting	Terrestrial	X		B8	HS Mirror collision - "Splat spot" on HS mirror	M	Days	28° 32.012"S 21° 5.060"E
27 December 2016	12:43	KHI 180	Systematic	SF - W	HS-3038029	*Quela quela*	Redbilled Quela	Terrestrial	X		D8	HS Mirror collision - "Splat spot" on HS mirror	M	Week	28° 32.142"S 21° 5.112"E
27 December 2016	12:52	KHI 181	Systematic	SF - W	HS-3038026	*Quela quela*	Redbilled Quela	Terrestrial	X		D8	HS Mirror collision - "Splat spot" on HS mirror	M	Week	28° 32.192"S 21° 5.116"E
27 December 2016	13:00	KHI 182	Systematic	SF - W	HS-3037034	*Quela quela*	Redbilled Quela	Terrestrial	X		D7	HS Mirror collision - "Splat spot" on HS mirror	M	Week	28° 32.088"S 21° 5.066"E
27 December 2016	13:11	KHI 183	Systematic	SF - W	HS-3036031	*Emberiza impetuani*	Lark-like bunting	Terrestrial	X		A8	HS Mirror collision - "Splat spot" on HS mirror	M	Week	28° 32.115"S 21° 5.070"E
27 December 2016	14:11	KHI 184	Systematic	SF - W	HS-3036031	*Emberiza impetuani*	Lark-like bunting	Terrestrial	X		A8	HS Mirror collision - "Splat spot" on HS mirror	M	Week	28° 32.115"S 21° 5.070"E
27 December 2016	13:26	KHI 185	Systematic	SF - W	HS-3035025	*Quela quela*	Redbilled Quela	Terrestrial	X		D8	HS Mirror collision - "Splat spot" on HS mirror	M	Weeks	28° 32.218"S 21° 5.084"E

27 December 2016	13:35	KHI 186	Systematic	SF - W	HS-3035028	*Quela quela*	Redbilled Quela	Terrestrial	X	D8	HS Mirror collision - "Splat spot" on HS mirror	M	Weeks	28° 32.175"S 21° 5.082"E
27 December 2016	13:48	KHI 187	Systematic	SF - W	HS-3035030	*Emberiza impetuani*	Lark-like bunting	Terrestrial	X	C8	HS Mirror collision - "Splat spot" on HS mirror	M	Week	28° 32.150"S 21° 5.073"E
27 December 2016	13:59	KHI 188	Systematic	SF - W	HS-3034003	*Emberiza impetuani*	Lark-like bunting	Terrestrial	X	D8	HS Mirror collision - "Splat spot" on HS mirror	M	Days	28° 32.482"S 21° 04.038"E
27 December 2016	14:24	KHI 189	Systematic	SF - W	HS-302012	*Quela quela*	Redbilled Quela	Terrestrial	X	A8	HS Mirror collision - "Splat spot" on HS mirror	M	Day	28° 32.346"S 21° 05.016"E
27 December 2016	14:33	KHI 190	Systematic	SF - W	HS-3031015	*Quela quela*	Redbilled Quela	Terrestrial	X	A8	HS Mirror collision - "Splat spot" on HS mirror	M	Day	28° 32.304"S 21° 05.022"E
27 December 2016	14:40	KHI 191	Systematic	SF - W	HS-3031038	*Emberiza impetuani*	Lark-like bunting	Terrestrial	X	B7	HS Mirror collision - "Splat spot" on HS mirror	M	Hours	28° 32.412"S 21° 05.077"E
27 December 2016	16:06	KHI 192	Systematic	SF-S	HS-2049035	*Quela quela*	Redbilled Quela	Terrestrial	X	A8	HS Mirror collision - "Splat spot" on HS mirror	M	Day	28° 32.784"S 21° 04.912"E
27 December 2016	16:14	KHI 193	Systematic	SF-S	HS-2049037	*Emberiza impetuani*	Lark-like bunting	Terrestrial	X	C8	HS Mirror collision - "Splat spot" on HS mirror	M	Day	28° 32.771"S 21° 04.945"E
27 December 2016	16:21	KHI 194	Systematic	SF-S	HS-2048014	*Philetairus socius*	Sociable weaver	Terrestrial	X	B8	HS Mirror collision - "Splat spot" on HS mirror	M	Day	28° 32.789"S 21° 04.527"E
27 December 2016	16:26	KHI 195	Systematic	SF-S	HS-2048014	*Emberiza impetuani*	Lark-like bunting	Terrestrial	X	D8	HS Mirror collision - "Splat spot" on HS mirror	M	Week	28° 32.793"S 21° 04.530"E

27 December 2016	16:41	KHI 196	Systematic	SF-S	HS-2046012	*Emberiza impetuani*	Lark-like bunting	Terrestrial	X		A8	HS Mirror collision - "Splat spot" on HS mirror	M	Week	28° 32.767"S 21° 04.509"E
27 December 2016	16:50	KHI 197	Systematic	SF-S	HS-2046013	*Quela quela*	Redbilled Quela	Terrestrial	X		B8	HS Mirror collision - "Splat spot" on HS mirror. Secondary predation	M	Weeks	28° 32.731"S 21° 04.547"E
27 December 2016	17:08	KHI 198	Systematic	SF-S	HS-2041028	*Quela quela*	Redbilled Quela	Terrestrial	X		A8	HS Mirror collision - "Splat spot" on HS mirror. Secondary predation	M	Days	28° 32.666"S 21° 04.789"E
27 December 2016	17:08	KHI 199	Systematic	SF-S	HS-2041028	*Quela quela*	Redbilled Quela	Terrestrial	X		A8	HS Mirror collision - "Splat spot" on HS mirror. Secondary predation	M	Days	28° 32.666"S 21° 04.789"E
27 December 2016	17:08	KHI 200	Systematic	SF-S	HS-2041028	*Quela quela*	Redbilled Quela	Terrestrial	X		A8	HS Mirror collision - "Splat spot" on HS mirror. Secondary predation	M	Days	28° 32.666"S 21° 04.789"E
27 December 2016	17:08	KHI 201	Systematic	SF-S	HS-2041028	*Quela quela*	Redbilled Quela	Terrestrial	X		A8	HS Mirror collision - "Splat spot" on HS mirror. Secondary predation	M	Days	28° 32.666"S 21° 04.789"E
27 December 2016	17:08	KHI 202	Systematic	SF-S	HS-2041028	*Quela quela*	Redbilled Quela	Terrestrial	X		A8	HS Mirror collision - "Splat spot" on HS mirror. Secondary predation	M	Days	28° 32.666"S 21° 04.789"E
27 December 2016	17:08	KHI 203	Systematic	SF-S	HS-2041028	*Quela quela*	Redbilled Quela	Terrestrial	X		A8	HS Mirror collision - "Splat spot" on HS mirror. Secondary predation	M	Days	28° 32.666"S 21° 04.789"E
27 December 2016	17:21	KHI 204	Systematic	SF-S	HS-2041029	*Quela quela*	Redbilled Quela	Terrestrial	X		A8	HS Mirror collision - "Splat spot" on HS mirror. Secondary predation	M	Days	28° 32.654"S 21° 04.842"E
31 December 2016	07:43	KHI 205	Systematic	SF-W	HS-1030009	*Quela quela*	Redbilled Quela	Terrestrial		X		Body decapitaded - predation	M	Week	28° 32.053"S 21° 04.373"E

31 December 2016	08:00	KHI 206	Systematic	SF-W	HS-1026029	*Emberiza impetuani*	Lark-like bunting	Terrestrial		X			D8	Specimen survived collision	I	N/A	N/A
31 December 2016	08:15	KHI 207	Systematic	SF-W	HS-1026010	*Quela quela*	Redbilled Quela	Terrestrial		X			A8	HS Mirror collision - "Splat spot" on HS mirror. Secondary predation	M	Day	28° 32.106"S 21° 04.403"E
31 December 2016	08:46	KHI 208	Systematic	SF-W	HS-1008014	*Emberiza impetuani*	Lark-like bunting	Terrestrial		X			C8	HS Mirror collision - "Splat spot" on HS mirror. Secondary predation	M	Week	28° 32.280"S 21° 04.513"E
31 December 2016	08:55	KHI 209	Systematic	SF-W	HS-1007008	*Emberiza impetuani*	Lark-like bunting	Terrestrial		X			A8	HS Mirror collision - "Splat spot" on HS mirror. Secondary predation	M	Weeks	28° 32.203"S 21° 04.523"E
31 December 2016	09:00	KHI 210	Systematic	SF-W	HS-1007010	*Emberiza impetuani*	Lark-like bunting	Terrestrial			X			Body decapitaded - predation	M	Weeks	28° 32.226"S 21° 04.512"E
16 January 2017	08:30	KHI 211	Systematic	Ware house	Inside warehouse	*Hirundo albignularis*	Whitethroated Swallow	Air				X		No physical injuries	M	Day	28° 32.880"S 21° 04.801"E
16 January 2017	08:35	KHI 212	Systematic	Ware house	Inside warehouse	*Hirundo albignularis*	Whitethroated Swallow	Air				X		No physical injuries	M	Day	28° 32.884"S 21° 04.794"E
16 January 2017	13:30	KHI 213	Systematic	SF-S	HS-2043015	*Amadina erythrocephala*	Red-headed finch	Terrestrial		X			D8	HS Mirror collision - "Splat spot" on HS mirror.	M	Day	28° 32.706"S 21° 04.575"E
16 January 2017	14:30	KHI 214	Systematic	SF-S	HS-2039015	*Emberiza impetuani*	Lark-like bunting	Terrestrial		X			ND	Possible collision, "no splat spot" recorded	M	Day	28° 32.649"S 21° 04.613"E
16 January 2017	14:40	KHI 215	Systematic	SF-S	HS-2037006	*Apus caffer*	White-rumped swift	Air	X					Grade 3 Flux Injury	M	Day	28° 32.599"S 21° 04.508"E

16 January 2017	15:35	KHI 216	Systematic	SF-S	HS-2020003	*Apus caffer*	White-rumped swift	Air	X			Grade 3 Flux Injury	M	Day	28° 32.417"S 21° 04.574"E
16 January 2017	16:00	KHI 217	Systematic	SF-S	HS-2002008	*Apus caffer*	White-rumped swift	Air	X			Grade 3 Flux Injury	M	Weeks	28° 32.295"S 21° 04.731"E
16 January 2017	16:15	KHI 218	Systematic	SF-S	HS-2002007	*Apus caffer*	White-rumped swift	Air	X			Grade 3 Flux Injury	M	Weeks	28° 32.320"S 21° 04.705"E
16 January 2017	16:30	KHI 219	Systematic	SF-S	HS-2002004	*Apus caffer*	White-rumped swift	Air	X			Grade 3 Flux Injury	M	Weeks	28° 32.326"S 21° 04.653"E
16 January 2017	16:45	KHI 220	Systematic	SF-S	HS-2004001	*Apus caffer*	White-rumped swift	Air	X			Grade 3 Flux Injury, secondary predation	M	Weeks	28° 32.300"S 21° 04.594"E
16 January 2017	16:50	KHI 221	Systematic	SF-S	In main Access road between Southern and Western solarfield	*Apus caffer*	White-rumped swift	Air	X			Grade 3 Flux Injury	M	Days	28° 32.329"S 21° 04.761"E
19 January 2017	09:30	KHI 222	Systematic	SF-E	HS-3047006	*Ploceus velatus*	Southern Masked-Weave	Terrestrial		X		Heliostat in stow position due to high wind could not observe "splat spot" on mirrors. Possible collision	M	Hours	28° 32.623"S 21° 04.103"E
19 January 2017	10:40	KHI 223	Systematic	SF-E	HS-3034006	*Emberiza impetuani*	Lark-like bunting	Terrestrial			X	Heliostat in stow position due to high wind could not observe "splat spot" on mirrors. Possible collision	M	Days	28° 32.455"S 21° 04.970"E
19 January 2017	11:33	KHI 224	Systematic	SF-E	HS-3011008	*Apus caffer*	White-rumped swift	Air	X			Grade 3 Flux Injury, secondary predation	M	Weeks	28° 32.215"S 21° 04.832"E
19 January 2017	11:40	KHI 225	Systematic	SF-E	HS-3012010	*Apus caffer*	White-rumped swift	Air	X			Grade 3 Flux Injury, secondary predation	M	Weeks	28° 32.189"S 21° 04.839"E

19 January 2017	11:45	KHI 226	Systematic	SF-E	HS-3013010	*Apus caffer*	White-rumped swift	Air	X		Grade 3 Flux Injury, secondary predation	M	Weeks	28° 32.186"S 21° 04.855"E
19 January 2017	11:55	KHI 227	Systematic	SF-E	HS-3003008	*Apus caffer*	White-rumped swift	Air	X		Grade 3 Flux Injury, secondary predation	M	Weeks	28° 32.241"S 21° 04.785"E
19 January 2017	12:00	KHI 228	Systematic	SF-E	HS-3001004	*Apus caffer*	White-rumped swift	Air	X		Grade 3 Flux Injury, secondary predation	M	Weeks	28° 32.270"S 21° 04.769"E
19 January 2017	12:05	KHI 229	Systematic	SF-E	HS-3002002	*Apus caffer*	White-rumped swift	Air	X		Grade 3 Flux Injury, secondary predation	M	Weeks	28° 32.276"S 21° 04.754"E
19 January 2017	12:10	KHI 230	Systematic	SF-E	HS-3002008	*Apus caffer*	White-rumped swift	Air		X	Heliostat in stow position due to high wind could not observe “splat spot” on mirrors. Possible collision	M	Day	28° 32.300"S 21° 04.727"E
19 January 2017	12:15	KHI 231	Incidental	SF-S	In main Access road between Southern and Eastern solarfield	*Apus caffer*	White-rumped swift	Air	X		Grade 2 Flux Injury	M	Day	28° 32.503"S 21° 04.895"E
20 January 2017	13:15	KHI 232	Incidental	Power Block	Power Block underneath South Cavity	*Apus caffer*	White-rumped swift	Air	X		Grade 3 Flux Injury	M	Day	28° 32.239"S 21° 04.656"E
23 January 2017	11:40	KHI 233	Systematic	SF-W	HS-1011013	*Apus caffer*	White-rumped swift	Air	X		Grade 3 Flux Injury	M	Days	28° 32.287"S 21° 04.507"E
23 January 2017	12:15	KHI 234	Systematic	SF-W	HS-1024024	*Columba guinea*	Rock Pigeon	Terrestrial		X	Heliostat in stow position due to high wind could not observe “splat spot” on mirrors. Possible collision	M	Days	28° 32.302"S 21° 04.399"E
23 January 2017	12:50	KHI 235	Systematic	SF-W	HS-1025024	*Apus caffer*	White-rumped swift	Air	X		Grade 2 Flux Injury	M	Days	28° 32.317"S 21° 04.385"E

23 January 2017	13:00	KHI 236	Systematic	SF-W	HS-1036043	*Emberiza impetuani*	Lark-like bunting	Terrestrial		X		Heliostat in stow position due to high wind could not observe "splat spot" on mirrors. Possible collision	M	Days	28° 32.506"S 21° 04.389"E
23 January 2017	13:40	KHI 237	Systematic	SF-W	HS-1050010	*Quela quela*	Redbilled Quela	Terrestrial		X		Heliostat in stow position due to high wind could not observe "splat spot" on mirrors. Possible collision	M	Day	28° 32.238"S 21° 04.964"E
30 January 2017	08:15	KHI 238	incidental	SF-S	HS-2050026	*Pelecanus onocrotalus*	Great white pelican	Water		X		Bird was recorded at back of warehouse on the 27/01. I had difficulty flying. Could have died due to starvation.	M	Day	28° 32.848"S 21° 04.712"E
31 January 2017	08:40	KHI 239	Systematic	Power Block	Power Block north of tower	*Clamator jacobinus*	Jacobin cuckoo	Terrestrial		X			M	Days	28° 32.191"S 21° 04.678"E
31 January 2017	10:30	KHI 240	Systematic	SF-S	HS-2050039	*Quela quela*	Redbilled Quela	Terrestrial	X		C8	HS Mirror collision - "Splat spot" on HS mirror	M	Days	28° 32.799"S 21° 04.941"E
31 January 2017	10:50	KHI 241	Systematic	SF-S	HS-2049009	*Quela quela*	Redbilled Quela	Terrestrial	X		A8	HS Mirror collision - "Splat spot" on HS mirror	M	Days	28° 32.802"S 21° 04.461"E
31 January 2017	11:00	KHI 242	Systematic	SF-W	HS-3048011	*Quela quela*	Redbilled Quela	Terrestrial	X		D8	HS Mirror collision - "Splat spot" on HS mirror	M	Days	28° 32.583"S 21° 04.175"E
31 January 2017	11:10	KHI 243	Systematic	SF-S	HS-2048021	*Quela quela*	Redbilled Quela	Terrestrial	X		D8	HS Mirror collision - "Splat spot" on HS mirror	M	Days	28° 32.816"S 21° 04.658"E
31 January 2017	11:25	KHI 244	Systematic	SF-W	HS-3046028	*Quela quela*	Redbilled Quela	Terrestrial	X		C8	HS Mirror collision - "Splat spot" on HS mirror	M	Days	28° 32.106"S 21° 04.261"E
31 January 2017	12:28	KHI 245	Systematic	SF-W	HS-3046027	*Quela quela*	Redbilled Quela	Terrestrial	X		B8	HS Mirror collision - "Splat spot" on HS mirror	M	Days	28° 32.103"S 21° 04.253"E

31 January 2017	11:40	KHI 246	Systematic	SF-W	HS-3046025	*Quela quela*	Redbilled Quela	Terrestrial	X			D8	HS Mirror collision - "Splat spot" on HS mirror	M	Days	28° 32.144"S 21° 04.273"E
31 January 2017	12:20	KHI 247	Systematic	SF-W	HS-3040041	*Quela quela*	Redbilled Quela	Terrestrial	X			B8	HS Mirror collision - "Splat spot" on HS mirror	M	Days	28° 32.030"S 21° 04.107"E
31 January 2017	12:20	KHI 248	Systematic	SF-W	HS-3040041	*Quela quela*	Redbilled Quela	Terrestrial	X			B8	HS Mirror collision - "Splat spot" on HS mirror	M	Days	28° 32.030"S 21° 04.107"E
31 January 2017	11:25	KHI 249	Systematic	SF-W	HS-3040034	*Quela quela*	Redbilled Quela	Terrestrial	X			B8	HS Mirror collision - "Splat spot" on HS mirror	M	Days	28° 32.131"S 21° 04.152"E
01 February 2017	08:45	KHI 250	Systematic	SF-W	HS-3036044	*Quela quela*	Redbilled Quela	Terrestrial	X			A6	HS Mirror collision - "Splat spot" on HS mirror	M	Days	28° 31.951"S 21° 04.953"E
01 February 2017	08:50	KHI 251	Systematic	SF-W	HS-3036036	*Quela quela*	Redbilled Quela	Terrestrial			X		Undetermined, secondary predation, no visible “splat spot”.	M	Days	28° 32.045"S 21° 05.043"E
01 February 2017	08:55	KHI 252	Systematic	SF-W	HS-3036034	*Emberiza impetuani*	Lark-like bunting	Terrestrial			X		Undetermined, secondary predation, no visible “splat spot”.	M	Days	28° 32.072"S 21° 05.058"E
01 February 2017	09:00	KHI 253	Systematic	SF-W	HS-3036032	*Quela quela*	Redbilled Quela	Terrestrial			X		Undetermined, secondary predation, no visible “splat spot”.	M	Days	28° 32.103"S 21° 05.068"E
01 February 2017	09:30	KHI 254	Systematic	SF-W	HS-3033024	*Quela quela*	Redbilled Quela	Terrestrial			X		Undetermined, secondary predation, no visible “splat spot”.	M	Days	28° 32.170"S 21° 05.042"E
01 February 2017	10:00	KHI 255	Systematic	SF-W	HS-3030017	*Emberiza impetuani*	Lark-like bunting	Terrestrial		X			Predation, no visible “splat spot”.	M	Days	28° 32.268"S 21° 05.016"E

01 February 2017	10:10	KHI 256	Systematic	SF-S	HS-2030025	*Quela quela*	Redbilled Quela	Terrestrial		X	D8	HS Mirror collision - "Splat spot" on HS mirror	M	Days	28° 32.492"S 21° 04.849"E
01 February 2017	10:20	KHI 257	Systematic	SF-W	HS-3028001	*Emberiza impetuani*	Lark-like bunting	Terrestrial		X	B8	HS Mirror collision - "Splat spot" on HS mirror	M	Days	28° 32.438"S 21° 04.870"E
01 February 2017	10:25	KHI 258	Systematic	SF-S	HS-2028009	*Emberiza impetuani*	Lark-like bunting	Terrestrial		X	D8	HS Mirror collision - "Splat spot" on HS mirror	M	Days	28° 32.520"S 21° 04.633"E
01 February 2017	11:00	KHI 259	Systematic	SF-S	HS-2020008	*Apus caffer*	White-rumped swift	Air	X			Grade 2 Flux Injury	M	Days	28° 32.448"S 21° 04.655"E
01 February 2017	11:05	KHI 260	Systematic	SF-S	HS-2010010	*Apus caffer*	White-rumped swift	Air	X			Grade 3 Flux Injury	M	Days	28° 32.347"S 21° 04.747"E
01 February 2017	11:15	KHI 261	Systematic	SF-S	HS-2014003	*Apus caffer*	White-rumped swift	Air	X			Grade 3 Flux Injury	M	Days	28° 32.394"S 21° 04.597"E
01 February 2017	11:20	KHI 262	Systematic	SF-S	HS-2007003	*Apus caffer*	White-rumped swift	Air	X			Grade 3 Flux Injury	M	Days	28° 32.357"S 21° 04.608"E
01 February 2017	11:25	KHI 263	Systematic	SF-S	HS-2001006	*Apus caffer*	White-rumped swift	Air	X			Grade 3 Flux Injury	M	Days	28° 32.327"S 21° 04.703"E
01 February 2017	11:30	KHI 264	Systematic	Power Block	South of tower	*Apus caffer*	White-rumped swift	Air	X			Grade 3 Flux Injury	M	Days	28° 32.348"S 21° 04.615"E
08 February 2017	09:00	KHI 265	Systematic	Power Block	Top of East cavity	*Apus caffer*	White-rumped swift	Air	X			Grade 3 Flux Injury	M	Days	28° 32.229"S 21° 04.688"E

08 February 2017	09:05	KHI 266	Systematic	Power Block	Top of East cavity	*Apus caffer*	White-rumped swift	Air	X				Grade 3 Flux Injury	M	Days	28° 32.227"S 21° 04.682"E
08 February 2017	09:10	KHI 267	Systematic	Power Block	Top of East cavity	*Apus caffer*	White-rumped swift	Air	X				Grade 3 Flux Injury	M	Days	28° 32.230"S 21° 04.680"E
17 February 2017	08:30	KHI 268	Systematic	SF-S	HS-2050024	*Emberiza impetuani*	Lark-like bunting	Terrestrial			X		Heliostat in stow position due to breakdown in South cavity no “splat spot” could be observed on mirrors. Possible collision	M	Weeks	28° 32.845"S 21° 04.671"E
17 February 2017	09:20	KHI 269	Systematic	SF-S	HS-2030007	*Quela quela*	Redbilled Quela	Terrestrial			X		Heliostat in stow position due to breakdown in South cavity no “splat spot” could be observed on mirrors. Possible collision	M	Days	28° 32.519"S 21° 04.554"E
17 February 2017	10:00	KHI 270	Systematic	SF-S	HS-2015005	*Apus caffer*	White-rumped swift	Air	X				Grade 3 Flux Injury	M	Weeks	28° 32.399"S 21° 04.639"E
17 February 2017	11:00	KHI 271	Systematic	SF-S	HS-2006002	*Apus caffer*	White-rumped swift	Air	X				Grade 3 Flux Injury	M	Weeks	28° 32.334"S 21° 04.628"E
17 February 2017	12:10	KHI 272	Incidental	SF-W	Next to main road	*Apus caffer*	White-rumped swift	Air	X				Grade 3 Flux Injury	I	Hours	28° 31.928"S 21° 04.450"E
22 February 2017	09:05	KHI 273	Systematic	SF-W	HS-1050039	*Emberiza impetuani*	Lark-like bunting	Terrestrial		X		D8	HS Mirror collision - "Splat spot" on HS mirror	M	Week	28° 32.648"S 21° 04.157"E
22 February 2017	10:00	KHI 274	Systematic	SF-W	HS-1050012	*Quela quela*	Redbilled Quela	Terrestrial		X		B8	HS Mirror collision - "Splat spot" on HS mirror	M	Days	28° 32.261"S 21° 04.963"E
22 February 2017	10:30	KHI 275	Systematic	SF-W	HS-1037037	*Emberiza impetuani*	Lark-like bunting	Terrestrial			X		Mirror cleaned before collision could be recorded. No “splat spot” could be observed on mirrors. Possible collision	M	Week	28° 32.458"S 21° 04.314"E

22 February 2017	10:35	KHI 276	Systematic	SF-W	HS-1036040	*Emberiza impetuani*	Lark-like bunting	Terrestrial			X		Mirror cleaned before collision could be recorded. No "splat spot" could be observed on mirrors. Possible collision	M	Week	28° 32.480"S 21° 04.358"E
22 February 2017	11:00	KHI 277	Systematic	SF-W	HS-1035039	*Philetairus socius*	Sociable weaver	Terrestrial			X		Mirror cleaned before collision could be recorded. No "splat spot" could be observed on mirrors. Possible collision	M	Days	28° 32.455"S 21° 04.345"E
22 February 2017	11:30	KHI 278	Systematic	SF-W	HS-1032007	*Sporopipes squamifrons*	Scalyfeathered Finch	Terrestrial			X		Mirror cleaned before collision could be recorded. No "splat spot" could be observed on mirrors. Possible collision	M	Days	28° 32.036"S 21° 04.365"E
22 February 2017	11:45	KHI 279	Systematic	SF-W	HS-1024023	*Emberiza impetuani*	Lark-like bunting	Terrestrial			X		Mirror cleaned before collision could be recorded. No "splat spot" could be observed on mirrors. Possible collision	M	Days	28° 32.293"S 21° 04.393"E
22 February 2017	12:00	KHI 280	Systematic	SF-W	HS-1024025	*Euplectes orix*	Red bishop	Terrestrial		X		ND	HS Mirror collision - "Splat spot" on HS mirror	M	Week	28° 32.318"S 21° 04.402"E
22 February 2017	12:05	KHI 281	Systematic	SF-W	HS-1002010	*Apus caffer*	White-rumped swift	Air	X				Grade 3 Flux Injury	M	Weeks	28° 32.275"S 21° 04.573"E
22 February 2017	12:10	KHI 282	Systematic	SF-W	HS-1002010	*Apus caffer*	White-rumped swift	Air	X				Grade 2 Flux Injury	M	Days	28° 32.278"S 21° 04.575"E
06 March 2017	09:10	KHI 283	incidental	SF-W	HS-1003001	*Apus caffer*	White-rumped swift	Air	X				Grade 1 Flux Injury	M	Hours	28° 32.147"S 21° 04.615"E
06 March 2017	09:00	KHI 284	Systematic	SF-S	HS-2045011	*Quela quela*	Redbilled Quela	Terrestrial		X		ND	Possible collision, "no splat spot" recorded. Mirroir washed previous day	M	Day	28° 32.724"S 21° 04.503"E
06 March 2017	09:10	KHI 285	Systematic	SF-S	HS-2043002	*Oena capensis*	Namaqua Dove	Terrestrial		X		A8	HS Mirror collision - "Splat spot" on HS mirror. Secondary predation	M	Week	28° 32.644"S 21° 04.381"E

06 March 2017	09:35	KHI 286	Systematic	SF-S	HS-2037007	*Quela quela*	Redbilled Quela	Terrestrial		X		C8	HS Mirror collision - "Splat spot" on HS mirror.	M	Week	28° 32.596"S 21° 04.525"E
06 March 2017	09:45	KHI 287	Systematic	SF-S	HS-2029015	*Quela quela*	Redbilled Quela	Terrestrial		X		NDN	HS Mirror in stow position - No "Splat spot" visible on HS mirror.	M	Week	28° 32.519"S 21° 04.695"E
06 March 2017	10:20	KHI 288	Systematic	SF-S	HS-2021011	*Apus caffer*	White-rumped swift	Air	X				Grade 3 Flux Injury	M	Weeks	28° 32.454"S 21° 04.697"E
06 March 2017	10:30	KHI 289	Systematic	SF-S	HS-2015001	*Apus caffer*	White-rumped swift	Air	X				Grade 1 Flux Injury	M	Hours	28° 32.362"S 21° 04.562"E
06 March 2017	11:13	KHI 290	Systematic	SF-S	Next to main access road	*Caprimulgus rufigena*	Rufous-cheeked nightjar	Terrestrial		X			Collusion with vehicle	M	Days	28° 32.947"S 21° 04.405"E
09 March 2017	09:30	KHI 291	Systematic	SF-W	HS-3048037	*Quela quela*	Redbilled Quela	Terrestrial		X		ND	Possible collision, "no splat spot" recorded. Mirroir washed previous day	M	Days	28° 32.187"S 21° 05.314"E
23 March 2017	09:30	KHI 292	Systematic	Ware house	Inside warehouse	*Apus caffer*	White-rumped swift	Air			X			M	Days	28° 32.895"S 21° 04.808"E
23 March 2017	09:35	KHI 293	Systematic	SF-S	HS-2050041	*Quela quela*	Redbilled Quela	Terrestrial		X		ND	Possible collision, "no splat spot" recorded. Mirroir washed previous day	M	Weeks	28° 32.785"S 21° 04.973"E
23 March 2017	09:40	KHI 294	Systematic	SF-S	HS-2047040	*Emberiza impetuani*	Lark-like bunting	Terrestrial		X		C8	HS Mirror collision - "Splat spot" on HS mirror.	M	Weeks	28° 32.712"S 21° 04.969"E
23 March 2017	09:50	KHI 295	Systematic	SF-S	HS-2046030	*Quela quela*	Redbilled Quela	Terrestrial		X		ND	Possible collision, "no splat spot" recorded. Mirroir washed previous day	M	Days	28° 32.746"S 21° 04.813"E

23 March 2017	10:00	KHI 296	Systematic	SF-S	HS-2043005	*Emberiza impetuani*	Lark-like bunting	Terrestrial	X		D7	HS Mirror collision - "Splat spot" on HS mirror.	M	Hours	28° 32.658"S 21° 04.416"E
23 March 2017	10:30	KHI 297	Systematic	SF-S	HS-2042029	*Quela quela*	Redbilled Quela	Terrestrial	X		ND	Possible collision, "no splat spot" recorded. Mirroir washed previous day	M	Days	28° 32.658"S 21° 04.877"E
23 March 2017	10:40	KHI 298	Systematic	SF-S	HS-2040032	*Emberiza impetuani*	Lark-like bunting	Terrestrial	X		ND	Possible collision, "no splat spot" recorded. Mirroir washed previous day	M	Week	28° 32.616"S 21° 04.886"E
23 March 2017	10:55	KHI 299	Systematic	SF-S	HS-2040004	*Quela quela*	Redbilled Quela	Terrestrial	X		ND	Possible collision, "no splat spot" recorded. Mirroir washed previous day	M	Week	28° 32.619"S 21° 04.440"E
23 March 2017	11:10	KHI 300	Systematic	SF-S	HS-2038009	*Ploceus velatus*	Southern Masked-Weaver	Terrestrial	X		ND	Possible collision, "no splat spot" recorded. Mirroir washed previous day	M	Week	28° 32.618"S 21° 04.548"E
23 March 2017	11:15	KHI 301	Systematic	SF-S	HS-2036002	*Quela quela*	Redbilled Quela	Terrestrial	X		C7	HS Mirror collision - "Splat spot" on HS mirror.	M	Week	28° 32.548"S 21° 04.442"E
23 March 2017	11:25	KHI 302	Systematic	SF-S	HS-2033025	*Quela quela*	Redbilled Quela	Terrestrial	X		ND	Possible collision, "no splat spot" recorded. Mirroir washed previous day	M	Week	28° 32.505"S 21° 04.873"E
29 March 2017	09:00	KHI 303	Systematic	SF-S	HS-2050017	*Quela quela*	Redbilled Quela	Terrestrial	X		C8	HS Mirror collision - "Splat spot" on HS mirror.	M	Day	28° 32.834"S 21° 04.549"E
29 March 2017	09:10	KHI 304	Systematic	SF-W	HS-1050001	*Quela quela*	Redbilled Quela	Terrestrial	X		B8	HS Mirror collision - "Splat spot" on HS mirror.	M	Hours	28° 32.087"S 21° 04.985"E
05 April 2017	10:30	KHI 305	Systematic	SF-S	HS-2047034	*Tricholaema leucomelas*	Acacia pied barbet	Terrestrial	X		D8	HS Mirror collision - "Splat spot" on HS mirror.	M	Days	28° 32.747"S 21° 04.872"E

05 April 2017	10:40	KHI 306	Systematic	SF-S	HS-2047018	*Philetairus socius*	Sociable weaver	Terrestrial		X			ND	Possible collision, "no splat spot" recorded. Mirroir washed previous day	M	Days	28° 32.781"S 21° 04.597"E
05 April 2017	10:45	KHI 307	Systematic	SF-S	HS-2046032	*Philetairus socius*	Sociable weaver	Terrestrial		X			ND	Possible collision, "no splat spot" recorded. Mirroir washed previous day	M	Days	28° 32.740"S 21° 04.844"E
05 April 2017	11:20	KHI 308	Systematic	SF-S	HS-2045032	*Philetairus socius*	Sociable weaver	Terrestrial		X			ND	Possible collision, "no splat spot" recorded. Mirroir washed previous day	M	Week	28° 32.705"S 21° 04.878"E
05 April 2017	11:25	KHI 309	Systematic	SF-S	HS-2045031	*Emberiza impetuani*	Lark-like bunting	Terrestrial		X			ND	Possible collision, "no splat spot" recorded. Mirroir washed previous day	M	Days	28° 32.710"S 21° 04.856"E
05 April 2017	11:45	KHI 310	Systematic	SF-S	HS-2045003	*Quela quela*	Redbilled Quela	Terrestrial		X			ND	Possible collision, "no splat spot" recorded. Mirroir washed previous day	M	Week	28° 32.670"S 21° 04.373"E
20 April 2017	11:20	KHI 311	Systematic	SF-S	HS-2039029	*Quela quela*	Redbilled Quela	Terrestrial		X			ND	Heliostat in stow position no “splat spot” could be observed on mirrors. Possible collision	M	Days	28° 32.612"S 21° 04.838"E
24 April 2017	15:30	KHI 312	Incidental	SF-E	HS-3030004	*Falco biarmicus*	Lanner falcon	Terrestrial	X					Grade 1 Flux Injury, bird was still alive. Dr. Lategan in Upington advised that we take it to Machel Niekerk that specialises in bird of prey rehabilitation. Contact number: 0731679119	I	Hours	28° 32.531"S 21° 04.989"E
02 May 2017	10:00	KHI 313	Systematic	Power Block	Infront of Control Room	*Ptyonoprogne fuligula*	Rock martin	Air				X			M	Days	28° 32.169"S 21° 04.641"E
03 May 2017	09:00	KHI 314	Systematic	SF-S	HS-2045007	*Quela quela*	Redbilled Quela	Terrestrial		X			D7	HS Mirror collision - "Splat spot" on HS mirror.	M	Days	28° 32.697"S 21° 04.442"E
03 May 2017	09:15	KHI 315	Systematic	SF-S	HS-2044012	*Quela quela*	Redbilled Quela	Terrestrial		X			ND	Possible collision, "no splat spot" recorded. Mirroir washed previous day	M	Days	28° 32.711"S 21° 04.533"E

12 May 2017	10:00	KHI 316	Systematic	Evaporation ponds	Evaporation pond 3	*Tachybaptus ruficollis*	Little grebe	Water			X			M	Days	28° 32.871"S 21° 04.594"E
12 May 2017	10:00	KHI 317	Systematic	Evaporation ponds	Evaporation pond 3	*Tachybaptus ruficollis*	Little grebe	Water			X			M	Days	28° 32.871"S 21° 04.594"E
12 May 2017	10:10	KHI 318	Systematic	Evaporation ponds	Evaporation pond 2	*Alopochen aegyptiaca*	Egyptian goose	Water			X			M	Days	28° 32.874"S 21° 04.557"E
18 May 2017	14:00	KHI 319	Systematic	SF-S	HS-2050034	*Quela quela*	Redbilled Quela	Terrestrial		X		A8		M	Hours	28° 32.827"S 21° 04.856"E
18 May 2017	14:20	KHI 320	Systematic	SF-S	HS-2049030	*Quela quela*	Redbilled Quela	Terrestrial		X		D8		M	Hours	28° 32.802"S 21° 04.823"E
18 May 2017	15:00	KHI 321	Systematic	SF-S	HS-2048011	*Columba guinea*	Rock Pigeon	Terrestrial		X		B8		M	Days	28° 32.775"S 21° 04.475"E
18 May 2017	15:10	KHI 322	Systematic	SF-S	HS-2041004	*Quela quela*	Redbilled Quela	Terrestrial		X		ND		M	Hours	28° 32.620"S 21° 04.432"E
26 May 2017	16:40	KHI 323	Systematic	Power Block	Main elecktrical building	*Ploceus velatus*	Southern Masked-Weaver	Terrestrial			X			M	Days	28° 32.181"S 21° 04.681"E
08 June 2017	14:00	KHI 324	Systematic	Power Block	Top of East cavity	*Apus caffer*	White-rumped swift	Air	X				Grade 3 Flux Injury	M	Month	28° 32.224"S 21° 04.688"E