The impact of a ‘trough’ Concentrated Solar Power facility on birds and other animals in the Northern Cape, South Africa

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Minor Dissertation presented in partial fulfillment of the requirements for the degree of Masters of Science in Conservation Biology

March 2017

Contents

Abstract:

The environmental impacts of solar power generation and particularly Concentrated Solar Power (CSP) are not well understood. There have been reports of birds injured and killed by concentrated solar radiation at power 'towers' and from collisions with mirrors at both tower and 'trough' facilities. This study assesses the impacts of a utility-scale 50 MW 'trough' CSP facility - Bokpoort CSP Power Plant - in the Northern Cape, South Africa. To assess the changes in functional and structural changes in bird communities, bird counts in the solar fields (mirror arrays) were compared with transects from rangelands adjacent to the CSP plant. Invertebrates were sampled with sticky and pitfall traps adjacent to the power block, in the solar fields, and in the rangeland landscape to assess changes in invertebrate communities. There were significant changes in bird distribution across the landscape with more species richness and two orders of magnitude greater abundance in the rangeland compared to the solar fields. Fewer invertebrates were caught, but with a greater taxonomic richness in rangeland compared to the power block and solar field. The facilities' evaporation ponds created novel wetland habitat for birds; 23 species were recorded that would have been absent from the area prior to construction, including three breeding species. The solar fields were surveyed for bird injuries or fatalities over 3 months; only eight dead birds were found, all but one was too old to determine the cause of death (>1 month); the remaining carcass likely died from a mirror impact. Western Barn Owls (*Tyto alba*) made up half of the mortalities. Biases in mortality estimates due to searcher efficiency and scavenger removal were substantial only for small birds. Twenty-one animals (3 reptiles, 12 mammals, 6 birds) likely drowned in the evaporation ponds after being unable to escape. The recorded mortalities were very low in comparison with similar studies on CSP facilities. No threatened

or endangered species were killed. Overall, the facility had a low impact on bird populations, but the drowning risk posed to animals by evaporation ponds requires mitigation. The negative impacts observed could be minimised through careful site selection of solar facilities and careful design and mitigation considerations particularly with regard to evaporation and water ponds in arid areas such as the Northern Cape.

General introduction

This study assessed the environmental impacts of a 'trough' utility-scale Concentrated Solar Power (CSP) facility. The significant expansion of solar energy and the limited information on the potential environmental impacts makes this study highly important. This study is the first of its kind on this type of technology in the southern hemisphere. It assessed: 1) mortality risk associated with the facility on birds; 2) the changes in bird and invertebrate communities within the solar facility and the adjacent rangeland landscapes and 3) if the site attracts birds and invertebrates.

Solar power development

The renewable energy industry has seen substantial growth throughout the world in the past decade, and with the adoption of the 'Paris Agreement' on climate change in 2015 (UNFCCC 2015), we are likely to see greater global pressure on governments to move away from fossil fuels to clean renewable energy. Solar power is one of the largest sources of renewable energy and South Africa has one of the highest potential solar energy regimes in the world, with the average daily direct normal radiation in excess of 7 kWh/m^2 (Department of Energy 2011; Eberhard et al. 2014). Four types of industrial solar power generation technologies have been used in developments in South Africa: Concentrator or Concentrated Photovoltaic (CPV), Photovoltaic (PV) and two forms of Concentrated Solar Power (CSP) developments - 'power tower' and 'trough' projects. PV facilities directly convert the sun's energy into electricity, while CSP utilises mirrors to concentrate the sun's radiation to a receiver, through a medium such as oil, molten salt or directly heating water to generate steam to drive a turbine and produce electricity. CSP has an advantage over PV facilities by being able to store thermal heat. It is more expensive, but decreasing costs in recent years is making CSP more competitive with PV (Eberhard et al. 2014; Department of Energy 2015a). CSP technologies have been implemented in 33 countries across the globe (CSP World.org 2015) with substantial growth in the last decade not only globally, but also within South Africa.

Two distinct CSP technologies have gained dominance in solar power production: solar 'power towers', which use flat mirrors called heliostats to reflect solar radiation to a central focal point on a tower, and 'troughs', which use parabolic mirrors to reflect solar radiation to a receiver tube (Hernandez et al. 2014) (Figure 1).

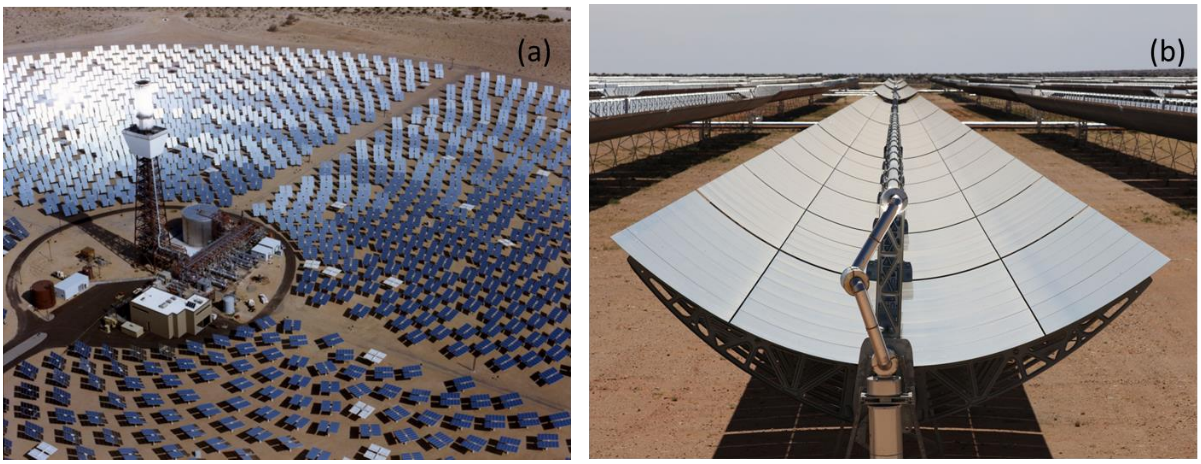

Figure 1: Visual comparison of CSP technologies (a) 'power tower' photo credit CSP World.org 2014 (b) 'trough' photo credit P.G. Ryan

The release of the South African White Paper on renewable energy (Department of Minerals and Energy 2003) paved the way for renewable energy development in South Africa and the Department of Energy's Strategic plan 2015-2020 highlights the government's vision for 30% of energy to be "clean and green" by 2025 (Department of Energy 2015b). The Department of Energy's Integrated Resource Plan (IRP) (released in 2010), set out the energy sources and capacities that will be used, as well as new infrastructure that will be built between 2010 – 2030 in South Africa (Department of Energy 2011; Silinga et al. 2015). The Integrated Resource Plan (IRP) 2010-2030 set out a target of 17 800 MW new generation capacity for renewables by 2030 (Department of Energy 2015c). To implement these energy allocations, the Department of Energy designed the Renewable Energy Independent Power Producer Procurement Programme (REIPPPP) (Department of Energy 2015c; Silinga et al. 2015). This programme has seen the substantial development of solar power generation facilities through Independent Power Producers (IPP) as a means of increasing and diversifying energy capacity and reducing the carbon footprint of the country (Department of Energy 2016a). The South African government's target for renewable energy generation by 2030 is 42% (17.8 GW), comprising of 8.4 GW wind energy production, 8.4 GW of PV and 1 GW of CSP (Department of Energy 2016b).

Solar power and biodiversity

The benefits of reducing CO_2 and other toxic or greenhouse gas emissions, and reducing the effects of climate change by the development of renewable energy facilities, are clearly evident. Biodiversity is under significant threat from numerous global change drivers, with climate change being a major contributing factor to many impacts (Pereira et al. 2010). Foden et al. (2013) show 6-9% of threatened bird species and 11-15% of threatened amphibian species are highly vulnerable to the impacts of climate change. There are, however, environmental trade-offs with the implementation of renewable energy installations which affect biodiversity (Smallwood 2007; Klugmann-Radziemska 2014; Wu et al. 2014; McCombie & Jefferson 2016). Renewable energy is under increasing scrutiny when it comes to environmental impacts, particularly regarding its impacts on birds (Desmond 2014; Smith & Dwyer 2016; USGS 2016). Potential environmental impacts of solar energy facilities include vegetation/habitat removal, increases in noise and dust, collisions with solar infrastructure or from increased vehicle traffic, and alterations to water availability (Lovich & Ennen 2011). Water storage and evaporation ponds needed at CSP facilities may increase mortality risk and change bird community structures by attracting birds and other animals, particularly in arid landscapes (McCrary et al. 1986; Kagan et al. 2014; Smith & Dwyer 2016). Insects may also be attracted to solar towers (Kagan et al. 2014) as well as PV facilities (Horváth et al. 2010), but as yet there is no evidence suggesting the same for trough CSP plants. Solar power facilities are often constructed in arid areas which have reliable, high levels of solar radiation; these areas can also be areas of high endemism, exacerbating any detrimental impacts on populations (Lovich & Ennen 2011). The Northern Cape Province has attracted all of the CSP projects approved to date in South Africa as it has the most favourable levels of solar radiation (Fluri 2009; Department of Energy 2015c) (Figure 2).

While other renewable energies like wind have a substantial amount of published data on their impacts on birds (Marti Montes & Jaque 1995; Anderson et al. 1999; Drewitt & Langston 2006; Bernardino et al. 2013; Marques et al. 2014; Manikandan & Umayal 2015; Loss 2016; Smith & Dwyer 2016), CSP impacts on birds are not well understood and there is need for further research into these effects (McCrary et al. 1986; Kagan et al. 2014; Walston et al. 2015).

This study is the first of its kind on a ‘trough’ facility outside the USA. It measures the impact of a CSP ‘trough’ facility on birds by: a) recording avian mortality associated with the plant; b) estimating fatality rates taking into account searcher efficiency and carcass persistence biases, and c) assessing changes in bird and invertebrate communities to analyse if the site could potentially act as an ecological trap (Dwernychuk & Boag 1972; Horváth et al. 2010).

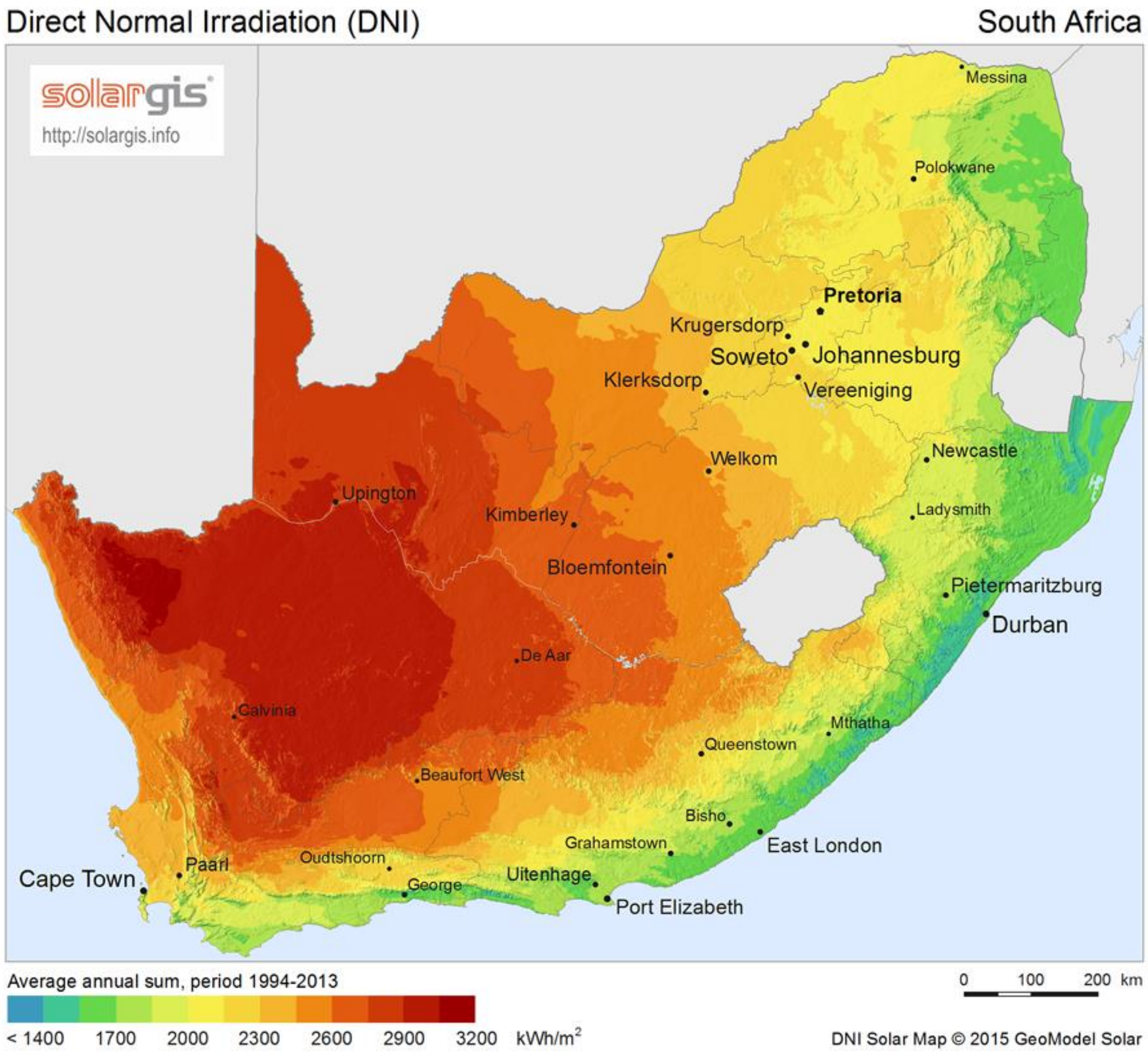

Figure 2: Map of South Africa indicating the levels of Direct Normal Irradiation (GHI Solar Map © 2015 Solargis)

Study site

This study was conducted at the ACWA Power SolAfrica Bokpoort CSP Power Plant (Pty) Ltd (RF), a 50 MW 'trough' CSP facility located in the Northern Cape Province of South Africa, approximately 30 km northwest of Groblershoop. Construction began on the facility in August 2013, the first trials commenced at the end of 2015 and commercial operation began on 19 March 2016.

As a ‘trough’ CSP facility, it uses concave mirrors to concentrate solar rays onto a receiver tube containing a Heat Transfer Fluid (HTF) (Figure 3). The HTF is heated to ~390°C and piped to a ‘power block’ where it produces steam through a heat exchanger that drives a turbine to generate electricity. The water used to generate steam is pumped from the Orange River, ~15 km away, and is purified through reverse osmosis before being utilised in the turbine. The facility has two water storage ponds (85 x 85 m) for use in the power block and two evaporation ponds (200 x 280 m) to dispose of wastewater.

Figure 3: Concave mirrors used to concentrate solar energy onto the receiving tube at ‘trough’ CSP facilities. Photo credit: P. G. Ryan

Bokpoort also contains thermal storage in the form of molten salt. The purified salt is heated by the HTF and stored to generate electricity at night or when solar radiation is low during the day. At full capacity, the molten salt can run the turbines for 8.4 hours, which (at the time of writing) is the largest storage capacity for a ‘trough’ facility in the world. The ability to store thermal energy enables CSP technology to produce electricity at times of peak demand, which typically occur in the early morning and evening when there is little or no solar radiation. To account for the extra thermal requirements of the molten salt storage, the facility is over specified to that of a 75 MW facility, however grid output is limited to 50 MW. This gives the facility a bigger footprint (~200 ha solar field) when compared to a similar 50 MW ‘trough’ facility without thermal storage.

Each section of concave mirrors consists of 28 mirrors, 2887 mm high x 1700 mm wide. There are 24 sections in each row (see Figure 3), and two rows form a loop. HTF enters cold on one row and exits hot on the other. The facility is divided into solar fields consisting of 20 -25 loops each. There are 180 loops with 360 rows in the entire plant. Rows are approximately 300 m long, which gives a total solar collector length of approximately 108 km in an area of ~250 ha. Mirrors are cleaned with demineralised water as needed, because dust accumulation reduces mirror efficiency.

Waste water from the power block is pumped into two evaporation ponds lined with a black PVC membrane to prevent seepage and to increase evaporation rates by increasing water temperature (E. Julies, pers. comm.). The evaporation ponds are shallow, with a maximum depth of 1.5-1.75 m, although the typical operational depth is < 50 cm. The smaller holding ponds are deeper, with a maximum depth of 6 m (Figure 4).

Bokpoort CSP is situated within the Nama Karoo Biome in the Northern Cape Province, an arid region of South Africa with extensive areas of low-density rangelands. Rangelands adjacent to the CSP facility were utilised as a control site for assessing changes in bird and invertebrate communities. The vegetation type in the area is Kalahari Karroid Shrubland with some elements of Gordonia Duneveld (Mucina & Rutherford 2006), characterised by low karroid shrubland on flat, gravel plains. This vegetation type is listed as least threatened (Mucina & Rutherford 2006). The area has a mean annual precipitation of 100-200 mm while solar radiation recorded here is the highest for the entire Nama Karoo during winter (Mucina & Rutherford 2006). Land use in the area is predominantly stock land (cattle and sheep) and game farming, with irrigated agriculture along the Orange River valley.

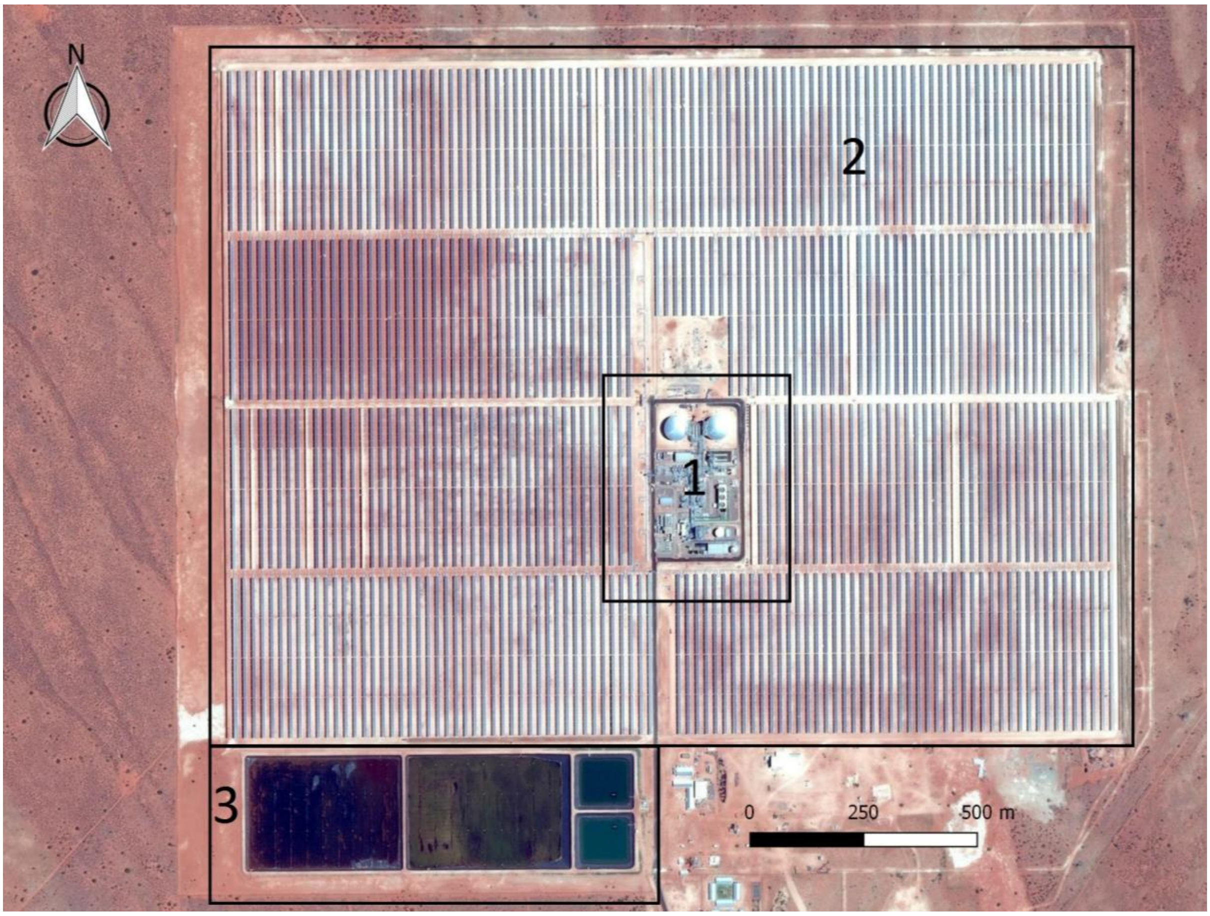

Figure 4: Map of Bokpoort CSP Facility, Northern Cape, South Africa. 1) Power block, 2) Solar fields, 3) Evaporation ponds. Map data©2017 AfriGIS (Pty) Ltd, Google.

The area around the study site has been surveyed for birds as a part of the Southern African Bird Atlas Project (SABAP), a citizen science project where volunteers submit bird data under strict guidelines (SABAP2 2017). Two quarter degree squared grids which transect the study site, (NW corners located at S 28°15’ E 21˚45’ and 28˚30’ E 22˚00’) recorded 150 bird species comprising 42 endemic or near-endemic species and four near-threatened, vulnerable or endangered species (Appendix 1).

Thesis overview

My study investigates the impact of Bokpoort CSP facility on bird and invertebrate communities. It also quantifies bird mortality associated with the facility whilst accounting for searcher efficiency and carcass persistence. The study also adds to the limited knowledge base associated with environmental impacts at this type of facility, informs stakeholders of these impacts, and guides possible mitigation strategies. It is set out in two chapters, each with their own introduction, methods, results and discussion, with general conclusions at the end. Chapter 1 assesses how the Bokpoort trough CSP facility affects bird and invertebrate communities through surveys of the facility and the adjacent rangeland. Chapter 2 estimates the bird mortality at the Bokpoort CSP facility through carcass searches and bias correction trials.

Chapter 1: Changes in bird and invertebrate communities

Introduction

The limited data available suggests that CSP plants can have significant effects on the bird and invertebrate communities present in the plant footprint (Kagan et al. 2014; Walston et al. 2016). Bird communities can be affected by changes in landscape (connectivity, fragmentation, habitat degradation) and direct habitat loss (vegetation removal or structural changes) (Walston et al. 2015; Smith & Dwyer 2016). Utility-scale solar energy facilities require large spatial footprints of 1.4 to 6.2 ha per MW of production (Walston et al. 2016), and involve extensive removal and control of vegetation, which can cause biodiversity losses (Hernandez et al. 2014). The Bokpoort CSP 50 MW facility has a footprint of ~ 250 ha, 5 ha per MW. Previous studies suggest that solar developments can have a negative impact on bird abundance and diversity in the plant footprint, particularly in areas associated with mirrors (H.T. Harvey and Associates 2015; Western EcoSystems Technology 2016). CSP facilities typically have a higher level of habitat loss when compared to PV sites as vegetation is managed to reduce fire risk from high temperatures associated with concentrated sunlight (Dessouky 2013). ‘Trough’ CSP facilities utilising flammable HTF pose an even greater fire risk (Grippo et al. 2014), and thus require high levels of vegetation management, such as brush cutting and herbicide spraying.

Another possible impact of solar facilities is through the emission of polarised light (Walston et al. 2015), which has the potential to attract birds and invertebrates to the facility. Many animals including birds and invertebrates can see polarised light, and insects have been reported to be attracted to the polarised light from man-made sources, including solar facilities (Horváth et al. 2009; Walston et al. 2015). Natural light reflected off man-made surfaces such as glass and mirrors can undergo strong horizontal polarisation similar to water (the primary natural source of horizontally polarised light), which could cause a solar facility to become an ecological trap (Horváth et al. 2009, 2010). There are also concerns about the possibility of migrating birds being attracted to a “lake effect” of utility-scale solar facilities - if the mirrors or PV panels are confused with a lake (Kagan et al. 2014). However, studies have been unable to substantiate or refute this potential impact (Lovich & Ennen 2011; Kagan et al. 2014; Walston et al. 2015).

CSP tower plants can attract invertebrates through the solar flux generated around the tower, with insects being burnt when entering the flux. This is thought to also attract insectivorous birds to the facilities, thereby increasing the risk to birds and amplifying mortality rates potentially causing a “mega-trap” around solar towers (Kagan et al. 2014). While solar flux related injuries have not been recorded at ‘trough’ CSP facilities, concentrated solar radiation at the receiving tube could attract invertebrates.

Evaporation ponds can attract animals to solar power sites through the addition of a potentially new habitat/resource, particularly in arid environments (Walston et al. 2015), and in one study 70% of all recorded species were found at the evaporation ponds (McCrary et al. 1986). Evaporation ponds create a water source as well as novel habitat, particularly in arid areas and invertebrates attracted to the evaporation ponds could also attract insectivorous birds (Herbst 2006). Arid environments often contain high levels of endemic species which could exacerbate the bird population impacts (Lovich & Ennen 2011) as restricted ranges could increase the impact of habitat loss and direct mortality. The potential for attraction of bird species to the evaporation ponds to the study site has been highlighted in the Environmental Impact Assessments (EIA) of Bokpoort CSP facility and the adjacent Bokpoort II (Chris van Rooyen Consulting 2010; Arcus Consultancy Services 2016).

However, facilities could provide benefits through increased habitat availability (evaporation ponds and roosting/nesting sites), increased food availability (insects at evaporation ponds), and a drinking source. This has the potential to offset some of the negative impacts of habitat loss. By understanding how bird communities are affected, we can understand the full impact of this type of infrastructure and not just the direct mortality.

This chapter assesses whether the Bokpoort CSP attracts birds and insects onto the facility by comparing bird and invertebrate communities inside the solar field and adjacent rangelands. I test whether the facility affects abundance and composition of bird and invertebrate communities, and whether invertebrate abundances explain changes in the bird community structure/composition at the facility.

Methods

Invertebrate communities

To survey the impact the CSP facility has on invertebrate communities, both pitfall trap and sticky trap surveying techniques were utilized. The traps were set in three sampling areas: 1) the power block (within the first three mirror rows from the power block); 2) the solar field (>100 m from the power block within the mirror rows); and 3) adjacent rangeland with native vegetation (the same location is used for the bird community surveys) (Figure 5). The evaporation pond was not surveyed for invertebrate abundances, and no traps were set within 200 m of the evaporation ponds to avoid the effect of the water body on invertebrate abundance.

Three sampling events were conducted between 4 October and 29 November 2016. In each sampling event, five trapping stations comprising one pitfall and one sticky trap were set in the three sampling areas. The trapping stations were set for 7 days, and all three areas were sampled at the same time to limit environmental factors influencing invertebrate abundance.

The pitfall traps consisted of a 500-ml plastic cups (95-mm diameter) buried with the lip flush with the soil surface. The cup was filled with ~120 ml of solution (1:1) of water and propylene glycol. The sticky traps consisted of a pre-glued white cardboard sheet (280 x 200 mm; Delta trap sticky liner, Insect Science (Pty) Ltd). Each sheet was stapled onto thick cardboard and mounted 120-160 cm above the ground on either an already existing structural pole or on a wooden stake hammered into the ground.

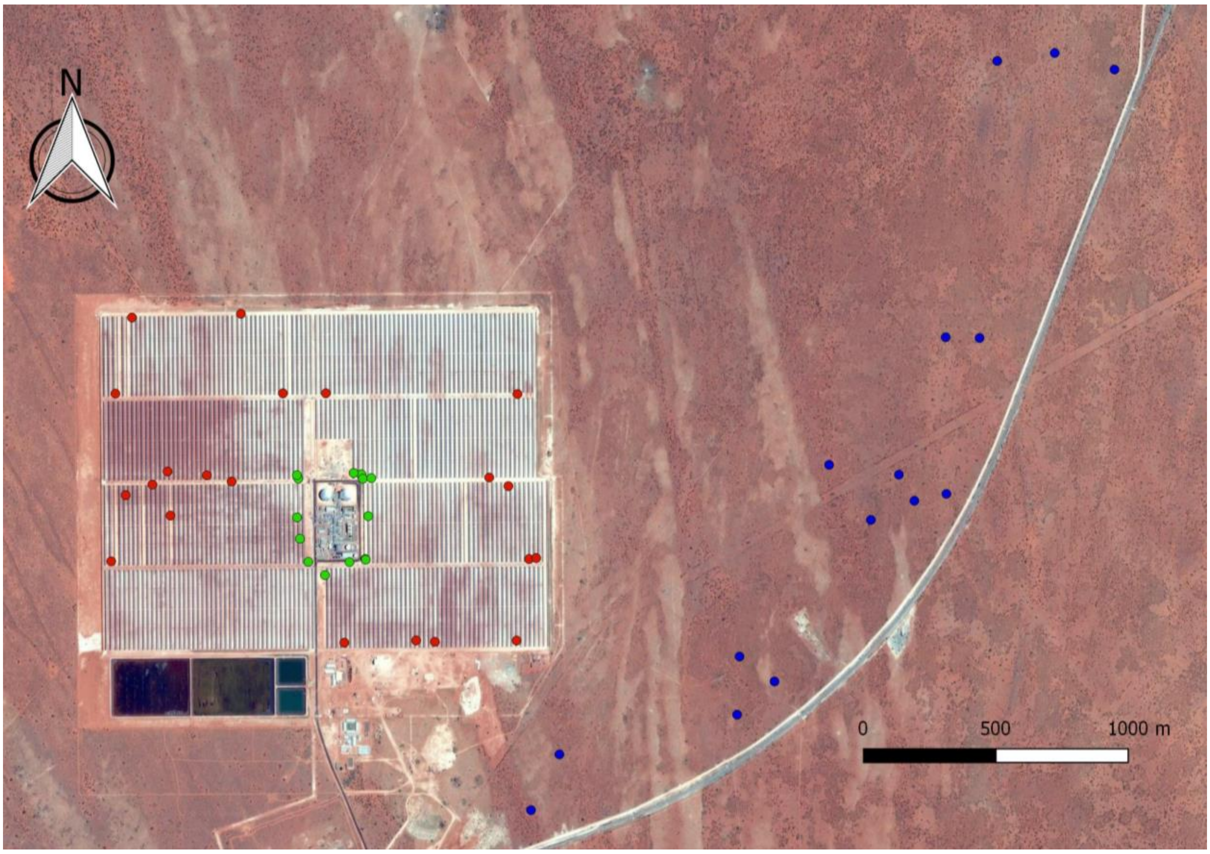

Figure 5: Map of invertebrate trapping stations across three sampling areas at Bokpoort CSP facility (green = powerblock, red = solar field, blue = rangeland. Map data©2017 AfriGIS (Pty) Ltd, Google.

After a week, the pitfall traps were collected and their contents poured into plastic jars and stored in a 70% ethanol solution until identified. The sticky traps were covered with plastic film to protect the samples and prevent more insects from being caught. All samples were sorted and identified under a dissecting microscope to order level. Only macroinvertebrates (>0.5 mm) were identified and counted.

Data analysis

Invertebrate samples were analysed to establish if there were differences in abundances between sample areas. The abundance from both trap types was combined for each order, and Shannon's diversity index, calculated for each sample area. The diversity index was compared using Hutcheson's t-test (Hutcheson 1970) to assess differences between sampling areas.

PRIMER v6. (Clarke 1993) was used to analyse the diversity of each trap site. Abundances were square-root transformed to reduce the impact of dominant orders in similarity calculations. Bray-Curtis similarity calculations were conducted on all sample pairs and used the similarity matrix throughout the analysis. ANOSIM was conducted over 999 permutations with pairwise comparisons of habitat type, as well as similarity comparisons with a Hierarchical Cluster analysis and Non-metric Multi-Dimensional Scaling (NMDS).

Bird Communities:

Species lists were gathered from the Southern African Birds Atlas Project 2 (SABAP2 2017). The study site straddles two quarter degree squares 28°15' S, 21˚45' E and 28˚30'S 22˚00' E (NW corner). The study area at Bokpoort CSP facility also falls into two higher resolution 5'x5' (minute) sampling grids called pentads of 10kmx10km, located at 28˚40' S 21˚55 E and 28˚40' S 22˚00' E (NW corners). Due to the low reporting rate of the 5'x5' girds (one reporting card each), the two lower resolution quarter degree squares (30kmx30km) were used to extract bird species list from the SABAP2 database and represent the broader study area (Appendix 1; Chris van Rooyen Consulting 2010). This species list covers a wide area and possibly many different habitat types, therefore not all species are expected to be found at the study site.

Bird community surveys were conducted from 10 September to 3 December 2016 in both the solar field and adjacent rangelands. The rangeland sampling site was of similar topography, geology and vegetation structure to that of the plant before it was constructed (Chris van Rooyen Consulting 2010) and the 350 ha sampling area supports low densities of cattle and small stock. A total of 44, 500 m transects were conducted in rangeland habitat (Figure 6) utilising Distance sampling (Buckland et al. 2001). Each transect lasted ~ 30 minutes and included stops to 'pish' to detect skulking species in dense cover. Surveys were conducted between 06h00 and 09h30, when the temperature was cooler and birds are more active and easy to detect. Birds were recorded by species, group size, and distance from the transect line in four categories: <50 m, 50-100 m, 100–200 m and >200 m.

Surveys of birds within the solar fields were conducted in conjunction with the carcass clearance checks, with all species seen being recorded in 300 m long transect lines. Due to the restricted field of view caused by the mirrors, most birds were observed at short distances (<50 m), so distance to the bird was not recorded. Surveys were conducted from 06h00–11h00 and 15h00–19h00. Birds entering the solar field from the evaporation ponds were not recorded on the transect data when their presence was deemed to be in response to the researcher.

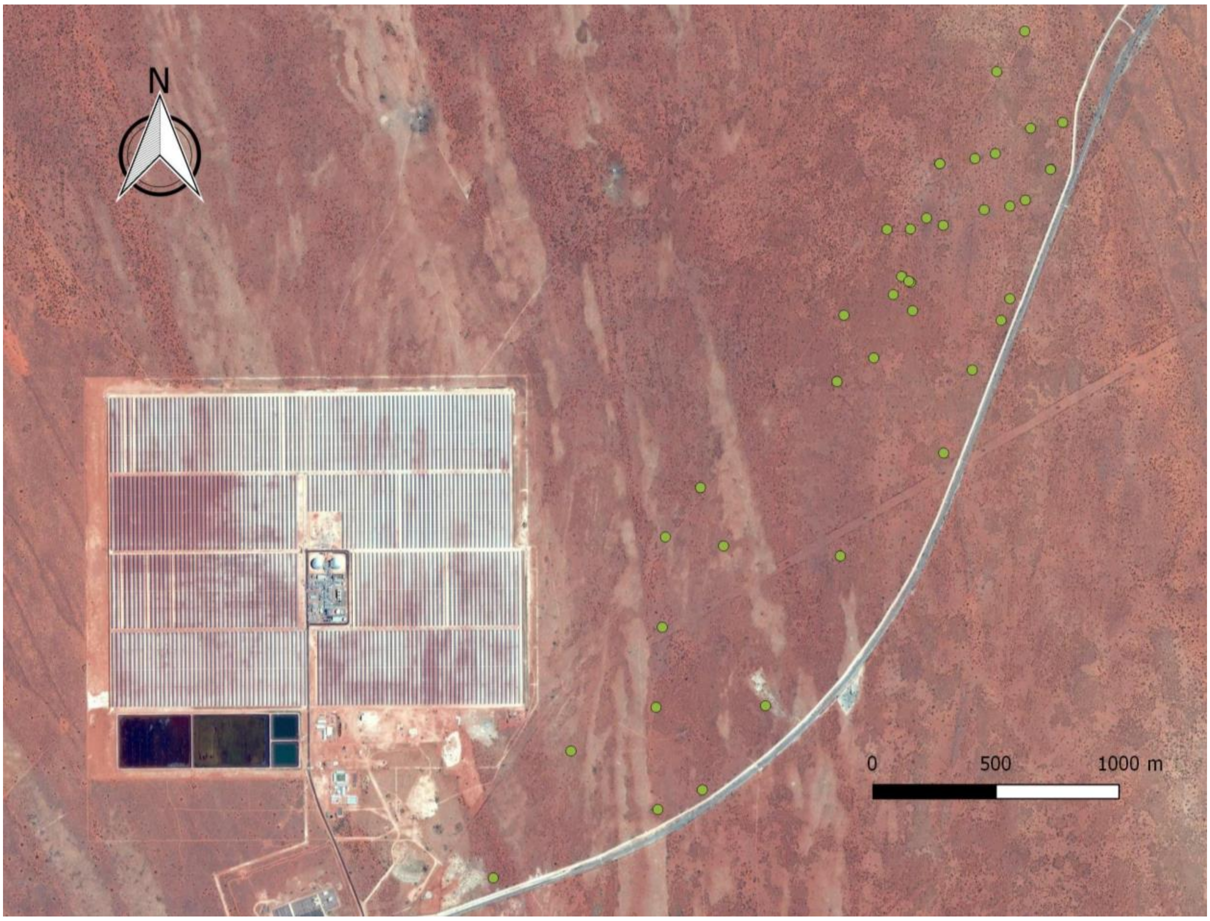

Figure 6: Map of rangeland area and starting point of transects conducted assessing avian communities. Map data©2017 AfriGIS (Pty) Ltd, Google.

Count surveys were also conducted on the birds at the evaporation ponds. The evaporation ponds and holding ponds were surveyed daily for 4 days of the week (Monday–Thursday) in the late afternoon (between 16h00–19h00), however on occasion was more or less frequent depending on weather conditions and other commitments. A total of 53 pond counts were conducted. The all bird species present at the ponds were recorded. The ponds were surveyed with binoculars and the perimeter checked by cycling, walking or driving surveys lasting 30–45 minutes. The two holding ponds and evaporation ponds were sampled as one pond count with species and count recorded.

Data analysis

For comparing bird communities from the solar field and rangeland transects, zero inflated modelling in R 3.3.2 (R Development Core Team 2016) was used to account for the excess of zero counts in the solar field data. For the transect comparison, only birds recorded <50 m from the rangeland transect data were used to make the counts comparable with the limited sighting distances possible in the solar field. This was only for making a comparison of transect data from rangeland and solar field sampling areas in the zero inflate model. Transect distances were logged and offset in the model to account for the different lengths. The model tested the number of birds per transect as well as number of species recorded per transect. A Vuong test was conducted to confirm Zero-inflated test superiority (Z=-4.94, P<0.001).

The bird communities within the adjacent rangelands were analysed for density using the Conventional Distance Sampling (CDS) engine of the programme Distance v7 (Thomas et al. 2010). The data which were collected in bands of <50, 50-100, 100-200, >200 m were imported into the program as midpoint distances of 25 m, 75 m, 150 m, and 300 m as these categories were better accepted by the programme, and were truncated into group-specific maximum detection distances. Eastern Clapper Lark (Mirafra fasciolata) and Pied Crow (Corvus albus) were exceptions with their sampling distances as 75-300 m combined into one interval to deal with difficult-to-model distribution where the majority of detections were at a larger distance. The number of detections per species (mean = 19.8) was generally too low for species-level model fitting, which requires ~ 60 detections (Buckland et al. 2001), so species were combined into groups based on similarity in the distribution of their detection distances. Detections within each group were summed and a common global detection function was fitted. Detection probability, encounter rate, group size, and density were then estimated at the species level using Distance's post-stratification functionality. This allows estimation of rarer species by fitting to pooled data (Buckland et al. 2001) which would normally be excluded due to a low number of observations. Species with < 9 detections were not grouped and excluded from further density analysis (Table 1).

Groups of birds (including groups of 1) were recorded as clusters with separate cluster size. To control for correlation of cluster size with detection distance, a size-bias regression was carried out within Distance, and the resulting correction factor applied to cluster size if this significantly improved model fit ($p = <0.15$). This was the case for Eastern Clapper Lark, Little Swift (*Apus affinis*), Namaqua Dove (*Oena capensis*) and Kalahari Scrub Robin (*Erythropygia paena*). The small number of detection intervals (2-4) did not allow the fitting of more complex models (e.g. hazard rate functions). The best fit for each group was a half-normal detection function without any series expansions, with the exception of group E, which was a half-normal function with one cosine series expansion.

Table 1: Grouping of species by distribution characteristics to pool distance sampling data for analysis in Distance v7. Distance sampling data collected in rangeland adjacent to Bokpoort CSP, Northern Cape, South Africa.

Group ID	Species	Distribution Characteristics	Number of detections
A	Eastern Clapper Lark	Most frequently recorded >200 m (displaying/flying)	40
	Pied Crow		13
B	Black-chested Prinia	High frequency at <50 m, medium 50-100 m low 100-200 m, Little or no observations >200 m	59
	Fawn-coloured Lark		169
	Little Swift		24
	Namaqua Dove		66
	Sociable Weaver		69
C	Chestnut-vented Tit-babbler	High frequency at <50 m, low 50-100 m, no observations >100 m	19
	Dusky Sunbird		18
	Fiscal Shrike		10
	Lark-like Bunting		26
	Rock Martin		10
	Rufous-eared Warbler		15
	Scaly-feathered Finch		106
	White-browed Sparrow-weaver		9
	Yellow-bellied Eromomela		10
	Yellow Canary		45
D	Ant-eating Chat	Linear frequency: high <50 m, medium 50-100 m, low 100-200 m, very few >200 m	17
	Kalahari Scrub-robin		31
E	Cape Turtle Dove	High frequency <50 m, low 50-200 m, medium >200 m	15
	Namaqua Sandgrouse		61

Results:

Invertebrate communities

The combined trapping yielded an overall catch of 10,257 invertebrates: 4,674 for the power block, 2,925 for solar field, and 2,658 in adjacent rangelands (Appendix 2). While abundance was greater in the CSP facility (power block and solar field) than the rangeland, taxonomic richness was greatest in the rangeland with 20 Orders recorded compared to 15 for the powerblock and 14 for the solar field. The order Araneae was unique as it was in greatest abundace in the rangeland (n=56) and lowest in the power block (n=7) against the general trend of other invertebrate abundances. Two orders were only recorded in the rangeland sampling area - Phasmatodea and Pseudoscorpiones - and no orders were unique to either the solar field or power block sampling areas. Orders recorded in the power block and solar field are a subset of the rangelands orders. Order evenness was greatest in the solar field (J'=0.557) compared to rangeland (J'=0.471) and power block (J'=0.470) (Table 2). Shannon's diversity index of the power block was significantly lower than the solar field (Hutchenson's T = 7.79 df = 6562 p = < 0.001) and rangeland (T = 5.08 df = 6582 p = < 0.001), and the solar field was slightly more diverse than the rangelands (T = 2.03 df = 5430 p = 0.04) (Figure 7). The solar field sampling area has the greatest level of diversity and eveness of all sampling areas, but the lowest richness.

Table 2: Invertebrate trapping results by sampling area at Bokpoort CSP, Northern Cape, South Africa. Results comprise; total catch (total abundance), Order richness, Shannon's diversity index (H') with 95% confidence intervals (CI), natural log of richness (H_{max}) and Order evenness (J')

	Power block	**Solar field**	**Rangeland**
Total	4674	2925	2657
Order richness	15	14	20
H'	1.272	1.470	1.411
95% CI	0.033	0.039	0.044
H_{max}	2.708	2.639	2.996
J'	0.470	0.557	0.471

The ANOSIM found a significant difference between all sampling areas (R=0.166 p=0.001), with pairwise comparisons showing rangelands and the power block to have the highest degree of difference (R=0.238 p=0.001), the lowest difference between the power block and solar field (R=0.99 p=0.03), and intermediate differences between rangelands and the solar field (R=0.166 p=0.001). The cluster analysis showed considerable overlap among habitats, with two minor groupings with ~75% similarity, whereas the NMDS showed no distinct groupings by sampling area (Figure 8).

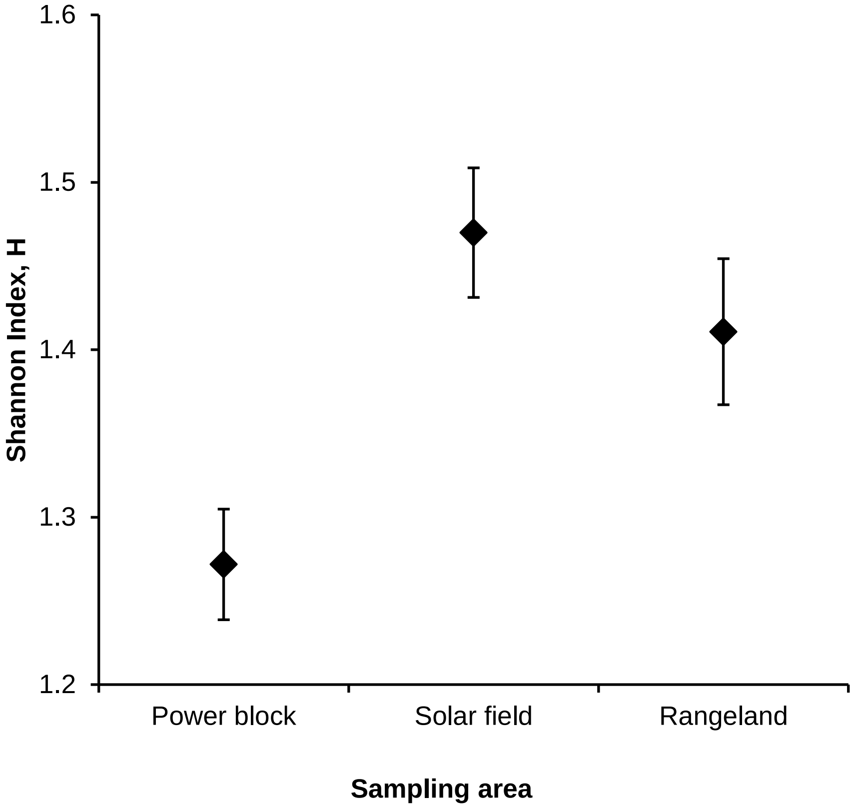

Figure 7: Hutcheson's T-test results comparing Shannon's diversity index on compiled invertebrate trap data per sample area, Power block (H'=1.27) Solar field (H'=1.47) and Rangeland (H'=1.41) error bars represent 95% confidence intervals. Sample areas located at Bokpoort CSP facility, Northern Cape, South Africa

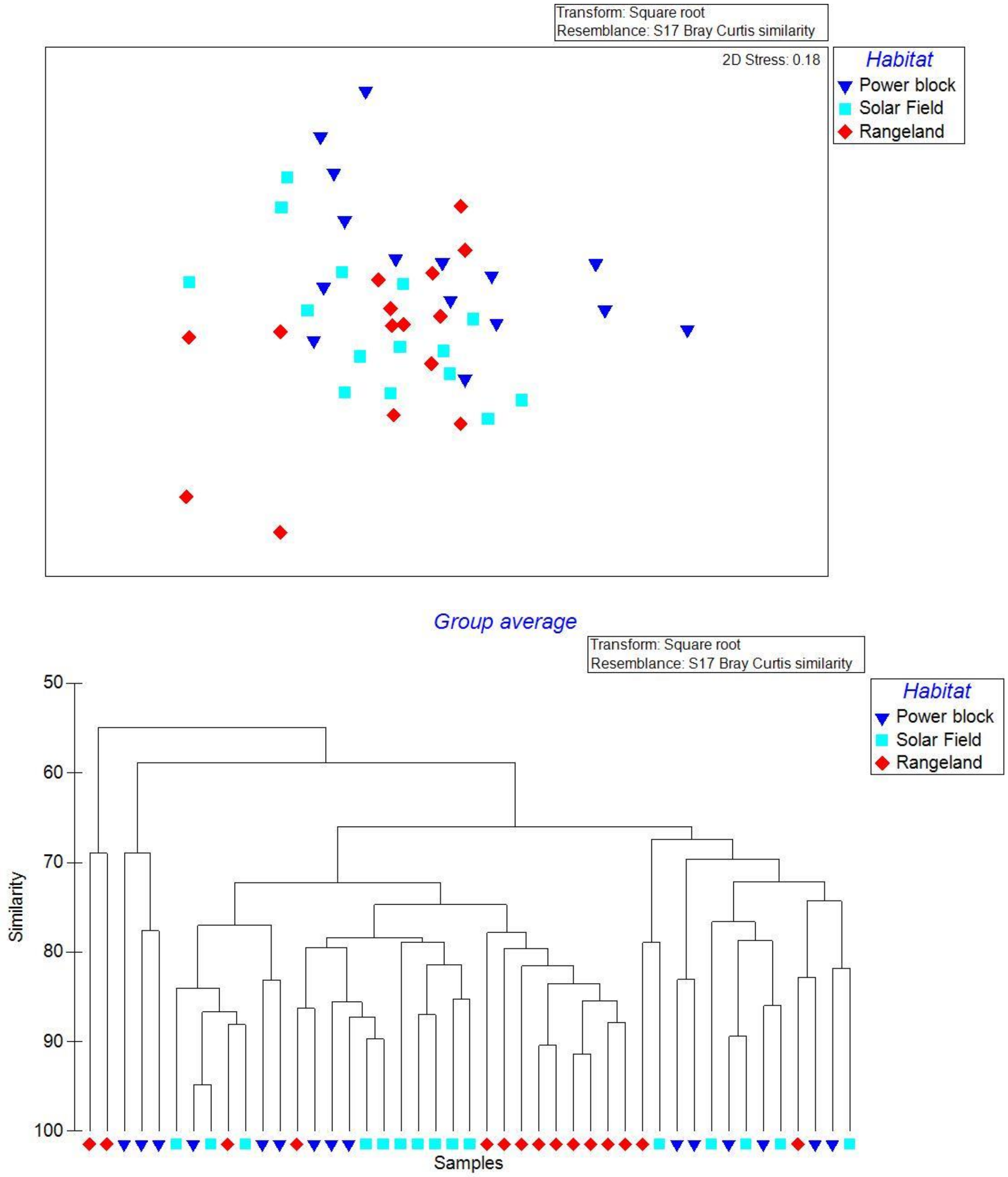

Figure 8: Cluster analysis and Non-metric Multi-dimensional Scaling (NMDS) of invertebrate traps across three habitat types of invertebrate traps across three sample areas (habitat) at Bokpoort CSP facility

Bird communities

In total, 81 bird species were recorded during the study (Appendix 3). Only one threatened species was recorded, the Kori Bustard *Ardeotis kori* (near threatened; BirdLife International 2016) but 15 species were endemic or near-endemic to Southern Africa.

The evaporation pond counts yielded 3,722 birds from 38 species, a mean of 70.23 ±16.51 SD birds per pond count over 53 pond counts (Table 3) and 24 species were only recorded at the ponds (Appendix 4). No species utilising the evaporation ponds were recorded within the solar fields, with the exception of Blacksmith Lapwings *Vanellus armatus*. Water birds were observed arriving and departing form evaporation ponds, but rarely flew over the solar fields.

Table 3: Summary of data collected from bird counts conducted at Bokpoort CSP facility, Northern Cape, South Africa

	Solar field	**Rangeland**	**Pond**
Species Number	22	45	38
Birds.km^{-1}	1.27	141.86/110*	70.23**
Unique species	2	33	24

*Only <50 m records **birds per pond count

A total of 1980 transects covering 594 km over ~ 230 hours were conducted in the solar field, recording 748 birds from 22 species. Of these, only six species were recorded on more than five occasions (Table 4): one insectivore (Familiar Chat *Cercomela familiaris*), three omnivores (Cape Sparrow *Passer melanurus*, Fawn-coloured Lark *Calendulauda africanoides*, Sociable Weaver *Philetairus socius*), one granivore (Namaqua Dove) and one raptor (Western Barn Owl *Tyto alba*) (Hockey et al. 2005). There was a mean of 0.38±2.18 SD birds per 300 m transect with 1.27 birds per km. Three species were only recorded from the solar field, House Sparrows *Passer domesticus*, Mountain Wheatear *Oenanthe monticola* and Western Barn Owls. However, House Sparrows also occurred at the accommodation and office facility next to the solar field. The rangeland transects yielded 3,121 birds from 45 species over 44 transects, with a mean of 70.93 ±6.36 SD birds per 500 m transect with 141.86 birds per km, or 110 birds per km with all records above 50 m discarded to compare rangeland and the solar field linear abundance.

Table 4: The total number of birds, mean group size and total number of records for each species recorded within the solar field transects conducted at Bokpoort CSP facility, Northern Cape, South Africa.

Species		**Total count**	**Mean group size**	**No. of records**
Familiar Chat	*Cercomela familiaris*	71	1.45	49
Cape Sparrow	*Passer melanurus*	213	4.53	47
Western Barn Owl	*Tyto alba*	63	1.50	42
Fawn-coloured Lark	*Calendulauda africanoides*	37	1.16	32
Sociable Weaver	*Philetairus socius*	197	19.70	10
Namaqua Dove	*Oena capensis*	10	1.25	8
Red-headed Finch	*Amadina erythrocephala*	20	4.00	5
Rufous-eared Warbler	*Malcorus pectoralis*	13	2.60	5
Cape Wagtail	*Motacilla capensis*	8	2.00	4
Mountain Wheatear	*Myrmecocichla monticola*	5	1.25	4
Speckled Pigeon	*Columba guinea*	7	1.75	4
Cape/house Sparrow	*Passer melanurus/ domesticus*	66	22.00	3
Lark-like Bunting	*Emberiza impetuani*	9	3.00	3
Spike-heeled Lark	*Chersomanes albofasciata*	7	2.33	3
Blacksmith Lapwing	*Vanellus armatus*	5	2.50	2
Pied Crow	*Corvus albus*	2	1.00	2
Rock Martin	*Hirundo fuligula*	3	1.50	2
Yellow Canary	*Crithagra flaviventris*	7	3.50	2
Black-chested Prinia	*Prinia flavicans*	1	1.00	1
Cape Turtle Dove	*Streptopelia capicola*	1	1.00	1
Little Swift	*Apus affinis*	2	2.00	1
Red-eyed Bulbul	*Pycnonotus nigricans*	1	1.00	1
Total		**748**	**3.73**	**231**

Thirty four species were only found in the rangeland sampling area (Appendix 5). Density estimates of bird species show the species with the highest densities are Scaly-feathered Finch *Sporopipes squamifrons* (6.96/ha), Sociable Weaver *Philetairus socius* (6.09/ha), Yellow Canary *Crithagra flaviventris* (2.17/ha), Lark-like Bunting *Emberiza impetuani* (1.42/ha) and Fawn-coloured Lark *Calendulauda africanoides* (1.22/ha). All other species were below one individual per hectare (Appendix 6).

Several species were recorded utilizing the solar fields as either roosting or nesting sites with Cape Sparrows, Red-headed Finches *Amadina erythrocephala* nesting in the pipes supporting the mirror arrays and Familiar Chats and Rock Martins *Hirundo fuligula* nesting around buildings and the power block. A large number of Western Barn Owls were roosting in the pipes supporting the mirrors with as many as 15 owls recorded over two rows, and owl egg remains found near one roost site. Sixty three owls were recorded in the solar field, but numbers declined over the duration of the study with 30 owls recorded in September, 19 in October, and 14 in November. Owls were often flushed from roost sites by passing vehicles or pedestrians, with flushed owls making up the majority of records. One owl was observed heavily impacting with the mirrors after being flushed, but sustained no obvious injury or flight impairment. Some other owls flushed, experienced low speed mirror grazes with wings when returning to roost, and evidence on mirrors (smudges) indicates this is a common occurrence. The evaporation ponds also supported breeding pairs of South African Shelduck *Tadorna cana*, Egyptian Geese *Alopochen aegyptiacus*, and Blacksmith Lapwings, with 12 shelducks fledging during the survey period.

The solar field transects had a significantly lower abundance (Z=-64.68, P=<0.001) and lower species richness (Z=-16.94, P=<0.001) of birds than the rangeland sampling area. Species composition is distinct across sampling areas, with only eight species being recorded in all of the sampling areas. The solar field is mostly a subset of the rangeland area, with 15 of the 22 species from the solar field also detected in the rangeland transects (Appendix 3). The limited viewing distance (~50m) within the solar field (due to the mirrors) may have had a minor impact on richness. Four species (Hadeda Ibis *Bostrychia hagedash,* Karoo Scrub Robin *Erythropygia coryphoeus,* Pale Chanting Goshawk *Melierax canorus,* and Northern Black Korhaan *Afrotis afraoides*) recorded only at >50m within the rangelands, which would not be seen at these distances within the solar field. The evaporation ponds had 23 species (from a total of 34 recorded species) unique to that habitat. The majority of these were waterbirds, indicating that it provides novel habitat supporting species which would otherwise be absent from the area.

Invertebrate abundances were higher within the CSP facility, with power block having the highest abundance and the solar field sampling area contained the highest diversity indices scores for invertebrates (Table 2). However, this does not correspond with bird abundances, with only two insectivorous birds (Familiar Chat *Cercomela familiaris*, Fawn-coloured Lark *Calendulauda africanoides*) being recorded on more than five occasions (Table 4). This indicates that bird abundance within the facility is not related to invertebrate abundance.

Discussion

Previous reports have found that bird abundance and diversity is lower in solar fields than in adjacent land-use types, particularly with mirror arrays in CSP tower facilities (Kagan et al. 2014). My findings are consistent with these observations, with a significant reduction in both the abundance and diversity of birds within the solar fields compared to the rangeland landscape. Only a few species were recorded more often in the solar fields than in adjacent rangelands (Cape Sparrow, House sparrow, Familiar Chat and Western Barn Owl). These species roost or nest in or around buildings and in human settlements and adapt well to anthropogenic disturbance (Hockey et al. 2005).

Western Barn Owls were recorded in unusually high density within the solar field, and were not recorded in the rangeland area where there are no suitable roost sites. The owls roost in the ‘torque tubes’ that support the parabolic mirrors. The torque tubes have small openings at either end, which the owls use to access the tube (Figure 9) even though the tubes rotate constantly throughout the day. The lack of hollow trees or other natural cavities in the surrounding habitat is likely to be the reason for the uptake of roosting in the torque tubes. However, over the 3-month study period, there was an apparent decline in the number of owls flushed from torque tubes while conducting mortality searches. This could be due to either the rising temperatures in November and December or due to reductions in rodent numbers. On arrival to the site in August, many shrubs were flowering linked to unseasonal rainfall, which could have caused a population boom in rodents. As the weather shifted into the hotter seasons the rodent numbers may have declined and the owls moved on to other areas.

Figure 9: A Western Barn Owl roosting in a ‘torque tube’ at Bokpoort CSP facility, Northern Cape, South Africa. Photo Credit Corey Jeal

The vegetation in the solar fields is limited to control fire risk, resulting in sparse vegetation cover. These changes in the landscape and associated infrastructure and disturbance could explain the low bird numbers in the solar fields. The rangeland sampling area had a significantly larger bird abundance and diversity, however, two of the most common species recorded (Sociable Weaver and Namaqua Sandgrouse) were likely only present in such large numbers due to manmade influences. The construction of transmission lines has provided nesting platforms for sociable weavers, with nearly all of the transmission towers supporting one or more sociable weaver nests (Figure 10). The presence of a water trough for cattle and sheep in the rangeland sampling area may have led to disproportionately large numbers of Namaqua Sandgrouse being recorded as they flew overhead to drink in mid-morning (Hockey et al. 2005).

Figure 10: Sociable weaver nests on a transmission line tower, Northern Cape, South Africa. Photo credit Corey Jeal

There were substantial differences between the solar field and rangeland bird communities. The solar field species are mostly a subset of the rangeland species, with a few exceptions which are species adaptable to man-made environments (Appendix 3). The abundance of birds in the solar fields was very low compared to the rangeland, supporting concerns related to habitat loss, as few birds are utilising the solar field.

Photovoltaic and to a lesser degree tower CSP facilities have a reduced fire risk compared to ‘trough’ CSP facilities, as there is no flammable HTF fluid used in the mirror/collector fields (Lovich & Ennen 2011). Fire in CSP facilities has the potential to cause severe damage should the HTF ignite and in response ‘trough’ facilities typically have stricter vegetation management requirements to manage that risk. This reduces the available habitat, potentially reducing bird numbers within the facility. If we compare bird surveys from Jasper photovoltaic facility (~150 km from Bokpoort CSP) there was no significant difference in bird density and diversity between the solar collectors and the adjacent rangeland (Visser 2016). However, my study while not calculating density in the solar fields has shown distinct differences amongst bird community abundance and diversity in the solar fields and the rangeland land. These differences are likely attributed to the habitat availability (or lack thereof) within the two sites due to the different vegetation management practices. It is reasonable to assume that lower bird numbers utilising the facility would equate to a lower risk of collision.

Evaporation Ponds

The construction of evaporation and holding ponds on the site has created a novel wetland habitat at a local landscape level and created a semi-functional wetland. The ponds support an array of invertebrates (including dragonfly nymphs). With 24 bird species recorded only at the ponds, they provide a substantial contribution to overall birds' use of the facility. The birds successfully nesting around the evaporation ponds and the large amount of unique species (24) indicate that the evaporation pond is acting as novel habitat. The 12 Shelducks fully fledging during the study indicate there may be positive impacts from the evaporation ponds. However, three Blacksmith Lapwing chicks, which likely hatched in the area surrounding the evaporation ponds, were recorded as pond mortalities. These chicks likely slipped into the water and drowned. Wader species (like the Blacksmith Lapwing) may be attracted to the evaporation pond habitat and could have unnaturally high chick mortality due to drowning, in which case the ponds would act as an ecological trap/sink for those species. Very few species utilising the evaporation ponds were seen within or flying over the solar fields, but many water birds travel at night. The species observed arriving and departing from the ponds in late afternoon, did not fly over the solar fields. This could be because they actively avoided the solar field, or could simply be a consequence of the fact that the closest wetland (the Orange River) was in the opposite direction to the solar fields. Further investigation is needed to investigate if the birds are actively avoiding flying over the solar field, which would lend no support to the 'lake effect' hypothesis.

Invertebrate communities

The CSP facility had a less distinct impact on invertebrate communities than bird communities. There was an increase in invertebrate abundance from the rangelands, through the solar field to the power block, but an inverse relationship in taxonomic richness. Insects that are adapted to disturbance are known to increase exponentially in response to disturbance (Schowalter 1985), which can lead to high abundances of a few insect species (Seymour & Dean 1999). This is consistent with invertebrate assemblages in degraded habitats in other parts of the Karoo where abundance increases but diversity decreases in areas subject to heavy grazing (Seymour & Dean 1999). The intensive vegetation management in the solar field is comparable to overgrazing by livestock. The heavily grazed area studied by Seymour and Dean (1999) also had a lower diversity and abundance of bird (Joubert & Ryan 1999). These two studies provide insight into the effect vegetation degradation can have on both invertebrate and bird communities, and could explain the changes in invertebrate and bird communities seen at Bokpoort CSP facility with vegetation changes. However this does not take into account the provisioning of roosting and nesting sites associated with infrastructure.

The invertebrate community data can be used to assess any potential attractive effect this facility may have on invertebrates. As reported by Kagan et al. (2014) flying insects were attracted to the receiver tower, however when the sticky trap abundance data is examined (Table 2) we see minimal differences between the solar field (1143 invertebrates) and adjacent rangelands (1127 invertebrates). The power block had the lowest abundance of flying invertebrates (790) in spite of the substantial amount of lighting in this area. However the traps were set in the field 20-50 m from the power block, which may have limited the lighting effect. These data suggest that flying insects are not attracted into the solar fields from the surrounding area.

The low number of birds present in the solar fields compared to the rangeland area would also suggest a minimal level of attraction of birds into the solar fields. Kagan et al. (2014) suggest that this attraction to the receiver tower and the corresponding solar flux could cause an ecological trap/sink. However, my study shows no evidence of any birds being injured or killed by concentrated solar radiation or an attraction of either flying invertebrates or birds (with the exception of Barn Owls) into the solar fields.

Chapter 2: Estimating bird mortality at a CSP trough facility

Introduction

The environmental benefits of clean renewable energy relative to burning fossil fuels are well known (Haddad & Dones 1991; Lynas 2014; McCombie & Jefferson 2016), but there is potential for negative effects of solar energy facility development. Studies into avian mortality associated with CSP plants are limited with little knowledge on the potential impacts and their magnitude (Walston et al. 2016). The type of CSP technology used (tower or trough), as well as the size and location of the facility, influences the magnitude and nature of the impact to bird communities and populations (Hernandez et al. 2014; Walston et al. 2016).

The available literature identified two known causes of bird mortalities specific to solar facilities: (McCrary et al. 1986; Kagan et al. 2014; Smith & Dwyer 2016):

- Collision-related mortality results when birds strike a part of the solar infrastructure (e.g. mirrors and support structures.). Mortality can be instantaneous (direct cause) or resulting injury can reduce flying ability, foraging ability or predator avoidance, leading to death (indirect cause). The reflective surfaces of mirrors utilised at CSP facilities have the potential to be a source of mortality, comparable to high-rise buildings (Loss et al. 2014).
- Solar flux/burn mortality results when birds are exposed to extreme temperatures caused by the concentration of solar radiation know as solar flux (Kagan et al. 2014). When a bird passes through the solar flux, it can be killed directly or indirectly, by damaging (singeing) the bird's feathers, causing the bird to collide with infrastructure

or the ground, or reducing foraging, flying or predator avoidance ability. This type of impact has only been recorded at power tower facilities where the solar flux can reach temperatures of up to 400ºC (McCrary et al. 1986; Kagan et al. 2014; Walston et al. 2016).

While not specific to solar, habitat loss due to the construction of these types of facilities does have an impact on birds with both direct and indirect mortality. The facilities footprint of 200ha is quite large but from a regional perspective (Northern Cape) the impact is minor, however, the cumulative impact of habitat loss with multiple facilities needs to be considered, particularly as this is a growing technology.

Previous studies

Most studies assessing the impact of CSP facilities on birds were on power tower facilities, with only one study assessing mortality at a 'trough' CSP plant (Genesis) in California, USA (Kagan et al. 2014; Ho 2016). Most recorded mortalities have resulted from collision impacts: at Solar One (10 MW Tower CSP facility), 81% of mortalities were collision related (McCrary et al. 1986). Among mortalities, where the cause of death was confirmed, Kagan et al. (2014) found that 31% of bird deaths at Ivanpah Solar Electric Generating Systems (ISEGS, 390 MW Tower CSP facility) and 75% at Genesis (250 MW trough CSP facility) were from collision with infrastructure (mostly associated with mirror arrays). However, the mortalities in the Kagan et al. (2014) study were recorded opportunistically without a predetermined sampling schedule or protocol and did not correct for factors such as searcher bias or carcass persistence. During the study period, Kagan et al. (2014) found 233 avian mortalities: 141 at the Ivanpah Tower CSP, 31 at the Genesis Trough CSP and 61 at the Desert Sun PV site. The Ivanpah CSP was subsequently systematically surveyed over one year from October 2013 – October 2014 which resulted in a further 703 mortalities (H.T. Harvey and Associates 2015).

The McCrary et al. (1986) study on the 10 MW Solar One project is the only study on the impacts of a CSP facility published in the primary literature at the time of writing. This study, conducted over 40 weeks, recorded 70 bird mortalities of 26 species with a scavenger removal of 10-30%, raising the mean mortality rate from 1.7 birds per week (± 1.8 SD) to 1.9 – 2.2 birds per week. With only one published study for CSP towers and only incidental evidence for ‘trough’ facilities, there is a strong need to investigate the potential impacts of these types of facilities.

Walston et al. (2015) conducted a review of avian mortality at utility-scale solar facilities, with the mortalties of seven facilties being summarised. Systematic studies of mortatlties were conducted at four of the facilties, two at CSP facilities; (Kagan et al. (2014) McCrary et al. (1986)) and two at PV facilities. Incidental faltatlities at CSP facilities recorded in the Walston et al. (2015) review inlcude 14 fatalities at Mohave solar (trough CSP) and 183 at Genisis (trough CSP) (Table 5).

Other documented evidence of bird mortality at CSP facilities include:

- Crescent Dunes Solar Energy Project (110 MW power tower, Nevada, USA): incidental evidence of 115 bird deaths (attributed to solar flux), as reported by SolarReserve (the plant operators) (Kraemer 2015).
- Gemasolar (20 MW power tower, Spain): no fatalities or injuries reported during a 14-month study (California Energy Commission 2012). This study did not stipulate exact methods of survey or if bias were corrected.

- Demonstration power tower facility (near Dimona, Israel): systematic study reporting three mortalities (unknown facility power output and study length), bias corrections were not applied (Labinger 2012).

Table 5: Summary of Avian mortality at utility-scale solar facilities adapted from Walston et al. (2015) with replicated studies omitted.

Project Name	Technology	Survey period	Incidental fatalities	Systematic fatalities (unadjusted)
Mohave Solar	CSP trough	Aug. 2013 - Mar. 2014	14	-
California Valley Solar Ranch	PV	16 Aug. 2012 – 15 Aug. 2013	NA	368*
Desert Sunlight	PV	12 Sept. 2011 – 4 Mar. 2014	154	-
Genesis	CSP trough	Jan. 2012 - May 2014	183	-
Topaz Solar Farm	PV	1 Jan. 2013 - 16 Jan. 2014	19	41

*Includes fatalities from all known and unknown causes including background control plots, fence lines, generation tie-line, medium voltage lines, and arrays.

Evaporation ponds at solar power facilities have been identified as a food and drinking source for birds but also an area of potential impact by being a source of toxicity (Herbst 2006; Lovich & Ennen 2011). Selenium has been identified in solar facility evaporation ponds (Herbst 2006), and has been linked to high egg mortalities and birth defects in birds utilising evaporation ponds (Tanji et al. 2002; Marn 2003). Evaporation ponds with high salinity can also affect birds potentially adversely, affecting survival (Euliss et al. 1989).

Mortality detection is subject to a number of biases; not all carcasses are equally detectable and scavengers can remove carcasses before detection. Searcher efficiency trials determine the likelihood of a bird carcass being detected, this depends on factors such as searcher experience, vegetation type, carcass size and species (Schutgens et al. 2014; Huso et al. 2016). Carcass persistence trials assess the number of carcasses scavengers remove, and length of time the carcass persist, with size and carcass type affecting carcass removal rates (Costantini et al. 2016). When assessing mortality rates, it is important to account for these imperfect detectability biases in searcher efficiency and carcass persistence and adjust the mortality estimates accordingly, to establish accurate details on the impacts to bird populations (Smallwood 2007; Sovacool 2009; Ponce et al. 2010; Huso 2011; Schutgens et al. 2014; Huso et al. 2016; Walston et al. 2016; Costantini et al. 2016).

This chapter assesses the impact of Bokpoort CSP facility by quantifying the mortalities associated with the facility. It accounts for carcass detection and persistence biases through the use of searcher efficiency and carcass persistence trials and quantifies the overall risk of mortality to birds.

Methods

Collision mortality in the solar field

The study site was surveyed for bird fatalities by an observer walking adjacent to the mirrors to detect any injured birds or carcasses. The solar field is divided into eight sub-fields, each comprising 40 – 50 rows of mirrors (Figure 11). The facility was surveyed for injured or dead birds over 3 months (10 September – 1 December 2016). All bird carcasses found were identified to species (where possible), photographed, estimated time of death, the location recorded, and a search for collision evidence (e.g. mirror smudges or impact sites) conducted. Carcasses were removed to avoid double counts and (if fresh) were frozen for later examination. Carcass age was determined by the presence of soft flesh remaining and fresh feathers.

The entire solar field (360 mirror rows) was surveyed at the start (September 10 - 26) and end of the study (16 November to 1 December). 50% of the entire solar field (180 rows) was searched twice over the study period in October and November. Every second row was surveyed with odd numbered rows being surveyed in even numbered sub-fields and vice versa. This search was conducted over 4 weeks, with an interval of 4 weeks between each row being checked twice. Searches began at sub-field 1 covering subfields in chronological order, finishing in subfield 8 (Figure 11).

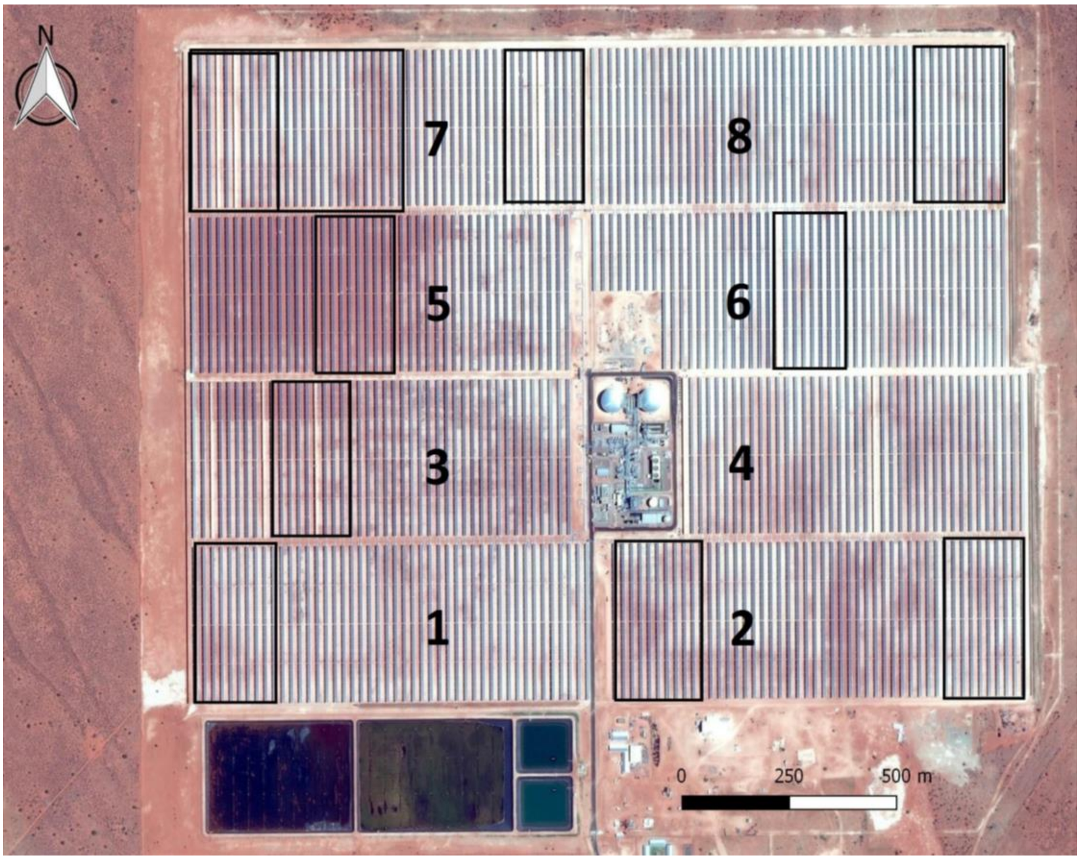

Figure 11: Map of daily bird mortality search areas at Bokpoort CSP facility solar field (with numbered sub-fields), Northern Cape, South Africa. Black polygons indicate where daily checks were conducted over a six day period. Map data©2017 AfriGIS (Pty) Ltd, Google.

A small group of select rows (~9% of total rows) were checked daily over a 6-day period. These daily checks were conducted during October (5-10, 20-25) and November (2-7, 14-19) covering 30-32 rows from 06h00 – 11h00, with four replicates (Figure 11). The checks covered a total of 125 rows representing 35% of all rows. Rows utilised in the daily checks were surveyed in groups of 10 – 11 rows evenly spread across the facility, with the exception of one group of 30 rows in an area of high bird activity which overlapped a previously searched area.

Mortality associated with evaporation ponds

The evaporation and holding ponds were surveyed for mortality in conjunction with conducting pond bird counts, utilising the same methods as evaporation pond counts in Chapter 1. Mortalities were checked for by cycling, walking or driving and when possible, carcasses were removed from ponds to avoid double counts.

Searcher efficiency trials

Searcher efficiency trials to assess the probability of a searcher finding bird carcasses were conducted on 11 September 2017, with four searchers used. Each researcher placed 18 bird carcasses, which were searched for by the other three observers (54 possible detections per trial, and 4 trials, each in a different location, giving a total of 216 possible detections). Carcasses were divided into three size classes: nine small birds (<100 g), six medium-sized birds (100–1000 g) and three large birds (>1000 g). Frozen whole carcasses were used as it was not expected that collisions with plant infrastructure would cause dismemberment. To ensure a degree of ‘natural’ placement, carcasses were tossed in a variety of areas and levels of vegetation cover representative of the entire solar field mirror arrays. The carcasses were placed by one person under 10 rows of solar collectors (~3 km). The three searchers then independently conducted carcass searches within these rows, attempting to match their search effort (walking speed and areas visually checked) to that implemented during a normal solar field check. The species found were identified and their location recorded to distinguish each carcass found and to eliminate the possibility of additional carcasses being identified. The efficiency trials were only conducted within the solar fields as this is where most mortalities were expected, and where most carcass searches were conducted. The probability of carcasses being found during the trials was determined for each size class, calculated by the number of carcasses found over the total number of carcasses placed for all searchers.

Carcass persistence trials

Carcass persistence refers to the length of time a carcass remains detectable to a searcher in the field, this is affected by decomposition as well as removal by scavengers. Previous studies have found that larger birds last longer and are easier to detect compared to smaller birds (Ponce et al. 2010). Carcass persistence depends on many factors such as habitat, climate, predator/scavenger communities, carcass size and species (Smallwood 2007, 2013; Urquhart et al. 2015; Costantini et al. 2016; Farfán et al. 2017). Season also can affect scavenger biases in the Karoo (Shaw et al. 2015). Other studies on carcass persistence within the Karoo biome indicated high carcass persistence rates of large carcasses (>1000 g) of 84% over a 90 day period in Schutgens et al. (2014) and 80% over 7-16 days in Shaw et al. (2015), which may result from predator control efforts by livestock farmers (Blaum et al. 2009) reducing the abundance of scavenging mammals such as jackals.

Carcass persistence trials were conducted to determine the probability of a carcass persisting between search intervals in the solar field. Trials were conducted from 7 September to 5 December to determine the probability of carcasses of different size classes being removed by scavengers over 28-days. A total of 34 bird carcasses were used: nine small (<100 g), 16 medium (100–1000 g) and nine large carcasses (>1000 g). Carcasses used in the searcher efficiency trials were reused for the persistence trial, where the carcass condition was acceptable. The carcasses used were from fresh roadkill (intact), collisions with infrastructure (e.g. windows), birds found dead in other ornithological studies, or fresh carcasses from the evaporation pond. Carcasses were frozen from a fresh state and consisted of species of which some were found locally and others not (Appendix 7). Although some bird carcasses were from different environments (e.g. seabirds) which can affect carcass removal (Ponce et al. 2010), they resemble (size, weight, and colouration) wader species found at the site. Carcasses were placed periodically in the solar fields over the 3-month period and monitored for 28 days. They were evenly distributed across the solar fields to eliminate effects of natural edges, human disturbance, and vegetation changes. Carcasses were minimally handled and transported in plastic bags to avoid scent contamination which could be used as cues by predators/scavengers (Whelan et al. 1994). The carcasses were placed within the solar fields in locations which would represent a mirror collision. Nine carcasses were monitored with Ltl-5310 ACORN motion-triggered scouting cameras to identify predators removing carcasses. Carcasses were checked daily for at least the first 6 days after placement, every second day until day 14, and then at day 21 and 28. When visited the carcasses were classified as:

- Intact: whole carcass, undamaged with the exception of invertebrate activity;
- Scavenged: carcass remained but partly dismembered (flesh or feathers removed);
- Feather spot: carcass removed but sufficient feathers remain to identify the presence of a carcass;
- Removed: no considerable evidence of a carcass being present.

Carcasses which were found during mortality searches and were determined as being moved by scavengers >50 m were classified as being removed, as the potential for carcasses to fall outside the search area would affect trial results. The probability of a carcass's daily 'survival' was estimated using the Mayfield's approach (1975), in which number of carcass removals is divided by 'at risk days' to calculate the daily removal probability. This was extrapolated to give the probability of carcasses of each size class surviving for 28 days.

Results

Bird mortality in solar field

Eight bird carcasses from at least three species were discovered within the solar fields (Table 6), but all were aged as having died outside the 3-month monitoring period. Five carcasses were discovered during the initial clearance search, and only one (Cape Turtle Dove *Streptopelia capicola*) was recent (dead ≤ 1 week). The cause of death probably was trauma caused by collision with a mirror. Three additional old carcasses were found during subsequent searches, having been overlooked among vegetation during the initial clearance. Western Barn Owls (*Tyto alba*) made up half of the mortalities recorded during the searches and were present in high numbers in the solar field (n=63). Owls were regularly flushed from the torque tubes when conducting carcass searchers and on occasion were observed colliding with mirrors after being flush and on attempting to return to roost in the tubes, with no noticeable negative effect on the owls.

Table 6: Summary of bird fatalities and unidentified remains detected at the CSP site in Northern Cape, South Africa (Fresh = <1 week old; Old = >1 week).

Species		Number detected	Size class	Age class
Western Barn Owl	*Tyto alba*	4	Medium	Old
Cape Turtle Dove	*Streptopelia capicola*	1	Medium	Fresh
Lapwing sp.	*Vanellus* sp.	1	Medium	Old
Unidentified bird		2	Medium - Large	Old

Evaporation Pond Mortality

During the study, 37 carcasses were found in the evaporation ponds, and two Rock Monitor Lizards (*Varanus albigularis*) rescued from the ponds alive, probably would have drowned if not for my intervention. Of these, 21 are likely to have drowned after being unable to escape from a pond: 6 birds, 12 mammals and 3 reptiles (monitor lizards, including the two rescued animals). The remaining 18 mortalities were of water birds: one emaciated immature White-breasted Cormorant (*Phalacrocorax lucidus*), which may have died from starvation or disease, and 17 chicks of species breeding at the site (Table 7). Of four South African Shelduck (*Tadorna cana)* chicks dissected to establish the cause of death, three showed evidence of internal trauma and hemorrhaging probably caused by attacks from Cape Teals (*Anas capensis*), which were observed behaving aggressively towards the chicks, this likely accounts for the majority of the chick deaths. The other chicks were found in an advanced state of decay (>1 week); therefore cause of death could not be ascertained. The juvenile White-breasted Cormorant was dissected and showed no internal damage but was emaciated, suggesting that it died of starvation - the ponds contain no fish or frogs for this piscivore. Water samples tested as a part of normal operations showed all parameters to be well within the South African Department of Water and Sanitation requirements. African Shelduck (*Tadorna cana)*, Egyptian Goose (*Alopochen aegyptiaca)*, Blacksmith Lapwing (*Vanellus armatus)* and Black-winged Stilts *(Himantopus himantopus)* were observed breeding at the evaporation ponds and the surrounding vegetation.

Table 7: Species list, number of mortalities and suspected cause of death for carcasses recorded at the evaporation ponds at Bokpoort CSP facility, Northern Cape, South Africa.

Species		**Number of mortalities**	**Suspected cause of death**
South African shelduck	*Tadorna cana*	14 chicks	Unknown
Rock Monitor	*Varanus albigularis*	3*	Drowning
Blacksmith Lapwing	*Vanellus armatus*	3 chicks	Drowning
Egyptian Goose	*Alopochen aegyptiaca*	3 chicks	Unknown
Springhare	*Pedetes capensis*	3	Drowning
Bat-eared/Cape Fox	*Otocyon megalotis* *Vulpes chama*	4**	Drowning
Aardvark	*Orycteropus afer*	1	Drowning
Cape Hare	*Lepus capensis*	1	Drowning
Common Buttonquail	*Turnix sylvaticus*	1	Drowning
Gerbil sp.	*Gerbilliscus spp.*	1	Drowning
Little Swift	*Apus affinis*	1	Drowning
Steenbok	*Raphicerus campestris*	1	Drowning
Striped Polecat	*Ictonyx striatus*	1	Drowning
Western Barn Owl	*Tyto alba*	1	Drowning
White-breasted Cormorant	*Phalacrocorax lucidus*	1	Unknown
	Total:	**39**	

* Two of the rock monitors were rescued alive but likely would have drowned.
** Identification to species level uncertain due to advanced decomposition.

Searcher efficiency trials

Searchers detected 72% of bird carcasses (Appendix 7), with larger birds being more likely to be detected than small birds ($\chi^2 = 28.154$, df = 2, $P < 0.001$; Table 8).

Table 8: Searcher efficiency trial results including size class of bird carcasses, number of detections placed and percentage detected at Bokpoort CSP facility, Northern Cape, South Africa.

Size class	Detections/number placed	% Detected
Small (<100 g)	62/108	57%
Medium (100-1000 g)	58/72	81%
Large (>1000 g)	36/36	100%
Total:	156/216	**72%**

Carcass persistence trials

During the carcass persistence trials, 94% of the carcasses deployed survived the first 24 hrs, 68% survived the first 7 days, and 56% survived the full 28 day period (Figure 12). Of the size classes, no large bird carcasses (>1 kg) were removed entirely by scavengers after 28 days, whereas only 42% of medium-sized carcasses (100-1000 g) and 17% of small carcasses (<100g) were still present after 28 days (Figure 12). 26% of carcasses were recorded as scavenged at one point during the trials and 6% were recorded as feather spots, but no carcasses were recorded as feather spots at the end of the 28 day trials and only 21% of carcasses were recorded as being scavenged, all of these Medium and Large Carcasses (Appendix 8, 9).

Camera traps recorded the fate of nine carcasses. Small carcasses were often removed whole, medium carcasses were heavily scavenged often leaving only feathers or some body parts, whereas large carcasses were fed on *in situ* (Appendix 8). A number of scavengers were recorded visiting/investigating carcasses, however, only three were recorded removing carcasses (Table 9). Many predator tracks were observed entering the facility through the fences, indicating that the fence is not a barrier to predator movement.

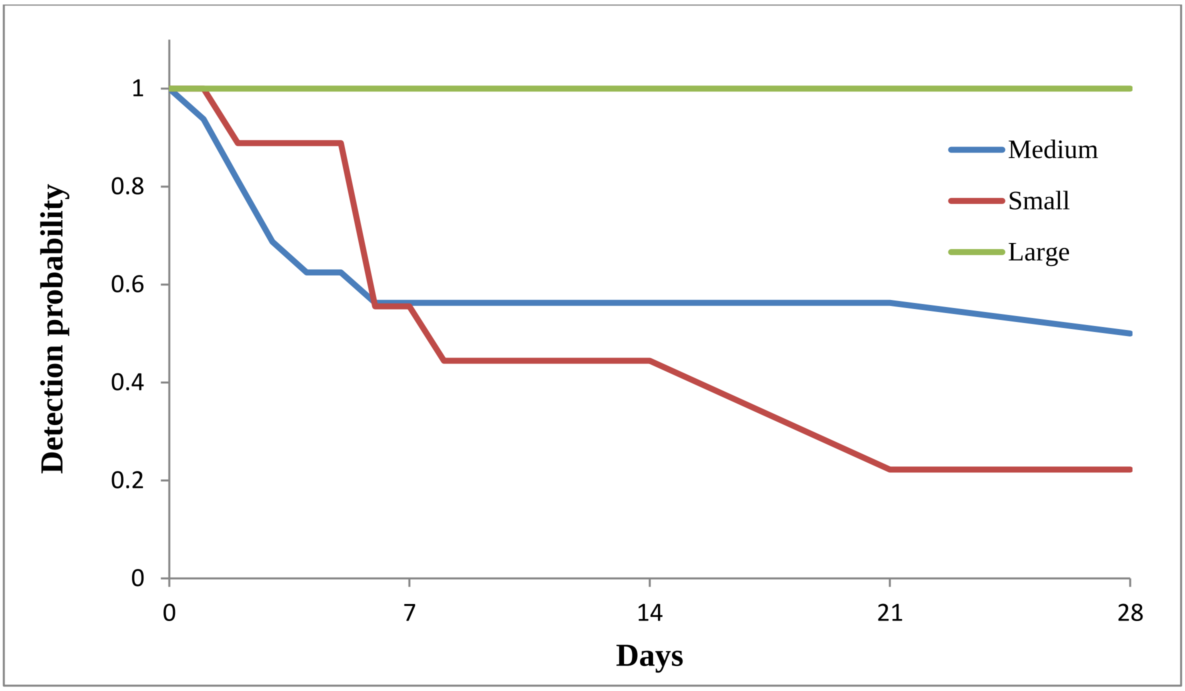

Figure 12: The detection probability of different sized bird carcasses for a 28 day period utilized in the carcass persistence trials, at Bokpoort CSP facility, Northern Cape, South Africa.

Mortality estimates for the facility based on the recorded mortality over the three month study period indicated that 84 vertebrate animals (24 birds, 48 mammals and 12 reptiles) are potentially killed within the evaporation ponds at this facility each year, with a low degree of certainty without bias corrections. Searcher efficiency and carcass persistence trials conducted in the solar field indicate that my study was unlikely to miss any large bird mortality and to a lesser degree medium bird mortality, but a high proportion of small bird mortality may not have been detected.

Table 9: List of scavenger species recorded, number of visits to bird carcasses and number of carcasses removed during bird carcass persistence trials at Bokpoort CSP facility, Northern Cape, South Africa.

Species	Scientific name	Visits	Removals
Pied Crow	*Corvus albus*	8	1
Cape Fox	*Vulpes chama*	5+1*	1
Slender Mongoose	*Galerella sanguinea*	1+1*	1
African Polecat	*Ictonyx striatus*	2	0
Caracal	*Caracal caracal*	1*	0

* Recorded on camera trap adjacent to evaporation pond inside facility's fenced area during trial phase.

Discussion

No birds were recorded having died in the mirror fields during the three-month study period. Eight old bird carcasses were found that had died prior to the study period, at least one of which probably resulted from a mirror collision. This makes any quantifiable mortality estimate and the use of a fatality rate estimator difficult (e.g. Huso 2011; Huso et al. 2016b). I can say with a high degree of confidence that mortality rates for large birds are negligible and with somewhat less confidence that mortality of small birds is not very high. Apart from disturbance and loss of habitat during construction, direct impacts on avifauna in the solar field were very low when compared to other solar impact studies (Walston et al. 2015; Visser 2016). The environmental impact assessment (EIA) of Bokpoort CSP regarded the impact of collisions of birds with mirrors and burning of birds to be of moderate significance (Chris van Rooyen Consulting 2010), but my study shows that these impacts may not be as significant as first thought. However, with a short 3-month study, higher mortalities may be recorded outside this period, given the number of old carcasses found during my initial carcass surveys. Visser's (2016) study in the nearby Jasper photovoltaic site had more mortality records with 12 carcasses, eight of which occurred during the 3-month study (Sept-Dec

2015). This difference may be attributed to the lack of vegetation/habitat and a low number of birds utilising Bokpoort CSP facility compared to the Jasper PV site, as there was no significant difference in overall bird density and diversity between the PV collector area and the adjacent rangelands area (Visser 2016).

The predominance of Western Barn Owls in the recorded mortalities (50%), is likely due to the large number of Barn Owls roosting in the torque tubes that support the mirrors in the solar fields. The presence of these artificial roost sites attracted large numbers of owls to the CSP facility, which may have increased mortality risk. Raptor carcasses, like those of Barn Owls, are more likely to persist as they are thought to be less palatable than non-raptorial birds (Smallwood 2007; Urquhart et al. 2015). The increased presence of owls in the solar field from suspected rodent ‘boom’ (Chapter 1) could increase the mortality risk to the owls as collision likelihood is increased. The owls were often disturbed when their roost site was passed either on foot or by a vehicle. The owl, when flushed, would have to then negotiate the rows of mirrors and the intense light reflected from the mirrors. Of all the owls observed in the mirror fields (n=63), only one heavily impacted with a mirror. This impact was slow speed and had no noticeable effect on the owl. The impact left an imprint of the dust from the bird’s feathers. Imprints from other impacts could also be seen on mirrors (although typically to a lesser degree), however, these never coincided with a carcass, which would indicate that the impact is unlikely to have killed the bird. There were also a large number of imprints/smudges left on the mirrors around roost site entrances and owls were observed failing to enter a roost site, sliding down the mirror, then flying to another roost site to try again. While these impacts appear to cause no damage to the owls, owls did make up a disproportionate number of carcasses found on the site. The results indicate that the presence of the owls roosting in the torque tubes is likely to increase the mortality/injury risk to the owls. Bokpoort facility management has begun implementing steps to reduce this risk with the installation of nest boxes in the surrounding rangeland landscape to provide alternative ‘safer’ roosting (and nesting) sites.

The evaporation ponds are a greater cause of mortality than the solar field, with an estimate of 84 vertebrate deaths attributed to the ponds annually. This highlights a potential impact which may have gone largely unnoticed, as in the EIA the evaporation pond was thought to only increase the risk of collision and burning of birds attracted to the water and not pose a risk in itself (Chris van Rooyen Consulting 2010). However, the EIA for the neighbouring planned CSP project Bokpoort II did highlight the potential toxicity and drowning risk to birds as a moderate risk (Arcus Consultancy Services 2016). Solar power facilities are often built in arid areas, and evaporation ponds are likely to attract animals from the surrounding landscape. Direct impacts on mammals other than bats have not been well documented in solar power, but evaporation ponds have been identified as having the potential for impacts on birds (Huso et al. 2016; Jenkins et al. 2017). There are recorded evaporation pond impacts on birds associated with other power production methods (Sovacool 2009) as well as industries such as mining and agriculture (Euliss et al. 1989; Savard & Smith 1991; Tanji et al. 2002; Marn 2003; Herbst 2006). Other recorded mortalities at the evaporation ponds were probably not related to birds becoming trapped in the evaporation ponds, and chick deaths are likely attributed to other factors like intraspecific aggression which is not uncommon in water birds (e.g. Savard & Smith 1991). The evaporation ponds, which are constructed to industry standards (E. Julies, Nov. 2016, pers. comm.), have a plastic lining which becomes slippery when wet to the point that many water birds slip and have difficulty escaping the water (Figure 13). Terrestrial birds and mammals that come to drink from the ponds risk falling in and being unable to escape. Neither the number of animals coming to drink at the evaporation ponds nor the proportion that fall in and are unable to escape is known but we can estimate that 84 vertebrates could die in these ponds annually. The impact of this mortality on populations requires further study and quantification. The fact that the evaporation ponds accounted for most vertebrate mortality at the CSP facility is of interest, but mitigation strategies could significantly reduce the risk of drowning. Improved fencing around the evaporation ponds to prevent access by terrestrial animals is one possible measure. This exclusion fencing would have likely been an effective barrier to prevent drowning (USFWS 2016a). Fencing, however, should not be installed in a way that it could potentially increase the risk of collision for water birds. In locations where this is not feasible, other mitigation options could be employed such as:

- Water points installed outside of the site would reduce the need for animals to enter the evaporation ponds to drink.
- The use of ‘ladders’ along the sides of the evaporation pond to facilitate the escape of animals which fall in. There would need to be good coverage of the edges and the ladders should not entangle mammals or birds.
- The integration of natural edges to evaporation ponds would prevent slippage and enable escape, but this may affect the evaporation efficiency of ponds.
- Bird exclusion netting which has been effective in aquacultural practices (Littauer et al. 1997) and oil waste evaporation pits (USFWS 2016b) and could be an effective way to stop both birds and mammals from entering the water. However, birds can become entrapped in the net, which could potentially become an impact in itself. The netting also could impact on evaporation rates.
- Development of non-slip lining; should this be possible, it could be made a requirement of future evaporation pond installations.
- Experimenting with changing the angle of the slope of the edge of the evaporaiton ponds so that slipping is reduced and animals can escape.

The effectiveness of these possible mitigation strategies requires further analysis, testing and monitoring.

Figure 13: Shore birds foraging along the plastic edge of the evaporation ponds at Bokpoort CSP, Northern Cape, South Africa.

Searcher efficiencies trials showed a distinct bias towards larger carcasses, which is consistent with Visser's (2016) study in a similar habitat. During the carcass persistence trials, more rapid removal rates were recorded for small bird carcasses, likely due to their ease of removal by scavengers, especially smaller scavengers such as Pied Crows and Slender Mongooses. Carcasses were more likely to be removed early in the trial, whereas older carcasses were often damaged/consumed by invertebrates and dried by the sun, remaining detectable to searchers longer (Figure 12). Although the facility has surrounding security and game fencing, it does not prevent small and medium-sized terrestrial mammals from entering the facility because many mammal entry points were observed along the fence, and such animals were observed inside the fenced area.

This study indicates that the Bokpoort ‘trough’ CSP facility has a modest direct impact on birds, less than tower CSP and photovoltaic facilities (Visser 2016; Walston et al. 2016). Tower CSP heliostats are well-spaced, large flat mirrors that are close to vertical at sunrise and sunset, increasing the risk of bird strikes. By comparison, ‘trough’ CSP facilities have concave mirrors in tight rows with relatively few birds moving through the solar field, greatly reducing the risk of bird strikes. The concave mirrors reflect a warped view of the sky, ground, and back of the mirror in the next row, likely reducing collision risk to birds (Figure 14).

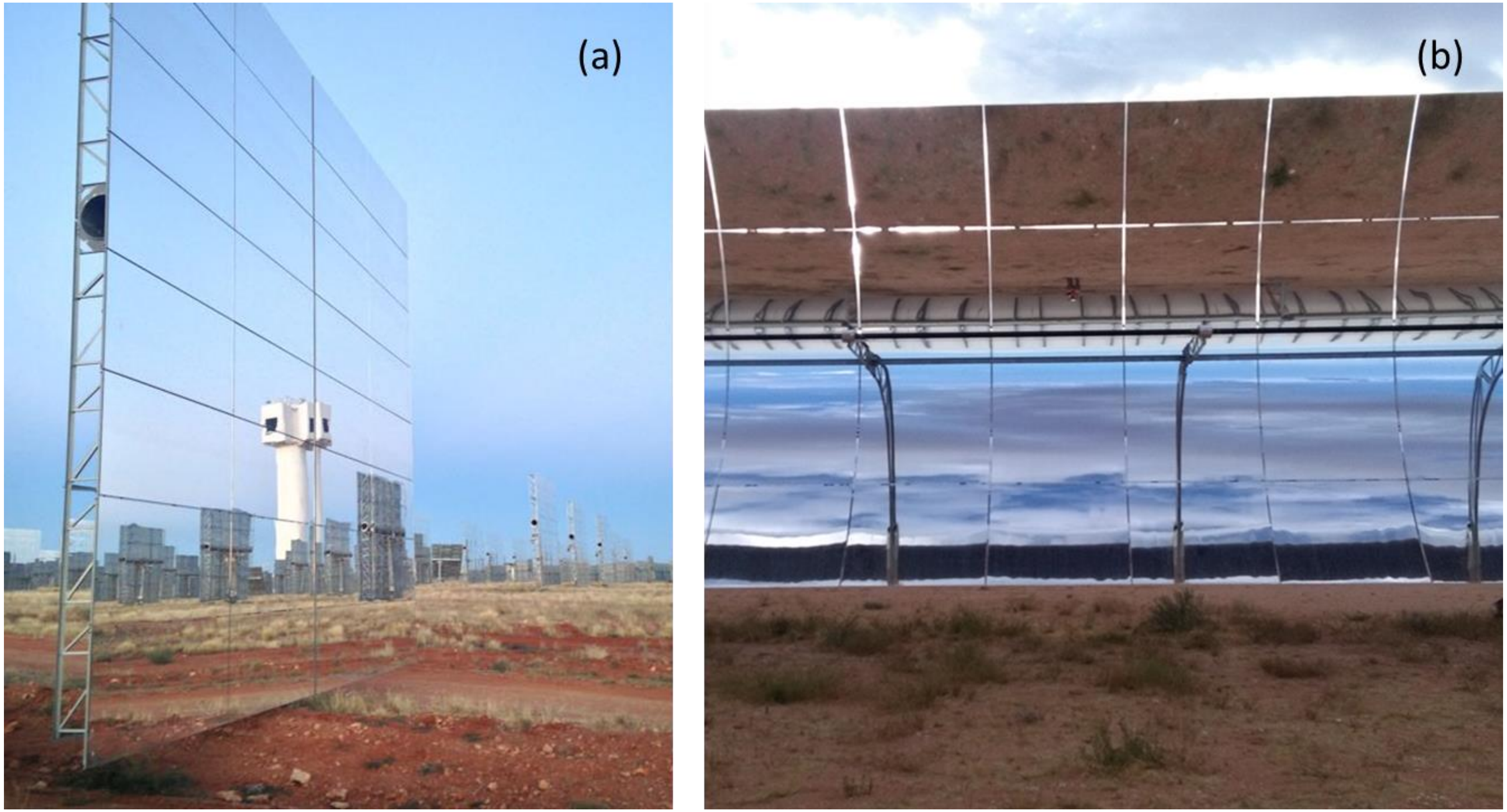

Figure 14: Comparison of reflections from CSP facilities; (a) straight heliostat mirrors of a power tower CSP facility, (b) the concave parabolic mirrors of a trough CSP facility

Conclusions and recommendations

Bird communities are significantly affected by the solar facility, with a depauperate subset of the surrounding rangeland species utilising the solar field. However, the evaporation ponds provide a novel wetland habitat in the arid landscape for more than 20 bird species. The changes in the bird community structure and composition within the solar fields demonstrate the effect of habitat loss on birds, with habitat loss associated with this type of facility larger than tower CSP (Walston et al. 2016) and more disruptive than photovoltaic (Visser 2016). While a single facility may be relatively small from a landscape perspective, the cumulative effects of habitat loss and fragmentation from multiple facilities will be much greater. The South African Government's target for solar energy of 9.4 GW (9400 MW) by 2030 (Department of Energy 2016b) extrapolates to 13,000-58,000 ha in South Africa alone. These cumulative effects will need to be managed to avoid negative effects on bird populations.

I found little evidence that invertebrates are attracted to the solar field, with assemblages comparable to other degraded overgrazed habitats. Flying invertebrates were not attracted to the facility, contrary to other CSP studies which propose that insects attracted to the CSP facility attract birds, potentially acting as an ecological sink (Kagan et al. 2014). Although a subset of invertebrates was more abundant in the plant area, there was no marked attraction of invertebrates to the facility or of birds that forage on invertebrates.

A few bird species use the facilities infrastructure for roosting or breeding, with a large number of Western Barn Owls roosting in the mirror supports. Eight bird mortalities were recorded during the mortality searches within the solar field, with no mortalities occurring during the study period. This is a lower solar field mortality rate than reported at tower CSP and photovoltaic facilities (Visser 2016; Walston et al. 2016). Thirty-nine mortalities were recorded in evaporation ponds at the facility, with mammals making up the majority of mortality. The sides of the evaporation pond are slippery when wet and animals that slip into the pond have difficulty escaping. Evaporation pond mortality has not been reported from other studies, and may be an overlooked impact associated with CSP facilities. While mitigation strategies are already being implemented at Bokpoort CSP facility that should reduce pond mortality, I recommend that current and future developments of evaporation ponds or similar structures mitigate this risk by fencing ponds to limit animal access and provide escape routes for any animals that do fall in, while working to develop anti-slip pond linings to prevent slipping and aid escape.

Any mitigation strategies will require further monitoring to gauge their success, and I recommend the use of guidance documents from organisations like BirdLife South Africa (Jenkins et al. 2017) and the US Geological Service (Huso et al. 2016) to assist solar power operators to monitor their impacts and plan mitigation accordingly.

Acknowledgements:

I thank my supervisors, Peter Ryan and Samantha Ralston-Paton, whose wisdom and guidance was essential to the success of the thesis. Vonica Perold also provided invaluable guidance and assistance. ACWA Power and NOMAC and their employees kindly supplied the accommodation for me to stay on site and conduct the study, and assisted with many of (often to them strange) requests; special thanks to Elton Julies and Jerome van Staden for accommodating my requests and ensuring the project ran smoothly. I appreciate that ACWA Power was proactive in measuring the environmental impacts of their site. Thank you also to Mark Williams for his hospitality and assistance in data collection as well as for his words of wisdom.

I especially thank those who assisted me with choosing the right methods and analysis of the many different disciplines within this project, Mike Picker (invertebrate sampling methods and analysis), Florian Weller (Distance sampling analysis and programme use), and Chevonne Reynolds, Petra Sumasgunter and Arjun Amar (statistical analysis). A special thank you to Susie Cunningham, Robert Thompson and Clare Spottiswoode for guiding me in developing the structure behind the research project. I want to thank my class mates from the Conservation Biology Master’s course for their support, and last but not least my family for making me the person I am today.

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Appendices:

Appendix 1: List of bird species from SABAP2 data collected in quarter degrees squared (QDGC) 2821DB and 2822CA including pentads 2840_2155 and 2840_2200 which are both present in Bokpoort CSP facility (SABAP2 2017). Conservation status: *Near-threatened, ** Vulnerable, *** Endangered.

Species		**QDGC 2821DB**	**Pentad 2840_2155**	**QDGC 2822CA**	**Pentad 2840_2200**	**Endemism**
Acacia Pied Barbet	*Tricholaema leucomelas*	x	x	x	x	-
African Darter	*Anhinga rufa*	x				-
African Fish Eagle	*Haliaeetus vocifer*	x				-
African Hoopoe	*Upupa africana*	x		x	x	-
African Palm Swift	*Cypsiurus parvus*	x				-
African Pied Wagtail	*Motacilla aguimp*	x				-
African Pipit	*Anthus cinnamomeus*	x		x		-
African Red-eyed Bulbul	*Pycnonotus nigricans*	x	x	x	x	near-endemic
African Reed Warbler	*Acrocephalus baeticatus*	x				-
African Rock Pipit	*Anthus crenatus*			x	x	endemic
African Sacred Ibis	*Threskiornis aethiopicus*	x				-
Alpine Swift	*Tachymarptis melba*	x				-
Ant-eating Chat	*Myrmecocichla formicivora*	x	x	x		endemic
Ashy Tit	*Parus cinerascens*	x	x	x	x	near-endemic
Barn Swallow	*Hirundo rustica*	x		x		-
Black Crake	*Amaurornis flavirostris*	x				-
Black-chested Prinia	*Prinia flavicans*	x	x	x	x	-
Black-faced Waxbill	*Estrilda erythronotos*			x		

Black-headed Canary	*Serinus alario*			x		endemic
Black-headed Heron	*Ardea melanocephala*	x				-
Blacksmith Lapwing	*Vanellus armatus*	x				-
Black-throated Canary	*Crithagra atrogularis*	x		x		-
Black-winged Stilt	*Himantopus himantopus*	x				-
Bokmakierie	*Telophorus zeylonus*	x		x	x	near-endemic
Bradfield's Swift	*Apus bradfieldi*	x		x		near-endemic
Brown-crowned Tchagra	*Tchagra australis*	x		x		-
Brown-hooded Kingfisher	*Halcyon albiventris*	x				-
Brown-throated Martin	*Riparia paludicola*	x				-
Brubru	*Nilaus afer*			x	x	-
Burchell's Coucal	*Centropus burchellii*	x				-
Burchell's Sandgrouse	*Pterocles burchelli*			x		near-endemic
Cape Bunting	*Emberiza capensis*			x	x	-
Cape Glossy Starling	*Lamprotornis nitens*	x		x		-
Cape Robin-Chat	*Cossypha caffra*	x				-
Cape Sparrow	*Passer melanurus*	x	x	x		near-endemic
Cape Turtle Dove	*Streptopelia capicola*	x	x	x	x	-
Cape Wagtail	*Motacilla capensis*	x				-
Capped Wheatear	*Oenanthe pileata*	x		x		-
Cattle Egret	*Bubulcus ibis*	x		x		-
Chat Flycatcher	*Bradornis infuscatus*	x		x		near-endemic
Chestnut-vented Tit-Babbler	*Parisoma subcaeruleum*	x	x	x	x	near-endemic
Cinnamon-breasted Bunting	*Emberiza tahapisi*			x		
Common (Southern) Fiscal	*Lanius collaris*	x	x	x	x	-
Common Buttonquail	*Turnix sylvaticus*			x	x	-

Common Ostrich	*Struthio camelus*	x		x		-
Common Quail	*Coturnix coturnix*	x		x	x	-
Common Scimitarbill	*Rhinopomastus cyanomelas*	x	x	x	x	-
Common Swift	*Apus apus*	x		x		-
Common Waxbill	*Estrilda astrild*	x				-
Crested Barbet	*Trachyphonus vaillantii*	x				-
Crimson-breasted Shrike	*Laniarius atrococcineus*	x		x		-
Crowned Lapwing	*Vanellus coronatus*	x	x	x		-
Desert Cisticola	*Cisticola aridulus*	x		x	x	-
Diderick Cuckoo	*Chrysococcyx caprius*	x		x		-
Double-banded Courser	*Rhinoptilus africanus*	x	x			-
Dusky Sunbird	*Cinnyris fuscus*	x	x	x	x	near-endemic
Eastern Clapper Lark	*Mirafra fasciolata*	x	x	x	x	near-endemic
Egyptian Goose	*Alopochen aegyptiacus*	x		x		-
European Bee-eater	*Merops apiaster*			x		-
Familiar Chat	*Cercomela familiaris*	x		x		-
Fawn-coloured Lark	*Calendulauda africanoides*	x	x	x	x	near-endemic
Fiscal Flycatcher	*Sigelus silens*	x		x		endemic
Fork-tailed Drongo	*Dicrurus adsimilis*			x		-
Giant Kingfisher	*Megaceryle maximus*	x				-
Golden-tailed Woodpecker	*Campethera abingoni*	x				-
Great Crested Grebe	*Podiceps cristatus*	x				-
Greater Striped Swallow	*Hirundo cucullata*	x		x		-
Green-winged Pytilia	*Pytilia melba*			x		-
Grey-backed Cisticola	*Cisticola subruficapilla*	x		x	x	near-endemic
Grey-backed Sparrowlark	*Eremopterix verticalis*	x		x	x	near-endemic

Hadeda Ibis	*Bostrychia hagedash*	x	x			-
Hamerkop	*Scopus umbretta*	x				-
Helmeted Guineafowl	*Numida meleagris*	x				-
House Sparrow	*Passer domesticus*	x	x	x		-
Jacobin Cuckoo	*Clamator jacobinus*			x		-
Kalahari Scrub Robin	*Cercotrichas paena*	x	x	x	x	near-endemic
Karoo Korhaan	*Eupodotis vigorsii*	x				endemic
Karoo long-billed Lark	*Certhilauda subcoronata*	x		x		endemic
Karoo Scrub Robin	*Cercotrichas coryphoeus*	x		x		endemic
Karoo Thrush	*Turdus smithi*	x				endemic
Kori Bustard*	*Ardeotis kori*	x	x	x		near-endemic
Lappet-faced Vulture***	*Torgos tracheliotus*	x		x		-
Large-billed Lark	*Galerida magnirostris*			x		-
Lark-like Bunting	*Emberiza impetuani*	x		x	x	near-endemic
Laughing Dove	*Streptopelia senegalensis*	x	x	x	x	-
Layard's Tit-Babbler	*Parisoma layardi*			x	x	endemic
Lesser Grey Shrike	*Lanius minor*	x		x		-
Lesser Honeyguide	*Indicator minor*	x				-
Lesser Swamp-Warbler	*Acrocephalus gracilirostris*	x				-
Levaillant's Cisticola	*Cisticola tinniens*	x				-
Little Grebe	*Tachybaptus ruficollis*	x				-
Little Swift	*Apus affinis*	x		x		-
Long-billed Crombec	*Sylvietta rufescens*	x	x	x	x	-
Marico Sunbird	*Cinnyris mariquensis*	x				-
Mountain Wheatear	*Oenanthe monticola*			x	x	near-endemic
Namaqua Dove	*Oena capensis*	x	x	x	x	-

Namaqua Sandgrouse	*Pterocles namaqua*	x	x	x	x	near-endemic
Namaqua Warbler	*Phragmacia substriata*	x				endemic
Northern Black Korhaan	*Afrotis afraoides*	x	x	x		endemic
Orange River White-eye	*Zosterops pallidus*	x				endemic
Pale-winged Starling	*Onychognathus nabouroup*			x	x	-
Pied Crow	*Corvus albus*	x	x	x		-
Pink-billed Lark	*Spizocorys conirostris*	x				near-endemic
Pin-tailed Whydah	*Vidua macroura*	x				-
Pririt Batis	*Batis pririt*	x	x	x	x	near-endemic
Pygmy Falcon	*Polihierax semitorquatus*	x		x		-
Red-backed Shrike	*Lanius collurio*	x		x		-
Red-billed Firefinch	*Lagonosticta senegala*	x				-
Red-billed Quelea	*Quelea quelea*	x	x	x		-
Red-crested Korhaan	*Lophotis ruficrista*	x	x	x		near-endemic
Red-eyed Dove	*Streptopelia semitorquata*	x				-
Red-faced Mousebird	*Urocolius indicus*	x	x	x	x	-
Red-headed Finch	*Amadina erythrocephala*	x			x	near-endemic
Reed Cormorant	*Phalacrocorax africanus*	x				-
Rock Kestrel	*Falco rupicolus*			x	x	-
Rock Martin	*Hirundo fuligula*	x	x	x	x	-
Rufous-cheeked Nightjar	*Caprimulgus rufigena*			x		
Rufous-eared Warbler	*Malcorus pectoralis*	x	x	x		endemic
Sabota Lark	*Calendulauda sabota*	x	x	x	x	near-endemic
Scaly-feathered Finch	*Sporopipes squamifrons*	x	x		x	near-endemic
Secretary Bird**	*Sagittarius serpentarius*	x				-
Short-toed Rock Thrush	*Monticola brevipes*			x	x	-

Sociable Weaver	*Philetairus socius*	x	x	x	x	endemic
South African Cliff-Swallow	*Hirundo spilodera*	x				endemic
Southern Grey-headed Sparrow	*Passer diffusus*	x		x		-
Southern Masked-Weaver	*Ploceus velatus*	x	x	x		-
Southern Pale Chanting Goshawk	*Melierax canorus*	x		x		near-endemic
Southern Red Bishop	*Euplectes orix*	x	x			-
Speckled Pigeon	*Columba guinea*	x	x	x	x	-
Spike-heeled Lark	*Chersomanes albofasciata*	x	x	x	x	-
Spotted Eagle Owl	*Bubo africanus*			x		-
Spotted Thick-knee	*Burhinus capensis*	x		x		-
Spur-winged Goose	*Plectropterus gambensis*	x				-
Swallow-tailed Bee-eater	*Merops hirundineus*	x		x		-
Three-banded Plover	*Charadrius tricollaris*	x				-
Verreaux's Eagle	*Aquila verreauxii*	x	x	x	x	-
Violet-eared Waxbill	*Granatina granatina*			x		-
Wattled Starling	*Creatophora cinerea*	x		x		
Western Barn Owl	*Tyto alba*	x		x	x	-
White-backed Mousebird	*Colius colius*	x	x	x	x	endemic
White-backed Vulture**	*Gyps africanus*	x				-
White-breasted Cormorant	*Phalacrocorax carbo*	x				-
White-browed Sparrow-Weaver	*Plocepasser mahali*	x	x	x	x	-
White-fronted Bee-eater	*Merops bullockoides*	x				-
White-rumped Swift	*Apus caffer*	x		x		-
White-throated Canary	*Crithagra albogularis*	x		x		near-endemic
White-throated Swallow	*Hirundo albigularis*	x				-

Yellow Canary	*Crithagra flaviventris*	x	x	x		near-endemic
Yellow-bellied Eremomela	*Eremomela icteropygialis*	x	x	x	x	-
Zitting Cisticola	*Cisticola juncidis*	x				-

Appendix 2: The number of invertebrates caught in each order using sticky traps and pitfall traps within the power block, solar field and rangeland sampling sites at Bokpoort CSP facility, Northern Cape, South Africa. (SF = solar field; PW = power block; R = rangeland)

	Sticky trap			**Pitfall Trap**			
Classification	**SF**	**PB**	**R**	**SF**	**PB**	**R**	**Total**
Formicidae (ants)*	4	4	2	2782	1421	1209	**5422**
Diptera (flies/mosquitoes)	775	194	445	67	111	16	**1608**
Thysanoptera (thrips)	234	384	359	0	2	0	**979**
Coleoptera (beetles)	15	12	37	328	307	175	**874**
Hemiptera (bugs)	53	78	52	158	157	8	**506**
Hymenoptera (bees/wasps)	42	103	223	17	35	13	**433**
Orthoptera (crickets/locusts)	0	0	0	146	56	2	**204**
Araneae (spiders)	14	10	7	7	22	56	**116**
Lepidoptera (moths/butterflies)	1	1	1	4	8	4	**19**
Collembola (springtails)	0	0	0	10	3	1	**14**
Isoptera (termites)	1	0	0	0	0	13	**14**
Blattodea (cockroaches)	4	7	1	0	0	1	**13**
Diplura (bristletails)	0	0	0	1	0	12	**13**
Isopoda (crustaceans)	0	0	0	4	5	1	**10**
Scorpiones (scorpions)	0	0	0	0	3	6	**9**
Acari (ticks/mites)	0	0	0	5	0	2	**7**
Solifugae (solifuges)	0	0	0	0	1	4	**5**
Dermaptera (earwigs)	0	0	0	2	0	2	**4**
Mantodea (mantids)	0	0	0	0	1	2	**3**
Pseudoscorpiones (pseudoscorpions)	0	0	0	0	0	3	**3**
Phasmatodea (stick insects)	0	0	0	0	0	1	**1**
Total	**1143**	**793**	**1127**	**3531**	**2132**	**1531**	**10257**

*Formicidae a family of the order Hymenoptera

Appendix 3: Species list of birds recorded during the study period in the solar field, rangeland and the evaporation ponds at Bokpoort CSP facility, Northern Cape, South Africa with endemism status.

Species		**Rangeland**	**Mirror field**	**Pond**	**Endemism**
Cape Sparrow	*Passer melanurus*	x	x	x	near-endemic
Cape Turtle Dove	*Streptopelia capicola*	x	x	x	
Familiar Chat	*Cercomela familiaris*	x	x	x	
Lark-like Bunting	*Emberiza impetuani*	x	x	x	
Little Swift	*Apus affinis*	x	x	x	
Namaqua Dove	*Oena capensis*	x	x	x	
Rock Martin	*Hirundo fuligula*	x	x	x	
Speckled Pigeon	*Columba guinea*	x	x	x	
Back-chested Prinia	*Prinia flavicans*	x	x		
Fawn-coloured Lark	*Calendulauda africanoides*	x	x		near-endemic
Pied Crow	*Corvus albus*	x	x		
Rufous-eared Warbler	*Malcorus pectoralis*	x	x		endemic
Sociable Weaver	*Philetairus socius*	x	x		endemic
Spike-heeled Lark	*Chersomanes albofasciata*	x	x		
Yellow Canary	*Crithagra flaviventris*	x	x		
Laughing Dove	*Streptopelia senegalensis*	x		x	
White-throated Swallow	*Hirundo albigularis*	x		x	
Acacia Pied Barbet	*Tricholaema leucomelas*	x			
Ant-eating Chat	*Myrmecocichla formicivora*	x			endemic
Black-throated Canary	*Crithagra atrogularis*	x			
Brown-crowned Tchagra	*Tchagra australis*	x			
Chat Flycatcher	*Bradornis infuscatus*	x			near-endemic
Chestnut-vented Tit-Babbler	*Sylvia subcaerulea*	x			near-endemic
Common Buttonquail	*Turnix sylvaticus*	x			
Common Scimitarbill	*Rhinopomastus cyanomelas*	x			
Desert Cisticola	*Cisticola aridulus*	x			
Dusky Sunbird	*Cinnyris fuscus*	x			near-endemic
Eastern Clapper Lark	*Mirafra fasciolata*	x			near-endemic
Greater Kestrel	*Falco rupicoloides*	x			
Hadeda Ibis	*Bostrychia hagedash*	x			
Kalahari Scrub Robin	*Erythropygia paena*	x			near-endemic
Karoo Scrub Robin	*Erythropygia coryphoeus*	x			endemic
Kori Bustard	*Ardeotis kori*	x			
Long-billed Crombec	*Sylvietta rufescens*	x			
Namaqua Sandgrouse	*Pterocles namaqua*	x			
Northern Black Korhaan	*Afrotis afraoides*	x			endemic
Pale Chanting Goshawk	*Melierax canorus*	x			endemic
Pririt Batis	*Batis pririt*	x			
Pygmy Falcon	*Polihierax semitorquatus*	x			
Red Crested Korhaan	*Lophotis ruficrista*	x			

Red-billed Quelea	*Quelea quelea*	x			
Sabota Lark	*Calendulauda sabota*	x			
Scaly-feathered Finch	*Sporopipes squamifrons*	x			
Short-toed Rock Thrush	*Monticola brevipes*	x			
Southern Fiscal	*Lanius collaris*	x			
Southern Masked Weaver	*Ploceus velatus*	x			
Violet-eared Waxbill	*Uraeginthus granatinus*	x			
White-backed Mousebird	*Colius colius*	x			endemic
White-browed Sparrow-Weaver	*Plocepasser mahali*	x			
Yellow-bellied Eremomela	*Eremomela icteropygialis*	x			
Bokmakierie	*Telophorus zeylonus*	x			near-endemic
African Red-eyed Bulbul	*Pycnonotus nigricans*		x	x	
Blacksmith Lapwing	*Vanellus armatus*		x	x	
Cape Wagtail	*Motacilla capensis*		x	x	
Red-headed Finch	*Amadina erythrocephala*		x	x	
House Sparrow	*Passer domesticus*		x		
Mountain Wheatear	*Oenanthe monticola*		x		
Western Barn Owl	*Tyto alba*		x		
African Fish Eagle	*Haliaeetus vocifer*			x	
Black-headed Heron	*Ardea melanocephala*			x	
Black-winged Stilt	*Himantopus himantopus*			x	
Brown-throated Martin	*Riparia paludicola*			x	
Cape Shoveler	*Anas smithii*			x	
Cape Teal	*Anas capensis*			x	
Common Greenshank	*Tringa nebularia*			x	
Curlew Sandpiper	*Calidris ferruginea*			x	
Egyptian Goose	*Alopochen aegyptiaca*			x	
Grey Plover	*Pluvialis squatarola*			x	
Kittlitz’s Plover	*Charadrius pecuarius*			x	
Little Grebe	*Tachybaptus ruficollis*			x	
Little Stint	*Calidris minuta*			x	
Malachite Kingfisher	*Alcedo cristata*			x	
Red-billed Teal	*Anas erythrorhyncha*			x	
Red-knobbed Coot	*Fulica cristata*			x	
Ruddy Turnstone	*Arenaria interpres*			x	
Ruff	*Philomachus pugnax*			x	
Sanderling	*Calidris alba*			x	
South African Shelduck	*Tadorna cana*			x	
Three-banded Plover	*Charadrius tricollaris*			x	
Whiskered Tern	*Chlidonias hybrida*			x	
White-breasted Cormorant	Phalacrocorax carbo			x	

Appendix 4: Summary of results from bird counts at the evaporations ponds, Bokpoort CSP facility, Northern Cape, South Africa

Species	**Total Count**	**Mean group size**	**No. of Records**
Black-winged Stilt	1149	21.7	53
South African Shelduck	716	14.9	48
Egyptian Goose	353	6.8	52
Cape Teal	317	6.1	52
Little Stint	279	6.1	46
Blacksmith Lapwing	209	4.3	49
Whiskered Tern	135	10.4	13
Three-banded Plover	131	2.7	48
Little Grebe	98	3.5	28
Ruddy Turnstone	65	1.6	40
Rock Martin	58	4.1	14
Cape Wagtail	52	2.0	26
Little Swift	35	5.0	7
Kittlitz Plover	31	1.9	16
Speckled Pigeon	22	3.1	7
Grey Plover	12	1.0	12
Cape Shoveler	9	3.0	3
Ruff	8	1.3	6
Black-headed Heron	8	1.0	8
White-throated Swallow	6	1.0	6
Common Greenshank	5	1.0	5
Sanderling	5	1.3	4
Red-billed Teal	4	2.0	2
Cape Sparrow	2	2.0	1
Namaqua Dove	2	1.0	2
Red-eyed Bulbul	1	1.0	1
Red-headed Finch	1	1.0	1
Familiar Chat	1	1.0	1
Laughing Dove	1	1.0	1
African Fish Eagle	1	1.0	1
Lark-like Bunting	1	1.0	1
Malachite Kingfisher	1	1.0	1
Curlew Sandpiper	1	1.0	1
Red-knobbed Coot	1	1.0	1
Cape Turtle Dove	1	1.0	1
Total	**3721**	**3.4**	**558**

Appendix 5: The total numbers of birds, distance, mean group size and total number of records for each species recorded within the rangeland area adjacent to Bokpoort CSP facility, Northern Cape, South Africa.

		Count distance				**Total count**	**Mean group size**	**Number of records**
Species		**<50**	**50-100**	**100-200**	**>200**			
Fawn-coloured Lark	*Calendulauda africanoides*	161	44	27		232	1.37	169
Scaly-feathered Finch	*Sporopipes squamifrons*	451	59			510	4.81	106
Sociable Weaver	*Philetairus socius*	883	74	200		1157	16.77	69
Namaqua Dove	*Oena capensis*	85	12	6		103	1.56	66
Namaqua Sandgrouse	*Pterocles namaqua*	151	51	20	19	241	3.95	61
Back-chested Prinia	*Prinia flavicans*	60	7	3		70	1.19	59
Yellow Canary	*Crithagra flaviventris*	147	12			159	3.53	45
Eastern Clapper Lark	*Mirafra fasciolata*	14	4	8	32	58	1.45	40
Kalahari Scrub Robin	*Erythropygia paena*	24	13			37	1.19	31
Lark-like Bunting	*Emberiza impetuani*	104				104	4.00	26
Little Swift	*Apus affinis*	50	2	5	28	85	3.54	24
Chestnut-vented Tit-babbler	*Sylvia subcaerulea*	23				23	1.21	19
Dusky Sunbird	*Cinnyris fuscus*	19	1			20	1.11	18
Ant-eating Chat	*Myrmecocichla formicivora*	12	4	4	1	21	1.24	17
Cape Turtle Dove	*Streptopelia capicola*	8	1	3	3	15	1.00	15
Rufous-eared Warbler	*Malcorus pectoralis*	16				16	1.07	15
Pied Crow	*Corvus albus*	3	1	4	11	19	1.46	13
Northern Black Korhaan	*Afrotis afraoides*				14	14	1.17	12
Southern Fiscal	*Lanius collaris*	10	1			11	1.10	10
Rock Martin	*Hirundo fuligula*	12				12	1.20	10
Yellow-bellied Eremomela	*Eremomela icteropygialis*	11	1			12	1.20	10

White-browed Sparrow-weaver	*Plocepasser mahali*	26				26	2.89	9
Red-billed Quelea	*Quelea quelea*	88		12		100	14.29	7
White-backed Mousebird	*Colius colius*	17	2			18	4.50	4
White-throated Swallow	*Hirundo albigularis*	9				9	2.25	4
Common Buttonquail	*Turnix sylvaticus*	4				4	1.33	3
Greater Kestrel	*Falco rupicoloides*	2			1	3	1.00	3
Pale Chanting Goshawk	*Melierax canorus*				3	3	1.00	3
Sabota Lark	*Calendulauda sabota*	3				3	1.00	3
Laughing Dove	*Streptopelia senegalensis*	2				2	1.00	2
Pririt Batis	*Batis pririt*	3				3	1.50	2
Common Scimitarbill	*Rhinopomastus cyanomelas*	2				2	1.00	2
Speckled Pigeon	*Columba guinea*			2	2	4	2.00	2
Spike-heeled Lark	*Chersomanes albofasciata*	2	1			3	1.50	2
Acacia Pied Barbet	*Tricholaema leucomelas*	1				1	1.00	1
Black-throated Canary	*Crithagra atrogularis*	2				2	2.00	1
Bokmakierie	*Telophorus zeylonus*	4				4	4.00	1
Cape Sparrow	*Passer melanurus*	4				4	4.00	1
Chat Flycatcher	*Bradornis infuscatus*	4				4	4.00	1
Familiar Chat	*Cercomela familiaris*	1				1	1.00	1
Hadeda Ibis	*Bostrychia hagedash*				2	2	2.00	1
Karoo Scrub-robin	*Erythropygia coryphoeus*			2		2	2.00	1
Pygmy Falcon	*Polihierax semitorquatus*	1				1	1.00	1
Violet-eared Waxbill	*Uraeginthus granatinus*	1				1	1.00	1
Total		**2420**	**289**	**296**	**116**	**3121**	**3.50**	**891**

Appendix 6: Density estimates of birds sampled within a rangeland sampling area adjacent to a CSP facility in Northern Cape, South Africa. Species are in ascending order of the CV of density (%).

Species		**Group ID**	**Number of detections in group**	**Effort in Group* (Km)**	**Density estimate (per/ha)**	**CV of density (%)**	**CI of density (95%)**
Fawn-coloured Lark	*Calendulauda africanoides*	B	387	110	1.22	10.1	1.00 – 1.49
Namaqua Dove	*Oena capensis*	B	387	110	0.47	13.38	0.34 – 0.65
Black-chested Prinia	*Prinia flavicans*	B	387	110	0.37	13.62	0.28 – 0.48
Scaly-feathered Finch	*Sporopipes squamifrons*	C	268	220	6.96	14.91	5.18 – 9.34
Kalahari Scrub Robin	*Erythropygia paena*	D	55	66	0.13	21.74	0.9 – 0.20
Yellow Canary	*Crithagra flaviventris*	C	268	220	2.17	22.72	1.39 – 3.39
Dusky Sunbird	*Cinnyris fuscus*	C	268	220	0.27	24.59	0.17 -0.44
Roufous-eared Warbler	*Malcorus pectoralis*	C	268	220	0.22	24.73	0.13 – 0.36
Sociable Weaver	*Philetairus socius*	B	387	110	6.09	25.54	3.70 – 10.03
Namaqua Sandgrouse	*Pterocles namaqua*	E	76	44	0.38	26.17	0.23 – 0.64
Cape Turtle Dove	*Streptopelia capicola*	E	76	44	0.02	27.04	0.01 – 0.04
Ant-eating Chat	*Myrmecocichla formicivora*	D	55	66	0.09	28.65	0.05 – 0.15
Fiscal Shrike	*Lanius collaris*	C	268	220	0.15	30.09	0.08 – 0.27
Chestnut-vented Tit-babler	*Sylvia subcaerulea*	C	268	220	0.31	30.19	0.17 -0.57
Little Swift	*Apus affinis*	B	387	110	0.21	33.43	0.11 – 0.40
Rock Martin	*Hirundo fuligula*	C	268	220	0.16	33.92	0.08 -0. 32
Yellow-bellied Eromomela	*Eremomela icteropygialis*	C	268	220	0.16	33.92	0.08 – 0.32
Eastern Clapper Lark	*Mirafra fasciolata*	A	53	44	0.11	33.99	0.06 – 0.22
Lark-like Bunting	*Emberiza impetuani*	C	268	220	1.42	34.97	0.72 – 2.80
White-browed Sparrow-weaver	*Plocepasser mahali*	C	268	220	0.35	41.51	0.16 – 0.79
Pied Crow	*Corvus albus*	A	53	44	0.04	42.61	0.02 – 0.10

*Total combined transect distance in kilometres of pooled data

Appendix 7: Bird species and detection results of searcher efficiency trials conducted at a Bokpoort CSP facility, Northern Cape, South Africa

			No. of birds observed					
Species	**Size**	**No. times deployed**	**Searcher 1**	**Searcher 2**	**Searcher 3**	**Searcher 4**	**Total**	**Observation probability**
African Pipit 1	S	3	2	3	3	2	10	0.83
African Pipit 2	S	3	0	1	3	1	5	0.42
African Pipit 3	S	3	1	2	1	3	7	0.58
House Sparrow	S	3	2	2	2	3	9	0.75
Rufous-eared Warbler	S	3	2	2	1	2	7	0.58
Cape Canary	S	3	1	1	1	0	3	0.25
Fiscal Flycatcher	S	3	3	2	3	3	11	0.92
Red-capped Lark	S	3	2	3	1	1	7	0.58
Lark-like Bunting	S	3	2	0	0	1	3	0.25
Subtotal		27	15	16	15	16	62	0.57
African Hoopoe	M	3	2	2	1	2	7	0.58
Rock Kestrel	M	3	3	3	3	3	12	1.00
South African Shelduck	M	3	2	3	1	3	9	0.75
Alpine Swift	M	3	2	3	2	3	10	0.83
Bokmakierie	M	3	3	3	1	2	9	0.75
Namaqua Sandgrouse	M	3	3	3	2	3	11	0.92
Subtotal		18	15	17	10	16	58	0.81
Helmeted Guineafowl	L	3	3	3	3	3	12	1.00
Red-knobbed Coot	L	3	3	3	3	3	12	1.00
Kelp Gull (immature)	L	3	3	3	3	3	12	1.00
Subtotal		9	9	9	9	9	36	1.00
Total		**54**	**39**	**42**	**34**	**41**	**156**	**0.72**

Appendix 8: Results from bird carcass persistence trials conducted at Bokpoort CSP facility, Northern Cape, South Africa

			Days												
Species		**Size**	**0**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**10**	**14**	**21**	**28**
African Hoopoe**	*Upupa africana*	S	X	X	X	X	X	X	X	X	X	X	F	R	
African Pipit*	*Anthus cinnamomeus*	S	X	X	R[3]										
African Pipit	*Anthus cinnamomeus*	S	X	X	X	X	X	X	R						
African Pipit	*Anthus cinnamomeus*	S	X	X	X	X	X	X	X	X	R				
African Pipit	*Anthus cinnamomeus*	S	X	X	X	X	X	X	X	X	X	X	X	X	X
Alpine Swift	*Tachymarptis melba*	M	X	R											
Fiscal Flycatcher (Juv.)	*Melaenornis silens*	S	X	X	X	X	X	X	X	X	X	X	X	X	X
Black-headed Heron	*Ardea melanocephala*	L	X	X	X	X	X	X	X	X	X	X	X	X	X
Bokmakierie	*Telophorus zeylonus*	M	X	X	X	X	X	X	X	X	X	X	X	X	S
Broad-billed Prion	*Pachyptila vittata*	M	X	X	X	R									
Cape Eagle Owl	*Bubo capensis*	L	X	X	X	X	X	X	X	X	X	X	X	X	X
Common Diving Petrel	*Pelecanoides urinatrix*	M	X	X	X	R									
Common Diving Petrel	*Pelecanoides urinatrix*	M	X	X	X	X	X	X	R						
Egyptian Goose	*Alopochen aegyptiacus*	L	X	X	X	X	X	X	X	S	S	S	S	S	S
Egyptian Goose	*Alopochen aegyptiacus*	L	X	X	X	X	X	X	X	X	X	X	X	X	X
Helmeted Guineafowl	*Numida meleagris*	L	X	X	X	X	X	X	X	X	X	X	X	X	X
Helmeted Guineafowl	*Numida meleagris*	L	X	X	X	X	X	X	X	X	S	S	S	S	S
House Sparrow	*Passer domesticus*	S	X	X	X	X	X	X	X	X	X	X	X	X	R
Kelp Gull	*Larus dominicanus*	L	X	X	X	X	X	X	X	X	X	X	X	X	X
Kelp Gull*	*Larus dominicanus*	L	X[4]	X[2]	X	X	X	X[1]	X	X	X	X[1,2,1]	X[2]	X	X
Kelp Gull (Immature)	*Larus dominicanus*	L	X	X	S	S	S	S	S	S	S	S	S	S	S
Southern Masked-weaver	*Ploceus velatus*	S	X	X	X	X	X	S	R						

Namaqua Sandgrouse*	*Pterocles namaqua*	M	X	X[1]	R										
Red-winged Starling	*Onychognathus morio*	M	X	X	X	X	X	X	X	X	X	X	X	X	S
Red-capped Lark**	*Calandrella cinerea*	S	X	X	X	X	X	X	R						
Red-knobbed Coot	*Fulica cristata*	M	X	X	X	S	R								
Rock Kestrel**	*Falco rupicolus*	M	X	X	X	X	X[4]	X	X	S	S	S	S	S	S
South African Shelduck (chick)	*Tadorna cana*	M	X	X	R										
South African Shelduck (chick)*	*Tadorna cana*	M	X	X[2]	X	X[1]	X	X	X	X	X	X[1]	X	X	X
South African Shelduck (chick)*	*Tadorna cana*	M	X	X	X	X	X	X	X	X	X	X	X	X	X
Southern Black Korhaan	*Afrotis afra*	M	X	X	X	X	X	X	X	X	X	X	X	X	X
Spotted Eagle Owl	*Bubo africanus*	M	X	X	X	X	X	X	X	X	X	F	F	F	R
Tern spp. (chick)		M	X	X	X	X	X	X	S	S	S	S	S	S	S
Yellow-billed Kite*	*Milvus aegyptius*	M	X	X	X[2]	X[1]	X	X	X	X	X	X	X	X[1]	X

*Carcass monitored with Ltl-5310 ACORN motion-triggered scouting cameras for scavenger activity: 1) Pied Crow, 2) Cape Fox, 3) Slender Mongoose, 4) African Polecat

** Camera malfunctioned during trial

Appendix 9: Probability of detection rates for small, medium and large carcasses in carcass persistence trial at a concentrated power facility, Northern Cape, South Africa

				Carcass survival rates					
Size	**No. of carcasses**	**No. undetectable**	**Total No. of days**	**daily**	**4 days**	**7 days**	**14 days**	**21 days**	**28 days**
Small	9	7	112.5	0.94	0.77	0.64	0.41	0.26	0.17
Medium	16	8	264	0.97	0.88	0.81	0.65	0.52	0.42
Large	9	0	252	1.00	1.00	1.00	1.00	1.00	1.00
Total	**34**	**15**	**376.5**	**0.98**	**0.91**	**0.84**	**0.71**	**0.60**	**0.51**