The influence of a changing environment on the breeding biology and diet of Kelp Gulls (*Larus dominicanus vetula*) in Plettenberg Bay, South Africa

Minke Witteveen

Dissertation presented for the degree of Master of Science

Percy FitzPatrick Institute of African Ornithology, DST/NRF Centre of Excellence,

Department of Biological Sciences, Faculty of Science,

University of Cape Town.

February 2015

Supervised by Professor Peter G. Ryan (University of Cape Town)

Co-supervised by Dr Mark Brown (University of KwaZulu-Natal)

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CONTENTS

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I know the meaning of plagiarism and declare that all of the work in the document, save for that which is properly acknowledged, is my own.

Minke Witteveen

Abstract

We live in a constantly changing world, where recent human-induced changes and climate change affect virtually every component of the Earth's surface and systems. Coastal ecosystems are particularly at risk, as one of the most utilised and urbanised of natural systems worldwide, as well as being at risk from sea level rise. This will degrade or even destroy many feeding and breeding sites. Those species colonising new habitats in an attempt to escape rising sea level and climate change related threats, will be competing for space with the growing human population and urbanisation. Although 97 of 346 seabird species (28%) are globally threatened, 57 (17%) have increasing populations, including 17 gulls (Larinae). The Kelp Gull *Larus dominicanus* is a cosmopolitan species with an increasing population worldwide. Kelp Gulls in southern Africa *L. d. vetula* are one of 15 seabird species that breed in the region, and one of only five breeding seabirds listed as Least Concern in the region.

Three Kelp Gull breeding colonies in Plettenberg Bay, Western Cape, were surveyed to provide an updated count for this area. A combination of direct counts and the trial use of an unmanned aerial vehicle (UAV), were used as methods of counting nests. The direct monitoring of nests allowed for the effect of different microhabitats on the breeding performance of Kelp Gulls to be investigated, which has implications for their ability to adapt to future habitat changes. The importance of anthropogenic food items in the diet of Kelp Gulls breeding in Plettenberg Bay was explored through the use of regurgitated pellets of indigestible matter, and chick regurgitations, and how this is reflected in the time spent in various areas as shown by GPS loggers and point counts in urban areas. Another aspect of the urban adaptation of Kelp Gulls is the incorporation of anthropogenic debris in their nests, which was examined at eight breeding colonies throughout the Western Cape.

Aerial surveys of Keurbooms Peninsula estimated 1373 breeding pairs in December 2012, and 1217 in November 2013. Lookout Beach had a minimum breeding population estimate of 50 pairs, and Robberg Island 18 breeding pairs. Gulls breeding on Keurbooms Peninsula did so in a variety of microhabitats, and multivariate microhabitat models show no significant effects on clutch size and average egg mass at laying. Overall trends in breeding performance variables show a positive relationship with vegetation cover and height, and a negative relationship with distance to nearest cover. Anthropogenic food items are an important component in adult Kelp Gull diet, predominating pre-breeding (98%) and breeding season (96%) regurgitated pellets, but this was not reflected in the limited time spent at the urban waste landfill. A much smaller proportion of chick regurgitations contained anthropogenic items (32%), suggesting a switch to more natural dietary sources when provisioning chicks. Anthropogenic debris items were recorded in nests at all eight colonies surveyed throughout the Western Cape, ranging from 4-67% frequency of occurrence. Some litter is used in nest construction, but many items are brought in with food to provision chicks. The incidence of litter was affected by a number of factors (nest type, location type, breeding period), but was not as strongly correlated with the distance to nearest urban waste landfill as expected.

My study shows that population estimates through the use of UAVs can prove useful once the correct protocols and ground truthing methods have been established. Estimates suggest a slight decline in Kelp Gull numbers in Plettenberg Bay but the cause of this, whether due to errors in aerial counts, part of the population not breeding, predation, or other factors, is unknown. Kelp Gulls in Plettenberg Bay are capable of breeding almost equally successfully in a variety of microhabitats, which suggests that they could breed successfully in future habitats. Anthropogenic food sources are important for Kelp Gulls in Plettenberg Bay, both during the non-breeding and breeding seasons, but are not favoured for feeding chicks. The high occurrence of anthropogenic items in Kelp Gull diet and nests is a concern, but reaffirms the adaptability and generalist nature of this species. Regardless of the habitat changes that this species may face, it would appear they would be able to adapt.

Acknowledgements

This dissertation would not be a reality had I been without the support of a number of extraordinary people who have put their time, energy and resources into my project, and my life, over the past two years.

Firstly, I would like to express my appreciation and thanks to my supervisors Prof. Peter Ryan and Dr. Mark Brown. Peter has taught me to think critically about my data collection (because with enough monkeys at a typewriter something will make sense), as well my writing and analyses. I have learnt so much through his copious editing of previous drafts, which has been invaluable to this dissertation. Mark has been a pillar of strength throughout the past years, smoothing over project wobbles, allaying fieldwork concerns, clarifying chronic confusion, and being a general go-to guy. His enthusiasm and commitment to this project has allowed me to be where I am today.

Just as my fieldwork season was starting, Shirley Van de Voorde arrived from The Netherlands for a five month internship with Mark at Nature's Valley Trust. A better fieldwork companion I could not have asked for! Thank you for your assistance in the field catching birds and monitoring nests, and mostly for your constant enthusiasm and positive attitude throughout the five months. I so enjoyed your company on the many adventures of a summer season in Plettenberg Bay!

A number of Plettenberg Bay locals have gone out of their way in supporting my project, for which I am ever grateful. Jason van Greunen made himself available on a number of days to fly his UAV, and GoPro cargo, over the breeding colony. Louis Ollerman donated the use of his boat for the duration of the project, which made trips to Keurbooms Peninsula infinitely easier. Errol and Elaine Finkelstein arranged the sale of a Parsun outboard motor, and provided excellent after sale service, and general boating advice. Elaine's cheerful smile and greetings did wonders after a long day in the field, as they cruised by for sundowners or stopped in for a chat. Butch Ballack from Butch's Outboard Services undertook all servicing of the motor for the duration of the project.

The CapeNature team in Plettenberg Bay were always cheerful and helpful, and were often happy to stop for a chat about my project when we met on Robberg hiking trails or the beach. Henk Nieuwoudt is thanked especially for his assistance in the beginning stages of this project.

A number of people at the FitzPatrick Institute are thanked for their varying contributions throughout the term of my MSc. Hilary Buchanan was a huge help in organising a variety of documents and Margaret Koopman was always willing to scan in and email any references I required, making being an off-campus student far easier than expected. Otto Whitehead was exceptionally helpful in introducing me into the world of CatTraqs, and the analyses thereof. Similarly, both Kim Stevens and Stefan Schoombie were more than willing to help me navigate the intricacies of using R to analyse GPS data, though this was eventually not used. Tim Reid was helpful during the initial stage of data analysis. Katya Mauff from the Statistical Consulting Service at UCT was instrumental in developing my understanding of R and how to analyse my data, which was always done with a smile and instructive scribbles. Any opinion, findings and conclusions or recommendations expressed in this document are those of the author and the Statistical Consulting Service (UCT) does not accept responsibility for the statistical correctness of the research results reported.

The financial assistance of the National Research Foundation (NRF) towards this research is hereby acknowledged. Opinions expressed and conclusions arrived at, are those of the author and are not necessarily to be attributed to the NRF. Funding was also received in the form of a Gordon Sprigg Bursary, for which I am thankful. BirdLife Plettenberg Bay is thanked for donating funding towards the running costs of this project, as well as organising and funding the first UAV flight done in December 2012. BirdLife South Africa's Ornithological Trust Fund also contributed funding toward the running costs of this project, for which I am grateful.

A number of people made my relocation to Plettenberg Bay easier, thanks to the Brown family, the van Eeden family, and Bettina and Michiel Meyer. Thank you to a number of close friends (Christine, Claire, Falon, Lindy, Lisa, Stacey) who have supported my endeavours and have endured hearing about Kelp Gulls, of all creatures, for the past two years! Finally, thank you to my family and Mr and Mrs Crossman, whose steadfast love and support got me through some dark days. Dad, I've conquered the elephant!

Chapter 1: General introduction

A changing world

We live in a constantly changing world, where recent human-induced changes are significantly altering every component of the Earth's surface: land, coast, ocean and atmosphere (Steffen et al. 2004; Steffen et al. 2011). Recent climate change has been attributed to anthropogenic causes (IPCC 2013), and is one of the better-known impacts of humans and their associated activities on planetary functioning. However, climate change is only a small piece of the bigger picture. Humans are altering biogeochemical cycles; terrestrial water cycles; water vapour flow; transforming land cover; destroying and modifying ecosystems; and reducing biological diversity (Steffen et al. 2004; Steffen et al. 2011). The term Anthropocene has been proposed as a new geological epoch or era in Earth history, showing the escalating effects of human-induced changes at a global scale (Crutzen 2002).

Urbanisation

The Earth's land cover is a finite resource that is fundamental to human wellbeing and the functioning of the Earth's system (Steffen et al. 2004; Seto et al. 2011). Urbanisation, the transformation of natural areas to urban use, is considered one of the most irreversible of human-induced land cover changes (Seto et al. 2011). Historically, urban centres were compact, densely occupied and their outer boundaries grew slowly and in a linear manner (Seto et al. 2010). Contemporary urbanisation and urban centres, by contrast, are increasingly vast and spread-out, growing rapidly in a complex manner (Ramalho & Hobbs 2012). The average growth of the proportion of the human population living in urban areas is 1% per year, yet the growth of urban areas far exceeds this (Seto et al. 2011; Aronson et al. 2014). Due to the vast, sprawling nature of contemporary urbanisation, natural areas become islands surrounded by a sea of urbanisation, ranging from high density built-up city centres to low density smallholdings (Ramalho & Hobbs 2012). The remaining natural areas need to be conserved as they may be able to support a large number of species (Aronson et al. 2014), as well as provide a diverse array of ecosystem services (Díaz et al. 2005).

In addition to being largely irreversible, urbanisation poses one of the worst threats to biodiversity (McKinney 2006), because it alters and fragments the natural land-cover; reduces and degrades habitats; food sources become concentrated pockets spread over a vast area, and may be artificial; anthropogenic disturbance increases; the predator community is altered; exotic species are introduced; chemical, light and noise pollution becomes more severe; and hydrological systems, biogeochemistry and climate are altered (Chace & Walsh 2006; Grimm et al. 2008; Sol et al. 2013; Aronson et al. 2014). Environmental changes can be drastic and rapid, and a species' tolerance and ability to adapt may be surpassed, resulting in a local extinction (Grimm et al. 2008; Sol et al. 2013). However, some small to medium-sized vertebrates are able to adapt to urban environments (Ditchkoff et al. 2006). Species have been able to adapt to new stresses (noise and light pollution), alternate food sources (roadkill, landfill sites, garden feeders), altered predator community (often reduced human persecution and natural predation), and alternate breeding sites (often buildings) (Marzluff 2001; Luniak 2004; Chace & Walsh 2006; Ditchkoff et al. 2006; Hunter 2007).

Understanding the manner in which ecosystem structure, functioning and service provision is affected by a rapidly expanding human population, and how species may adapt to these changes, is especially important in coastal areas due to concentrated urbanisation effects in coastal zones (Coverdale et al. 2013).

Coastal development

Humans have a long history of settling in coastal areas due to a rich supply of resources and trading opportunities (McGranahan et al. 2007). Coastal development and growth is ongoing in many areas (Abel et al. 2011), making coastal areas among the most populated habitats (McGranahan et al. 2007). Despite coastal areas within 10 m of sea level comprising only 2% of the Earth's surface area, they contain 10% of the world's population, and 13% of the world's urban population (McGranahan et al. 2007).

Coastal ecosystems are one of the most utilised, urbanised and thereby threatened of natural systems worldwide (Barbier et al. 2011; Moser et al. 2012). They provide several ecosystem services including carbon sequestration, coastal protection, erosion control, generation of raw materials and food, provide breeding grounds for fish, crabs, shellfish (among others), and water purification (Barbier et al. 2011). Uncontrolled human population growth, economic development, and urbanisation in coastal areas are leading to ecosystem degradation, and the slow collapse of ecosystem services, exacerbated by climate change (Moser et al. 2012; Wong et al. 2014).

Climate change

The fact that the global climate is changing is unequivocal (IPCC 2013) and a result largely of anthropogenic activities (Cubasch et al. 2013). Global climate change is one of the most severe threats to biodiversity (Wormworth & Mallon 2006; Shoo et al. 2013), estimated to threaten 18-35% of species with extinction by 2050 (Thomas et al. 2004). Indicators of climate change include increased atmospheric water vapour, glacier retreat, shrinking ocean and land ice coverage, precipitation changes, global mean sea level rise, increasingly severe weather events, and increasing global surface temperature (Cubasch et al. 2013). These changes are expected to intensify, although accurate predictions are uncertain due to the roles of dynamic future anthropogenic and natural forcings, inadequate understanding and modelling of the climate system, and internal climate variability (Collins et al. 2013). Nevertheless, changes predicted by 2100 include mean sea level rise of 0.4-1.2 m (Hinkel et al. 2014); mean surface air temperature rise of 1.0-3.7°C; and an increase in ocean surface (top 100 m) temperature of 0.6-2.0°C (Collins et al. 2013).

The rising tide

Two of the greatest climate change related threats to coastal ecosystems are sea level rise and ocean temperature changes (Wong et al. 2014). Coastal areas can also expect increasing occurrences of submergence, coastal flooding, erosion, and storm surges as a result of more frequent and severe storm events (Wong et al. 2014). Without the intervention of protective measures, hundreds of millions of people living in coastal areas are expected to be displaced by 2100 (Hinkel et al. 2014; Wong et al. 2014). Similarly, the increases in climate change related natural disasters will destroy many feeding and breeding sites of coastal-breeding species, including marine birds (Galbraith et al. 2002; Wormworth & Mallon 2006).

Urban development should be planned with sea level rise in mind, where buildings are made to be moveable, or on stilts, where eventual retreat behind natural or man-made defences may be required (Abel et al. 2011). However, just as urban development will be retreating, coastal ecosystems too will begin to colonise inland habitats which will be met with competition by moving and expanding development (Abel et al. 2011). As coastal ecosystems are one of the most threated by climate change (Moser et al. 2012), marine birds are especially at risk (Wormworth & Mallon 2006).

Climate change and its various interactions and underlying mechanisms have been the subject of extensive research, which could be aided through the use of a model species (Møller et al. 2010). Weather affects avian metabolic rate and many aspects of their ecology and behaviour (Crick 2004). As most birds are able to fly they are highly mobile, and are thus less constrained than plants and most terrestrial animals, and can be highly reactive to environmental changes (Wormworth & Şekercioğlu 2011). Their mobility may allow birds to have a lower extinction rate compared to other, less mobile species (Simmons et al. 2004). Birds are easy to observe and identify, and are followed by millions of scientists, birdwatchers and laymen, which has in part led to the vast knowledge of their biology (Møller et al. 2010). This also has resulted in changes in bird abundance, distribution and behaviour, thought to be at least in part in response to climate change, being among the most well-documented changes in the animal world (Wormworth & Mallon 2006; Møller et al. 2010; Hockey et al. 2011). As a result, birds are considered forerunners as bio-indicators of climate change (Wormworth & Mallon 2006).

Marine birds

Despite 60% of the world's surface being covered by oceans, only a small percentage (~3%) of the world's birds exploit oceanic resources (Croxall 1987). Seabirds, more than other avian groups, have been seen to be important first responders to climate change (Wormworth & Mallon 2006). Changes in range distributions of many seabirds have been attributed to fluctuations in marine resources caused by climate change (Wormworth & Mallon 2006; Crawford et al. 2008). These range distribution shifts, for the most part, have been consistent in their direction, similar in timing, and have been widely reported in a number of species leading to the conclusion that they are climate change induced (Wormworth & Mallon 2006; Crawford et al. 2008). However, caution is needed when attributing species range shifts, and other responses, to climate change as often these effects are confounded by other anthropogenic factors (Hockey & Midgley 2009; Hockey et al. 2011). Other aspects of avian lifecycles that have been affected by climate change include changes in migratory times, breeding dates, breeding biology, body size, timing of moult, as well as changes in predator-prey and host-parasite interactions (Wormworth & Mallon 2006; Brown & Oschadleus 2009; Møller et al.

2010; Møller 2013). Although not all avian species are equally vulnerable to the effects of climate change, those with complex life cycles are particularly susceptible (Møller 2013).

Gulls

Despite 97 of 346 seabird species (28%) being globally threatened, 17% have increasing populations, including 17 gulls (Larinae, Croxall et al. 2012). Due to their generalist nature and ability to adapt to and exploit an urban environment, many gulls have benefited from an increasing and expanding urban population and related activities (Yorio & Giaccardi 2002; Duhem et al. 2008; Lisnizer et al. 2011). Some gull species have managed to adapt to the urban environment so efficiently that in some areas they are considered to be pests (Belant 1997; Auman et al. 2011). Interaction/conflict areas include: airports where birds roost or forage posing bird-aircraft collision hazards (Rochard & Horton 1980; Belant 1997); buildings where birds roost or nest causing damage to buildings due to chemical erosion by gull droppings and water damage due to water drains blocked by nesting material (Vermeer et al. 1988; Belant 1997); beaches where faeces contaminate the water (Engeman et al. 2012); and a variety of public places including restaurants where they may transmit parasites and pathogens (Hatch 1996), and be a nuisance by stealing food (Belant 1997).

Kelp Gull

The Kelp Gull *Larus dominicanus* is listed as Least Concern globally with an overall increasing population (BirdLife International 2014) which has been attributed to their ability to adapt to an urban environment and associated activities (Brooke & Cooper 1979b; Steele & Hockey 1990; Bertellotti et al. 2001; Frixione et al. 2012). It is a cosmopolitan species, breeding in southern Africa, South America, New Zealand, Australia, coastal Antarctica, sub-Antarctic islands, and southern Madagascar (Brooke & Cooper 1979a). Six subspecies are recognised: *L. d. judithae* Jiguet, 2002 (southern Indian Ocean), *L. d. austrinus* Fleming, 1924 (Antarctic Peninsula), *L. d. antipodus* G.R. Gray, 1844 (New Zealand), *L. d. melisandae* Jiguet, 2002 (Madagascar), *L. d. dominicanus* Lichtenstein, 1823 (Brazil), and *L. d. vetula* Bruch, 1853 (southern Africa) (Jiguet et al. 2012). Genetic evidence suggests that *L. d. vetula* are the basal group, and are most closely related to nominate birds from South America (Sternkopf 2011). Morphologically, *vetula* differs from nominate birds in the bare part colouration of breeding birds: dark (not pale) iris, greyish green (not yellowish) legs, and orange-yellow (not red) orbital ring (Brooke & Cooper 1979a; Jiguet et al. 2012).

L. d. vetula is one of 15 seabird species that breed in southern Africa (Cooper et al. 1984; Whittington et al. 1999), and only one of five species listed as Least Concern in the region (BirdLife South Africa 2014). Although over the past 15 years experiencing an overall population decline in South Africa, some breeding colonies are increasing (Whittington et al. in press). The population decline has been attributed to the predation of chicks by Great White Pelicans *Pelecanus onocrotalus* and the re-implementation of culling programs, and at some colonies, observed increases have been attributed in part to the supplementary food made available through expanding urbanisation, primarily fishery discards and urban waste landfills (Steele 1992; Crawford et al. 2009; Whittington et al. in press).

Dissertation overview

With so many species unable to cope with the pressures of a changing environment, from climate change, anthropogenic environmental alteration, and urbanisation effects, it becomes important to understand those species that are able to adapt, and even thrive under these conditions. Although it may seem more important to elucidate causes for species decline, and how to save those species that are threatened, it is equally important to monitor thriving species, to identify the forces driving their population increase and potentially mitigate before the species becomes a pest, as well as to identify potential problems before population declines become a reality.

This dissertation comprises four substantive chapters written as stand-alone papers to facilitate subsequent publication. Repetition has been avoided where possible. Chapter 2 reports on the population estimates and breeding status of Kelp Gulls breeding in Plettenberg Bay. Kelp Gulls are present in large numbers in Plettenberg Bay, Western Cape, and when last counted in 2006 (P. Whittington, in litt.) their population was decreasing; an updated count was necessary. In addition to providing current population estimates and current breeding status of the populations, this study also trialled the use of an unmanned aerial vehicle (UAV) as a method of counting breeding pairs.

Kelp Gulls breed in a variety of microhabitats in Plettenberg Bay and this allowed an opportunity to investigate the breeding performance of pairs in different microhabitats which has important implications for the successful acclimation to future climate change and urbanisation induced habitat changes. Chapter 3 explores the effects of various nest site variables on Kelp Gull breeding performance namely clutch size, average egg mass at laying and daily survival rate (DSR). It is hypothesised that there will be differences in clutch size, egg mass at laying, and DSR over different microhabitats, where nests in open microhabitats (no shelter, short vegetation) will have smaller clutch sizes, egg mass at laying, and DSR compared to nests in more sheltered microhabitats (among tall vegetation).

The Kelp Gull's adaptation to urban environments makes it a useful study species to investigate the extent to which urban environments are used to forage, and anthropogenic food items have replaced natural ones. Chapter 4 assesses the effects of urbanisation on diet, and where gulls spend their time. GPS loggers were used to record in which areas breeding birds spent their time, and were supplemented by weekly counts of gulls at three urban foraging areas around Plettenberg Bay. Regurgitated pellets of indigestible prey remains were used to determine diet. It is hypothesised that of the time not spent at the nest, birds would mostly be in urban areas, and this would be reflected in their diet where the majority of items would be of anthropogenic origin. Pre-breeding season pellets will have a higher incidence of anthropogenic items than breeding season. Furthermore it is hypothesised that counts at urban foraging areas would increase over the breeding season.

Another aspect of the urban adaptation of Kelp Gulls is the incorporation of anthropogenic debris in their nests. Chapter 5 investigates the use of litter in the nests of Kelp Gulls breeding at eight colonies in the Western Cape in relation to colony location, nesting microhabitat, and breeding stage. It is hypothesised that colony location, nesting microhabitat, and breeding stage would affect the frequency of occurrence of anthropogenic debris items in nests. Nests in vegetated areas would use surrounding vegetation to build nest bowls with minimal debris, while nests in unvegetated areas would collect items, including a high incidence of debris, to use as nesting material. Finally, nests that were sampled during the chick rearing stage would have a higher occurrence of anthropogenic debris in the nest due to the accumulation of items through food provisioned by the adult, as compared to nests sampled during incubation. The dissertation concludes with a synthesis of the main findings (Chapter 6).

With the exception of some field-work and assistance with data analysis, this work is all my own. My supervisor Mark Brown facilitated the UAV count in December 2012 (Chapter 2), and my supervisor Peter Ryan collected nest plastics from five Kelp Gull breeding colonies in the Western Cape (Chapter 5). Katya Mauff from the Statistical Consulting Service advised me on R statistical analyses during the write-up period.

During my MSc I co-authored other publications relevant to this dissertation, although they are not included here. These include a review of the status of Kelp Gulls in South Africa (Whittington et al. in press. Waterbirds), and a study on the effect of human disturbance on African Black Oystercatchers *Haematopus moquini* and Kelp Gulls (Van de Voorde et al. 2015. Ostrich). I also authored a short note on pseudo-egg and exotic egg adoption by Kelp Gulls (Witteveen et al. 2015. African Zoology).

Chapter 2: The status of Kelp Gulls breeding in Plettenberg Bay

Abstract

Kelp Gulls *Larus dominicanus* have been recorded as increasing in many areas of the world, although it appears that the African race *L. d. vetula* has been experiencing a population decrease over the past 15 years, with large changes in population distribution. Kelp Gulls breed at three sites in Plettenberg Bay, South Africa. Aerial surveys of Keurbooms Peninsula reveal 1373 breeding pairs in December 2012, and 1217 in November 2013. Lookout Beach had 62 active nests (eggs) over the 2013/14 breeding season, with a minimum population estimate of 50 pairs. At Robberg Island, 38 nests were active over the 2013/14 breeding season, with a minimum population of 18 pairs. On Keurbooms Peninsula, 352 eggs were laid in 184 monitored nests (average clutch size 1.91 ± 0.69 eggs), of which 48% were lost prior to hatching (presumed predated). At Lookout Beach, 62 nests yielded 121 eggs (1.95 ± 0.61), of which 53% were lost, and at Robberg Island 38 nests yielded 61 eggs (1.61 ± 0.68), of which 98% were lost. Daily survival rates (DSR) of nests were 0.976, 0.979, and 0.889 for Keurbooms Peninsula, Lookout Beach, and Robberg Island respectively, although clutch size significantly affected these values with larger clutch sizes showing higher DSR. Relative to the 2003/4 counts the breeding population at Keurbooms Peninsula has slightly decreased, potentially due to movement of pairs to breed on Lookout Beach. Due to landscape changes of Keurbooms Estuary the Lookout Beach location became available and hosts a Kelp Gull breeding colony for the first time. The breeding population at Robberg Island has decreased, most likely due to the presence of natural predators such as mongooses and otters.

Key words: breeding status, hatching success, population estimate, UAV counts

Introduction

Many seabirds are ground-nesting, colonial species and their populations can be monitored at their breeding colonies (Piatt et al. 2007; Huffeldt & Merkel 2013). One of the basic parameters of colonial seabird monitoring is that of breeding population development, reflected as the number of birds present at the breeding site (Piatt et al. 2007; Huffeldt & Merkel 2013). Besides colony size, breeding performance is also a useful measure to monitor in breeding colonies, as breeding performance can reflect the status of aspects of the natural environment (Frederiksen et al. 2007).

Kelp Gulls occur in many temperate and sub-Antarctic areas of the Southern Hemisphere (Jiguet et al. 2012). There are estimated to be 3.3–4.3 million Kelp Gulls worldwide (BirdLife International 2014), and most populations are increasing (Coulson & Coulson 1998; Yorio et al. 1998; Branco et al. 2009; Dantas & Morgante 2010; Abel et al. 2011; Lisnizer et al. 2011; Whittington et al. in press). Kelp Gulls are opportunistic predators that have adapted to exploit urban environments and associated food sources (particularly fisheries and landfill sites) (Yorio & Giaccardi 2002; Crawford & Hockey 2005). It is this ability to adapt to urbanisation that makes investigations into population change of this species so useful (Sander et al. 2006). However, some gull populations have begun to cause conservation and health problems (Hatch 1996; Bosch et al. 2000; Tjorve & Underhill 2008; Ramos et al. 2010; Engeman et al. 2012; Pichegru 2013), another reason why population monitoring is important.

Remote photography or videography has revolutionised colonial bird counts. Unmanned aerial vehicles (UAVs), fixed- or rotary-wing aircraft that are flown remotely (Hardin & Jensen 2011), have begun to transform ecological research, especially spatial ecology (Anderson & Gaston 2013). Aerial photography using an UAV has been used successfully to quantify colonially nesting birds (Jones et al. 2006), obtaining accurate, georeferenced data for a Black-headed Gull *Chroicocephalus ridibundus* breeding colony with minimal disturbance (Sardà-Palomera et al. 2012).

Previous Kelp Gull research in South Africa has focused on population size, movement and distribution, providing a good record of population change (Steele & Hockey 1990; Crawford et al. 1997; Calf et al. 2003; Whittington et al. 2006; Crawford et al. 2007; Crawford et al. 2009; Whittington et al. in press). The Plettenberg Bay Kelp Gull population was last quantified at 931 pairs in 2006 (P. Whittington, in litt). Plettenberg Bay breeding colonies are on the mainland, one of which, Keurbooms Peninsula, supported the largest mainland Kelp Gull breeding colony in South Africa when counted in 2003 (Whittington et al. in press). This chapter reports population trends at the three colonies in Plettenberg Bay and interprets these trends in terms of inter-colony differences in breeding success. In addition, the use of an UAV to conduct aerial population estimates was trialled for the first time in Africa.

Materials & methods

Study sites

Kelp Gulls currently breed at three sites in the Plettenberg Bay region (Fig. 1). The Keurbooms Peninsula (34°02.4'S, 023°23.1'E) forms part of a 39 ha provincial nature reserve, the Keurbooms River Seagull Breeding Colony, administered by CapeNature. Vegetation in the breeding colony is predominantly Sprawling Duneweed *Tetragonia decumbens* and Sea Wheat *Thinopyrum distichum*, interspersed with small patches of Beach Pumpkin *Arctotheca populifolia*. Farther into the colony there are patches of Dune Gazanias *Gazania rigens* and large patches of Goat's Foot *Ipomoea pes-caprae*. Many birds nest on the beach shoreline, often collecting dried Cape Eelgrass *Zostera capensis* to use as lining for their nests.

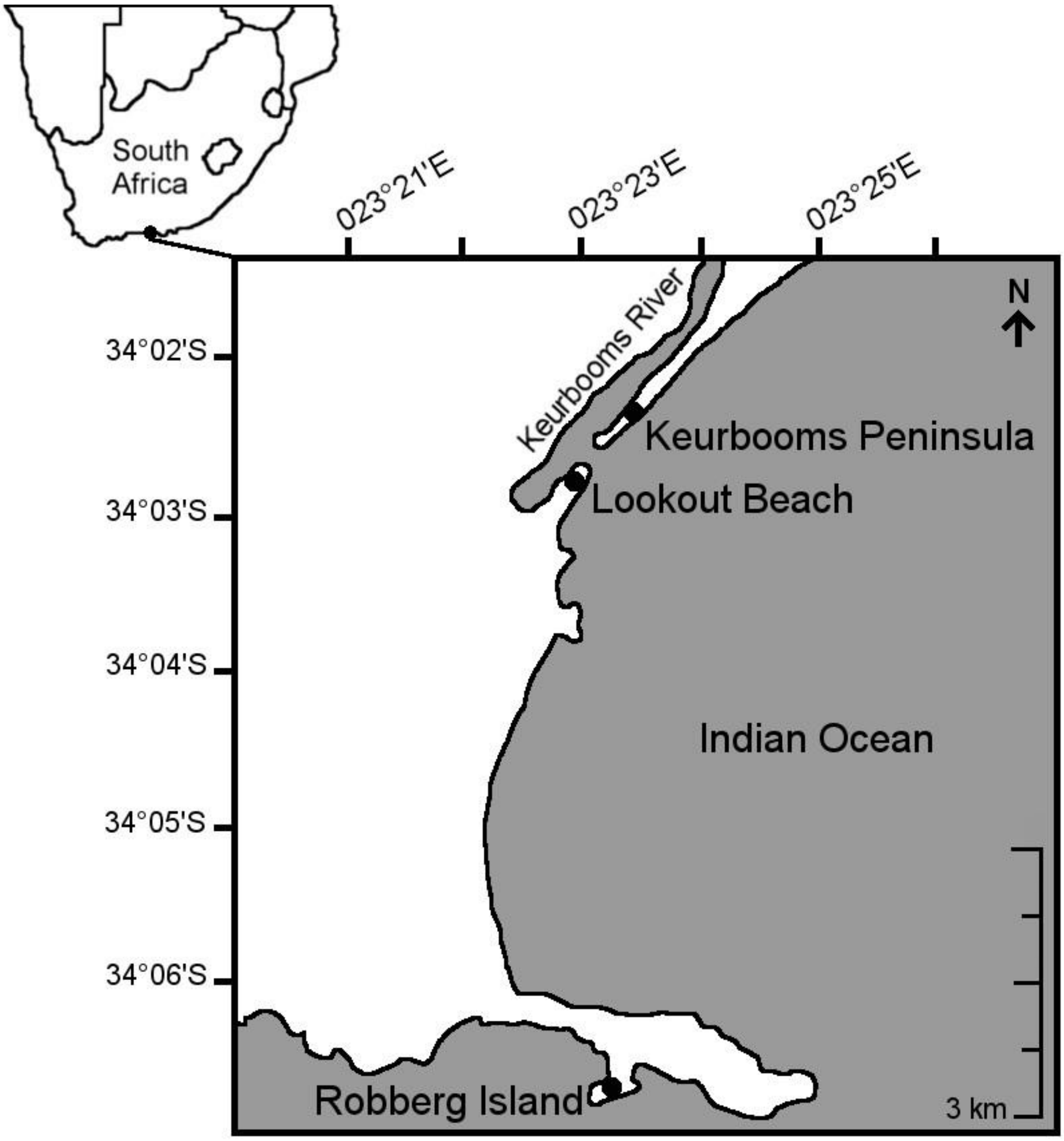

Fig. 1. Kelp Gull breeding colonies in Plettenberg Bay, Western Cape, South Africa.

Lookout Beach (34°02.7’S, 023°22.8’E) is not a formally protected area, and has only recently become viable to support a breeding population of Kelp Gulls. Historically it was heavily vegetated, including sections of dense trees and bush, but in 2007 the Keurbooms River flooded and the entirety of Lookout Beach was washed away. Over the past few years Lookout Beach has been built back into a sandbank by the tides, and has since been colonised by coastal vegetation. The dunes are predominantly vegetated with Beach Pumpkin, Sprawling

Duneweed, and Sea Wheat which are the main components of gulls' nests; there are also dispersed patches of Dune Gazania. Birds make their nests on the slightly raised, vegetated, dunes.

Robberg Island (34°06.5'S, 023°23.2'E) is part of Robberg Nature Reserve (RNR), another provincial reserve administered by CapeNature. The island is connected to the mainland by a tombolo that is flooded occasionally. It is exposed to more extreme weather, mainly high winds, than the other two colonies, as it lies on the south-facing, exposed side of Robberg Peninsula. Robberg Island is composed mostly of sandstone, with Soutbossie *Chenolea diffusa* and Dewplant *Disphyma crassifolium* interspersed with patches of Dune Gazania.

Population estimates

Two methods of population estimation were employed at the three breeding colonies. Due to the size and density of the breeding colony on Keurbooms Peninsula, counts of the nests on foot would result in a high level of disturbance. As a result an UAV was used to take a series of aerial photographs of the colony which were organised into a composite and nesting gulls were counted. Nesting birds were identified as individuals which were sitting, and where two birds were directly adjacent to each other, only one was counted. Ground truthing of an aerial image was done to check the accuracy of nest counts done off aerial images of the Keurbooms Peninsula breeding colony by comparing the nests identified from an aerial image of the tip of the colony against the GPS locations of nests in the same area identified through direct counts (see pg. 18); from this a correction factor was calculated.

The first flight was undertaken in December 2012 by SteadiDrone (www.steadidrone.com) using a battery operated EPO (expanded polyolefin) fixed-wing UAV (SteadiDrone Seagull, SteadiDrone, Knysna, South Africa) with a wingspan of 1.65 m. The

UAV was hand-launched, and needed a few metres of flat area to land as it had no undercarriage. It flew on an automated path that was synchronised with a base station on land. The UAV carried a Canon PowerShot S100 camera with a 24-120 mm lens (F2-5.9) and 12.1 megapixel resolution which was located in a custom designed box pointing directly down. During the flight the camera was set in wide-angle lens position (24 mm), taking an auto-focus image at highest resolution every two seconds.

Due to cost constraints, aerial surveys in 2013/14 were undertaken by a local hobbyist manually flying a battery operated fixed-wing foam UAV (Sky Surfer, Air Fly Limited, China) with a wingspan of 1.4 m. The UAV was hand-launched and caught on landing, as its landing gear did not allow the UAV to land safely on the sand. The UAV carried a GoPro Hero3 Black camera with a fixed-focus wide angle lens (170°) and five megapixel resolution, which was located in a custom designed box in the UAV pointing directly down. During the flight the camera was set to take images at highest resolution on continuous shoot mode (five frames per second).

As visual contact could not be maintained on the manually flown UAV during the 2013/14 flights the entire breeding colony was not covered, whereas the automated 2012 flight covered the entire breeding colony (Fig. 2). To compensate for the areas not surveyed in 2013/14 (60-70% of the area covered in 2012), the numbers of nests in unsurveyed areas were extrapolated based on distribution of nests in the 2012 count. It was assumed that the spread of nests and nest densities in the breeding colony were similar over the breeding seasons as there was minimal vegetation change and no extensive land changes resulting in similar nest site selection between breeding seasons. A measure of population change was calculated by dividing the count of nests from the 2013/14 survey by the counts of nests in the equivalent area from the 2012 aerial survey, this was then multiplied by the 2012 nest count of the entire breeding colony to give an extrapolated nest count of the entire breeding colony (Table 1). It is the extrapolated count of active nests which is multiplied by the correction factor calculated from ground truthing. Minimal habitat changes were observed between the 2012/13 and 2013/14 breeding seasons, allowing for landmark recognition to determine how much of the original area was covered in flights subsequent to that of December 2012.

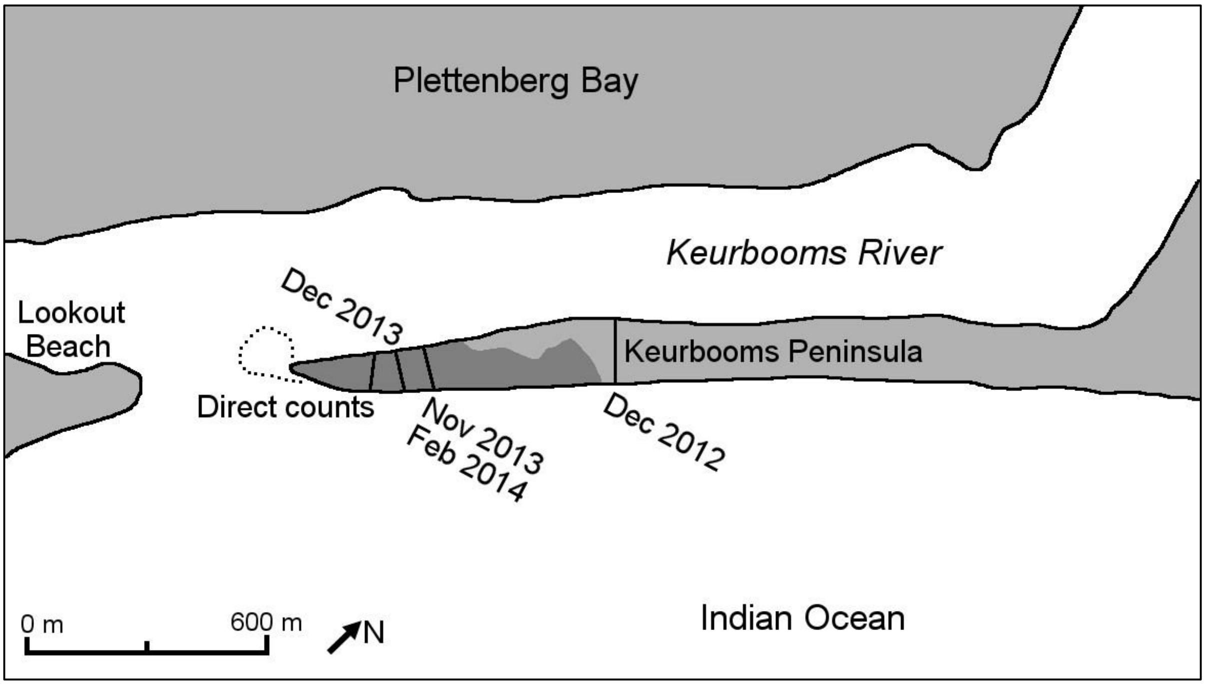

Fig. 2. Map of Keurbooms Peninsula showing the area occupied by breeding Kelp Gulls (dark grey area). Dotted area denotes an unvegetated sandbar on which a small number of gulls bred. Lines show the area covered by four UAV counts undertaken between December 2012 and February 2014, as well as the area covered by direct counts.

In addition to aerial counts, direct counts of nests were done. Throughout September 2013 to February 2014 Keurbooms Peninsula was visited every 3.6 ± 1.7 (mean ± SD) days, Lookout Beach was visited every 4.9 ± 2.8 days, and Robberg Island was visited every 8.1 ± 2.3 days. Every Kelp Gull nest was marked and monitored on Lookout Beach and Robberg Island but due to the size and nest density of the breeding colony on Keurbooms Peninsula only the tip of the peninsula, and surrounding beach shoreline, was monitored by direct counts (Fig.

2). Within the selected study zone, nest selection for monitoring was random, until late in the breeding season (January) when late breeding nests were specifically searched for and monitored farther into the colony as most chicks had fledged, reducing disturbance concerns.

Clutch size and nest success

Nests were marked using numbered 5x5 cm plastic squares attached to wire standing 50 cm high roughly 20 cm from the nest bowl. Some nests were marked as developing nest bowls whereas others were located already containing eggs (some of which could have already been lost). The number and status of eggs or chicks were recorded during each visit. Visits were conducted during early morning or late afternoon to avoid disturbance during the heat of the day, and all surveys were conducted as quickly and quietly as possible, remaining on the fringes of the colony when possible.

Clutch size was determined as the largest number of eggs simultaneously observed in the nest bowl, and was checked every 3-4 days to exclude incomplete clutches, as Kelp Gulls lay eggs 2-3 days apart (Crawford & Hockey 2005). Each egg was individually marked to facilitate differentiation, which allowed predated and newly laid eggs to be documented. Differences in clutch size were tested between locations using an analysis of variance (ANOVA) in R (version 3.1.2, R Foundation for Statistical Computing 2014).

Calculating apparent hatching success by dividing the number of eggs hatched by the number of eggs laid results in the loss of time-specific effects and inaccurate results (Mayfield 1975). To take this into account nest success was measured as daily survival rate (DSR) using the nest survival model (Dinsmore et al. 2002) in program MARK (White & Burnham 1999). Location-specific estimates of DSR were calculated using constant daily survival models (Mayfield 1975; Johnson 1979). An intercept only model was created for each location using a sine link function. Clutch size specific estimates of DSR were also of interest. Clutch size was described using three dummy variables as individual covariates where the record was coded as either belonging to the clutch size covariate (indicated by a 1) or not (indicated by a 0). To calculate clutch size dependent estimates of DSR a model using a reduced design matrix and logit link function was used.

A likelihood-ratio test was used to determine whether the model including clutch size provided a better fit to data (White & Burnham 1999). Estimated hatching success was calculated by raising the DSR estimate to the power of the incubation period (Mayfield 1975), assumed to be 27 days (Crawford & Hockey 2005).

As it was not possible to follow breeding success much beyond the hatching stage because chicks become mobile, and are particularly sensitive to disturbance at this stage, fledging success was not calculated.

Results

Population estimates

Breeding Kelp Gulls tend to fly up when disturbed, mobbing any intruder to the colony (Crawford & Hockey 2005). Most gulls remained on the ground when the UAV flew over the colony, and so did not appear to be greatly affected by its presence. Only a small number of birds were recorded flying in the photos from the UAV flight (2.2% ± 1.6%, n = 4), typical of when the colony is not disturbed.

Ground truthing of the point of Keurbooms Peninsula showed that 37 nests were correctly identified as active (either incubating or chick rearing) from an aerial photo confirmed through direct counts, although two nests active in the field were not identified from the photo (Fig. 3). An additional 12 nests were identified on the aerial photo which were not active nests in the field (Fig. 3), while 15 birds were correctly identified as not actively breeding from the photo confirmed in the field. Thus, the probability of a false-negative is taken as the number of falsely identified non-breeding birds divided by the sum of falsely identified non-breeding birds and correctly identified non-breeding birds, resulting in a 12% false-negative probability. Similarly, the probability of a false-positive is taken as the number of falsely identified breeding birds divided by the sum of falsely identified breeding birds and correctly identified breeding birds, resulting in a 24% false-positive probability. As a result of ground truthing it was found that the number of nests counted from aerial photos were over-estimated by 20% (49 nests identified, but only 39 nests were active in the field), and a correction factor of 0.80 was applied to all aerial counts of active nests.

The first eggs were found in early October, while the first chicks were found in early November. By December the colony was mostly provisioning chicks with a few birds incubating eggs. The aerial survey of Keurbooms Peninsula in December 2012 had a higher count of active nests (1373 corrected count) than that in December 2013 (642 corrected count of active nests) (Table 1). The count of active nests in 2013/14 peaked in November (1217 corrected count of active nests), falling to 87 active nests (corrected count) by February 2014 (Table 1). In the 2013/14 season 62 active nests (incubating or chick rearing) were monitored on Lookout Beach, of which 50 was the maximum count of simultaneously active nests. At Robberg Island, 38 active nests were monitored (maximum simultaneous count 18 nests). The maximum count of simultaneously active nests was used as the minimum population estimate for these two locations as the existence of re-nesting after a failed attempt cannot be ruled out, and summing both attempts would overestimate the population. These counts show that over the past decade the breeding population at Robberg Island has been experiencing a gradual decrease (Table 2). Keurbooms Peninsula breeding colony has also experienced a slight decline relative to the 2003/4 count, if a large drop in 2006/7 is excluded. Relative to the 2003/4 count however, the breeding colony has experienced an increase.

Table 1. Results of aerial surveys of active Kelp Gull nests on the Keurbooms Peninsula.

Date	Active nests from photos	Equivalent in 2012	Extrapolated active nests	Corrected active nests
2012-12-01	1716	-	-	1373
2013-11-10	608	686	1521	1217
2013-12-08	287	614	802	642
2014-02-09	42	661	109	87

Table 2. Trends in Kelp Gull numbers breeding at three locations in Plettenberg Bay since 1978. The absence of values show no count was conducted.

	Breeding season				
Location	1978/79	2003/4	2006/7[d]	2012/13[e]	2013/14[e]
Keurbooms Peninsula	250[a]	1453[c]	931	1373	1217
Lookout Beach	0[b]	0[b]			50
Robberg Island	18[a]	65[c]	46		18

[a]Crawford et al. 1982.

[b]Whittington et al. in press.

[c]Whittington et al. 2006.

[d]P. Whittington, in litt.

[e]This study. Maximum count for the breeding season displayed.

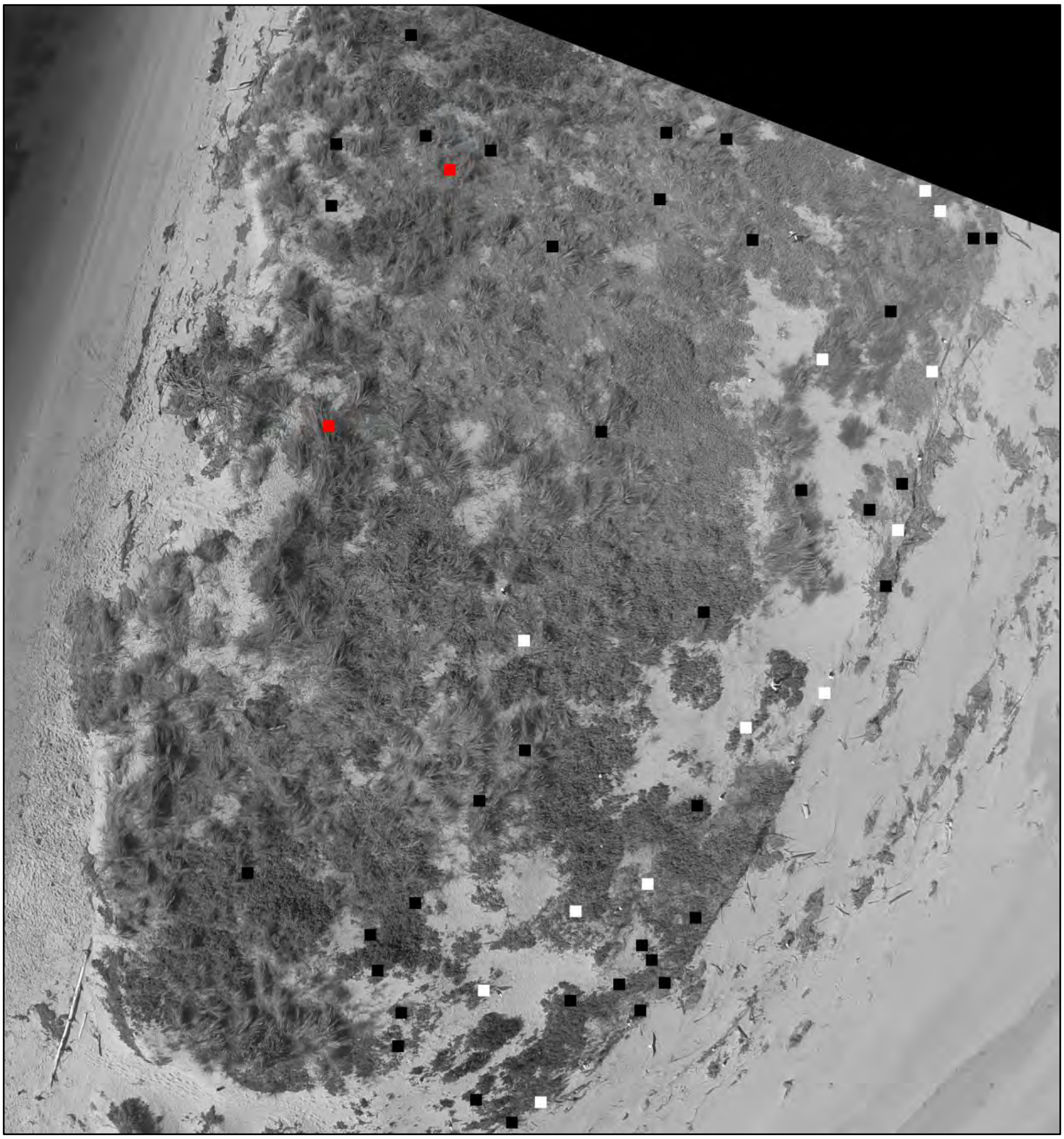

Fig. 3. Ground truthing of an image from November 2013 UAV count of the Kelp Gull breeding colony on Keurbooms Peninsula in Plettenberg Bay, Western Cape. Black squares show active nests (incubating or chick rearing) correctly identified in the photo. Red squares show active nests not identified from the photo. White squares show nests identified from the photo which were not identified as active in the field.

Clutch size and nest success

A total of 62 and 38 nests contained eggs on Lookout Beach and Robberg Island, respectively, while a subset of 184 nests with eggs was monitored on Keurbooms Peninsula (Table 3). Clutch size varied from 1-3 eggs and did not differ among colonies ($F_{2, 275} = 2.046$, $p = 0.131$, Table 3). Apparent hatching success (chicks hatched divided by eggs laid) was lowest on Robberg Island, where only one egg survived to hatching (1.6%), intermediate at Lookout Beach (40.5%) and highest on Keurbooms Peninsula (46.3%, Table 3). On Robberg Island the high incidence of cracked eggshells frequently observed near nests (pers. obs.) suggests a high predation rate.

Table 3. Details of the 2013/14 Kelp Gull breeding season at three colonies in Plettenberg Bay, Western Cape.

	Keurbooms Peninsula	Lookout Beach	Robberg Island
Nests marked	249	79	54
Nests abandoned pre-laying	60	12	16
Nests flooded prelaying	5	5	0
Nests containing eggs	184	62	38
Eggs laid	352	121	61
Average clutch size ± SD	1.91 ± 0.69	1.95 ± 0.61	1.61 ± 0.68
Eggs lost	168	65	60
Eggs addled	21	7	0
Chicks hatched	163	49	1
Average brood size ± SD	1.63 ± 0.63	1.36 ± 0.49	1

The models taking clutch size effects into consideration when estimating nest DSR received all the support (AICc weight of 1.0) for Keurbooms Peninsula and Lookout Beach analyses, whereas for Robberg Island both models are similarly weighted with substantial support for both (Table 4). For both Keurbooms Peninsula and Lookout Beach a likelihood ratio test showed that the best model fitted the data significantly better than the reduced model ($\chi^2 = 45.07$, d.f. = 2, $p < 0.001$, and $\chi^2 = 17.35$, d.f. = 1, $p < 0.001$, respectively). However, both models provided a similar fit to the data from Robberg Island ($\chi^2 = 3.59$, d.f. = 2, $p = 0.166$).

Table 4. Results for constant daily survival models for Kelp Gull nests in Plettenberg Bay, Western Cape.

Model	K^a	AICc	ΔAICc	AICc w^b	Deviance
Keurbooms Peninsula	-	-	-	-	-
$DSR_{constant}$ + clutch size	3	387.48	0.00	1.00	381.47
$DSR_{constant}$	1	428.54	41.07	0.00	426.54
Lookout Beach	-	-	-	-	-
$DSR_{constant}$ + clutch size	2	153.65	0.00	1.00	149.64
$DSR_{constant}$	1	169.00	15.35	0.00	167.00
Robberg Island	-	-	-	-	-
$DSR_{constant}$	1	84.64	0.00	0.56	82.63
$DSR_{constant}$ + clutch size	3	85.15	0.50	0.44	79.04

[a]Number of parameters.

[b]AICc weight.

Estimated hatching success (DSR extrapolated across the 27-day incubation period) was similar at Lookout Beach (56.4%) and Keurbooms Peninsula (51.9%), with both being markedly higher than the hatching success at Robberg (4.2%, Table 5). Estimated hatching success varied with clutch size, increasing as clutch size increased at both Keurbooms Peninsula (15.8-80.5%) and Lookout Beach (19.4-100%, Table 5). Due to the high rate of egg loss on Robberg, the same trend is not observed; estimated hatching success was highest in one-egg clutches (9.9%) and lower, but identical, for two- and three-egg clutches (5.4%, Table 5).

Table 5. Constant daily survival rates (DSR) and estimated hatching success for Kelp Gull clutches at three breeding colonies in Plettenberg Bay, Western Cape.

Clutch size	DSR ± SE	Estimated hatching success (%)	95% Confidence Interval	
			Lower	Upper
Keurbooms Peninsula	-	-	-	-
All data	0.976 ± 0.003	51.9	43.9	59.6
1 egg clutch	0.934 ± 0.010	15.8	7.8	26.5
2 egg clutch	0.983 ± 0.003	62.9	51.9	72.2
3 egg clutch	0.992 ± 0.003	80.5	61.2	89.7
Lookout Beach	-	-	-	-
All data	0.979 ± 0.004	56.4	43.9	68.3
1 egg clutch	0.941 ± 0.017	19.4	5.2	40.4
2 egg clutch	0.983 ± 0.004	62.9	46.5	76.2
3 egg clutch	1.000 ± 0.000	100		
Robberg Island	-	-	-	-
All data	0.889 ± 0.018	4.2	1.2	10.5
1 egg clutch	0.843 ± 0.036	9.9	2	25.8
2 egg clutch	0.918 ± 0.021	5.8	0	37.2
3 egg clutch	0.900 ± 0.050	5.8	0	37.2

Discussion

Kelp Gulls are breeding at three, two historical and one recently colonised, sites in Plettenberg Bay with differing success. Keurbooms Peninsula, a well-established colony, and Lookout Beach, a recently colonised site, have similar and relatively high estimates of hatching success (52% and 56%, respectively), which is very similar to the apparent hatching success for Kelp Gulls breeding on Marcus Island (53%, Williams et al. 1984). However, these values are below what has been calculated for Kelp Gulls *Larus dominicanus dominicanus* breeding on Marion Island (87%, Williams et al. 1984) and in Argentina (71-72%, Yorio & Borboroglu 2002).

Estimated hatching success at two of three colonies increased with increasing clutch size, a trend also observed at Marcus Island by Williams et al. (1984). As estimated hatching success is based on the DSR of the nest as a whole (not individual eggs) calculated by Program MARK the cause of clutch size specific variation in calculated hatching success is clear. Predation of an egg from a one egg clutch results in the failure of that nest, while the predation of an egg from a three egg clutch still leaves two other eggs to allow for the nest to be successful. As such the DSR of a one egg clutch is lower than that for a two egg and three egg clutch. Given this, it is worth in future studies investigating individual egg survival rather than nest survival, if possible.

The average clutch sizes of each of Keurbooms Peninsula (1.9 eggs), Lookout Beach (2.0), and Robberg Island (1.6) are lower than that recorded for other estimates for Kelp Gulls in South Africa (2.1, 2.1, and 2.2, Crawford et al. 1982; Williams et al. 1984; Calf et al. 2003), and southern Africa (2.2, Altwegg et al. 2007). Altwegg et al. (2007) showed that clutch size is not correlated to the size of the population, and suggested that population dynamics are most affected by changes in adult survival, and changes in reproductive aspects plays a lesser role.

Hence, the decrease recorded in breeding pairs on Robberg Island cannot be entirely attributed to small clutch sizes, nor low hatching success.

The low clutch size recorded on Robberg Island could be attributed to a number of factors. In colonies with high predation rates such as Robberg Island, a smaller clutch size is advantageous because it reduces the time the eggs are vulnerable to predation, given that gulls begin incubation at clutch completion (Winkler 1985). It is also possible that many of the breeding birds are young individuals which are known to lay smaller clutches (Ryder 1975; Haymes & Blokpoel 1980; Pugesek 1987). Young, inexperienced birds can also be the cause of the low hatching success on Robberg Island, as naïve birds often have a lower hatching success than mature, experienced adults (Ryder 1975; Haymes & Blokpoel 1980). However, it seems more likely that predation by natural predators such as mongooses and otters was the cause of the low hatching success. Adult Kelp Gulls have previously been found dead and partially eaten on Robberg Island suggesting that mammalian predation was probably having a detrimental effect on this colony (P. Whittington, in litt.). As the majority of the area surrounding Robberg Island is undisturbed by humans it is expected that the populations of natural predators (mongooses and otters) would be larger, and thus the higher predation impact on the Kelp Gull colony here than Keurbooms Peninsula and Lookout Beach. If breeding performance was as low as recorded for the 2013/14 breeding season in prior years, pairs may have chosen to relocate, perhaps to Lookout Beach, resulting in the decrease of breeding pairs on Robberg.

Yearly variation in colony size can be substantial, thus when investigating colony trends over time the approach of Whittington et al. (in press) is useful. The maximum count at a breeding colony over a five year period is taken and these values are used to show trends over time as the impact of unusually high or low estimates is reduced. Barring an unusually low count at Keurbooms Peninsula during the 2006/7 breeding season, there appears to be a slight decrease in the population over the past decade. The current counts of breeding pairs on Keurbooms Peninsula were corrected for error, however the uncertainty surrounding the accuracy of corrected counts is substantial, although it is more likely that the population has been over-estimated than underestimated. It is possible that the observed drop is within the error of the aerial estimates of the breeding population, but it can also be partially attributed to the relocation of some pairs across the Keurbooms River mouth to Lookout Beach. Lookout Beach is a relatively new breeding colony, with breeding attempts being recorded only since the 2008/9 breeding season, although unsuccessfully until more recently (H. Nieuwoudt, in litt.). Lookout Beach is not as densely populated as the well-established Keurbooms Peninsula colony which has a high rate of conspecific predation (pers. obs.), as is common in densely breeding gull colonies (Butler & Trivelpiece 1981; Brouwer & Spaans 1994; Good 2002). Additionally, not all adults breed each year which may result in population flux (Pugesek & Diem 1990; Kazama et al. 2013).

This study used an UAV to successfully collect aerial imagery of the Kelp Gull colony on Keurbooms Peninsula which allowed for a quantification of the breeding population. The accuracy of counts of nests from aerial photos, as well as ground truthing, can be affected by factors including vegetation type, where nests in high grass are more difficult to detect than those on open ground, and the altitude at which the images were taken. The ground truthing image encompassed a wide range of the habitat available on Keurbooms Peninsula and as such, the correction factor calculated is assumed to be representative of the entire colony. Unfortunately, differences between the various flights were not taken into consideration. In hindsight, it would have been ideal to measure vegetation height and composition in the field which could have been mapped onto aerial photo composites to enable analyses comparing active nests and ease of nest identification from aerial photos between vegetation types.

Further factors that could have affected counts of breeding birds from aerial photos are diurnal and seasonal fluctuations (Huffeldt & Merkel 2013). Diurnal and seasonal trends can reveal single or multiple peaks in colony attendance and should be used to determine the best time to conduct a total count of breeding birds (Harding et al. 2005; Huffeldt & Merkel 2013). As such, aerial surveys done later in the breeding season would have included nests with chicks, some highly mobile, which are harder to detect leading to an under-estimate of active nests. Regular counts throughout the breeding season should be used to determine the maximum count for the breeding season, which provides the best estimate of the breeding population.

Aerial surveys are an ideal method to minimise disturbance with very few birds taking to the sky in response to the UAV moving over the colony, but the accuracy of our methodology is brought into question with the high rate of false-negative and false-positive errors in the identification of active nests (12% and 25% respectively) in comparison to 2% and 8% error from Sardà-Palomera et al. (2012). This may be as a result of the resolution of the images, where although images were clear enough to identify individual birds, it was occasionally difficult to determine whether the birds were sitting or standing. Kelp Gull nests are typically a scrape which can be variably built up with a variety of items from the surrounding environment (Crawford & Hockey 2005). The lack of large, noticeable nest structures complicates the identification of nesting birds from aerial photos. The accuracy of identifying nests from images may be improved through the use of double flights a set time apart on the same day, where birds in the same position are counted as breeding (Sardà-Palomera et al. 2012). This method of ground truthing could be worthwhile to avoid being within the colony at all.

An ideal UAV for monitoring seabird colonies should be autonomous, electric powered, durable, launchable and recoverable in rugged terrain, modular, operable with minimal training, and collect georeferenced imagery (Jones et al. 2006). This study further shows the importance of an autonomous UAV which can be programmed to cover the entire breeding colony while a manually controlled UAV needs to be within clear view of the pilot to be operated safely, which can, as in this instance, prevent the entire colony from being covered. Furthermore, the camera needs to be appropriate to the aim of the flight. The use of high resolution imagery is needed for aerial counts such as this where many nests are not distinctive structures. Aerial imagery also has the benefit of allowing researchers to better evaluate overall habitat, nest spacing and distribution, and nest density (Dolbeer et al. 1997).

Although many Kelp Gull populations around the world are increasing, the Plettenberg Bay population shows conflicting trends. One of three colonies has a decreasing population with an exceptionally low hatching success, the largest of the three breeding colonies is suspected to be marginally decreasing in size, while the third, newly established colony has the highest hatching success; these trends all require further investigation. Using an UAV to conduct aerial surveys of gull colonies is also worth further investigation, as once the correct methodology (UAV model, camera, flight path, altitude) has been determined, the benefits of this method are high.

Chapter 3: The effect of nest microhabitat on Kelp Gull breeding performance

Abstract

Nest site selection in gulls is dependent, in part, on microhabitat characteristics which can affect breeding performance. However, existing habitats are expected to be altered in the near future through climate change and urbanisation. This study investigated the variability in microhabitat-dependent breeding performance of Kelp Gulls in Plettenberg Bay, which has potential implications for the ability of this species to adapt to habitat changes resulting from climate change and urbanisation. Clutch size was not significantly affected by the nest site variables measured. However, average egg mass at laying and daily survival rate (DSR) varied significantly according to surrounding vegetation cover and vegetation height. Generally, breeding performance variables were positively related to vegetation cover and height, and negatively affected by distance to nearest cover. Trends indicate that pairs with a larger clutch size and egg mass tended to nest in taller, denser vegetation and thus be close to cover, and have a higher DSR. However differences in measures of the three breeding performance variables investigated between microhabitats were minimal, suggesting that future habitat change will have little impact on these three measures of breeding performance, barring any other changes such as increased anthropogenic disturbance or mammalian predation.

Key words: adaptive preferences, egg mass, clutch size, daily survival rate, Program MARK

Introduction

The combined effects of climate change and habitat loss and degradation pose the most severe threats to biodiversity and are placing untold pressure on natural environments and ecosystems (Travis 2003). Predicting responses of species and communities to the effects of climate change, habitat loss and degradation, and other anthropogenic impacts, is a huge challenge and growing concern (Hughes 2000; Travis 2003; Thomas et al. 2004). Species under stress from the effects of climate change and other anthropogenic impacts ultimately have four choices: phenotypic adaptation; evolutionary adaptation; movement; or extinction (Bohning-Gaese & Lemoine 2004). In other words: acclimate, adapt, move, or die (Corlett & Westcott 2013).

Range changes of some species have been associated with climate change and other anthropogenic impacts (Parmesan & Yohe 2003; Root et al. 2003). Predicting range shifts and the future distribution of species is often done using easily quantified habitat/nest site variables, which may not accurately portray the effects of the interactions between climate change, habitat loss, and species plasticity and ability to adapt (Travis 2003). Climate change and habitat loss/degradation interact, such that species attempting to move to areas with a more suitable climate may be hindered by habitat loss and fragmentation (Travis 2003; Thomas et al. 2004; Huntley et al. 2006). Furthermore, species differ in their ability to adapt to changed habitats (Travis 2003). However, the ability of a population to adapt to climate change does not preclude the possibility of extinction if populations are unable to adapt at the rate that the environment is changing (Bradshaw & Holzapfel 2006).

Understanding habitat selection and preferences (Johnson 1980) is important in understanding animal natural history, quantifying animal-habitat relationships, and describing and predicting area use, and area importance (Conner et al. 2003; Beyer et al. 2010). Habitat selection may be under the influence of innate or learned mechanisms or a combination of both

(Burger & Gochfeld 1990). Furthermore, habitat preferences are site-specific and changes in preference can be expected with changes in habitat availability (Beyer et al. 2010).

Gulls show differential preference for nest site microhabitats, which often results in preferred sites showing a higher breeding success (Good 2002; García-Borboroglu & Yorio 2004b), and as such, microhabitat preferences are assumed to be adaptive (Martin 1998). Different nest site microhabitats may also show differences in other breeding parameters such as clutch size (Bosch & Sol 1998; Good 2002). However, a number of confounding factors may also affect breeding performance including age, experience, and quality of the breeding birds (Ryder 1975; Haymes & Blokpoel 1980; Kim & Monaghan 2005a). Gulls are aggressive birds, and competition for nest sites would lead dominant individuals (high individual quality, often older with more experience) to breed at the best nest sites (high microhabitat quality), where successful breeding is due to better individuals breeding in better microhabitats, not necessarily microhabitat alone (García-Borboroglu & Yorio 2004b; Kim & Monaghan 2005a).

This chapter examines the relationship between various nest site variables and breeding performance of Kelp Gulls in Plettenberg Bay to investigate how this species might acclimate to future habitat changes.

Materials & methods

Colony visits

A description of the study site for this study, Keurbooms Peninsula, and the protocol of colony visits can be found in Chapter 2.

Nest site variables

At each nest site the following microhabitat data were recorded: percentage vegetative coverage within 1 m of the nest (VegeCov); average height of the dominant vegetation within 1 metre of the nest (HiVege); maximum height of vegetation touching the rim of the nest bowl (NestVegeHi); distance to the nearest structure (vegetation/log) offering sufficient shade for a chick (DistCov); and distance to the high tide mark (DistTide). Height above sea level was also recorded for each nest using a Garmin eTrex® 10 (Hasl).

Measures of breeding performance

Clutch size was determined as the largest number of eggs simultaneously observed in the nest bowl. Nests were checked every 3-4 days to exclude incomplete clutches, as Kelp Gulls lay eggs 2-3 days apart (Crawford & Hockey 2005). Egg length and maximum width were measured to the nearest 0.1 mm using callipers. Egg mass at laying was estimated as

$$W = \text{length} \times \text{width}^2 \times 0.000527 \qquad \text{(Hoyt 1979)}$$

for all eggs, and averaged for each clutch to give average egg mass at laying. Clutch size and egg mass are measures of parental investment (Winkler 1985), as small eggs hatch small chicks which are less likely to survive to fledging than larger counterparts (Parsons 1975).

Statistical analyses

Six potential factors affecting two measures of breeding investment (clutch size and egg mass) were tested using univariate generalised linear models (GLM). Separate models were created for each response variable where clutch size had a Poisson distribution and square root link function and average egg mass at laying had a Gaussian distribution and identity link function. Correlated variables, tested using Pearson's correlation, were removed based on biological significance and Akaike's information criterion (AIC) values of univariate GLM analyses. Twenty-five models were run on uncorrelated variables, including both additive and interactive effects, following the same GLM format as the univariate analyses. Models were compared using the aictab function from the AICcmodavg package (Model Selection and Multimodel Inference Based on (Q)AIC(c)), and the most influential models were selected based on AICc values (Akaike's information criterion corrected for a small sample size (Burnham & Anderson 2002)). The selected models were averaged using the model.avg function from the MuMIn package (Multi-model Inference). A linear model was fitted to each of the four uncorrelated variables varying with average egg mass at laying. A linear model was fitted to clutch size and egg mass at laying to determine whether a trade-off exists between the two variables. The above statistics were analysed using R (version 3.1.2, R Foundation for Statistical Computing 2014).

Calculating apparent hatching success by dividing the number of eggs hatched by the number of eggs laid results in the loss of time-specific effects, and inaccurate results (Mayfield 1975). To take this into account nest success was measured as daily survival rate (DSR) using the nest survival model (Dinsmore et al. 2002) in Program MARK (White & Burnham 1999). Only constant daily survival models were considered to calculate estimates of DSR.

As timing of breeding has been shown to affect breeding performance in Kelp Gulls (García-Borboroglu et al. 2008) a variable representative of when in the breeding season each nest was active (had eggs laid) was included. This variable (DayFound) reflected the day in the season the eggs of each nest were found (this may be some days after laying), where 30 September 2013 = 1. This would allow for the loose approximation of the effects of timing of breeding on DSR to be calculated. The effect of each of six nest site variables, and DayFound, on DSR was investigated using a number of competing models. Models were created using a sine link function. Correlated variables, tested using Pearson's correlation, were again removed based on biological significance and AICc values, furthermore, variables which do not fit the data better than the null model were removed, tested using likelihood ratio tests (White & Burnham 1999). Further multivariate models were run on the remaining variables using a logit link function.

The influence of each covariate on DSR is represented by the beta (β) estimate calculated by Program MARK. Beta estimates with confidence intervals that do not encompass zero were taken to represent strong covariate effects (Burnham & Anderson 2002). Estimated hatching success can be calculated by raising the DSR estimate to a power indicating incubation period (Mayfield 1975). As it was not possible to follow breeding success much beyond the hatching stage because chicks become mobile and are particularly sensitive to disturbance at this stage fledging success was not calculated.

Results

A wide variety of microhabitats were available to Kelp Gulls breeding on Keurbooms Peninsula: some pairs bred on bare sand, others in slightly vegetated areas, and others in dense tall grasses. Of 192 Kelp Gull nests with a full complement of microhabitat measurements, percentage vegetative coverage within 1 m of the nest ranged from 0 to 100% (57 ± 34%); average height of the dominant vegetation within 1 metre of the nest ranged from 0 to 100 cm (25 ± 25 cm); maximum height of vegetation touching the rim of the nest bowl ranged from 0 to 100 cm (36 ± 33 cm); distance to the nearest structure (vegetation/log) offering sufficient shade for a chick ranged from 1 to 60 m (5 ± 10 m); distance to the high tide mark ranged from 1 to 50 m (17 ± 9 m); and height above sea level ranged from 1 to 10 m (3 ± 2 m).

None of the six measured nest site variables had a significant effect on clutch size analysed using univariate models (Table 1). After the removal of correlated variables (Table 2), multivariate models were included but were not well supported (AICc weight < 0.04; Table 3), and after model averaging variables showed no significant effects on clutch size (Table 4).

Interestingly, looking at the patterns of four uncorrelated nest site variables over clutch size, two vegetation variables (height of vegetation at the nest, and distance to cover) show an increasing trend with clutch size, while the other two (height above sea level and distance to high tide mark) do not show as clear a pattern with the averages for nests with 2- and 3-egg clutches quite similar (Fig. 1). Nests with no eggs (abandoned prelaying) were anomalous with the highest average values for these variables (Fig 1).

Table 1. Results of univariate generalised linear models (GLM) showing all variables affecting clutch size and average egg mass at laying of Kelp Gulls breeding at Keurbooms Peninsula.

Model	AIC	Estimate	SE	z value	Pr(>|z|)
Clutch size	-	-	-	-	-
Distance to nearest cover*	556.49	0.004	0.005	0.733	0.463
Max nest vegetation height	556.60	0.001	0.002	0.639	0.523
Surrounding vegetative cover	556.95	-0.000	0.002	-0.233	0.816
Height above sea level	556.97	0.004	0.024	0.189	0.850
Distance to high tide mark	556.97	-0.001	0.006	-0.185	0.853
Vegetation height*	556.97	-0.000	0.002	-0.178	0.859
Average egg mass at laying	-	-	-	-	-
Surrounding vegetative cover	1705.4	-0.175	0.065	-2.697	< 0.01
Vegetation height	1705.8	-0.228	0.087	-2.619	< 0.01
Max nest vegetation height*	1709.4	-0.123	0.069	-1.789	0.075
Distance to high tide mark	1710.0	-0.416	0.261	-1.598	0.112
Height above sea level	1710.4	-1.416	0.977	-1.450	0.149
Distance to nearest cover*	1710.8	0.299	0.229	1.304	0.194

*Variables removed from subsequent analyses.

Table 2. Pearson's correlation coefficient (*r*) of six variables varying with clutch size (light grey) and average egg mass at laying (dark grey). Correlations with absolute values > 0.5 (shown in bold) were regarded as strong and one of the variables was removed.

	Nest site variable					
	Hasl	VegeCov	HiVege	NestVegeHi[b]	DistCov[b]	DistTide
Hasl		0.402	0.258	0.410	-0.307	0.114
VegeCov	0.368		0.483	**0.503**	**-0.505**	0.030
HiVege[a]	0.229	0.487		**0.569**	-0.331	0.103
NestVegeHi	0.370	0.494	**0.528**		-0.390	0.090
DistCov[a]	-0.301	**-0.516**	-0.332	-0.395		0.212
DistTide	0.093	0.055	0.126	0.110	0.199	

[a]Variables removed from further analyses involving clutch size.

[b]Variables removed from further analyses involving average egg mass at laying.

Two of the six measured nest site variables (vegetation height, and surrounding vegetation cover) showed a significant effect on average egg mass at laying (Table 1) for 176 nests which had egg mass data available. After the removal of correlated variables (Table 2), multivariate models were included which improved the fit of the data (Table 5). Once the best fitting models were averaged, results revealed a significant interaction between height above sea level and surrounding vegetation cover, while all other interaction terms and main effects were not significant (Table 4). All four uncorrelated variables involved in multivariate analyses display positive, yet weak, linear relationships with average egg mass at laying, although the variability in points is high (Fig. 2).

Table 3. Comparison of generalised linear models (GLM) explaining clutch size of Kelp Gulls breeding at Keurbooms Peninsula as affected by vegetation height at the nest (NestVegeHi), height above sea level (Hasl), distance to the high tide mark (DistTide), and vegetation cover (VegeCov). Only models with ΔAICc < 4 are displayed. '+' represents additive effects.

Model	*K*[a]	AICc	ΔAICc	AICc w[b]	LL[c]
Null	1	555.03	0.00	0.23	-276.50
NestVegeHi	2	556.66	1.64	0.10	-276.30
VegeCov	2	557.01	1.99	0.08	-276.48
Hasl	2	557.03	2.01	0.08	-276.48
DistCov	2	557.03	2.01	0.08	-276.49
VegeCov + NestVegeHi	3	558.33	3.31	0.04	-276.10
NestVegeHi + DistTide	3	558.66	3.64	0.04	-276.27
Hasl + HiVegeNest	3	558.72	3.70	0.04	-276.30
VegeCov + Hasl	3	558.99	3.97	0.03	-276.43

[a]Number of parameters.

[b]AICc weight.

[c]Loglikelihood.

Table 4. The average of the best-fitting models weighted by AICc (ΔAICc < 4), showing the effects of vegetation height at the nest (NestVegeHi), vegetation cover (VegeCov), height above sea level (Hasl), distance to the high tide mark (DistTide), and average height of the dominant surrounding vegetation (HiVege) on clutch size and average egg mass at laying of Kelp Gulls breeding on Keurbooms Peninsula in Plettenberg Bay, Western Cape. '*' denotes interactions between variables.

Variable	Estimate	SE	Adjusted SE	z value	Pr(>|z|)
Clutch size	-	-	-	-	-
Intercept	0.535	0.095	0.096	5.581	< 0.001
NestVegeHi	0.001	0.002	0.002	0.678	0.497
VegeCov	-0.001	0.002	0.002	0.360	0.719
Hasl	0.004	0.025	0.025	0.151	0.880
DistTide	-0.001	0.006	0.006	0.205	0.837
Average egg mass at laying	-	-	-	-	-
Intercept	81.907	7.486	7.521	10.891	< 0.001
VegeCov	-0.048	0.115	0.116	0.419	0.675
HiVege	0.163	0.334	0.335	0.487	0.626
HiVege * VegeCov	-0.007	0.004	0.004	1.858	0.063
DistTide	-0.166	0.412	0.412	0.402	0.688
DistTide * VegeCov	-0.011	0.007	0.007	1.605	0.108
Hasl	0.976	2.950	2.950	0.330	0.741
Hasl * VegeCov	-0.092	0.043	0.043	2.130	< 0.05
Hasl * HiVege	-0.080	0.047	0.047	1.696	0.090
DistTide * HiVege	-0.009	0.011	0.011	0.789	0.430

Table 5. Comparison of generalised linear models (GLM) explaining average egg mass at laying of Kelp Gulls breeding at Keurbooms Peninsula as affected by vegetation cover (VegeCov), average height of the dominant surrounding vegetation (HiVege), distance to the high tide mark (DistTide), and height above sea level (Hasl). Only models with ΔAICc < 4 are displayed. '+' represents additive effects, while '*' represents interactive effects.

Model	K^a	AICc	ΔAICc	AICc w[b]	LL[c]
VegeCov * HiVege	5	1703.75	0.00	0.16	-846.70
VegeCov * HiVege + DistTide	6	1704.33	0.59	0.12	-845.92
VegeCov * DistTide	5	1704.64	0.89	0.10	-847.14
VegeCov * Hasl	5	1704.87	1.13	0.09	-847.26
Hasl + VegeCov * HiVege	6	1705.27	1.52	0.07	-846.39
VegeCov + HiVege + DistTide	5	1705.39	1.65	0.07	-847.52
VegeCov	3	1705.49	1.74	0.07	-849.68
HiVege	3	1705.90	2.15	0.05	-849.88
Hasl + VegeCov * HiVege + DistTide	7	1706.10	2.36	0.05	-845.72
Hasl * HiVege	5	1706.47	2.72	0.04	-848.06
Hasl + VegeCov * DistTide	6	1706.71	2.97	0.04	-847.11
Hasl + VegeCov + DistTide	5	1707.23	3.48	0.03	-848.44
Hasl + VegeCov + HiVege	5	1707.30	3.55	0.03	-848.47
Hasl + VegeCov + HiVege + DistTide	6	1707.51	3.76	0.02	-847.51
HiVege * DistTide	5	1707.60	3.85	0.02	-848.62
Hasl + HiVege + DistTide	5	1707.74	3.99	0.02	-848.69

[a]Number of parameters.

[b]AICc weight.

[c]Loglikelihood.

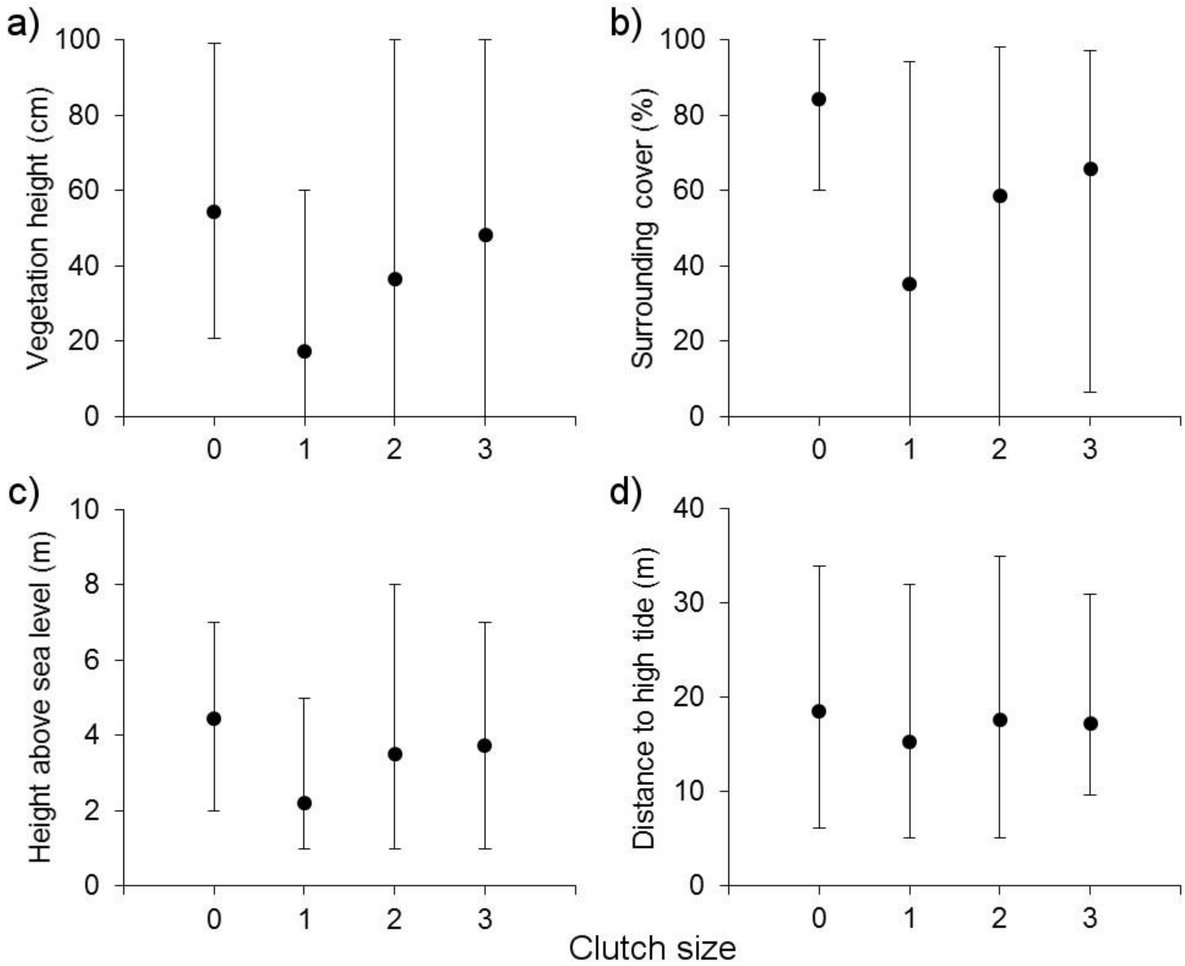

Fig. 1. Variation in uncorrelated nest site variables (means ± 95th and 5th percentile) in relation to clutch size for 192 Kelp Gull nests (23 with 0 eggs, 43 with 1 egg, 92 with 2 eggs, 34 with 3 eggs) on Keurbooms Peninsula in Plettenberg Bay, Western Cape. Variables include a) vegetation height at the nest, b) vegetation cover, c) height above sea level, and d) distance to the high tide mark.

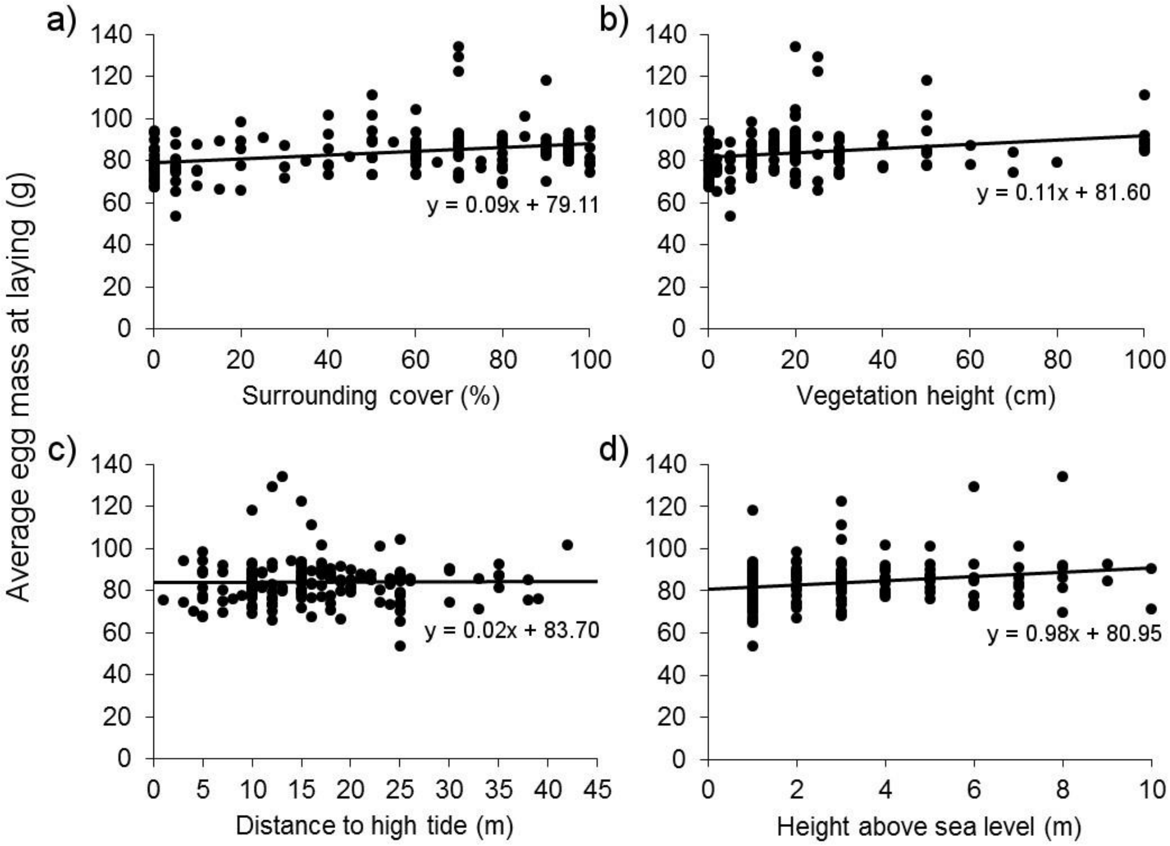

Fig. 2. Variation in uncorrelated nest site variables in relation to average egg mass at laying for 154 Kelp Gull nests where egg weight data were available (40 nests with 1 egg, 85 with 2 eggs, 29 with 3 eggs) on Keurbooms Peninsula in Plettenberg Bay, Western Cape. Variables include a) vegetation cover, b) vegetation height at the nest, c) distance to the high tide mark, and d) height above sea level.

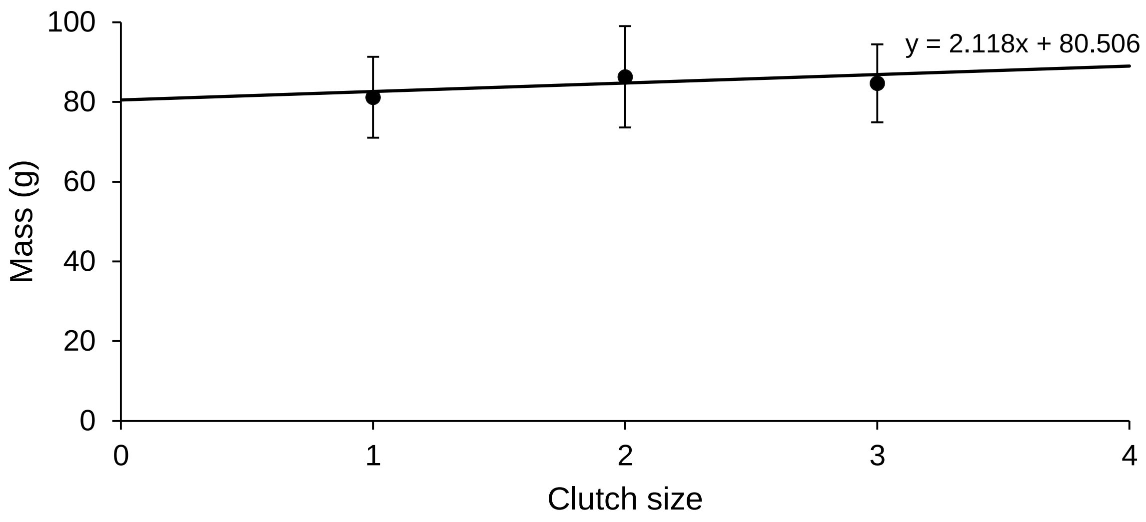

Fig 3. Relationship between clutch size and average egg mass at laying for Kelp Gull nests on Keurbooms Peninsula, Plettenberg Bay.

There does not appear to be a trade-off between average egg mass and clutch size; there was a tendency for average egg mass at laying to increase with clutch size, but this was not significant ($F_{1, 169} = 2.606$, $p = 0.108$; Fig. 3).

Three univariate models explaining DSR of 101 Kelp Gull clutches for which complete survival data were available, received most of the model support. Vegetation cover (AICc weight = 0.447), maximum vegetation height at the nest (AICc weight = 0.417), and day in the breeding season that the nest was first recorded (AICc weight = 0.128) were the top three fitting explanatory variables (Table 6). After removing correlated variables (Table 7), and one variable (distance to the high tide mark) which did not fit the data significantly better than the null model ($\chi^2 = 1.105$, d.f. = 1, $p = 0.293$), further multivariate models were run involving the four remaining variables. These models provided a better fit of the data than any of the univariate models (Table 8). Kelp Gull clutch survival models show that the best fitting model includes day in the breeding season that the nest was first recorded, maximum vegetation height at the nest, and vegetation cover (Table 8). Of these variables, only day in the breeding season that the nest was first recorded had a significant effect on DSR ($\beta = -0.016$, 95% CI = -0.029

to -0.003). The DSR of clutches based on this model is 0.980 (SE = 0.003, 95% CI = 0.975-0.985).

Table 6. Comparison of fixed-effects models showing the effects of each variable on daily survival rate (DSR) for Kelp Gull nests on Keurbooms Peninsula in Plettenberg Bay, Western Cape. Variables include vegetation cover (VegeCov), maximum vegetation height at the nest (NestVegeHi), day in the breeding season that the nest was first recorded (DayFound), average height of the dominant surrounding vegetation (HiVege), distance to nearest cover (DistCov), height above sea level (Hasl), and distance to the high tide mark (DistTide).

Explanatory variable	K^a	AICc	ΔAICc	AICc w^b	Deviance
VegeCov	2	363.76	0.00	0.45	359.76
NestVegeHi	2	363.90	0.14	0.42	359.89
DayFound	2	366.25	2.49	0.13	362.25
HiVege*	2	372.15	8.39	0.01	368.15
DistCov*	2	375.45	11.69	0.00	371.45
Hasl	2	382.18	18.42	0.00	378.18
$DSR_{constant}$	1	387.96	24.20	0.00	385.96
DistTide*	2	388.86	25.10	0.00	384.85

[a]Number of parameters.

[b]AICc weight.

*Variables removed from subsequent analyses.

Of the individual effects of four variables used in multivariate analyses, three had a significant positive effect on DSR: surrounding vegetation cover (β = 0.019, 95% CI = 0.011-0.026); maximum vegetation height at the nest (β = 0.024, 95% CI = 0.013-0.035); and height above sea level (β = 0.162, 95% CI = 0.040-0.284) (Fig. 4). While the fourth variable, day in the breeding season that the nest was found, had a significant negative effect on DSR (β = -0.027, 95% CI = -0.038 to -0.017; Fig.4).

Table 7. Pearson's correlation coefficient (*r*) of seven variables varying with daily survival rate (DSR). Correlations with absolute values > 0.5 (shown in bold) were regarded as strong and one of the variables was removed.

	Nest site variable						
	NestVegeHi	VegeCov	Hasl	HiVege	DistCov	DistTide	DayFound
NestVegeHi							
VegeCov	0.489						
Hasl	0.381	0.373					
HiVege[a]	**0.513**	0.490	0.223				
DistCov[a]	-0.384	**-0.505**	-0.293	-0.324			
DistTide	0.124	0.019	0.092	0.12	0.242		
DayFound	-0.395	-0.325	-0.465	-0.376	0.031	-0.219	

[a]Variables removed from further analyses.

Table 8. Summary of model-selection results for fixed-effects models of clutch survival of Kelp Gulls breeding at Keurbooms Peninsula as affected by day in the season the nest was found (DayFound), vegetation height at the nest (NestVegeHi), vegetation cover (VegeCov), and height above sea level (Hasl). Only models with ΔAICc < 4 are displayed.

Model	*K*[a]	AICc	ΔAICc	AICc w[b]	Deviance
DayFound + NestVegeHi + VegeCov	4	354.67	0.00	0.33	346.65
DayFound + Hasl + NestVegeHi + VegeCov	5	355.87	1.20	0.18	345.85
DayFound + NestVegeHi	3	356.08	1.41	0.16	350.07
DayFound + VegeCov	3	356.94	2.27	0.11	350.93
DayFound + NestVegeHi + Hasl	4	357.87	3.20	0.07	349.86
NestVegeHi + VegeCov	3	358.36	3.69	0.05	352.35
VegeCov + Hasl + DayFound	4	358.55	3.88	0.02	350.53

[a]Number of parameters.

[b]AICc weight.

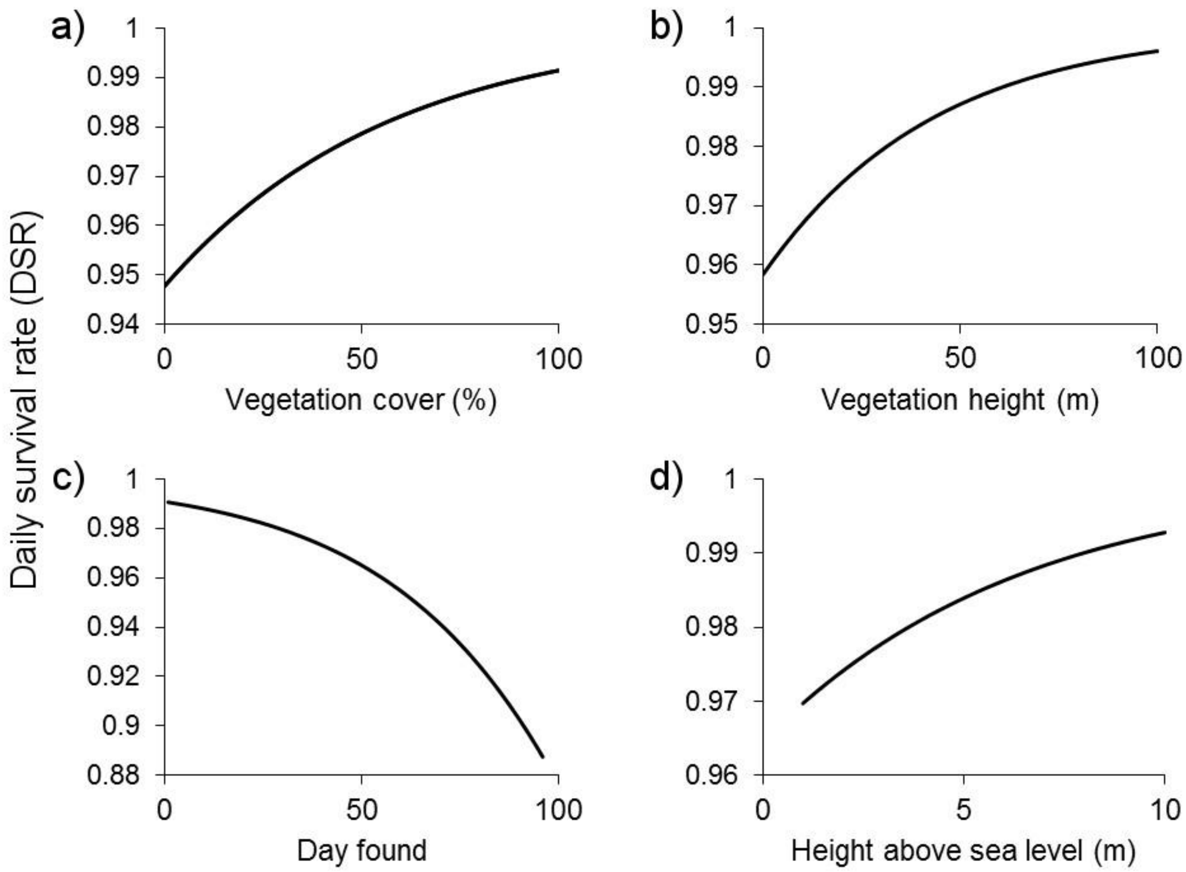

Fig. 4. Predicted daily survival rate (DSR) of 101 Kelp Gull clutches as affected by four variables. DSR was based on models presented in Table 6, where a) vegetation cover, b) maximum vegetation height at the nest, c) day in the breeding season that the nest was first recorded, and d) height above sea level.

Discussion

Choosing an appropriate breeding site is a central part of the life cycle of birds and other organisms (Kim & Monaghan 2005a), with breeding performance often varying among habitats (Good 2002; García-Borboroglu & Yorio 2004b; Lee et al. 2006, 2008). However, in this study, none of the nest site variables, either in singular or multivariate models, had a significant effect on clutch size. However, average egg mass at laying was significantly affected by surrounding vegetation cover, and the average height of the dominant surrounding vegetation, although once worked into multivariate models these effects were not apparent.

Regardless, trends are similar to those involving clutch size, where heavier eggs are laid in nests made in taller, denser vegetation which are thus close to cover. In addition, DSR, and as a result estimated hatching success, was significantly affected by day in the breeding season the nest was found (time of breeding within the breeding season) in multivariate models, and increased with surrounding vegetation cover, vegetation height, and height above sea level, but not significantly. In this study pairs with larger clutch size and egg mass tended to nest in taller, denser vegetation and thus be close to cover, and had a higher DSR.

This is similar to the pattern found in the Western and Glaucous-winged Gull (*Larus occidentalis glaucescens*) hybrid complex in Grays Harbor, Washington, which lay larger clutches in vegetated habitats than sandy habitats (Good 2002). Clutch size of Black-Tailed Gulls (*Larus crassirostris*) on Hongdo Island also tends to be larger, but not significantly so, in covered nests than in exposed nests (Lee et al. 2006). First-laid eggs of both the Herring Gull (*Larus argentatus*) and Lesser Black-backed Gull (*Larus fuscus*) were heavier in more vegetated habitats (Kim & Monaghan 2005a, b). Hatching success of both the Western/Glaucous-winged Gull hybrid complex (Good 2002) and Black-Tailed Gulls (Lee et al. 2006) are also larger in vegetated habitats than sandy habitats, showing the same pattern as Kelp Gulls in this study. Hatching success of Kelp Gulls in Patagonia was also positively related to vegetation cover, and negatively related to distance from the nearest bush (García-Borboroglu & Yorio 2004b), while Kelp Gulls in Punta Leon hatched more chicks in covered nests over exposed nests in 1990, but not in 1991 (Yorio et al. 1995).

These results show that cover is an important factor for gulls when choosing nest sites, preferring covered over open nests but without so much cover that visibility and escape are restricted (Burger & Gochfeld 1981; Bosch & Sol 1998; García-Borboroglu & Yorio 2004a; Lee et al. 2006), with least preferred sites being bare and open (Bosch & Sol 1998). Nest cover is important as it provides a favourable microclimate, including lower air temperature and wind speeds (Kim & Monaghan 2005a), as well as screening adjacent incubating adults and thus reducing neighbour interference (Good 2002; Lee et al. 2006). Nest cover also provides chicks and adults shelter from predators (Burger & Gochfeld 1981; Burger & Gochfeld 1990).

Although there was a tendency for breeding performance to be associated with differences in nest site microhabitat, the effect was not significant. However, this pattern might not reflect the direct benefits of specific microhabitats on breeding performance. Gulls are aggressive birds and competition for nest sites might lead dominant individuals (high individual quality, high breeding experience) to breed at the best nest sites (high microhabitat quality) which could result in observed breeding performance differences between microhabitats, the cause of which being difficult to separate out between individual quality and pair breeding experience, and microhabitat effects (Dexheimer & Southern 1974; García-Borboroglu & Yorio 2004b; Kim & Monaghan 2005a). Unfortunately it was not possible to test these hypotheses as the age, experience and condition of the adult gulls in this study were not known.

Clutch size variation could be attributed to several factors. Young/inexperienced birds tend to lay fewer eggs (Ryder 1975; Haymes & Blokpoel 1980; Pugesek 1987), and as such a change in population age structure might result in a change in most common clutch size. Predation can also influence maximum clutch size, because gulls begin incubation at clutch completion and a smaller clutch results in a smaller time where eggs are vulnerable to predation (Winkler 1985). Parents also might reduce clutch size (or skip breeding entirely) to increase their own survivorship in a year of environmental uncertainty to maximise breeding success in a good year (bet hedging, Winkler 1985).

There is often a wide variety of habitat available for nesting sites including various vegetative covers (short/tall herbs, grass, shrubs); substrate types and compositions; and slopes and gradients among other physical characteristics (García-Borboroglu & Yorio 2004a).

However, climate change is expected to bring about large vegetation changes (Svenning & Sandel 2013), as well as sea level rise resulting in habitat loss exacerbated by urbanisation (Travis 2003). An important question is whether these habitat changes will result in an associated reduction in breeding performance. This study has shown that Kelp Gulls in Plettenberg Bay are capable of breeding almost equally successfully in a variety of microhabitats as measured by clutch size, average egg mass at laying and hatching success. This would suggest that they would be able to breed successfully in future habitats that would be available barring any other changes such as increased anthropogenic disturbance or mammalian, or avian, predation.

Further research should focus on the fledging success of pairs in a variety of microhabitats, as although hatching success indicates flexibility of breeding success in a variety of microhabitats, if the chicks are not fledging then successful hatching is of little consequence. Thermoregulation and incubation capacity of gulls nesting in various microhabitats should also be investigated to determine whether they have the ability to buffer their own thermal environment, as well as the thermal environment of eggs or chicks, regardless of the microhabitat they are in. Furthermore, it could be of interest to determine whether chicks are able to thermoregulate independently at an earlier age in more extreme thermal environments.

Chapter 4: The importance of anthropogenic food items in Kelp Gull diet

Abstract

Populations of many gull species worldwide are increasing, and the factor most influencing their increase is the greater availability of anthropogenic food, mainly obtained from urban sources including urban waste landfills. This study investigated the importance of anthropogenic food items in the diet of Kelp Gulls breeding in Plettenberg Bay, South Africa, and how this is reflected in the time spent in various areas. In terms of frequency of occurrence, anthropogenic items (predominantly plastics) were most often present in regurgitated pellets collected before the 2013/14 breeding season (98%), followed by terrestrial (85%) and marine items (25%). There was only a slight decrease in anthropogenic items during the breeding season (96%), when both terrestrial (94%) and marine (36%) items increased. On average, anthropogenic items also dominated the volumetric proportion in breeding season pellets (80%), followed by terrestrial items (17%), with marine items having the smallest volumetric proportion (3%). However, marine prey had the highest frequency of occurrence in chick regurgitations (79%), with anthropogenic (32%) and terrestrial (29%) items being far less prevalent. Of three urban foraging areas surveyed weekly, counts of Kelp Gulls were highest at the urban waste landfill. These results suggest that anthropogenic food items are an important dietary component of adult Kelp Gulls in Plettenberg Bay, while chicks are fed a more natural diet. This is not reflected in the time spent in urban areas, however, as GPS loggers indicate gulls spent most of their time within the breeding colony or on the beach, only undertaking short, regular trips to the urban waste landfill.

Key words: GPS loggers, point counts, regurgitated pellets, urban waste landfill

Introduction

Urbanisation of previously natural areas is often detrimental to species survival (Chace & Walsh 2006; Aronson et al. 2014). Some species, however, manage to successfully adapt to urban environments to the point where they are able to survive and even thrive (Marzluff et al. 2001; Chamberlain et al. 2009); Kelp Gulls are one such species (Bertellotti et al. 2001; Yorio & Caille 2004; Crawford et al. 2009). The most important factor influencing the increase in many gull populations, including Kelp Gulls, worldwide is thought to be the availability of anthropogenic food sources, including urban waste landfills (Andersson 1970; Steele & Hockey 1990; Duhem et al. 2008), commercial fishery waste discards (Bertellotti et al. 2001; Yorio & Caille 2004; Lisnizer et al. 2011), fishing harbours (Steele & Hockey 1990), and smaller sources such as dumpsters, rubbish bins and offal from recreational/subsistence fishermen (Belant 1997). With the global human population and refuse tonnage both increasing, this food source will persist (Duhem et al. 2008), and probably increase (unless refuse management changes, e.g. to incineration).

As anthropogenic food sources often are locally abundant, highly predictable, and renewed daily, gulls have altered their natural diet and foraging patterns to be more urban-centric, resulting in reduced energy expenditure and foraging time (Belant et al. 1993; Garthe et al. 1996; Duhem et al. 2003; Yoda et al. 2012). The use of anthropogenic food sources is dependent on a number of factors including: location (Bertellotti & Yorio 1999; Duhem et al. 2003), time of year (Belant et al. 1993; Frixione et al. 2012), access to anthropogenic food sources like urban waste landfills (Duhem et al. 2003), and access to natural food sources (Belant et al. 1993).

Foraging at anthropogenic food sources can lead to a number of negative effects through entanglement in items and the ingestion of plastics and other indigestible items, including loss of limbs, blocked digestive tracts resulting in reduced appetite, starvation and possible death, damaged stomach lining, reduced quality of life and reproductive capacity, and potential absorption of toxic compounds (Laist 1987; Derraik 2002; Gregory 2009). Gulls are fortunately able to regurgitate indigestible matter in the form of pellets, which can be used to infer diet, although the biases inherent in this approach are well documented (Duffy & Jackson 1986; González-Solís et al. 1997). Despite this, the scavenging nature of gulls and their ability to regurgitate pellets makes them a useful study species to investigate spatial and temporal patterns of the use of anthropogenic food sources (Frixione et al. 2012; Lindborg et al. 2012).

In addition to the diet of a species, the identification of foraging sites as well as the spatio-temporal movements between urban and natural foraging sites is also of interest (Montevecchi et al. 2012; Yoda et al. 2012). This is important for the appropriate management of both urban areas used as foraging sites as well as urban-adapted animals themselves (Caro 2007). With the recent improvements in tracking and bio-logging including electronic tag miniaturization and cost reduction, such data have become more accessible (Bograd et al. 2010).

This chapter investigates the extent to which Kelp Gulls breeding in Plettenberg Bay, South Africa, include anthropogenic food items in their diet, as well as identifying key urban foraging areas.

Materials & methods

Study sites

The study site at Plettenberg Bay and the three Kelp Gull colonies in the region are described in Chapter 2.

Diet

Gulls frequently regurgitate pellets comprising the indigestible remains of prey. As such, pellets show a bias towards prey items with hard and distinctive parts (Duffy & Jackson 1986; González-Solís et al. 1997). As a result, pellets are considered the least useful for diet analysis (González-Solís et al. 1997), but they are often used in gull diet studies due to the ease of collection of a large sample size with minimal disturbance to the birds, making them useful for assessing spatial and seasonal dietary differences (Bertellotti & Yorio 1999; Frixione et al. 2012). However, a study has shown that the estimation of the importance of anthropogenic items in Glaucous Gull (*Larus hyperboreus*) diet was usually accurately estimated through the use of regurgitated pellets (Weiser 2010).

During May and June 2013 pellets regurgitated by Kelp Gulls were collected from roosting sites and beaches at all three breeding sites as a sample of non-breeding diet. It was not possible to ascertain the ages of the gulls regurgitating these pellets, and although plumage variation makes aging birds using plumage unreliable (Whittington 2007), most birds roosting in the colony were birds in adult plumage (assumed to be ≥4 years old, Crawford et al. 2000). During the 2013/14 breeding season (September-February) pellets were opportunistically collected from within the three breeding colonies, only some of which corresponded to an active nest and known breeding stage, thus pellets from both incubation and chick provisioning breeding stages were pooled. Fresh chick regurgitations were collected opportunistically during chick capture and handling on the Keurbooms Peninsula. Diet samples were frozen at *ca* -20°C until analysis. After defrosting, pellets were soaked in water and dissected to identify all food items. Prey remains were classified according to item origin: anthropogenic, marine, or terrestrial (Table 1). Items of marine and terrestrial origin were natural and independent of anthropogenic influence. Pre-breeding season pellets, due to the large number collected, only had items recorded on a presence/absence basis while breeding season pellets had, additionally, the proportion of items estimated as part of the whole pellet (by volume) after dissection.

Table 1. Classification of items from each origin

Origin	Examples
Anthropogenic	
Cloth	String, wetwipes, cotton
Foam	Foam, polystyrene
Food items	Domestic vegetables, bread
Glass	Glass shards
Livestock bones	Chicken, beef, lamb
Metal	Tin foil, fish hooks
Other	Eggshells, hair extensions
Paper	Paper, serviettes
Plastic	Hard plastic, clingwrap, plastic bags
Rubber	Balloons, elastic bands
Marine	
Cephalopods	Squids, octopus
Crustaceans	Crabs
Fish	Fish bones, fish scales
Shells	Limpets, periwinkles
Terrestrial	
Birds	Feathers, bones
Eggs	Eggshells (not domestic chicken)
Insects	Grasshoppers
Mammals	Fur, rodent bones
Plants	Seeds
Rock	Small stones

Weekly counts

To determine the use of three urban foraging areas of Kelp Gulls over the breeding season, 5 minute point counts were conducted once a week on a Sunday between 8 and 10 am of all gulls irrespective of age. The urban waste landfill, Market Square shopping centre, and Plettenberg Bay Primary School were surveyed (Fig. 1), as they had been previously identified as key congregational sites for the species in Plettenberg Bay (M. Brown, pers. comm.). At the urban waste landfill gulls rummage through bags of household waste for food items, while at Market Square there are restaurants from which gulls appropriate food items, as well as a dumpster in which they forage. Finally at Plettenberg Bay Primary gulls scavenge discarded food items and have been seen dipping into refuse bins. The breeding season was divided into three periods: pre-laying (28 July–22 September 2013), incubation (29 September–10 November 2013), and chick rearing (24 November–3 December 2013).

GPS loggers

To identify areas in which Kelp Gulls spent their time, seven incubating adults from the Keurbooms Peninsula breeding colony were tracked using GPS loggers (CatTraq^{TM}, 16Mb memory, 230 mA lithium-ion battery, Mr Lee Technologies), modified to a lesser weight and size (41.97 x 24.25 x 11.38 mm, 15 g) by removing the original packaging. Loggers were programmed using @trip PC (Version 5.0) to sample a position every 15 minutes. Before deployment loggers were sealed in heat shrink tubing. Adults were initially caught using a walk-in trap placed over the nest, and loggers attached to the back feathers using Tesa tape (Wilson et al. 1997). Attempts were made to re-catch birds using a noose-carpet, or a walk-in trap placed over the nest one week after deployment. The Tesa tape was carefully removed from the feathers and the logger retrieved. Each GPS point recorded was classified according to the area in which the bird was located, and the maximum distance from the nest site measured during incubation and post nest-failure periods 'as the crow flies'.

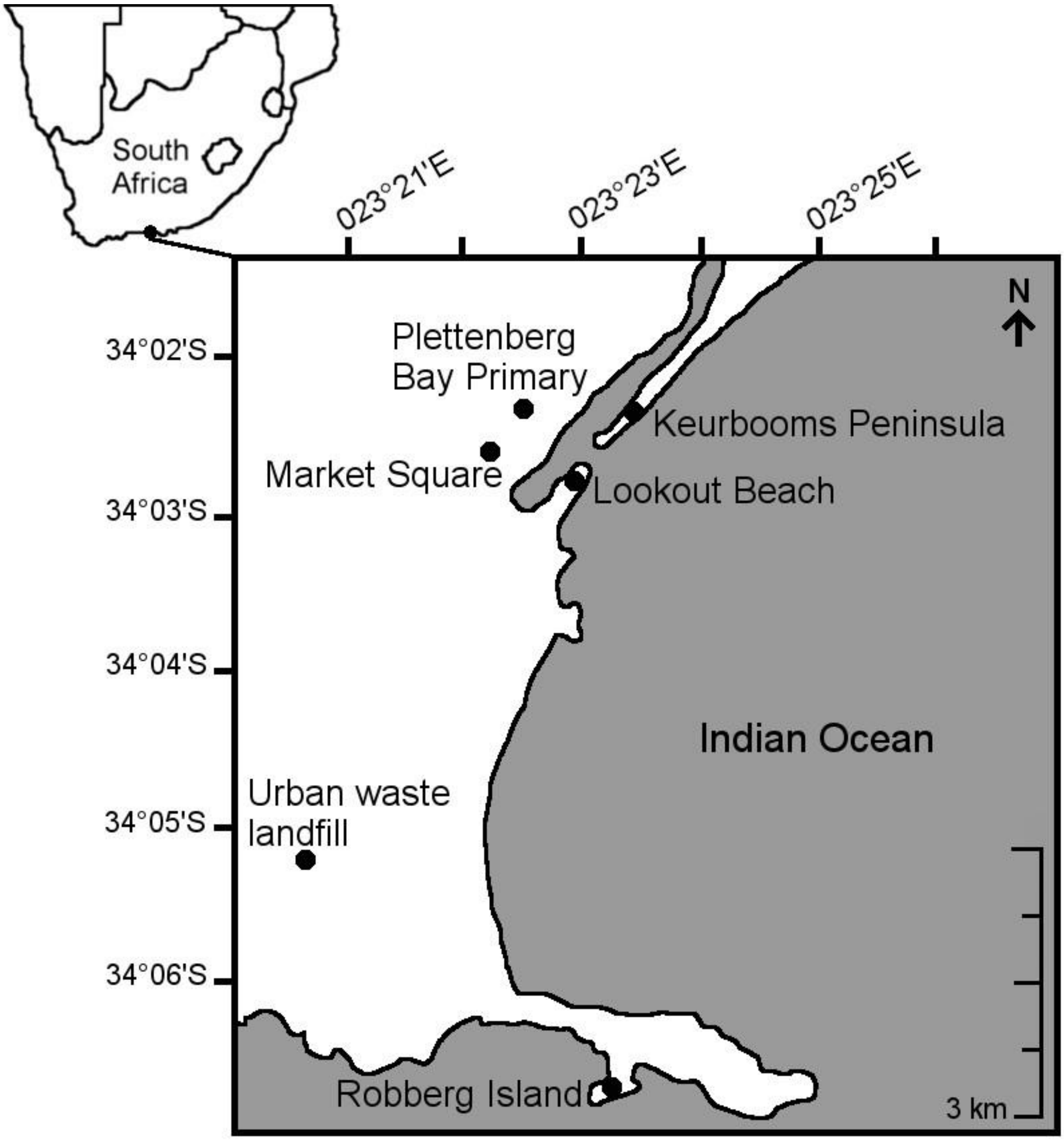

Fig. 1. Three urban foraging areas covered by direct counts in relation to the Kelp Gull colonies in Plettenberg Bay, Western Cape.

Statistical analyses

All statistics were analysed using R (version 3.1.2, R Foundation for Statistical Computing 2014). Values are reported as mean ± 1 SD. The effect of location and time period (pre-breeding and breeding season) on the occurrence of items of anthropogenic, marine, and terrestrial origin in regurgitated Kelp Gull pellets (presence/absence data) was investigated using generalised linear models (GLM) with a binomial distribution and logit link function; separate models were created for items of each origin. Additionally, differences in the volumetric proportion of items in breeding Kelp Gull regurgitated pellets between locations and item origins were investigated using a fractional logit generalised linear mixed model (GLMM), which supported a binomial distribution and logit link function. Finally, the effect of item origin on the occurrence of items of anthropogenic, marine, and terrestrial origin in chick regurgitations (presence/absence data) was investigated using GLMMs with a binomial distribution and logit link function. For GLMM analyses individual pellet (or regurgitation) was taken as a random effect, and models were created using the lme4 package (Linear, Generalized Linear, and Nonlinear Mixed Models). An analysis of variance (ANOVA) was used to determine the significance of variables in the aforementioned models. T-tests were used to detect significant differences within and between variables of volumetric proportion data, while significant differences within and between variables of occurrence (presence/absence) data were detected using a two-sample test for equality of proportions with continuity correction (prop.test function from the stats package).

A GLM with a poisson distribution and logarithmic link function was used to determine the effects of time period and location on counts of gulls at three urban foraging sites. After detecting over-dispersion, a GLM with a negative binomial distribution and square root link function was used from the MASS package (Support Functions and Datasets for Venables and Ripley's MASS).

Results

Diet

Almost all pellets (93-100%) contained items of anthropogenic origin, while marine and terrestrial items were less frequently encountered in pellets (19-60% and 77-95%, respectively; Table 2). Of anthropogenic items, plastics occurred most regularly (44-66%), with metal items less so (7-20%; Table 3). Non-synthetic anthropogenic items occurred less frequently than plastics: livestock bones (4-37%) and food items (3-21%; Table 3).

The occurrence of anthropogenic items was not affected by either location or time period, but both marine and terrestrial items were (Table 4). The occurrence of marine and terrestrial items increased during the breeding season (marine: 23-60%; terrestrial: 93-95%) compared to the pre-breeding season (marine: 19-36%; terrestrial: 77-93%), the difference of which was significant (Table 4).

Pre-breeding season pellets show the frequency of occurrence of anthropogenic items (98%) is significantly higher than the frequency of occurrence of marine (25%, $\chi^2 = 889.8$, d.f. = 1, $p < 0.001$), and terrestrial items (85%, $\chi^2 = 92.2$, d.f. = 1, $p < 0.001$, Table 2). Also, the frequency of occurrence of terrestrial items is significantly higher than that of marine items in pre-breeding season pellets ($\chi^2 = 562.6$, d.f. = 1, $p < 0.001$, Table 2).

For breeding season pellets, the frequency of occurrence of anthropogenic items (96%) was significantly higher than marine (36%, $\chi^2 = 103.1$, d.f. = 1, $p < 0.001$), but not terrestrial items (94%, $\chi^2 = 0.3$, d.f. = 1, $p = 0.57$, Table 2). Also, the frequency of occurrence of terrestrial items is significantly higher than that of marine items in breeding season pellets ($\chi^2 = 93.8$, d.f. = 1, $p < 0.001$, Table 2). Comparisons between pre-breeding and breeding season pellets show the frequency of occurrence of anthropogenic items does not differ ($\chi^2 = 1.7$, d.f. = 1, $p = 0.19$), but the frequency of occurrence of marine and terrestrial items were higher during the breeding than pre-breeding season (χ^2 = 6.5, d.f. = 1, p < 0.05; and χ^2 = 7.1, d.f. = 1, p < 0.01, respectively; Table 2).

Table 2. Percent frequency of occurrence of items of anthropogenic, marine, and terrestrial origins in adult Kelp Gull regurgitated pellets, and chick regurgitations.

Location (number of pellets)	Anthropogenic	Marine	Terrestrial
Pre-breeding season pellets	-	-	-
Lookout Beach (276)	99%	36%	93%
Keurbooms Peninsula (426)	98%	19%	81%
Robberg Island (88)	100%	25%	77%
Average (790)	98%	25%	85%
Breeding season pellets	-	-	-
Lookout Beach (27)	93%	33%	93%
Keurbooms Peninsula (65)	95%	23%	95%
Robberg Island (40)	100%	60%	93%
Average (132)	96%	36%	94%
Chick regurgitations	-	-	-
Keurbooms Peninsula (28)	32%	79%	29%

The proportionate content (by volume) of regurgitated breeding season pellets is not affected by the colony they came from but is significantly affected by item origin (Table 5, Fig. 2). T-tests show that the volumetric proportion of anthropogenic items (80 ± 27%) is significantly larger than that of marine (3 ± 10%; t = 30.9, d.f. = 163.5, p < 0.001) and terrestrial items (17 ± 26%; t = 19.3, d.f. = 261.3, p < 0.001), and that the volumetric proportion of terrestrial items is larger than that of marine items (t = -6.072, d.f. = 167.0, p < 0.001).

There were significant differences between the frequency of occurrence of items of varying origin in regurgitations of Kelp Gull chicks (Table 6). Marine items were most frequent (79%), significantly greater than anthropogenic (32%, $\chi^2 = 10.5$, d.f. = 1, $p < 0.01$), and terrestrial items (29%, $\chi^2 = 12.1$, d.f. = 1, $p < 0.001$, Table 2). The frequency of occurrence of anthropogenic and terrestrial items did not differ significantly (Table 5). Anthropogenic items were most regularly non-synthetic food items (14%), but plastics (7%) were also occasionally present (Table 3). Fish were the most frequently occurring marine item (68%), while plant material was the most frequently occurring terrestrial item (25%).

Table 3. Percent frequency of occurrence of four regularly occurring items of anthropogenic origin in adult Kelp Gull regurgitated pellets, and chick regurgitations.

Location (number of pellets)	Plastic	Metal	Livestock bones	Food items
Pre-breeding season pellets	-	-	-	-
Lookout Beach (276)	44%	18%	37%	21%
Keurbooms Peninsula (426)	65%	12%	36%	8%
Robberg Island (88)	51%	11%	16%	3%
Average (790)	56%	14%	34%	12%
Breeding season pellets	-	-	-	-
Lookout Beach (27)	55%	7%	4%	19%
Keurbooms Peninsula (65)	66%	20%	17%	20%
Robberg Island (40)	45%	13%	13%	10%
Average (132)	58%	15%	13%	17%
Chick regurgitations	-	-	-	-
Keurbooms Peninsula (28)	7%	0%	6%	14%

Table 4. Results of analyses of variance (ANOVA) summarising the significance of variables following generalised linear models (GLM) investigating the occurrence of anthropogenic, marine, and terrestrial items in regurgitated Kelp Gull pellets using location and item period as explanatory variables. '*' indicates the interaction between variables.

Explanatory variable	Df	Deviance	Pr(>Chi)
Anthropogenic origin	-	-	-
Location	2	5.623	0.060
Time period	1	3.491	0.062
Location * Time period	2	0.608	0.738
Marine origin	-	-	-
Location	2	30.565	< 0.001
Time period	1	6.108	< 0.05
Location * Time period	2	8.957	< 0.05
Terrestrial origin	-	-	-
Location	2	20.292	< 0.001
Time period	1	13.034	< 0.001
Location * Time period	2	2.499	0.287

Chick regurgitations had a significantly higher frequency of occurrence of marine items than breeding season pellets ($\chi^2 = 15.1$, d.f. = 1, $p < 0.001$), and a significantly lower frequency of occurrence of anthropogenic ($\chi^2 = 69.4$, d.f. = 1, $p < 0.001$), and terrestrial items ($\chi^2 = 63.9$, d.f. = 1, $p < 0.001$, Table 2).

Table 5. Summary of the generalised linear mixed model (GLMM) investigating differences in the proportionate content (by volume) of regurgitated Kelp Gull pellets between location and item origin, where individual pellet was taken as a random effect.

Fixed effects	Estimate	SE	z value	Pr(>|z|)
Intercept	1.787	0.443	4.037	< 0.001
Origin (Marine)[a]	-6.659	1.034	-6.440	< 0.001
Origin (Terrestrial)[a]	-3.998	0.383	-10.430	< 0.001
Location (Keurbooms Peninsula)[b]	0.029	0.489	0.059	0.953
Location (Robberg Island)[b]	-0.059	0.531	-0.111	0.912

[a, b]Categorical variables need to be compared to a baseline level. The baseline level for Origin was anthropogenic, while for Location it was Lookout Beach.

Table 6. Summary of the generalised linear mixed model (GLMM) investigating differences in the occurrence of items in Kelp Gull chick regurgitations using item origin as the explanatory variable and individual regurgitation as a random effect.

Fixed effects	Estimate	SE	z value	Pr(>|z|)
Intercept	-0.747	0.405	-1.847	0.065
Origin (Marine)[a]	2.047	0.613	3.338	< 0.001
Origin (Terrestrial)[a]	-0.169	0.582	-0.291	0.771

[a]Categorical variables need to be compared to a baseline level. The baseline level for Origin was anthropogenic.

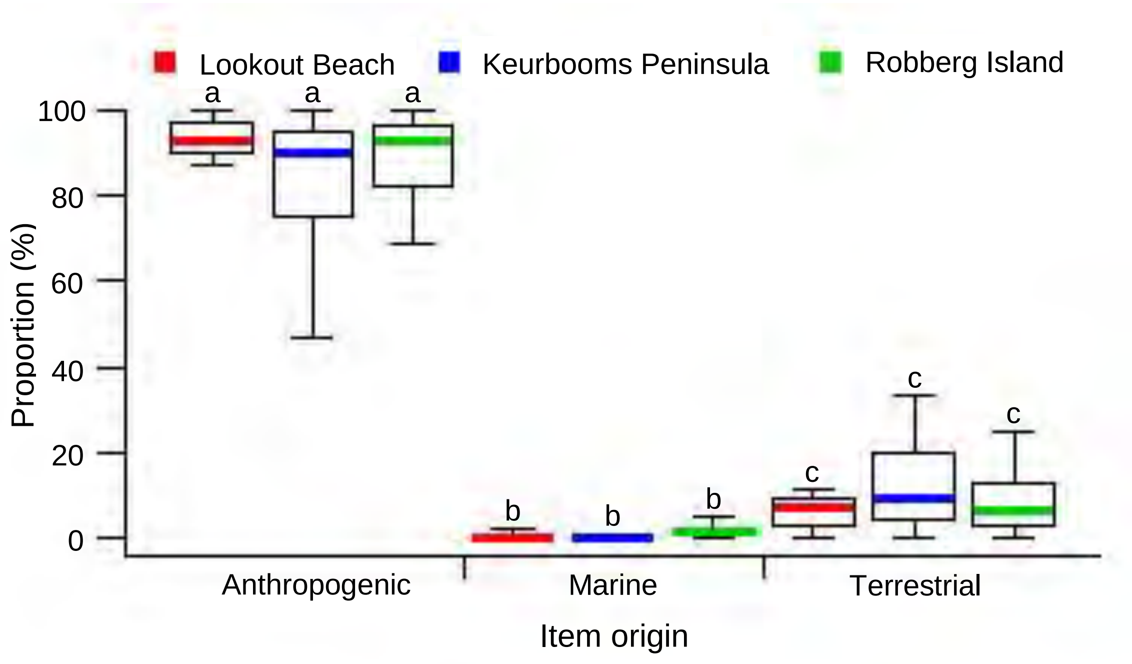

Fig. 2. Boxplot of proportionate composition (by volume) of pellets regurgitated by Kelp Gulls breeding at three locations in Plettenberg Bay, Western Cape. Letters denote significance between item origins.

Counts

The urban waste landfill consistently had the highest counts of Kelp Gulls, while a much smaller number of gulls was recorded at Market Square and Plettenberg Bay Primary (Fig. 3). During chick rearing counts at the urban waste landfill reached a maximum, while counts at Market Square and Plettenberg Bay Primary were at their lowest (Fig. 3).

Gull counts were significantly different over the three locations ($\chi^2 = 277.216$, d.f. = 2, $p < 0.001$), with counts at the urban waste landfill (range: 20-141 gulls) significantly higher than those at Market Square (range: 1-30) and Plettenberg Bay Primary (range: 1-19) ($t = 8.690$, d.f. = 17.899, $p < 0.001$, and $t = 9.246$, d.f. = 16.497, $p < 0.001$, respectively), while counts at Market Square and Plettenberg Bay Primary were not significantly different ($t = 1.362$, d.f. = 23.820, $p = 0.186$, Fig. 3). Time period also had significant effects on Kelp Gull counts ($\chi^2 = 6.085$, d.f. = 2, $p < 0.05$), but only at Market Square where counts during the pre-laying period (range: 3-30) were significantly higher than those during the incubation (range: 1-6; $t = -2.607$, d.f. = 8.993, $p < 0.05$), and chick rearing period (range: 1-3; $t = -2.965$, d.f. = 8.959, $p < 0.05$). Counts were not significantly different between the incubation and chick rearing periods ($t = -1.040$, d.f. = 2.497, $p = 0.389$; Fig. 3b).

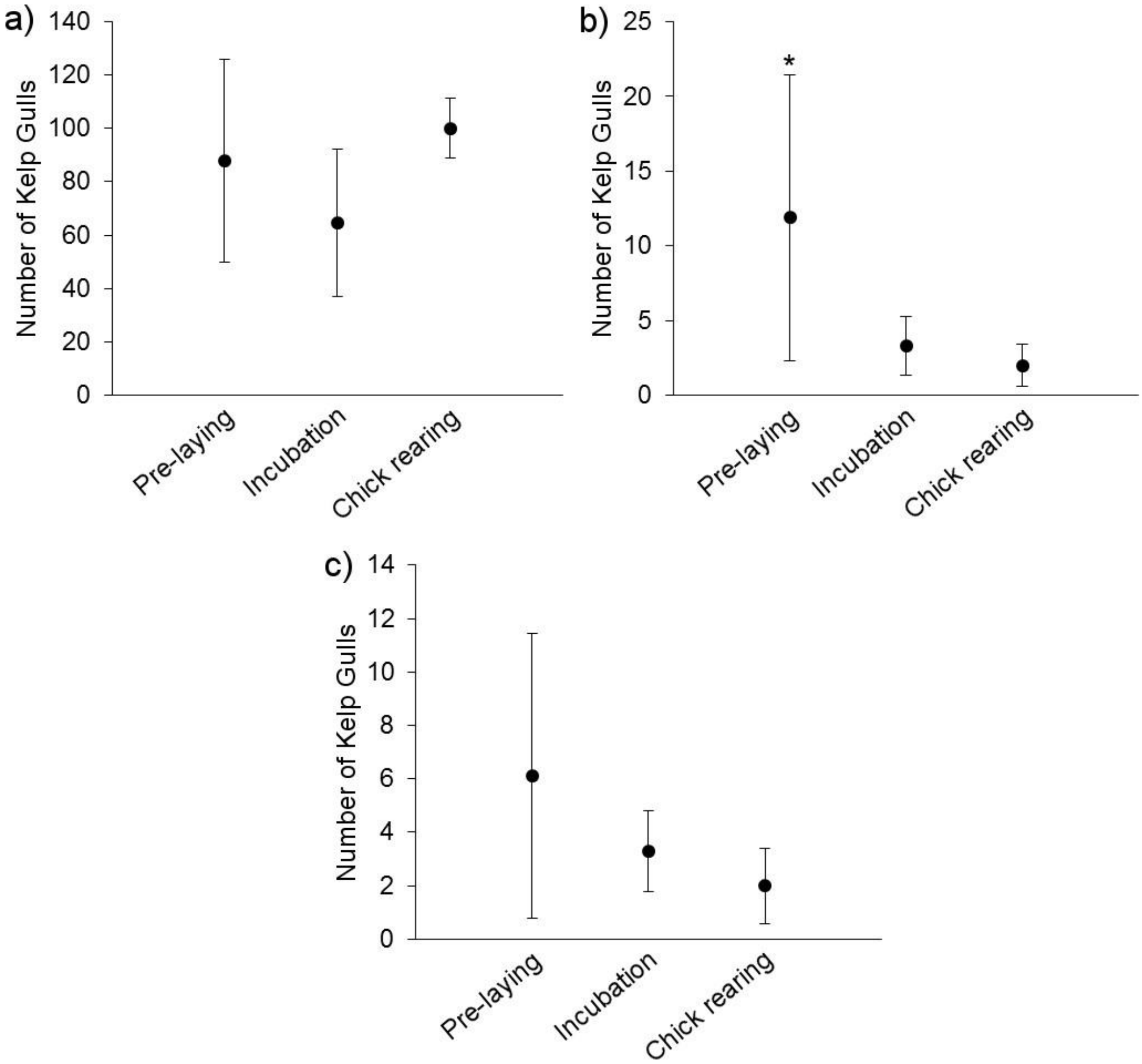

Fig. 3. Counts (mean ± SD) of all Kelp Gulls at three urban foraging areas (a) urban waste landfill, b) Market Square shopping centre, and c) Plettenberg Bay Primary School) in Plettenberg Bay, Western Cape, over three time periods. Significance differences denoted using *.

GPS loggers

Only four of seven loggers were retrieved as some birds abandoned the nest site circumventing the retrieval of loggers, of which one sustained water damage the day after attachment and was excluded from analyses. Two of the remaining three loggers were retrieved from birds after the nests were abandoned, collecting both incubating and non-incubating movement data.

Data collected from three incubating Kelp Gulls show that an average of 61.5 ± 8.2% of fixes were within the breeding colony, and 24.1 ± 6.7% of fixes were on the beach (Table 7). After the breeding attempt of two of three pairs failed, an average of 44.7 ± 11.3% of fixes were within the breeding colony and 31.8 ± 10.4% of fixes were on the beach (Table 7). Incubating birds spent 2.2 ± 1.9% of fixes at the urban waste landfill (Table 7), while after their breeding attempt failed birds spent an average of 2.5 ± 1.9% of the day there (Table 7).

During incubation, all three birds tracked remained within 10 km of the breeding colony. Bird 3 travelled 6 km to the urban waste landfill, Bird 2 travelled 6.5 km to the quarry, and Bird 1 travelled 9.8 km to farmed fields (Fig. 4). After their breeding attempts failed, birds travelled an order of magnitude farther from the colony: Bird 2 travelled 40.5 km out to sea, and Bird 1 travelled 97.5 km along the coastline (Fig. 4).

Table 7. Average percentage of fixes (± SD) per day spent by three incubating Kelp Gulls, and two failed breeders at each location for days with 24 hour GPS logging data.

Area	Incubators (n = 3 birds)	Failed breeders (n = 2 birds)
Colony	61.5 ± 8.2	44.7 ± 11.3
Beach	24.1 ± 6.7	31.8 ± 10.4
Fields	6.9 ± 1.8	2.0 ± 4.8
Urban waste landfill	2.2 ± 1.9	2.5 ± 1.9
Estuary	2.1 ± 1.7	1.8 ± 2.5
Sea <100 m from shore	1.2 ± 1.3	2.2 ± 3.1
Shrub/forest	1.0 ± 0.8	1.7 ± 2.2
Suburban	0.4 ± 0.6	0.7 ± 0.8
Quarry	0.1 ± 0.4	0.3 ± 0.8
Golf course	0.1 ± 0.4	0.3 ± 0.7
Sea >100 m from shore	0.1 ± 0.3	11.8 ± 11.2

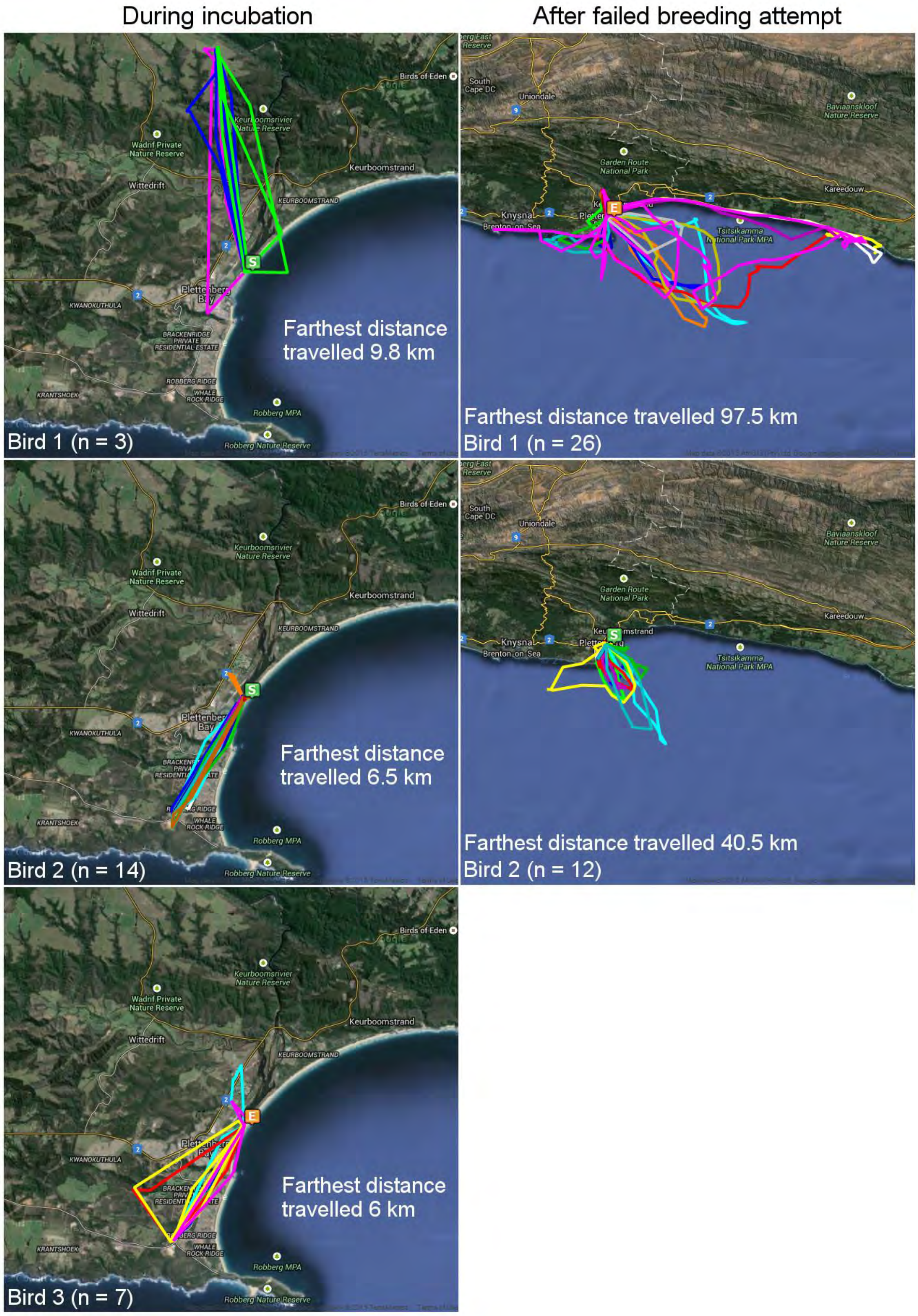

Fig. 4. Maps of GPS tracks for Kelp Gulls breeding at Keurbooms Peninsula, Plettenberg Bay, during incubation and after failed breeding attempts. Constructed with @trip PC (Version 5.0) with background from Google Earth. Different colours denote different 24 h tracking days.

Discussion

Urban areas such as the urban waste landfill represent a constant, easily exploited food source frequented by Kelp Gulls in Plettenberg Bay, as evidenced by anthropogenic items occurring in over 90% of regurgitated pellets, as well as being the most volumetrically prevalent items in regurgitated pellets, collected before and during the 2013/14 breeding season, from all three breeding colonies. This would suggest that anthropogenic food sources are an important component of adult Kelp Gull diets in Plettenberg Bay, both during the non-breeding and breeding season. Although the use of regurgitated pellets to determine diet has been criticised as hard-bodied prey may be overestimated, and soft-bodied prey under-estimated (Duffy & Jackson 1986; González-Solís et al. 1997), pellets are useful to monitor changes in the use of certain prey items (González-Solís et al. 1997).

Other studies have noted that egg hatching initiates a switch from a diet rich in anthropogenic prey to a more natural diet of fish (Annett & Pierotti 1989; Bertellotti & Yorio 1999), this study shows similar results. Adults feed their chicks nutritious, natural, and small, easily-handled food items (primarily fish as shown by chick regurgitations), though they themselves may still forage in urban areas as shown by the content of regurgitated pellets. Breeding season pellets do show a significant increase in the occurrence of more natural marine and terrestrial items, but this is not accompanied by a decrease in the anthropogenic component.

Counts at the urban waste landfill and other urban foraging areas show a constant presence of gulls, though fluctuating in numbers, leading up to and throughout the breeding season, supporting the notion that these areas are important food sources for adult birds year-round. Although numbers of gulls at two of three urban foraging sites dropped over the breeding season, counts at the urban waste landfill did not, displaying the highest average number of gulls during the chick-rearing period. The presence of gulls foraging at the urban waste landfill is consistent with the anthropogenic predominated regurgitated pellets, suggesting anthropogenic items are an important dietary component. All three breeding colonies are 6-7 km from the urban waste landfill, and so the lack of inter-colony differences in the incidence of anthropogenic items in pellets is not surprising. The Plettenberg Bay urban waste landfill is an open system where large amounts of household solid waste and organic waste is scavenged by gulls, as well as Sacred Ibis *Threskiornis aethiopicus*.

The proportion of items in regurgitated pellets does not necessarily reflect the foraging or handling time of the items. Often one anthropogenic item (particularly plastic bags) may contribute the majority of the volumetric proportion of the pellet (pers. obs.). GPS loggers show the propensity of gulls to make short, yet frequent, trips to the urban waste landfill, the farthest some birds travelled while incubating. As the foraging (<1 minute) and handling time (4 seconds) of items at urban waste landfills are minimal (Steele 1992) the birds are not required to spend a large amount of time in this area.

Gulls are well known to exploit urban dump sites (Duhem et al. 2003; Duhem et al. 2005; Auman et al. 2008; Frixione et al. 2012). A previous study of Kelp Gull diet in South Africa showed that gulls at three of four locations included waste items in their diet, ranging from 2-87% occurrence in regurgitated pellets (Steele 1992). The data from this study suggest the proportion is even higher than this, at least in these three colonies. Anthropogenic food sources can be advantageous as they allow for an increased mass and improved body condition, as well as breeding fitness, of breeding adults and contribute towards an increasing gull population (Auman et al. 2008; Weiser & Powell 2010).

As evidenced by the dietary composition of pre-breeding and breeding season pellets of Kelp Gulls and their recurrent use of the urban waste landfill in this study, the constant and easily exploited food source plays an important role in supporting the colonies in the Plettenberg Bay area. The urban waste landfill has, however, reached its volumetric capacity and domestic waste is now being disposed of in Mossel Bay (Bitou Municipality 2013).

Another study has shown that a switch of landfill to waste incineration resulted in a small decrease in the occurrence of garbage in diet samples, though it was still a substantial component of their diet (Weiser & Powell 2011). It would be interesting to investigate whether Kelp Gulls in this area will similarly reduce the frequency of occurrence and amount of anthropogenic items in their diet, whether the breeding population will experience a decrease, and whether the breeding success of the colonies is affected (see Pons 1992). It is possible gulls will find another source of anthropogenic food items; already, a small number of gulls have been seen tearing open refuse bags awaiting collection (pers. obs.). Perhaps they will change their behaviour to exploit the food source before it reaches the urban waste landfill in Mossel Bay. Regardless, minimising the anthropogenic food items that are available to gulls through management of urban waste landfills will aid in the prevention of Kelp Gulls becoming a pest species (Whittington et al. 2006).

Chapter 5: Anthropogenic debris in the nests of Kelp Gulls in South Africa

Abstract

Anthropogenic debris is becoming increasingly pervasive in the natural environment, resulting in detrimental interactions with a number of species. Several seabirds include debris items in their nests, which can lead to entanglement of chicks and adults resulting in injury or death. Of eight Kelp Gull breeding colonies surveyed in the Western Cape, South Africa, all contained nests with some anthropogenic debris items, but the incidence varied from 4-67% of nests surveyed. The frequency of occurrence of debris items was not correlated to distance from the nearest urban waste landfill. Gull nests contain two types of litter: items included in the nest structure during nest construction (mainly ropes and straps), and items included in meals delivered to the chicks (mainly bags and food wrappers) that accumulate during the chick-rearing period. During the incubation period, nests in open areas had a higher occurrence of debris items linked to nest construction, whereas after the chick-rearing period nests in vegetated areas had a higher occurrence of debris items brought in with food because the nests and surrounding vegetation in these areas are more likely to retain such items. The amount of anthropogenic debris recorded in Kelp Gull nests is a concern and highlights the need for improved debris management in areas such as urban waste landfills, through partial burning, or covering with soil or commercial cover though this may be logistically and financially impractical.

Key words: entanglement, nest lining, plastics, urban waste landfill

Introduction

The effects of anthropogenic debris on the marine and coastal environment has been receiving much attention lately, especially the effects of plastic debris (Derraik 2002; Barnes et al. 2009; Thompson et al. 2009; Browne et al. 2010; Cózar et al. 2014). Due to the durable, inexpensive, lightweight, strong nature of plastics, they are suitable for an immense range of products, including a number of single-use items (Barnes et al. 2009; Thompson et al. 2009). Plastic items polluting the natural environment have been increasing over the past years, corresponding to an increase in plastic production and use (Laist 1987; Derraik 2002; Barnes et al. 2009). Unfortunately, the same properties that make plastics suitable for a variety of applications make them a persistent problem in the natural environment (Barnes et al. 2009; Hopewell et al. 2009; Ryan et al. 2009).

Plastics are estimated to make up 10% of discarded anthropogenic waste mass (Barnes et al. 2009), yet constitute 30-90% of waste items in the marine environment (beach, seabed, shoreline, surface waters) (Derraik 2002; Barnes 2005). Due to the increasing abundance of anthropogenic debris in marine systems, species are increasingly likely to interact with it, often to their detriment (Laist 1987, 1997; Derraik 2002). Interactions include entanglement, ingestion, and nest incorporation (seabirds), and the likelihood of entanglement or ingestion may be exacerbated by behavioural patterns of certain species (Laist 1987, 1997; Derraik 2002).

A variety of marine mammals, birds, turtles and fish species are negatively affected by interactions with marine debris, with the number of species and individuals affected increasing since the early 1960s (Laist 1997; Derraik 2002; Barnes et al. 2009; Gregory 2009; Ryan et al. 2009). Unfortunately, as many entanglement and ingestion injuries and fatalities occur at sea, victims go unrecorded as they sink or are predated, confounding accurate estimates of the effects of anthropogenic marine debris (Laist 1987; Wolfe 1987). While the dangers faced by marine species through entanglement and ingestion of anthropogenic marine debris, particularly plastics, have received extensive focus (Laist 1997; Derraik 2002; Gregory 2009; Hammer et al. 2012), the collection and incorporation of anthropogenic debris as nest lining by marine birds (Clemens & Hartwig 1993), has only recently been receiving increased attention (Hartwig et al. 2007; Votier et al. 2011; Bond et al. 2012; Lavers et al. 2013; Provencher et al. 2014; Verlis et al. 2014).

Anthropogenic debris in nests poses an entanglement threat to both parents and chicks, potentially reducing breeding success (Votier et al. 2011). Debris items have been found in a number of marine birds' nests including albatrosses (Diomedeidae, Nel & Nel 1999), boobies and gannets (Sulidae, Montevecchi 1991; Norman et al. 1995; Ostrowski et al. 2005; Votier et al. 2011; Bond et al. 2012; Lavers et al. 2013; Verlis et al. 2014), cormorants (Phalacrocoracidae, Podolsky & Kress 1989), and kittiwakes (Larinae, Hartwig et al. 2007). Considering how well adapted to urbanisation gulls are (Yorio & Borboroglu 2002; Duhem et al. 2008; Lisnizer et al. 2011), it seems surprising that there is no published literature documenting the use of anthropogenic debris as nest lining by gulls, besides some ad hoc observations for the Black-headed (*Chroicocephalus ridibundus*) and Herring Gull (*Larus argentatus*) (Hartwig et al. 2007), and more detailed data for Kittiwakes (*Rissa tridactyla*) (Clemens & Hartwig 1993; Hartwig et al. 2007).

The aim of this study was to investigate the occurrence, quantity and type of anthropogenic items, particularly plastics, found in the nests of eight Kelp Gull colonies and how this was affected by distance to nearest urban waste landfill or the availability of natural nesting material.

Materials & methods

Eight Kelp Gull breeding colonies in the Western Cape, South Africa, were surveyed (Fig. 1). Five were in coastal dune systems: De Mond (34°42.1'S 20°08.9'E), Keurbooms Peninsula (34°02.4'S, 23°23.1'E), Lookout Beach (34°02.7'S, 23°22.8'E), Robberg Island (34°06.5'S, 23°23.2'E) and Strandfontein (34°05.5'S 18°31.9'E); two were on coastal salt pans: Dwarskersbos (32°43.7'S 18°12.2'E) and Yzerfontein (33°19.9'S 18°09.8'E); and one was in mountain fynbos, 350 m above sea level adjacent to Steenbras Dam (34°11.4'S 18°52.6'E). Colonies differed in distance to nearest urban waste landfill with the Strandfontein breeding colony 2.7 km from the nearest urban waste landfill, Robberg Island 4.2 km, Lookout Beach 5.3 km, Keurbooms Peninsula 6.0 km, De Mond 21.1 km, Dwarskersbos 25.4 km, Yzerfontein 30.9 km, and the Steenbras Dam breeding colony being the farthest from an urban waste landfill at 36.2 km.

Each breeding colony was visited towards the end of the breeding season (6-26 December 2013), when pairs at most sites were provisioning large chicks. However, only one pair with chicks was present at De Mond; all other pairs were incubating. Each breeding colony was walked through, collecting all anthropogenic debris in nests, with items collected and bagged separately for each nest. The colony at Steenbras Dam was in a remote part of an area closed to human visitors, so all litter in the colony was collected as it was most almost certainly carried to the site by gulls; no litter was found in vegetation adjacent to the colony. At most sites each nest was classified as open or vegetated based on the surrounding vegetation available for nest building, but nests were not categorised in this way at the two salt pan colonies (Dwarskersbos and Yzerfontein). At De Mond, two colonies were sampled: the main colony, 2.5 km east of the river mouth was on open dunes behind the beach with only marine debris (seaweed and litter) available for nest construction, whereas a smaller colony at the river mouth had access to vegetation deposited by the river (mainly Cape Eelgrass *Zostera capensis*) for nest material.

Debris items collected were identified in terms of type of material and function, and grouped into one of the following: fishing line (monofilament line and hooks), plastic packaging (cling wrap, bread bags, carrier bags, sandwich bags), ropes and plastic strapping (including some ropes used by fisheries), material (wetwipes, hairnets, clothing scraps), and other items (tinfoil, foam, cigarette butts, paper). Item length, width, mass (dry mass to the nearest 0.1 g) and colour was recorded. Items collected were untangled to measure maximum dimensions.

All statistics were analysed using R (version 3.1.2, R Foundation for Statistical Computing 2014). Values are reported as means ± 1 SD. The effect of nest type (vegetated/open), location type (coastal/inland/salt pan) and distance to nearest urban waste landfill (used as a proxy for location as these two variables are collinear and cannot be tested simultaneously) on the occurrence of anthropogenic debris items in Kelp Gull nests was tested using a generalised linear model (GLM) with a binomial distribution and logit link function. Similarly, the occurrence of five types of anthropogenic debris as affected by nest type, location type, and distance to the nearest urban waste landfill was tested using GLMs with a binomial distribution and logit link function. Models were compared using the aictab function from the AICcmodavg package (Model Selection and Multimodel Inference Based on (Q)AIC(c)), and the most influential models were selected based on AICc values (Akaike's information criterion corrected for a small sample size (Burnham & Anderson 2002)). The selected models were averaged using model.avg function from the MuMIn package (Multi-model Inference). The relationship between the frequency of occurrence of anthropogenic debris items and the distance to the nearest urban waste landfill was investigated using a Pearson's product-moment correlation (cor.test function in the stats package). Comparisons between occurrence (presence/absence) data were performed using a two-sample test for equality of proportions with continuity correction (prop.test function from the stats package).

A GLM with poisson distribution and log link function was used to determine the influence of nest type, location type, and distance to the nearest urban waste landfill on the number of anthropogenic debris items found in each nest. After detecting over-dispersion, a GLM with a negative binomial distribution and log link function was used from the MASS package (Support Functions and Datasets for Venables and Ripley's MASS). Models' AIC weights were calculated using the Weights function from the MuMIn package. The most influential models were selected based on AIC values. The selected models were averaged using the model.avg function from the MuMIn package. T-tests were done to determine significant differences in the number of anthropogenic debris items between levels of categorical variables.

Results

Anthropogenic debris items were found in Kelp Gull nests at every location sampled, with the frequency of occurrence ranging from 4-67%. Within sites, the frequency of occurrence of debris items varied according to whether nests were in vegetated areas (range 4-58%), or open areas (range 11-82%) which lacked natural items for nest construction (Table 1). The maximum number of items collected from a vegetated nest was 26 (averaging 0.1-2.5 items), and the maximum from an open nest was 19 (averaging 0.1-3.4 items; Table 1). Although anthropogenic debris items were present at all eight locations surveyed, when separated into debris type only plastic packaging was collected from every site (Table 2, Fig. 1). Both fishing line and rope/strapping were the least commonly occurring items, being collected at only three of the eight locations (Table 2, Fig. 1). On average, fishing line was the longest item type occurring in nests, while items from the 'other' debris type (tinfoil, foam, cigarette butts, paper) were the shortest (Table 2). Debris items collected from nests at Steenbras Dam are representative of items the birds brought to the colony, although items found in the nests were generally smaller than items in the general vicinity of, and within, the breeding colony (Table 2). In general, the colour of items of all five debris types tended toward more neutral tones (white/grey and brown/black) while brighter coloured items (purple/blue, green, and yellow/red) occurred less frequently (Table 3). As was expected, both fishing line and plastic packaging items were predominantly clear (Table 3).

Table 1. The occurrence and quantity of anthropogenic debris items found in Kelp Gull nests in the Western Cape, South Africa.

Location	Nest type (n nests)	Frequency of occurrence (%)	Avg # items (total items)	Maximum # items/nest
Yzerfontein	Veg/open (46)	22	0.48 (22)	5
Lookout	Open (7)	14	0.14 (1)	1
Lookout	Vegetated (47)	11	0.13 (6)	2
Keurbooms	Open (46)	11	0.28 (13)	3
Keurbooms	Vegetated (111)	58	2.52 (280)	26
Steenbras Dam	Vegetated (90)	13	0.20 (18)	3
Strandfontein	Open (60)	82	3.42 (205)	19
Strandfontein	Vegetated (62)	40	1.71 (106)	15
Dwarskerbos	Veg/open (54)	4	0.06 (3)	2
Robberg	Open (6)	17	0.33 (2)	2
Robberg	Vegetated (34)	29	0.93 (27)	6
De Mond	Open beach (37)	78	3.05 (113)	10
De Mond	Open estuary (30)	53	0.87 (26)	3

Table 2. Morphometrics (mean ± SD) of anthropogenic debris items collected from Kelp Gull nests at eight locations in the Western Cape.

Debris type		Location (number of nests surveyed)								
		De Mond (67)	Dwarskersbos (54)	Keurbooms Peninsula (157)	Lookout Beach (54)	Robberg Island (40)	Steenbras Dam (90)	Steenbras general	Strandfontein (122)	Yzerfontein (46)
Fishing line	Length (cm)	36.7 ± 28.9	-	37.0	-	-	-	-	62.7 ± 46.6	-
	Width (cm)	0.1 ± 0.1	-	0.1	-	-	-	-	0.1 ± 0.0	-
	Weight (g)	0.7 ± 1.0	-	0.7	-	-	-	-	0.3 ± 0.5	-
Material	Length (cm)	48.5 ± 27.9	-	14.0 ± 9.9	-	25.0	20.9	25.7 ± 9.0	18.1 ± 17.8	-
	Width (cm)	1.4 ± 0.8	-	4.3 ± 4.4	-	4.0	20.9	15.7 ± 10.7	4.7 ± 4.1	-
	Weight (g)	6.4 ± 11.3	-	1.5 ± 2.0	-	2.4	4.6	15.0 ± 8.4	1.4 ± 1.8	-
Plastic packaging	Length (cm)	19.8 ± 3.3	25.0	18.1 ± 10.5	16.7 ± 11.9	12.5 ± 8.7	20.0 ± 11.6	25.4 ± 14.8	20.1 ± 12.0	24.0 ± 10.0
	Width (cm)	3.0 ± 1.7	7.0	6.0 ± 13.9	2.8 ± 0.4	2.5 ± 1.4	4.6 ± 3.0	9.1 ± 5.5	6.9 ± 7.1	10.3 ± 8.1
	Weight (g)	3.2 ± 3.8	0.7	1.8 ± 2.4	1.8 ± 1.4	1.6 ± 1.4	1.4 ± 1.5	2.5 ± 3.4	1.3 ± 1.5	3.0 ± 2.0
Rope/ strapping	Length (cm)	31.3 ± 35.5	-	23.0	-	-	-	15.2 ± 7.0	32.2 ± 36.6	-
	Width (cm)	0.8 ± 0.9	-	2.0	-	-	-	5.1 ± 4.1	2.1 ± 3.3	-
	Weight (g)	2.4 ± 3.8	-	2.8	-	-	-	3.5 ± 3.4	1.6 ± 2.6	-
Other	Length (cm)	6.1 ± 3.7	5.5 ± 0.7	14.9 ± 12.2	11.0	12.0	8.5 ± 10.4	10.2 ± 5.3	15.2 ± 13.0	-
	Width (cm)	4.0 ± 3.6	4.8 ± 1.8	3.7 ± 3.1	10.0	3.5	2.0 ± 1.3	5.0 ± 3.8	3.4 ± 2.7	-
	Weight (g)	3.9 ± 6.1	1.8	1.8 ± 1.8	8.0	3.7	0.8 ± 0.5	1.7 ± 1.4	1.5 ± 1.7	-

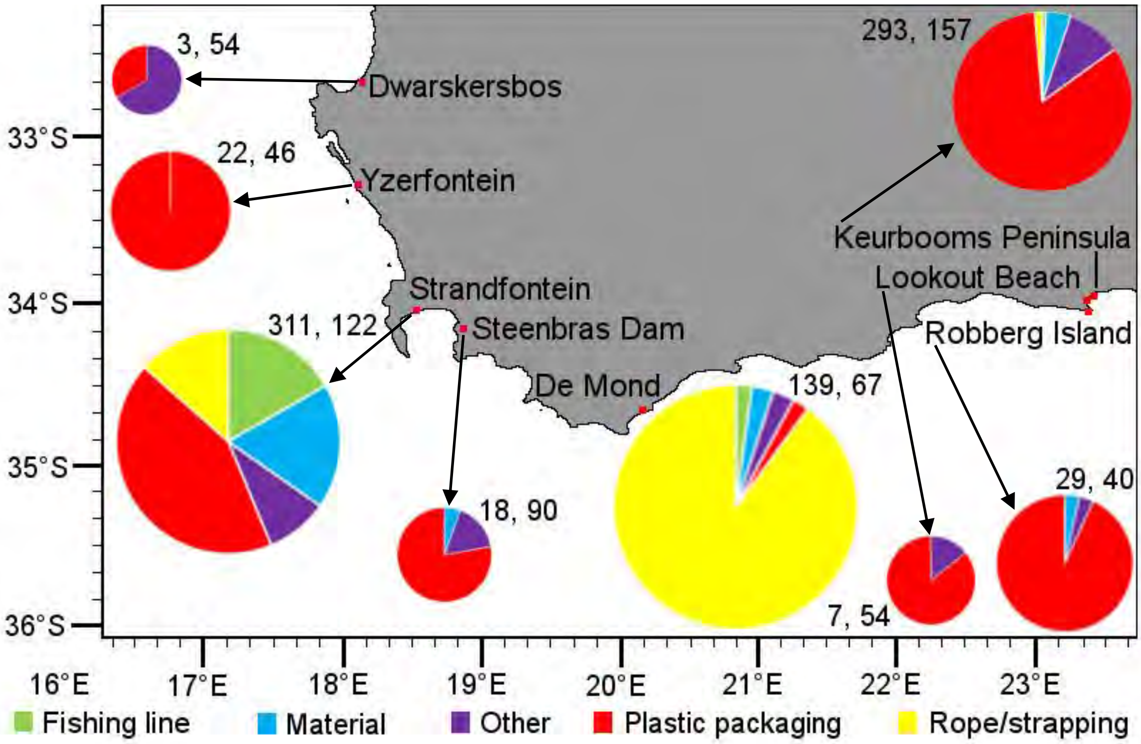

Fig. 1. Site-specific variation in the occurrence of anthropogenic debris items found in Kelp Gull nests in the Western Cape, South Africa. De Mond was surveyed during incubation whereas other locations were provisioning large chicks. Numbers adjacent to pie charts give total items collected and total nests surveyed at each location, respectively. Pie charts are scaled to the proportion of nests containing anthropogenic debris.

The best fitting model explaining the frequency of occurrence of all debris items in Kelp Gull nests contained all three explanatory variables under consideration and garnered most of the support (AICc weight 0.72; Table 4). Model averaging of the models with substantial support (ΔAICc < 4) showed that the frequency of occurrence of all debris items varied significantly according to distance to nearest urban waste landfill, nest type, and location type (Table 5). Overall, coastal breeding colonies had a higher frequency of occurrence of anthropogenic debris items (47%) than both inland (12%; $\chi^2 = 40.872$, d.f. = 1, $p < 0.001$) and salt pan breeding colonies (12%; $\chi^2 = 39.601$, d.f. = 1, $p < 0.001$), but there was no significant difference in the frequency of occurrence between inland and salt pan breeding colonies (χ^2 =

0.000, d.f. = 1, p = 1.000). Nests in open areas more frequently contained debris items (54%) than nests in vegetated areas (31%; χ^2 = 27.893, d.f. = 1, p < 0.001). Looking at within location trends for three breeding sites where a representative sample of nests in both open and vegetated areas were surveyed, De Mond had a higher occurrence of debris items in open (78%) than vegetated nests (53%) though this was not significant (χ^2 = 3.644, d.f. = 1, p = 0.056). A similar and significant trend was shown for Strandfontein with 82% occurrence in open nests vs 40% occurrence in vegetated nests (χ^2 = 20.142, d.f. = 1, p < 0.001). Keurbooms Peninsula showed the opposite trend where nests in vegetated areas (58%) had a higher occurrence of debris items than nests in open areas (11%; χ^2 = 27.033, d.f. = 1, p < 0.001).

Although analyses revealed significant variation in the frequency of occurrence of anthropogenic debris items in relation to distance to the nearest urban waste landfill, this merely shows that locations, which differ in the distance to nearest urban waste landfill, differ in the frequency of occurrence of debris items in nests; this does not show a significant relationship between distance to nearest urban waste landfill and the frequency of occurrence of debris items. The relationship was tested using a Pearson's product-moment correlation which shows a non-significant negative relationship between the frequency of occurrence of anthropogenic debris items and distance to the nearest urban waste landfill (r = -0.375; t = -0.992, d.f. = 6, p = 0.359; Fig. 2a).

Table 3. The proportion of anthropogenic debris items from each debris type classified by colour. Items were collected from Kelp Gull nests at eight locations in the Western Cape, South Africa.

	Colour classification					
Debris type	Clear	White/grey	Brown/black	Purple/blue	Green	Yellow/red
Fishing line	69%	18%	0%	4%	5%	4%
Material	0%	64%	11%	4%	7%	15%
Plastic packaging	81%	13%	2%	3%	0%	1%
Rope/strapping	1%	51%	7%	8%	22%	11%
Other	6%	72%	14%	4%	0%	4%

Table 4. Comparison of generalised linear models (GLM) explaining the occurrence of anthropogenic debris items in Kelp Gull nests from eight breeding colonies in the Western Cape, South Africa, using distance to nearest urban waste landfill, nest type, and location type as explanatory variables. '+' represents additive effects.

Model	K^a	AICc	ΔAICc	AICc w[b]	LL[c]
Nearest landfill + Nest type + Location type	5	743.67	0.00	0.72	-366.79
Nearest landfill + Location type	4	745.63	1.96	0.27	-368.79
Nest type + Location type	4	754.61	10.93	0.00	-373.27
Location type	3	758.29	14.62	0.00	-376.13
Nest type + Nearest landfill	3	783.75	40.08	0.00	-388.86
Nearest landfill	2	796.24	52.57	0.00	-396.11
Nest type	2	802.79	59.12	0.00	-399.38
Null	1	828.93	85.25	0.00	-413.46

[a]Number of parameters.

[b]AICc weight.

[c]Loglikelihood.

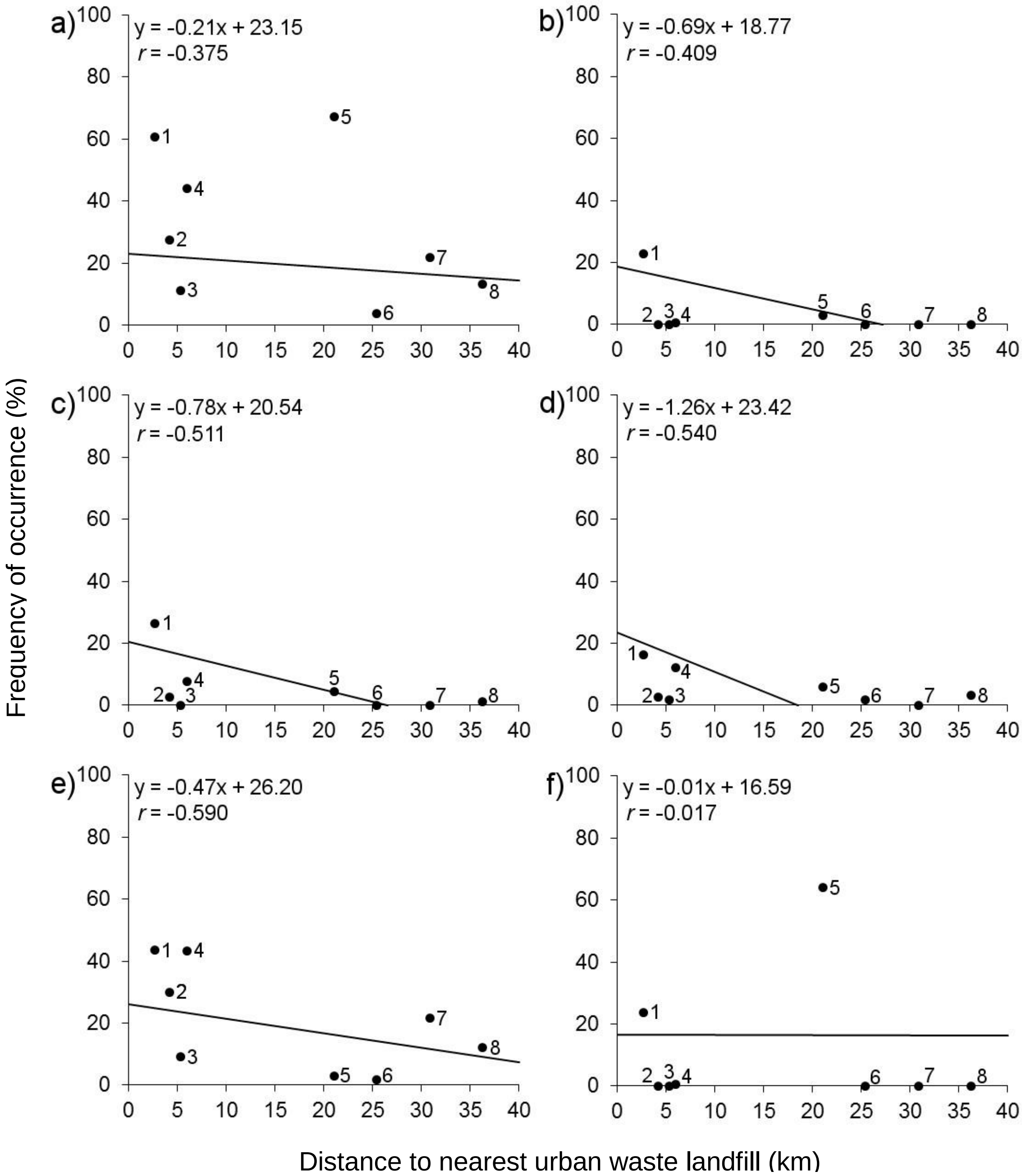

Fig 2. Correlation of the frequency of occurrence of anthropogenic debris items (%) and distance to nearest urban waste landfill (km) of a) all items found in Kelp Gull nests; b) fishing line; c) material; d) other; e) plastic packaging; and f) rope/strapping. Numbers represent the eight locations surveyed in order of distance to nearest urban waste landfill: 1) Strandfontein; 2) Robberg Island; 3) Lookout Beach; 4) Keurbooms Peninsula; 5) De Mond; 6) Dwarskersbos; 7) Yzerfontein; 8) Steenbras Dam.

When considering the effect of distance to nearest urban waste landfill, nest type, and location type on the frequency of occurrence of each of the five debris types collected, there was only one best fitting model for fishing line and rope/strapping, while the other debris types had more than one model with substantial support which were model averaged (Table 6). The effect of distance to nearest urban waste landfill, nest type, and location type on the frequency of occurrence of each of the five debris types collected varied according to the debris type considered (Table 7). Of the three explanatory variables tested, only distance to the nearest urban waste landfill had a consistent significant effect on all five debris types (Table 7). However, as mentioned above, this shows that locations with differing distance to urban waste landfills differ significantly in the frequency of occurrence of anthropogenic debris items, and does not show a significant correlative relationship. Pearson's product-moment correlations run on each of the five debris types show a non-significant negative relationship between the frequency of occurrence of anthropogenic debris items and distance to the nearest urban waste landfill (Fishing line: r = -0.409, t = -1.099, d.f. = 6, p = 0.314; Material: r = -0.511, t = -1.458, d.f. = 6, p = 0.195; Other: r = -0.540, t = -1.571, d.f. = 6, p = 0.167; Plastic packaging: r = -0.590, t = -1.791, d.f. = 6, p = 0.124; Rope/strapping: r = -0.017, t = -1.042, d.f. = 6, p = 0.968; Fig. 2b-f).

Although included in models with substantial support (Table 6), location type showed no significant effect on frequency of occurrence of any of the five debris types (Table 7). Nest type showed a significant effect on three of the five debris types (Table 7), where open nests had a significantly higher frequency of occurrence of fishing line than vegetated nests (18% vs 1%; χ^2 = 71.566, d.f. = 1, p < 0.001), as well as the frequency of occurrence of material (17% vs 5%; χ^2 = 24.517, d.f. = 1, p < 0.001), and rope/strapping (35% vs 4%; χ^2 = 104.359, d.f. = 1, p < 0.001).

A number of models investigating the number of anthropogenic debris items found in Kelp Gull nests received substantial support, and involved all three explanatory variables (Table 8). Interestingly, model averaging revealed that only location type had a significant effect on the number of debris items found in Kelp Gull nests, while the effects of distance to nearest urban waste landfill and nest type were non-significant (Table 9). Overall, coastal breeding colonies had a larger number of debris items in nests (average: 1.77, maximum: 15) than both inland (average: 0.20, maximum: 3; $t = 9.978$, d.f. = 525.576, $p < 0.001$) and salt pan breeding colonies (average: 0.25, maximum: 5; $t = 9.125$, d.f. = 528.646, $p < 0.001$), but there was no significant difference in the number of debris items between inland and salt pan breeding colonies ($t = -0.498$, d.f. = 177.429, $p = 0.619$).

Table 5. The average of the best fitting models weighted by AICc (ΔAICc < 4), showing the effects of distance to nearest urban waste landfill, nest type, and location type on the occurrence of anthropogenic debris items in Kelp Gull nests from eight breeding colonies in the Western Cape, South Africa.

Variable	Estimate	SE	Adjusted SE	z	Pr(>|z|)
Intercept	-0.295	0.222	0.222	1.328	0.184
Nearest urban waste landfill	0.050	0.014	0.014	3.539	< 0.001
Nest type (Vegetated)[a]	-0.407	0.204	0.204	1.992	< 0.05
Location type (Inland)[b]	-3.106	0.542	0.543	5.716	< 0.001
Location type (Salt pan)[b]	-3.393	0.614	0.615	5.518	< 0.001

[a, b]Categorical variables need to be compared to a baseline level. The baseline level for Nest type was open nests, while for Location type it was coastal.

Table 6. Comparison of generalised linear models (GLM) explaining the occurrence of five types of anthropogenic debris in Kelp Gull nests from eight breeding colonies in the Western Cape, South Africa, using distance to nearest urban waste landfill, nest type, and location type as explanatory variables. Only models with ΔAICc < 4 are displayed. '+' represents additive effects.

Model	K^a	AICc	ΔAICc	AICc w[b]	LL[c]
Fishing line	-	-	-	-	-
Nest type + Nearest landfill	3	168.13	0.00	0.88	-81.05
Material	-	-	-	-	-
Nest type + Nearest landfill	3	299.23	0.00	0.67	-146.60
Nearest landfill + Nest type + Location type	5	300.71	1.47	0.32	-145.30
Other	-	-	-	-	-
Nearest landfill	2	330.21	0.00	0.40	-163.09
Nest type + Nearest landfill	3	331.02	0.81	0.27	-162.49
Nearest landfill + Location type	4	332.50	2.29	0.13	-162.22
Nearest landfill + Nest type + Location type	5	333.20	2.99	0.09	-161.55
Location type	3	333.99	3.78	0.06	-163.97
Plastic packaging	-	-	-	-	-
Nest type + Nearest landfill	3	680.43	0.00	0.55	-337.19
Nearest landfill	2	681.56	1.13	0.31	-338.77
Nearest landfill + Nest type + Location type	5	684.17	3.74	0.08	-337.04
Rope/strapping	-	-	-	-	-
Nearest landfill + Nest type + Location type	5	282.25	0.00	1.00	-136.08

[a]Number of parameters.

[b]AICc weight.

[c]Loglikelihood.

Table 7. The average of the best fitting model(s) weighted by AICc (ΔAICc < 4), showing the effects of distance to nearest urban waste landfill, nest type, and location type on the occurrence of five anthropogenic debris types in Kelp Gull nests.

Variable	Estimate	SE	Adjusted SE	z	Pr(>|z|)
Fishing line	-	-	-	-	-
Intercept	-0.274	0.422		-0.650	0.516
Nest type (Vegetated)[a]	-3.116	0.622		-5.013	< 0.001
Nearest landfill	-0.226	0.088		-2.565	< 0.05
Material	-	-	-	-	-
Intercept	-0.807	0.290	0.290	2.781	< 0.01
Nest type (Vegetated)[a]	-1.055	0.312	0.313	3.372	< 0.001
Nearest landfill	-0.118	0.038	0.039	3.052	< 0.01
Location type (Inland)[b]	2.133	1.809	1.813	1.177	0.129
Location type (Salt pan)[b]	-13.632	988.124	990.041	0.014	0.990
Other	-	-	-	-	-
Intercept	-1.941	0.295	0.295	6.573	< 0.001
Nearest landfill	-0.056	0.022	0.022	2.616	< 0.01
Nest type (Vegetated)[a]	0.383	0.353	0.353	1.085	0.278
Location type (Inland)[b]	0.021	1.252	1.253	0.017	0.987
Location type (Salt pan)[b]	-1.339	1.366	1.368	0.978	0.328
Plastic packaging	-	-	-	-	-
Intercept	-0.622	0.213	0.213	2.922	< 0.01
Nest type (Vegetated)[a]	0.386	0.220	0.221	1.750	0.080
Nearest landfill	-0.047	0.009	0.009	5.058	< 0.001
Location type (Inland)[b]	-0.033	0.602	0.604	0.055	0.623
Location type (Salt pan)[b]	-0.242	0.546	0.547	0.443	0.658
Rope/strapping	-	-	-	-	-
Intercept	-2.055	0.265		-7.745	< 0.001
Nearest landfill	0.163	0.021		7.781	< 0.001
Nest type (Vegetated)[a]	-2.061	0.333		-6.186	< 0.001
Location type (Inland)[b]	-21.337	1133.573		-0.019	0.985
Location type (Salt pan)[b]	-22.465	904.776		-0.025	0.980

[a, b]Categorical variables need to be compared to a baseline level. The baseline level for Nest type was vegetated, while for Location type it was coastal.

Table 8. Comparison of negative binomial generalised linear models (GLM) explaining the number of anthropogenic debris items in Kelp Gull nests from eight breeding colonies in the Western Cape, South Africa, using distance to nearest urban waste landfill, nest type, and location type as explanatory variables. '+' represents additive effects.

Model	K^a	AIC	ΔAIC	AIC w^b	$2LL^c$
Nearest landfill + Nest type + Location type	5	1730.64	0.00	0.34	-1718.65
Nearest landfill + Location type	4	1730.65	0.01	0.34	-1720.65
Nest type + Location type	4	1731.79	1.15	0.19	-1721.79
Location type	3	1732.78	2.14	0.13	-1724.78
Nest type + Nearest landfill	3	1761.46	30.82	0.00	-1753.46
Nearest landfill	2	1771.59	40.95	0.00	-1765.59
Nest type	2	1799.05	68.41	0.00	-1793.05
Null	1	1812.75	82.11	0.00	-1808.75

[a]Number of parameters.

[b]AIC weight.

[c]Two loglikelihood.

Table 9. The average of the best fitting models weighted by AIC (ΔAIC < 4), showing the effects of distance to nearest urban waste landfill, nest type, and location type on the number of anthropogenic debris items in Kelp Gull nests from eight breeding colonies in the Western Cape, South Africa.

Variable	Estimate	SE	Adjusted SE	z	Pr(>|z|)
Intercept	0.551	0.194	0.194	2.845	< 0.01
Nearest urban waste landfill	0.023	0.012	0.012	1.934	0.053
Location type (Inland)[a]	-2.589	0.543	0.544	4.763	< 0.001
Location type (Salt pan)[a]	-2.446	0.578	0.579	4.228	< 0.001
Nest type (Vegetated)[b]	-0.278	0.184	0.185	1.507	0.132

[a, b]Categorical variables need to be compared to a baseline level. The baseline level for Location type it was coastal, while for Nest type was open nests.

Discussion

Anthropogenic debris has spread to many areas of the natural environment, often collecting in coastal and marine locations, allowing for the interaction with a number of species (Laist 1987). It is therefore no surprise that nests of the urban-adapted Kelp Gull at all eight breeding sites surveyed had anthropogenic debris items present in nests. The frequency of occurrence of nests with debris items varied significantly according to location. Depending on the site, 4-67% of nests contained anthropogenic debris which is comparable to studies on other seabird species where 4-74% of Brown Booby *Sula leucogaster* (Lavers et al. 2013; Verlis et al. 2014), 2-98% of Northern Gannet *Morus bassanus* (Montevecchi 1991; Votier et al. 2011; Bond et al. 2012), 23-35% of Australasian Gannet *M. serrator* (Norman et al. 1995), 39-57% of Kittiwake (Clemens & Hartwig 1993; Hartwig et al. 2007), and 37% of Double-crested Cormorant *Phalacrocorax auritus* (Podolsky & Kress 1989) nests contained anthropogenic debris.

Although locations differing in the distance to nearest urban waste centre had significantly differing frequency of occurrence of debris items, there was no significant correlation between the two variables as was expected. One would expect that items such as plastic packaging were most likely to be primarily sourced from an urban waste landfill but this item type did not show a significant correlation between occurrence and distance. Anthropogenic debris can be transported to remote coastal locations through ocean currents (Barnes et al. 2009), such that seabirds nesting on islands far from an urban centre collect washed up marine debris to use as nest lining (Lavers et al. 2013). Furthermore, although not observed in Kelp Gulls, certain species such as gannets and cormorants collect nesting material at sea (Montevecchi 1991; Laist 1997), where concentrated collections of anthropogenic debris can be independent of distance to nearest urban centre. While not quantified in this study, types of debris used as nest lining by Brown Boobies has been shown to be related to the anthropogenic debris washed up on the shoreline (Lavers et al. 2013). However, Verlis et al. (2014) showed that the frequency of occurrence of debris in Brown Booby nests was not related to the availability of debris items on the shoreline.

The frequency of occurrence of anthropogenic debris in Kelp Gull nests varied according to nest type, related to the amount of natural vegetation available for nest building. Generally, open nests had a higher occurrence of debris than vegetated nests, as was expected. As open nests had only a small amount, or no, vegetation available in the immediate vicinity for nest building it was hypothesised that these pairs would be more likely to include anthropogenic debris as nest material than pairs nesting in a highly vegetated area, as was shown to be the case with Brown Boobies nesting at Ashmore Reef (Lavers et al. 2013). The nest structure of Kelp Gulls is typically a scrape, variably lined with vegetation, built on the ground or among low, dense vegetation, rarely under trees (Crawford & Hockey 2005). In open areas, they gather items from surrounding areas (vegetation, kelp, shells, feathers, litter) to form the outer walls of the nest, but in vegetated areas there is less attempt to gather materials, with the scrape being formed among vegetation which creates the outer rim of the nest (Crawford & Hockey 2005). This explains why in colonies predominantly incubating eggs open nests have a higher occurrence and number of debris items. Once chicks hatch parents begin bringing food to the nest, and debris items are added to the nest when food containing plastic is regurgitated to feed the chicks. Much of this blows away or lies adjacent to the nests, but, especially in vegetated areas, where the nest structure tends to be larger and more sheltered, some is trapped in the nest cup and walls, so sampling at the end of the breeding season results in a mix of construction and dietary material; such as was seen at Keurbooms Peninsula. Adult pellets regurgitated within the breeding colonies are also a source of debris items, particularly plastics (see Chapter 4, Table 3), that can become trapped adjacent to or within the nest bowl. As nest construction in Kelp Gulls relies on the local availability of materials, there are marked local differences in the amount of nest construction debris items associated with nest construction (fishing line and rope/strapping). However, at all colonies there are some debris items (primarily plastics) carried to the site in meals which would explain the preponderance of food-related bags and wrappers. Due to the remote location of the Kelp Gull colony breeding at Steenbras Dam all anthropogenic debris items from within the colony was collected, and is assumed to be items characteristically part of the gulls' diet. From this it can be seen that items found in the nests of gulls at the end of the breeding season are typical of the dietary composition.

The occurrence of debris type was heavily biased toward plastic packaging (predominantly from diet – see Chapter 4) and rope/strapping (likely predominantly from nest construction), with fishing line (most likely from nest construction) being the least frequent. Fishing gear has been a prevailing constituent of anthropogenic debris nesting material in locations where commercial fishing is a common activity and where birds collect nesting material at sea (Montevecchi 1991; Bond et al. 2012; Verlis et al. 2014). The low incidence of fishing line as nesting material in this study can be attributed to the lack of extensive commercial fishing activity, though recreational/subsistence fishermen are active in these areas, and that Kelp Gulls are unlikely to collect nesting material at sea, preferring to collect nesting material along the shoreline, surrounding terrestrial areas, and within the breeding colony. Much of the rope/strapping items are from fisheries, or fishing related activities collected from the shoreline. The large amount of plastic packaging found in Kelp Gull nests can be attributed to their scavenging nature. Much of the plastic packaging was from food packaging which would be scavenged at an urban waste landfill or from general litter, or stolen from beach goers and restaurant patrons.

Interestingly, location type is the only variable which significantly affects the number of debris items found in Kelp Gulls nests. The inland and salt pan breeding colonies are in more remote areas with limited access to anthropogenic debris items, whereas coastal breeding colonies are closer to urban areas, as well as having access to items washed up on the shoreline, which is why gulls breeding in coastal areas have a higher number of items in their nests.

Vegetated nests present more of an entanglement risk as debris items are more likely to be retained in the nest bowl and entangle with chicks or adults and surrounding vegetation, as has been seen in Kelp Gulls in Patagonia entangled in fishing line (Yorio et al. 2014). Entangled chicks and adults have been observed at Strandfontein (P. Ryan, in litt.) and Keurbooms Peninsula (pers. obs.). Kelp Gulls do not re-use the same nest in consecutive years (Crawford & Hockey 2005; Votier et al. 2011), which would reduce the risk of entanglement.

The high occurrence of anthropogenic debris items in Kelp Gull nests is of concern, and it will be important for the source location of these items to be identified, so that appropriate management of these areas can be implemented to reduce the amount of debris items available to gulls. It is suspected that many anthropogenic debris items are collected from urban waste landfills, which would require improved management to curb Kelp Gull presence. It has been suggested that during periods of high visitation, exposed areas could be covered with soil or a commercial cover material (Belant 1997), or burnt as partially burnt refuse is less appealing to gulls (Monaghan et al. 1986). However, this may be economically and logistically unfeasible.

Chapter 6: Synthesis and conclusions

This dissertation investigated the effects of a changing environment, particularly due to climate change and urbanisation, on the breeding biology and diet of Kelp Gulls *Larus dominicanus vetula* breeding in Plettenberg Bay, Western Cape. The primary motivation for this study was that there is little knowledge about the manner in which recent climate change and urbanisation affects aspects of the breeding biology and diet of Kelp Gulls, with the last studies investigating diet and habitat dependent breeding success taking place over 20 years ago (Brooke & Cooper 1979b; Burger & Gochfeld 1981; Williams et al. 1984; Steele 1992). The purpose of the study was to determine whether gulls can breed equally successfully in a variety of microhabitats, and the extent to which gulls have adapted to an urban environment by including anthropogenic food items in their diet, and anthropogenic debris items in their nests. This research was also undertaken to provide an updated population estimate for the Plettenberg Bay breeding colonies, last counted in 2006 (P. Whittington, in litt.). Population estimates of the largest mainland colony in Plettenberg Bay trialled the use of an unmanned aerial vehicle (UAV) in population estimates, the first of its kind in Africa, although this method has been used successfully in Spain to monitor breeding Black-headed Gulls (Sardà-Palomera et al. 2012).

The Kelp Gull is a cosmopolitan, mainly Southern Hemisphere species, and its numbers are increasing in many parts of the world (BirdLife International 2014). Kelp Gulls are one of 15 seabird species, and the largest gull, that breed in southern Africa (Cooper et al. 1984; Whittington et al. 1999). It is also one of only five of the 15 species that is classified as Least Concern (BirdLife South Africa 2014). With so many species threatened by environmental and climate change and urbanisation, it is easy to focus on the species that are immediately at risk to elucidate and mitigate threats to the population or species as a whole. However, species that are thriving under the circumstances of a changing environment are equally important to monitor, to identify the forces driving their population increase and potentially mitigate before the species becomes a pest, as well as to identify potential problems before population declines become a reality.

Summary of the main findings

Anthropogenic food items are an important component of both pre-breeding and breeding adult Kelp Gull diet in Plettenberg Bay. This was expected, as it has been shown for Kelp Gulls elsewhere in their range and for other gull species (Annett & Pierotti 1989; Duhem et al. 2003; Duhem et al. 2005; Weiser & Powell 2010; Frixione et al. 2012). The few birds tracked with GPS loggers appeared to spend little time at the urban waste landfill, and other urban sources of anthropogenic food. I hypothesised that the importance of anthropogenic food items would be reflected in the time that birds spent in urban areas, however, this was not the case. This was attributed to short search and handling time for anthropogenic food items in urban areas such as the urban waste dump (Steele 1992). Furthermore, it was found that Kelp Gull chicks were fed a diet dominated by marine items, with a much reduced frequency and proportion of anthropogenic food items, similar to the results found in other studies (Annett & Pierotti 1989; Bertellotti & Yorio 1999; Duhem et al. 2005).

Another aspect of Kelp Gull biology where anthropogenic items have become prevalent is in nest construction. All eight Kelp Gull breeding colonies surveyed throughout the Western Cape, South Africa, had a proportion of nests which contained anthropogenic debris items. This result, too, coincides with findings from other seabird breeding colonies around the world which contained anthropogenic debris items (Hartwig et al. 2007; Votier et al. 2011; Bond et al. 2012; Lavers et al. 2013; Verlis et al. 2014). These studies hypothesised that the items were brought in as nesting material, however, in this study nests were inferred to contain two types of debris items: those included during nest construction as nesting material (mainly ropes and straps), and those included in meals delivered to the chicks (mainly bags and food wrappers) which accumulate during the chick-rearing period. Overall, nests in open areas showed a higher frequency of occurrence of debris items then nests in vegetated areas, linked to nest construction. Nests in vegetated areas also showed a high occurrence of debris items as surrounding vegetation is more likely to retain bags and wrappers brought with chick meals. The frequency of occurrence of anthropogenic debris items was less strongly correlated to distance to the nearest urban waste landfill site than expected. This suggests that other factors affect the frequency of occurrence of anthropogenic debris items in nests besides distance to nearest landfill sites.

While urbanisation has had a large impact on aspects of Kelp Gull lifestyle in Plettenberg Bay, I surmise that gulls should be sufficiently adaptable to be able to buffer the effects of habitat changes due to climate change. Multivariate models show no significant effects of nest site variables on clutch size and average egg mass at laying. Clutch size, average egg mass at laying, and daily survival rate (DSR), were positively related to vegetation cover and height surrounding the nest, and negatively affected by distance to nearest cover, but I cannot rule out the potential effect of age and experience on nest site selection. Of the breeding performance variables investigated, differences between microhabitats were minimal, suggesting that future habitat change caused by climate change, and to a lesser extent urbanisation, will not significantly affect hatching success, barring changes such as increased anthropogenic disturbance or mammalian predation, however, similar investigations are necessary into fledging success.

Kelp Gulls in Plettenberg Bay breed at three sites, two historical and one recently colonised, with differing success. Robberg Island, a historical breeding site supporting the smallest colony, had a very low hatching success, most likely due to egg predation by natural predators (mongooses and otters). Keurbooms Peninsula, the second historical breeding site, and Lookout Beach, a newly established breeding site immediately adjacent (and formed by recent flooding altering the topography), had similar, much higher rates of hatching success than at Robberg. An UAV was successfully used to collect aerial imagery of the Keurbooms Peninsula breeding colony allowing for population quantification. However, the error associated with the trials of the method could be the cause of the slight recorded decrease in breeding pairs recorded at this site since 2003/4. Counts at Robberg Island also show that this site has experienced a drop in the number of breeding pairs, possibly due to birds relocating to other sites after unsuccessful breeding attempts.

Implications of the findings

The ease with which Kelp Gulls have managed to adapt to an urban environment, while not surprising, is a concern. Although the urban waste landfill in Plettenberg Bay is now closed, similar results may be found for other Kelp Gull populations in South Africa, and it would be advisable to implement improved waste management services in these areas. This would not only prevent a potential population increase of a species known for their negative impacts on other species (Hockey 1980; Tjorve & Underhill 2008; Fazio et al. 2012), but also reduce the incidents of entanglement and ingestion (Gregory 2009), and other debris related health concerns (Burger & Gochfeld 2001; Bouwman et al. 2008), of this and other species. Hopefully this has been the first of many studies into the extent to which Kelp Gulls, and other species, have adapted to and are utilising an urban environment, highlighting the need for improved anthropogenic debris management. However, more studies of this nature need to be implemented in other Kelp Gull colonies before the appropriate course of action, if any, can be decided.

The tentative investigations into the plasticity of three measures of breeding performance in response to a varying microhabitat has shown that changes to the current habitat are unlikely to negatively affect Kelp Gull breeding performance. This suggests that the expected future changes in breeding habitat due to climate change as well as urbanisation may not be detrimental to the breeding of this species, although post hatching survival needs investigation.

Updated counts of the Kelp Gull breeding colonies in Plettenberg Bay contribute to the overall status of Kelp Gulls in South Africa. These status updates are important when monitoring species which have the potential to reach pest status, to prevent damage by implementing the appropriate and necessary control measures. Although Kelp Gull populations worldwide have been increasing (BirdLife International 2014), this trend is not apparent for the southern African race. As has been shown in this study, some Kelp Gull populations in South Africa are decreasing, and although there are some local increases, these are more than offset by local decreases (Whittington et al. in press).

Using an UAV to estimate the breeding population of a colonially breeding seabird has shown how the method can be successfully used to monitor densely breeding populations where direct counts can cause high levels of disturbance. More so, these trials have shown the importance of choosing the UAV model, camera, flight mode, altitude, and ground truthing method for the data that will be collected. This will hopefully help direct and focus those who are willing to use UAV for surveys of colonially breeding seabirds.

Limitations of the current study and suggestions for future research

The effects of climate change and urbanisation on the life processes of species will remain of interest due to the extensive changes wrought upon the natural environment. The Kelp Gull is one species that appears to have adapted successfully to the current changing environment, but more extensive and in-depth research in southern Africa is necessary. Specifically of interest in Plettenberg Bay is how Kelp Gulls will react to the closing of the local urban waste landfill, whether their diet will continue to be dominated by anthropogenic food items, whether the slight decrease in population size documented in this study will be exacerbated, and whether breeding success will be affected. Estimates of the breeding population on Keurbooms Peninsula where a slight decrease was recorded could be attributed to error associated with the use of an UAV. Estimates were limited due to incomplete coverage of the entire breeding colony, and the lack of appropriate ground truthing for each flight done. Year-to-year variability in the population size of colonially nesting seabird species throughout southern Africa can be monitored easily through the use of UAVs conducting aerial surveys. However, initial research is required to determine the ideal methodology (UAV model, camera, flight mode, altitude, and ground truthing method) required to maximise the benefits associated with this method of population estimation. Estimates of the breeding population on Keurbooms Peninsula would have benefitted through the use of an UAV set on an automated course covering the entire breeding colony using a high resolution camera. Furthermore, using the double-flight method of ground truthing, or directly counting a set of nests in a small area of the colony after each flight, would have increased the accuracy and precision of the correction factor and thereby the estimates of the population, rather than ground truthing one image from one flight and applying that correction factor to the other flights.

A clearer picture of the composition of anthropogenic debris items used as nesting material could have been garnered through nest surveys being conducted at the beginning of the breeding season during the incubation period, as well as at the end of the breeding season. This would have allowed for a comparison of the amount and composition of items used in nest construction, and those more likely to have been brought in with meals while provisioning chicks. As many of the litter items found in nests throughout the Western Cape were attributed to dietary components, nest surveys could have been augmented by the collection of pellets as a comparison of dietary composition. Pellets could also have been used to elucidate the predominance of anthropogenic, and other, items in Kelp Gull diet and how this related to distance to the nearest urban waste landfill.

It is also of interest to determine where gulls forage for anthropogenic items. Unfortunately, the small sample of GPS loggers retrieved in this study limited the inference that could be made from these data. It may be worth undertaking marking experiments similar to that of Bertellotti et al. (2001) at certain colonies located close to urban waste landfills to estimate the number of birds that use the landfill and other urban areas. Bertellotti et al. (2001) marked an individual from a number of breeding pairs by replacing the natural clutch with a domestic chicken egg applied with a dye mixture, when birds came to incubate the dye transferred to the breast and abdominal feathers allowing for clear identification. If landfills are revealed to be the primary anthropogenic foraging site, it will become important to investigate the most appropriate method for reducing the amount and appeal of food items, and the accessibility of this food source.

A valuable addition to the investigation of microhabitat effects on breeding performance would have been the effect of microhabitat on other breeding related parameters such as incubation temperature and egg and chick development. With increasing ambient temperature, the thermoregulation and incubation capacity of gulls nesting in various microhabitats should be investigated to determine whether they have the ability to buffer their own thermal environment, as well as the thermal environment of eggs or chicks, regardless of the microhabitat they are in. Furthermore, it could be of interest to determine whether chicks are able to develop independent thermoregulation at an earlier age in more extreme thermal environments.

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