The balance between predators and prey in a mixed seabird colony: managing biodiversity and the conservation of rare species

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Abstract

Increases in seabird population sizes on islands, resulting from reduced mortality and/or increased reproductivity, has resulted from the control of avian predators when predation was confirmed to be the main driver of seabird decline. A substantial conflict in conservation management arises when the control operation targets a protected predator. Tensions and divisions between regulators and conservation managers can be exacerbated when the prey species is of high conservation concern. This latter situation underpins this research study based on Coquet Island, UK, where the core of conservation management is targeted at mitigating predation on Roseate Tern (RT) by breeding Large Gulls (LG), represented by Lesser Black-backed Gull *Larus fuscus* (LBBGU) and Herring Gull *L. argentatus* (HGU). In recent years, the conservation status of HGU has changed to red and LBBGU to Amber categories in the light of increasing concern of notable decline for unknown reasons in the UK. Hence, it is important to have evidence on which to base management strategies for conserving Roseate Terns which minimises the conservation conflicts between prey and predators, all of which are of conservation concern.

A complete understanding of predator-prey relationships relies on determining the dynamic stability of prey and predator populations, and how the food web containing predator-prey pairs responds to environmental influences and other indirect effects. This research investigates the main drivers of LG predation activity over the RT colony during the breeding season. A particular dilemma in estimating the impact of predation by breeding LG on the Coquet Island RT colony resulted from the presence of loafing LG, either non-breeding subadult birds or birds from other colonies, using the intertidal area around the island. Therefore, to test the hypothesis that LG breeding on the island also used the island's seabird colonies as a foraging resource, indirect (Camera traps and dietary analysis of LG pellets) and direct (Observation of predation activity, foraging range estimation from tracking technologies) methods were used.

The results of this study suggest that the frequency of LG events over the RT colony increased towards the end of the breeding season in relation to the number of loafing LG in the intertidal area, and was influenced by tidal state and decreased during the period of RT chick biomass availability. This study provided evidence that LG breeding on the island also used the reserve as part of their foraging territory. The outputs of the tracking data were compatible with the outputs of the pellet analyses which showed a high utilization of available prey from the reserve. LG on Coquet Island utilizing all types of prey sources with no difference between of breeding

or roosting LG with respect to the range of prey types. Indirect evidence that LG predation would be a threat to the small colony of RT was based on the finding that other tern species nesting on Coquet Island were identified using combined molecular and morphological techniques as prey in LG pellets collected from the breeding and roosting LG on Coquet Island. In addition, a study of laser hazing carried out as part of the thesis work shows that this is an efficient non-lethal deterrent for LG management on Coquet Island. Overall, the results of this study provide evidence showing how small numbers of LG may be allowed to breed on Coquet Island by managing the timing of their breeding in relation to the arrival and breeding of RT, and by efficient deterrence of loafing, non-breeding birds. Such an approach will facilitate a wider understanding of how to resolve conservation conflicts between protected predator and protected prey species.

Declaration

The material contained within this thesis has not previously been submitted for a degree at Newcastle University or any other university. The research reported within this thesis has been conducted by the author unless indicated otherwise.

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Dedication

This thesis is dedicated to ……

PROF. FAWAZ ALAZKI RIP.

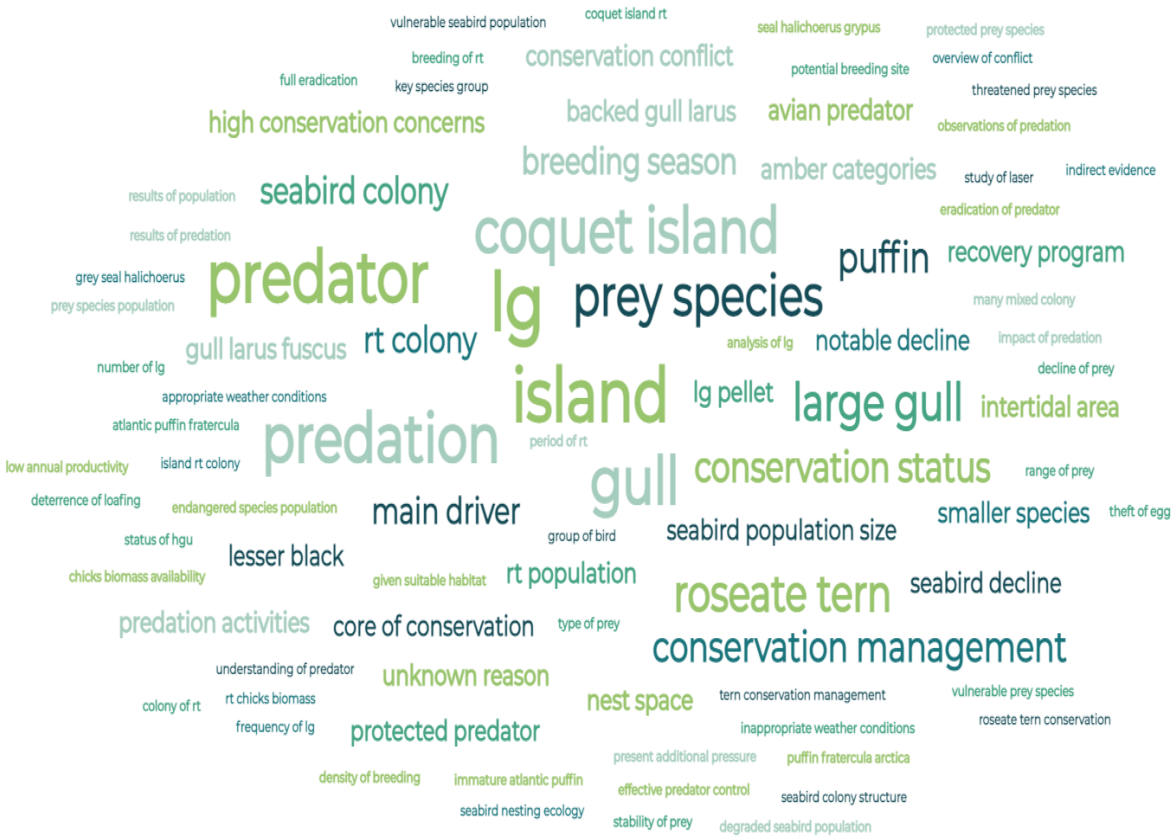
"SCIENTISTS DON'T DREAM BUT THEY HAVE AMBITIONS TO ACHIEVE THEM!"

DR. PAUL G. MORRISON

"NEVER EVER GIVE UP, GET BACK TO WORK…TOUT EST POSSIBLE!"

My Mother & Father

"I HOPE THIS MAKES YOU PROUD!"



Abbreviations

AHD
Active Human Disturbance 100

AIC
Akaike Information Criterion 30

AT
Arctic Terns 7

CT
Common Terns 7

ELH
Efficacy of the Laser Hazing 94

GBBGU
Great Black-backed Gulls 84

HGU
Herring Gull 6

LBBGU
Lesser Black-backed Gull 6

LG
Large Gulls 6

mle
Maximum likelihood estimation 30

NGS
Next generation DNA sequencing 82

PCR
Polymerase Chain Reaction 73

RT
Roseate Terns 3

ST
Sandwich Terns 7

TLGN
Total number of LG nesting over the reserve plateau 98

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Chapter 1 General introduction

1.1 The nature of predation

Numerous ecological studies give well documented examples of predator-prey systems in a wide range of organisms in nature and in artificial experimental environments (Hoi and Winkler, 1994; Whittam and Leonard, 1999; Christina *et al.*, 2007; Gibbons *et al.*, 2007; Cresswell, 2008; Donehower and Bird, 2008; Camphuysen *et al.*, 2010; Stevens, 2012; Osterback *et al.*, 2013; Veitch *et al.*, 2016). However, interactions between predators and prey have not been framed in a satisfactory mathematical model (Nicholson, 1933; Krausman and Leopold, 2013; Wikan and Kristensen, 2019). Hence, fluctuations in the nature of predator-prey systems have over decades provoked debate between ecologists because of the lack of understanding of predator population abundance on individual rates of prey consumption and the potential effects of species other than predator and targeted prey (Tyutyunov *et al.*, 2008; Schmitz, 2017).

A complete understanding of predator-prey relationships relies on determining the dynamic stability of prey and predator populations, and how the food web containing predator-prey pairs responds to environmental influences and other indirect effects (Abrams and Ginzburg, 2000; Stevens, 2012). This, then requires both the functional responses (the rate of prey consumption by an average predator), and numerical responses (describes rate of per capita population growth) to be included in models (Abrams and Ginzburg, 2000; Schmitz, 2017). Both functional and numerical responses can be classified as: (1) Frequency prey-dependent predation (Merilaita, 2006), (2) Frequency predator-dependent predation (Trân, 2008), and (3) Frequency multispecies- dependent predation (Johnson *et al.*, 2019).

In natural ecosystems, most prey consumption rates probably depend on population densities of predator species and ambient conditions other than the prey species population status (Bowen and Lidgard, 2013; Peterson and Colwell, 2014). However, the most pressing task is determining and measuring these other dependencies which need more theoretical and

empirical work in artificial and natural habitats in parallel (Abrams and Ginzburg, 2000; Stevens, 2012; Johnson *et al.*, 2019).

1.2 Effects of predation

The effect of predation on prey population dynamics still raises controversy between two ecological dogmas with respect to whether such effects are regulatory or limiting factors (Nicholson, 1933; Gese and Knowlton, 2001; White, 2001; Blackshaw and Petrovskii, 2007). However, the simplicity of island ecosystems, with food webs of fewer key species with respect to levels of predator and prey, and fewer trophic levels, makes them relatively fragile with low tolerance of predation pressure and therefore ideal environments to test the effects of predation on prey populations (Simberloff and Rejmánek, 2011; Duron *et al.*, 2017).

Seabirds island colonies are well documented for investigating the effect of predation by introduced predators (Jones *et al.*, 2008; Towns *et al.*, 2011) or by invasive avian predators (Jones, 2013), causing in some cases the severe decline and disappearance of prey species from many locations, and a large number of the world's extinction events (Dumont *et al.*, 2010; Robinson, 2010; Drake *et al.*, 2011; Towns *et al.*, 2011). From another point of view, and mainly a result of changes in the local environment, predation by native predators such as seals, terrestrial birds, and gulls has had a significant negative impact on resident seabird populations (Capoulade *et al.*, 2010; Towns *et al.*, 2011) by limiting their breeding success and is considered to be a major factor in the decline of many colonial seabird species (Whittam and Leonard, 2011)

1.3 Effects of displacing

Interspecific competition for food around colonies may be limiting of seabird numbers during the breeding season in cases of high population density and food shortage (Furness and Birkhead, 1984; Lewis *et al.*, 2001; Kalaisekar *et al.*, 2017; Tarjuelo *et al.*, 2017). However, intraspecific competition for space and food may force some seabirds to move to alternative secondary and low-quality habitats (Tarjuelo et al., 2017) causing some vulnerable species to

shift their niche in mixed seabird fragile island ecosystems (Durant *et al.*, 2012; Calizza *et al.*, 2017).

1.4 Impacts of Large Gull on breeding seabirds

Large gulls (LG) represent a key species group affecting seabird colony structures in many ecosystems (Thomas, 1972). They have been identified as a threat for different groups of birds: gulls and terns, puffins, tubenose petrels, herons and greater flamingos, raptors, waterfowl (including ducks and coots), waders, shags and cormorants, and auks (Finney et al., 2003; Oro and Martínez-Abraín, 2007). These threats result, firstly, from competition for nesting space (Quintana and Yorio, 1998), where at many mixed colonies of seabirds, LG often displace smaller species from their territories, in some cases forcing them to abandon the breeding colony altogether (Quintana and Yorio, 1998). In addition, larger larids generally have a competitive advantage over smaller species because they arrive at breeding sites earlier (Quintana and Yorio, 1998; Coulson, 2019). Secondly, by kleptoparasitism, where LG are generally considered to reduce significantly the attractiveness of potential breeding sites for other birds. For example, Finney et al. (2003) found that reducing the density of breeding gulls substantially attracted more immature Atlantic Puffins *Fratercula arctica* to approach the colony as breeding area. Finally, by predation, and some LG become 'specialist' seabird predators, preying significantly on seabird adults, eggs, and chicks (Thomas, 1972; Christina et al., 2007). Terns with their small size, high longevity but low annual productivity, and ground-nesting behaviour (Furness and Tasker, 2000) appear to be one of the most affected seabirds; some tern colonies have decreased substantially as a result of population expansion by LG (Guillemette and Brousseau, 2001; O'Connell and Beck, 2003; Scopel and Diamond, 2017).

1.5 Roseate Tern conservation management

Roseate Terns (RT) declined substantially as a breeding species in the UK during the 1970s (Lloyd *et al.*, 2010), with an average of only around 25 pairs annually on Coquet Island, the sole remaining UK colony, in the last quarter of the 20th century (Capoulade *et al.*, 2010).

This triggered a recovery program since 2000 for the RT population (Morrison and Gurney, 2007). Evaluation of the main threats to the RT colony on Coquet Island suggested a mix of physical and biological factors (Morrison, 2010). Weather conditions and food availability significantly affects their productivity. Another factor was disturbance from human activity such as pleasure boats around the jetty close to the RT terraces and the theft of eggs by egg-collectors (Morrison, 2010). Other species breeding or using Coquet Island, such as Puffins, Grey Seals *Halichoerus grypus* and Large Gulls, present additional pressures limiting the recovery of the RT population, but from different perspectives. Puffins prospecting the terraces at the start of the breeding season create competition for nest space; Grey Seals attempt to access the plateau from a small gully on south foreshore, and can damage nesting areas if not controlled. However, LG present the most significant threat as a result of predation and competition for nest space (Capoulade *et al.*, 2010; Morrison, 2010).

1.6 Controlling predation

Controlling predators by culling (Sanz-Aguilar *et al.*, 2009; Bowen and Lidgard, 2013), disturbance (Peterson and Colwell, 2014), or translocation (Combreau and Smith, 1998; Musil and Connelly, 2009) is still a controversial tool with insufficient knowledge of whether it is a practice effective in preserving a threatened prey species or not (Ormerod, 2002; Malpas *et al.*, 2013). In addition, controlling predation is expensive, time-consuming, and often temporary (Smith *et al.*, 2010b); many studies have shown that population declines of prey species were not driven by the predation pressure but by food shortage, habitat loss and inappropriate weather conditions (Yasué *et al.*, 2003; Hammerschlag *et al.*, 2006). However, controlling predators is one of the key techniques in the recovery programs of degraded seabird populations and becomes central to many conservation and management plans (Palomares *et al.*, 1995; Jones, 2004; Russell *et al.*, 2016). Effective predator control, given suitable habitat, has often been approved as a policy to recover endangered species populations, at least at the level of local

abundance to improve their conservation status (Fletcher *et al.*, 2010; White *et al.*, 2014; Walsh *et al.*, 2015; Russell *et al.*, 2016).

Removing and controlling mammalian predators from islands has had a positive effect on vulnerable seabird populations (Nogales *et al.*, 2004; Amaral *et al.*, 2010; Ratcliffe *et al.*, 2010; Bird *et al.*, 2019). This resulted mainly not just because seabirds are often poor walkers but from the nature of seabird nesting ecology where they nest on the ground or in burrows (Sutherland *et al.*, 2019). Similarly, an increase in seabird population sizes on islands, with success in reducing mortality (Priddel and Carlile, 1995) and/or increasing productivity (Roby *et al.*, 2002) has resulted from the control of avian predators on islands when predation was confirmed to be the main driver of seabird decline (Paracuellos and Nevado, 2010).

1.7 Research to resolve controversy

1.7.1 Overview of conflicts

Full eradication of predators from seabird colonies creates conflict in cases where a predator may be a "keystone species," which means if it is removed for a long period, other species will be affected negatively (Duron *et al.*, 2017). i.e., it will cause an imbalance in the managed ecosystem (Musil and Connelly, 2009; Wikan and Kristensen, 2019). Another conflict occurs when the predation is not (or perhaps only partially) causing declining in the prey species population. It may be the case that habitat improvement, sufficient food, and appropriate weather conditions are more-essential factors which would support the recovery of a vulnerable prey species rather than removing the predators (Smith *et al.*, 2010a; Calizza *et al.*, 2017). Moreover, one of the most complicated conservation-management dilemmas is when the target of the controlling operation is itself a protect species (Sanz-Aguilar *et al.*, 2009; Sutherland *et al.*, 2019). For instance, when prey species have socio-economic value and the predator has conservation status as a protected species (Bro *et al.*, 2006). More tensions and divisions, within conservation decision-makers, occur when the prey species itself is categorized as of high conservation concern (Jones, 2004; Sutherland *et al.*, 2019).

The case study of this research falls under the latter statement, where the core of conservation management is targeted at mitigating predation on Roseate Tern by breeding Large Gulls (LG), i.e., Lesser Black-backed Gull *Larus fuscus* (LBBGU) and Herring Gull *L. argentatus* (HGU) on Coquet Island, UK. The conservation status of the HGU changed to red and LBBGU to Amber categories in the light of increasing the concern of notable decline for unknown reasons. Hence, it is important to re-evaluate the efficacy of controlling them from all available evidence.

1.7.2 Study area and conservation status

The study was conducted on Coquet Island, Northumberland, England (55º 20' N, 1º 32' W, NU293046) located about 2 km from Amble Port, east of Coquet River mouth. Coquet Island is a low island with a flat plateau about 5 ha in area, rising only some 10 m above sea level and mostly covered with vegetation (mainly Yorkshire Fog *Holcus lanatus* with Nettle beds *Urtica dioica*). The plateau itself is surrounded by a low cliff and sandy beach on the southwest corner, and narrow shingle on the southeast corner. The extensive shelves of rocky foreshore are exposed at low tide (Figure 1.1).

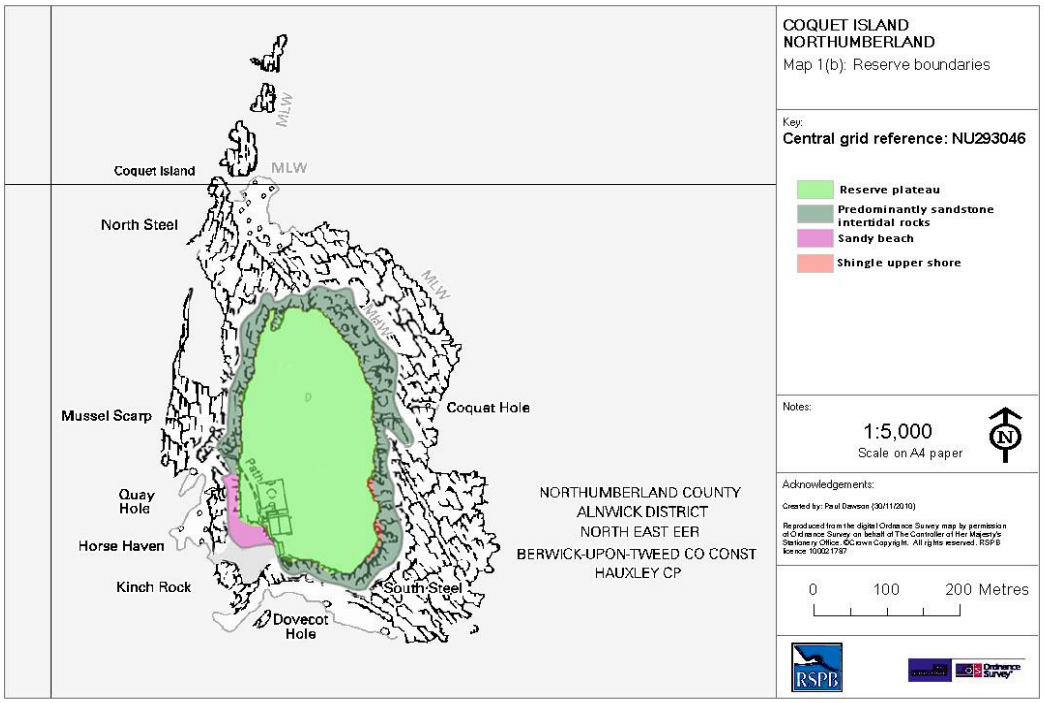


Figure 1.1 Map of Coquet Island, showing boundary and topography of the RSPB reserve, mean high water line (MHW) and mean low water line (MLW), (sources: Coquet Island archive, reproduced courtesy of the reserve site manager)

Coquet Island is a Special Protection Area (SPA) and a Site of Special Scientific Interest (SSSI) designated for housing nationally important populations of breeding seabirds. The island is, aside from Puffins *Fratercula arctica*, Eiders *Somateria mollissima*, Kittiwakes *Rissa tridactyla* and Fulmars *Fulmarus glacialis*, it is also home to four tern species, Arctic Terns *Sterna paradisaea* (AT), Common Terns *Sterna hirundo* (CT), Sandwich Terns *Sterna sandvicensis* (ST), and the only the UK breeding colony of Roseate Tern *Sterna dougallii*. Roseate Tern are listed on Annex I of the Birds Directive and Schedule 1 of the Wildlife and Countryside Act 1981 (JNCC, 1985; Davies and Morrison, 2015). In terms of range size, Roseate Tern is far from the threshold to be vulnerable at a European level. Moreover, the population-size trend was estimated to be increasing according to the European Red list assessment (BTO, 2015a; BTO, 2015b; Symes, 2015; BirdLife, 2016). However, among the six tern species regularly recorded in the UK, only Roseate Tern is considered highly threatened on national level and listed in the Red categories. (BTO, 2015a; BTO, 2015b; Symes, 2015; BirdLife, 2016).

Roseate Tern is currently identified as a conservation priority in the following:

- Red listed in Birds of Conservation Concern 3 (2009 update)
- Wildlife and Countryside Act 1981 - protected under Schedule 1
- EC Birds Directive - e.g., listed in Annex 1 and as a migratory species
- UK BAP - priority species
- Amber listed in Birds of Conservation Concern in Ireland 2008-2013 (2013 update)
- OSPAR List of Threatened and/or Declining Species and Habitats

1.8 The threats and protection measures

Roseate Tern has the highest mortality rate among the terns in west Africa, their wintering grounds, because of capture for food or sport (Cabot, 1996), whereas in breeding habitats the Roseate Tern has been affected by human recreation, the taking of eggs and chicks, or disturbance by small mammals and LG nesting in the same area (Cabot, 1996; Nisbet and Spendelow, 1999). Additionally, some uncontrollable factors such as coastal erosion, high tides and bad weather conditions contributed to this decline as was the case at Tern Island, Co.

Wexford in south-eastern Ireland in 1970s (Cabot, 1996). Moreover, different studies carried out in different parts of the world have suggested that the dominant nesting of gulls is the primary effect limiting the number of secure sites available to tern species for nesting (Nisbet and Spendelow, 1999).

All reports from the Coquet Island study area have suggested that the Roseate Tern population there has been similarly negatively affected by food shortage, weather conditions, and human disturbance, but mainly by the pressure for nesting space and predation from Large Gulls (Evans *et al.*, 2000; Capoulade *et al.*, 2010).

Lethal control using alphachloralose to target breeding Herring Gull and Lesser Black-backed Gull adults on Coquet Island was applied from 1976 leading to a reduction in breeding LG to 27 nests in 1980. This program was stopped in 1984 in the light of stability of the LG population around this level, except for some seasons where the LG population exceed 30 pairs. Otherwise, the LG population was controlled by removing the nests/eggs (Evans et al. 2000). Both Herring gull and Lesser Black-backed Gull numbers increased noticeably by 445% and 920%, respectively, in the study area between 1997-2000, leading to an increase in their nesting range towards the main tern breeding site on the Island (Evans *et al.*, 2000) (Figure 2.17).Therefore, an appropriate recovery management plan for the Roseate Tern began in 2000 on Coquet Island (Davies and Morrison, 2015) aiming to mitigate LG predation pressure. As part of this, the gull-scaring programme starts in March each year including series of scaring techniques. This varies from using laser hazing, gas gun, scary man, pyrotechnics, distress caller and active human disturbance, and includes the removal of LG nests and eggs and the occasional lethal control of 'specialist' gulls which have learnt to attack the main tern colony. Consequently, since the late 1990s, the Roseate Tern population has increased from around 25 pairs to 130 pairs in 2020 (Kinchin-Smith and P.G.Morrison, 2020) (Figure 1.2). The Seabird Monitoring Programme (SMP) has also shown a steady recovery in the Roseate Tern population from large declines during the 1980s. However, most of the gull populations showed worrying declines in the costal

colonies across the UK (Eaton MA *et al.*, 2013) with decreases by more than 60 % since the 1980s in the breeding population of Herring Gulls and by an estimated 48 % in Lesser Black-backed Gulls, resulting in Red and Amber listing, respectively, as birds of conservation concern (Mitchell *et al.*, 2004; Balmer *et al.*, 2013; Eaton *et al.*, 2015; Davis *et al.*, 2018; JNCC, 2020; Natural England, 2020).

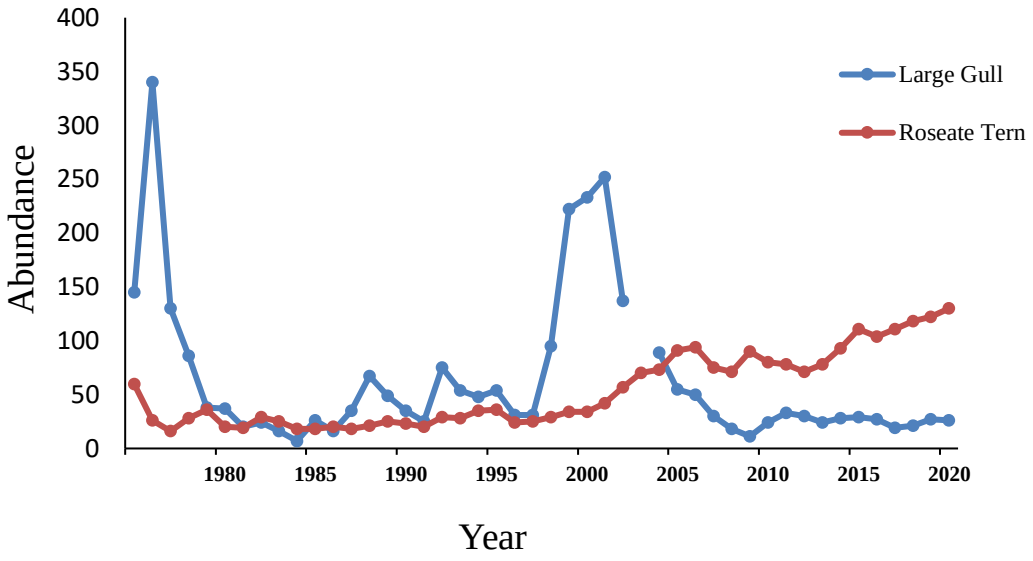


Figure 1.2 Breeding population abundance of two Large Gulls species (Herring and Lesser Black-backed Gull) and Roseate Tern (number of breeding pairs) on Coquet Island from 1975–2020. Estimates of LG breeding population is missing for 2003 – Records were taken from Coquet Island natural reserve annual reports.

1.9 Research objectives

The relatively small populations of RT in Western Europe make the conservation of this species a priority, not just for Europe but also the UK. Allowing LG, one of the main predators of RT, to breed unchecked on Coquet Island presents a substantial threat to the RT colony there. However, this raises a substantial conflict for island management given that LG are also now of conservation concern. There is, therefore, a clear need to understand the impact of LG on RT and whether or not it is safe, from the perspective of the RT colony, to allow small numbers of LG to breed successfully on the island. Therefore, the objectives of this study are to:

1. Investigate the frequency of LG foraging events in the RT colony and the factors, both seasonal and environmental, which affect the interest of LG in the RT colony (Chapter 2).
2. Test the hypothesis that LG breeding on Coquet Island also use the island as part of their foraging range (Chapter 3).
3. Evaluate whether laser technology can be used as an efficient non-lethal technique to control the use of Coquet Island as a breeding and roosting site by LG (Chapter 4).

The results of these studies will provide conservation managers with evidenced-based data on which to manage populations of predator and prey species which have conflicting conservation priorities (Chapter 5).

1.10 Permissions and licensing

All work was carried out on Coquet Island was with permission from the Royal Society for the Protection of Birds (RSPB a charitable organisation registered in England and Wales and in Scotland) and with the relevant consents and licences from Natural England which were granted annually throughout the study period. All gull ringing was carried out by Wesley Davies and Chris Redfern under the appropriate BTO licenses.

As tern and gull species are protected under the Wildlife and Countryside Act 1981, efforts were made to ensure minimal disturbance to tern colonies during censuses. A Licence to Disturb Schedule One Species (Roseate Tern and Mediterranean Gull) was granted throughout each study season. Herring Gull, being a red-listed species, required a licence for lethal control of rogue birds, from Natural England. The gull management and research proposals were reviewed and consented annually by the RSPB and Natural England and licensing granted on that basis.

1.11 Ethics statement

Natural England, the government's adviser for the natural environment in England has granted licences for all the fieldwork for this research. RSPB leases the Coquet Island and deploys a conservation management plan to benefit the breeding bird assemblage.

This research adhered to all the appropriate ethical standards recommended by Coquet Island Advisory Committee, a panel of researchers and conservationists, to be compatible with long term goals of the conservation management of the seabird populations in the reserve.

1.12 Funding

This project was funded by RSPB, Roseate Tern life project, Natura 2000, Newcastle University, Tishreen University (Syria), and The British Council.

Chapter 2 Predatory activity of Large Gulls in relation to a Roseate Tern colony

2.1 Introduction

Prey consumption rate will depend on population densities of predator species and ambient conditions in addition to prey availability in natural ecosystems. Ecological processes underlying the relationship between predators and their prey are, therefore, complex and subject to many variables. Empirical measurements within appropriate theoretical frameworks are essential to identify the key variables and their relative contributions to prey consumption rates. Such information is needed for effective management of biodiversity, particularly in relation to accelerating the recovery of endangered species and managing conflicts which may arise when prey and/or predator species have high economic value or high conservation status. For example, in the past culling Large Gulls was frequently the main component of predation mitigation measures within seabird colonies (Natural England, 2013). However, with the conservation status of LGs in the UK alongside growing evidence of declining offshore LG colonies, the licensing of LG control is now very restricted (Natural England, 2013). Hence, the evidence threshold to justify LG control is now much higher. Therefore, the aim of the work reported in this chapter was to investigate the frequency of LG predation activity over the RT colony and whether it changes during the breeding season in relation to LG breeding status and LG numbers on the island, or in relation to other environmental factors such as weather, habitat composition, and the availability of seabird chicks as prey across the island as a whole or the RT colony specifically (Morrison and Allcorn, 2006; Davies and Morrison, 2013; Natural England, 2020).

2.1.1 Effects of habitat composition on predation rates

Predation by LG may vary over mosaics of habitat patches depending on the density of prey species, as well as the contours of habitat patches in the ecosystems (Andrén, 1995) . It is essential to establish which habitats are targeted by LG to understand whether there are habitat-

related changes in predation rate on Coquet Island (Steenweg, 2010). Elucidating the habitat preferences of LG on Coquet Island will facilitate management strategies to minimise predation by LG on prey species of conservation concern. Furthermore, as LG are generalist and opportunist predators which consume a wide range of prey from different habitat types (Terraube *et al.*, 2011; Coulson, 2019), identifying habitat features attractive to hunting LG may enable the habitat to be managed, either to discourage LG activity or to provide protection for prey (Jones, 2004; Dumont *et al.*, 2010).

2.1.2 Changing the predation rate over the breeding season

Hoi and Winkler (1994) showed that the highest frequency of predation occurs during the main breeding phase, whereas the prey bird nests are rarely preyed upon during early and late in the breeding season when nest densities are low. This was the case when the nature of predation under prey-dependent predation (see 1.1. The nature of predation). Similarly, but from another point of view, Terraube *et al.* (2011) said when predators specialise on certain prey types, the predation rate of this species will increase with high prey density timed with the high peak of breeding season (Terraube and Arroyo, 2011; Terraube *et al.*, 2011). Whereas, the generalist species predation frequency might not follow this pattern, i.e., with their ability to switch to a new type of food or habitat, they probably will adjust their hunting tactics and foraging activity frequency in response to the change of their prey density during the breeding season (Votier *et al.*, 2003; Votier *et al.*, 2010; Terraube and Arroyo, 2011; Terraube *et al.*, 2011). This study will examine LG foraging activity frequency, with their ability to utilize a wide range of food items from small invertebrates to the carcasses of large vertebrates (Hunt and Hunt, 1973; Natural England, 2013; Coulson, 2019), over the breeding season periods. Determining the highest/lowest peak of the frequency of LG foraging activity or the pattern of this frequency during the breeding season will probably help detecting the main derives beyond this change in the frequency of LG activity leading to enhance the understanding of the dynamic of predation-prey cycle over the study area (Terraube and Arroyo, 2011; Robertson *et al.*, 2015).

2.1.3 Assess the extent of breeding LG contribution in the LG foraging activity

LG aggregate in large communal roosts on inland, coastal waters islands, and intertidal areas (Grant, 2010; Clark, 2014; Coulson, 2019) with the ability to travel long distances between feeding and roosting sites (Hunt and Hunt, 1973; Coulson, 2019). All the collected data from Coquet Island since the 1970s report that the intertidal area and north part of the plateau on the Coquet Island form attractive roosts for LG during the breeding season (Thain, 1987; Evans *et al.*, 2000; Fletcher *et al.*, 2002; Sheard *et al.*, 2004; Booth and Morrison, 2010; Robertson *et al.*, 2015). This creates the main problem for estimating the contribution of breeding LG to predation by LG on the Coquet Island RT colony: how can we distinguish between predation by breeding LG and opportunist predation by LG loafing in the intertidal area around the island. Therefore, different indirect (see Chapter.3) and direct methods are needed to overcome this problem; two approaches are to use modern technology of animal movement tracking with Global Positioning System (GPS) tags, in combination with marking the gulls with colour rings that may be visible in flight (Redfern and Clark, 2001) (Rock *et al.*, 2016). In the context of this thesis, 'loafing' is defined as an activity not connected with foraging or breeding, and includes preening and resting; many seabirds spend long hours loafing (Weaver, 2010).

2.2 Method

2.2.1 LBBGU and HGU counting and monitoring techniques

2.2.1.1 Counts breeding gull nests

The entire island plateau was searched systematically every two weeks during the breeding season from the first week of June (minimum 5 observers keeping 2-meter distance between them) by walking along transect lines delineated by the grid-post network (Figure 2.1, A). The counting unit was the active nest (fully constructed nest containing eggs and/or chicks); these were counted and contents noted (clutch size, warm or cold eggs, chicks with estimated age, grid number and coordinates) (Wanless and Harris, 1984; Walsh *et al.*, 1995). Surveys took 4-6 hours to cover the reserve and was carried out when the weather was as calm as possible to avoid disturbing protected species. Each nest was marked with a numbered flag attached to a blue plastic or bamboo post (Figure 2.1). Egg collection was carried out alongside the survey and active nests (eggs and/or chicks) were destroyed on location (Appendix 1, 2, 3, 4). Therefore, and to avoid recounting the relaying pairs as a new nest, the first count (which was also the largest) was considered as the breeding Large Gulls population in the reserve. ArcMap and ArcCatalog (version: 10.6.1.9270/2017) were used to produce distribution maps of Large Gull nests. The census and first egg collection were on 8th, 4th, 8th and 1st of June in 2016, 2017, 2018 and 2019, respectively (Appendix 1, 2, 3, 4). Three additional egg collections followed on 30th June, 9th July, and 4th August in 2016, 18th June, 2nd ,16th and 30th July in 2017, and four additional egg collections followed on 24th June, 1st, 12th, and 24th July in 2018, and 15th June, 2nd, 16th, and 30th July in 2019.

A B

Figure 2.1 A) Large Gulls Survey over the plateau and, (B) Marked LBBGU nest

2.2.1.2 Large Gull study nests

2.2.1.2.1 Catching and ringing the gulls

Ten nests kept for research purposes were situated away from the Tern colonies where it was possible to set up a walk-in trap or whoosh net easily.

Adult Large Gulls were caught in 2015 and 2016 using a 'whoosh' net under licence (Appendix 5 for full specifications). Each gull received a BTO ring (right leg) and a 'Darvic' green coded ring (left leg); weight, wing length and head length were also measured for each gull (Appendix 7, 8, 9) using the same system as in 2014 (Davies and Morrison, 2015; Davies *et al.*, 2016).

Towards the end of egg incubation and the start of hatching is the ideal time to catch adult Large Gulls when the parents will be strongly linked to the nest. Therefore, after finding and allocating the target nests, regular visits were made in 1-3 day intervals to determine the incubation stage (Nol and Blokpoel, 1983; Walter and Rusch, 1997; Liebezeit *et al.*, 2007). With the approach of egg hatching, the trap was set around the nest a day before the capture attempt, to minimise disturbance. The net with the leading poles were placed at the sides, away from the path of the nest-entry, anchored and fixed with heavy stones. Then the rubber ropes were stretched in the opposite direction at appropriate angles and attached to sandbags (Appendix 5). Once the trap was ready, one person would hide at the cliff at either side of the island, whilst another would

walk first around the nest to distract the gull's attention from the hidden researcher and then walk towards the lighthouse to watch the gull from the lighthouse roof using binoculars (8.5x42 W B) and telescope (ATS STS 80 HD). This technique enabled the 'whoosh' net to be triggered from over 50m away from the nest. If the gull did not return to the nest after 60 minutes, the attempt was considered a failure and the whoosh net was removed to allow the gull to return. A new attempt followed in the next day. No attempts were made to mark both adults from a single nest due to the perceived pressure on nesting success.

In 2017, improvements in trapping techniques were made by using the walk-in trap (Appendix 6 for full specifications) in addition to few attempts to catch the birds using 'whoosh' net.

2.2.1.2.2 GPS Tagging the gulls

Two types of GPS tags were used in this study, Mataki (Mataki-classic, dimensions 43 x 21 x 7 mm, weight *ca*. 18.75 g with a battery) and Movetech GPS-GSM (Flyway-18/ Standard dimensions - 57.5mm x 26.5mm x 14.5mm, weight < 20g) for full technical details in see (Appendix 12, 13).

2.2.1.2.2.1 Mataki (Mataki-classic) tags

Mataki tag batteries were charged and the tags were programmed by the researcher following the guide by Freeman and Tavakoli (2013), two hours before fitting them on the LG with following settings:

SETRADIO: Configures the radio experiment

setradio <initial on time=180 seconds> <sleep time between radio heartbeats=1800 seconds> <max time to wait for a response=10 seconds>

SETGPS: Configures the GPS experiment

setgps <initial on time = 120 seconds> <sleep time between fixes=150 seconds> <max time to wait for fix= 30 seconds> <logging time after a fix=5 seconds>

The tag was sealed with silicone rubber tubing using a heat gun (Figure 2.2) and attached to the mantle feathers of LBBGU using Tesa tape according (Figure 2.3, A) to the BTO licensing conditions (Tag weight was =< 3% of the bird weight).

- **Mataki tags data processing, Base Station Commands and Configuration**

Devices communicate with the base station which is configured to listen for 'heartbeats' from tracking devices on the general channel.

One base-station (covered with waterproof box) was deployed daily in different positions of the island for three hours (Figure 2.3, B). When a heartbeat is detected, the base station requests the tracking device to download logs to the base station memory. Then, logs were uploaded from the base station to the laptop in the field.

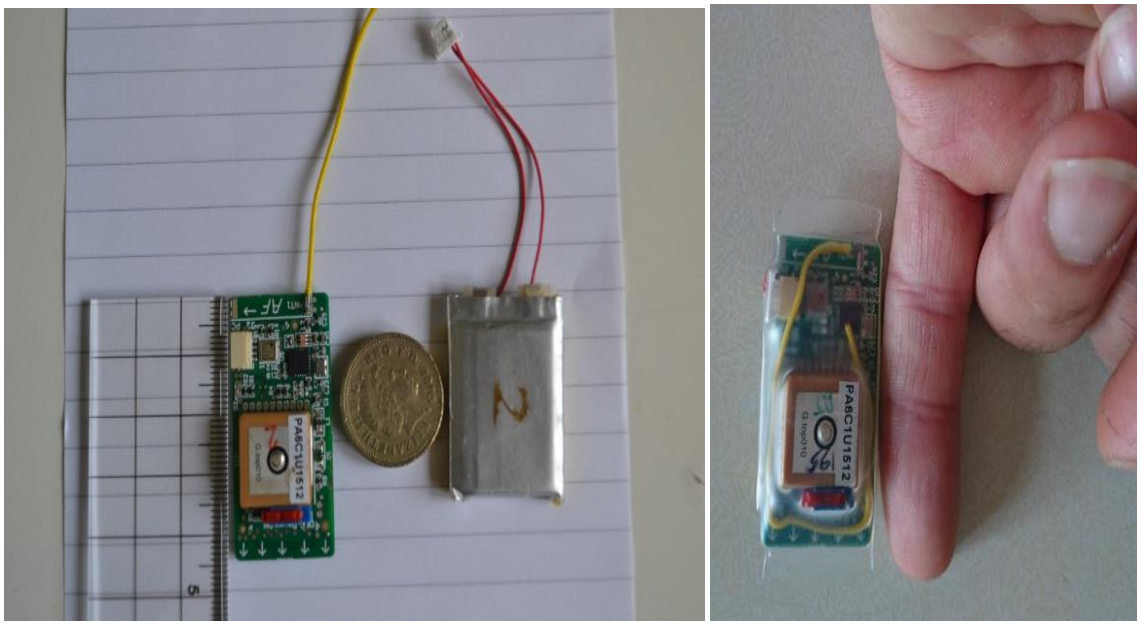


Figure 2.2 Mataki-classic tag sealed with silicone rubber tubing

A B

Figure 2.3 A) Mataki-classic tag (Tag_192) attached to LBBGU adult/Nest 18 in 2016, B) Mataki-classic tag (Tag_2) attached to LBBGU subadult/Nest 29 in 2017

2.2.1.2.2.2 Movetech GPS-GSM tags

The tags were initially put on the roof of the lighthouse to enable the built-in solar panel to keep the integrated battery fully charged. The tags were set up remotely by the provider to take fixes at a high frequency (every 2 minutes) for three hours, then stop to recharge the battery for the rest of the day. This high-frequency logging period was in the morning (09:30-12:30) at the start but was then moved to evening (17:00-20:00) after two weeks to reduce bias in the data.

These GPS loggers were attached to LBBGU or HGU using a permanent wing harness Thaxter et al. (2014) (Figure 2.4, A & B). Birds were handled for a maximum of 60 minutes, during which time biometric measurements were taken, and the tag was attached. Then birds were released, and the nests were observed remotely to confirm that the bird had resumed normal incubating behaviour and was flying normally.

- **Movetech tags data processing**

Tracking data were transmitted as soon as the bird came within the range of suitable cell phone (GSM) reception. Then, the data were accessed and download from the Movebank online platform (https://www.movebank.org/) in different formats (csv files, ESRI shapefiles and

Google Earth / Tracks). ArcMap and ArcCatalog (version: 10.6.1.9270/2017) were used to display LG movements maps.

A B

Figure 2.4 Movetech GPS-GSM tags attached to A) Lesser Black-backed Gull (Tag_780) /Nest 20 and one Herring Gull (Tag_746)/Nest 26

2.2.2 Gull counts from the Lighthouse

The count was carried out every day 4 hours after high tide whenever possible (i.e., if the weather was clear and the count did not conflict with other activities in the reserve). The counts started mid-May to the end of July using binoculars (8.5x42 W B) and telescope (ATS STS 80 HD). The count unit was every single gull species adult, subadult and unknown gull species adult and subadult. The average of repeated three counts of each unit was taken. The presence of other species, time of day, human activities in the reserve, fishing boats around the island and weather conditions were noted. The southwest intertidal area counts were aided by the CCTV system. It was not possible to view the northeast intertidal area. The counts give a good indication of total loafing gulls present and seasonal/yearly variation.

2.2.3 Large Gull activities over the Tern colony

2.2.3.1 Behavioral watches

Daily observational watches of the Roseate Tern terraces were conducted from a hide (Night Watch hide at the jetty or Vera hide beside the south terrace), which gave good views of the Roseate Tern breeding area. Observational periods consisted of recording behavioural events for three species of Large Gulls regularly frequenting the island (Herring Gull, Lesser Black-backed Gull and Great Black-backed Gull). The behavioural events classification is shown in (Table 2.1). Events were also classified into four zones as shown in (Figure 2.6). Zones were defined so that intertidal and plateau zones could be compared north and south of the hide. **B** and **D** zones included the Roseate Tern terraces. **A** and **C** zones consisted, respectively, of the intertidal rocks and the southwest beach where semi-fledged/fledged Roseate Tern roost.

The watches were divided into two-hour slots from 0400hrs to 2200hrs and spread over all tidal states as shown in (Figure 2.5). Over the season, effort was made to cover all states of the tides at all times of day, however, adverse weather prevented some observations taking place, because these may have had adverse consequences for other species *en route* to the study area. After 23rd July, watches before 0600hrs and after 2000hrs were discontinued because of diminishing daylight. Although watches were planned as two-hour slots, sometimes several slots had to be carried out consecutively.

Date	04:00-05:00	05:00-06:00	06:00-07:00	07:00-08:00	08:00-09:00	09:00-10:00	Key		
28/05/2016	L2	L3	L4	L5	H	H1	High Tide		
29/05/2016	L2	L3	L4	L5	L6	H	H	H1	High tide and one hour after high tide
30/05/2016	L	L1	L2	L3	L4	L5	H2	H3	Two and three hours after high tide
31/05/2016	H4	L	L1	L2	L3	L4	H4	H5	Four and five hours after high tide
01/06/2016	H4	H5	L	L1	L2	L3		H6	Six hours after high tide
02/06/2016	H3	H4	H5	L	L1	L2	Low Tide		
03/06/2016	H2	H3	H4	H5	L	L1	L	L1	Low tide and one hour after low tide
04/06/2016	H1	H2	H3	H4	H5	L	L2	L3	Two and three hours after low tide
05/06/2016	H1	H2	H3	H4	H5	H6	L4	L5	Four and five hours after low tide
06/06/2016	H	H1	H2	H3	H4	H5		L6	Six hours after low tide
07/06/2016	L5	H	H1	H2	H3	H4			
08/06/2016	L5	L6	H	H1	H2	H3			
09/06/2016	L4	L5	H	H1	H2	H3			
10/06/2016	L3	L4	L5	H	H1	H2			

Figure 2.5 Six-hour gap sample table of Large Gulls behavioural watches between 28May and 10 June.

Table 2.1 Behaviours of Large Gulls recorded at the Roseate Tern terraces

Key	Behaviour	Description
UP	Unsuccessful Predation	Acceleration towards prey but returning to the air unsuccessfully
SP	Successful predation	Same as UP, but remaining on the ground or returning to the air with prey
PP	Possible predation	Same as SP, but predation success unknown
F	Fly through	Flying over zones without any apparent interest on the ground
D	Deviation	Sudden flight change with clear intention of predation but without completing the predation attempt
H	Hunting	Gliding and searching for prey on the ground
L	Landed	Moving from the air onto the ground without any obvious desire to predate

Figure 2.6 Map of the southwest portion of Coquet Island showing the zones (A, B, C, D) from which the Large Gulls had their behavioural events recorded.

2.2.3.2 Estimation of biomass of potential prey available on the reserve

The biomass representing the number of eggs and chicks of Black Headed Gull (BHGU), ST, AT, CT and RT were calculated using data recorded by RSPB for the population size, first egg date seen, mean clutch size, last fledged chick date and the productivity each breeding season (Table 2.2, Figure 2.11)

Number of eggs:

Number of eggs (E) = number of pairs * mean clutch size

Chick numbers:

Number of chicks = E* Productivity

Biomass:

The available chick biomass for the BHGU, AT,CT and ST was calculated by estimating body mass using logistic growth curves (Ricklefs, 1967):

$$y = A/ (1 + e^{(-k*(age-ti)})$$

where: A = asymptotic value, k = growth constant,

ti = time of inflection and y being the mass.

2.2.3.2.1 Arctic and Common Tern

Arctic and Common Terns start the incubation with the first egg and this results in asynchronous hatching (Robinson and Hamer, 2000; Robinson *et al.*, 2001; Morris, 2013). According to (Robinson and Hamer, 2000; Morris, 2013), time to fledging is between 18 and 22 days for Arctic Terns and Common Terns, with chick weight at hatching of approximately 14g and 16g, respectively (Chapdelaine *et al.*, 1985). Parameters for AT and CT growth curve were taken form (Klaassen *et al.*, 1989; Robinson *et al.*, 2001) (Figure 2.7).

Arctic Tern: $$\text{chick mass} = \frac{111}{1 + e^{-0.29(a-8.5)}}$$

Common Tern: $$\text{chick mass} = \frac{123}{1 + e^{-0.29(a-8.2)}}$$

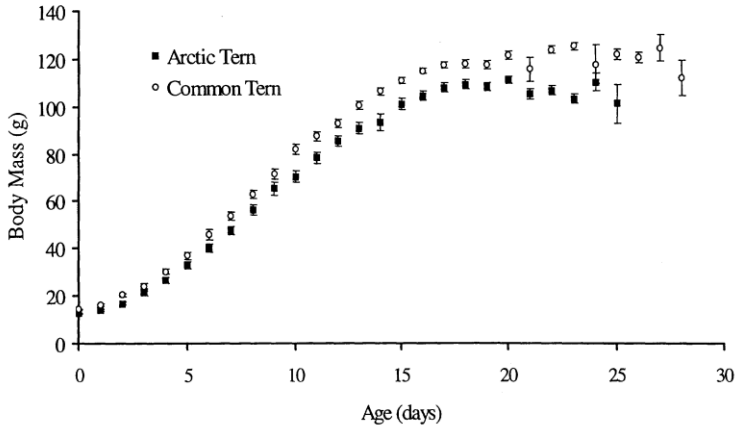


Figure 2.7 Growth curve of Common Tern chicks and Arctic Tern chicks on Coquet Island (Robinson *et al.*, 2001)

2.2.3.2.2 Sandwich tern

Incubation period for ST is about 25 days and the time to fledging is about 29 days (Stienen and Brenninkmeijer, 2002; Cabot, 2013; Robertson *et al.*, 2015).

Parameters for ST growth curve were taken form Drent *et al.* (1992). On Coquet Island the ST colony on the south beach was established later in the season and this was dealt with as a separate estimation (Figure 2.8).

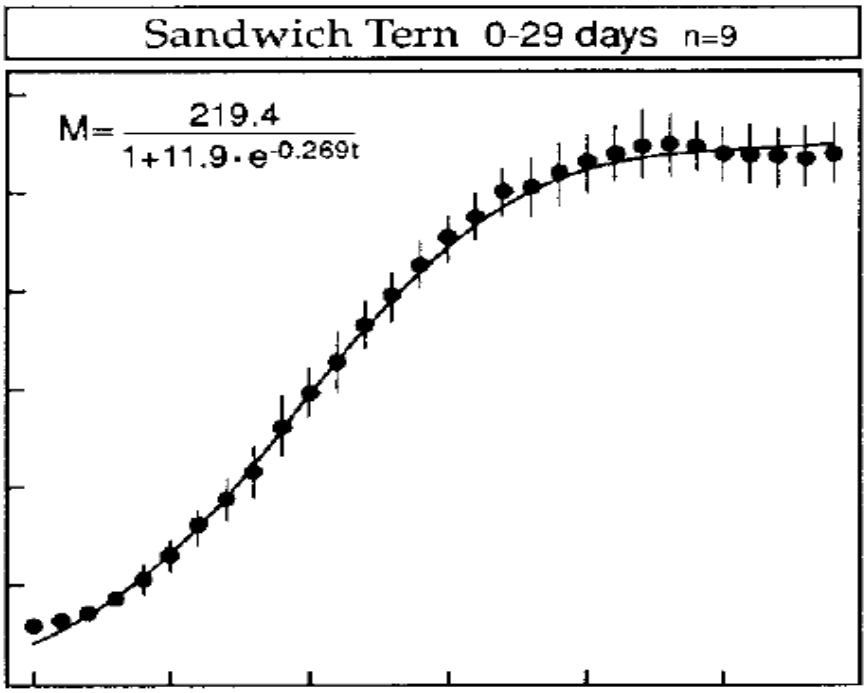


Figure 2.8 Growth curve of Sandwich tern chick (Drent *et al.*, 1992)

2.2.3.2.3 Roseate Tern

Incubation period is 20-23 days for RT (Nisbet and Spendelow, 1999). The chicks use the box as shelter for a few days after hatching. Therefore, the start of RT chick biomass availability was shifted by 3 days (Nisbet *et al.*, 1998) (Figure 2.9).

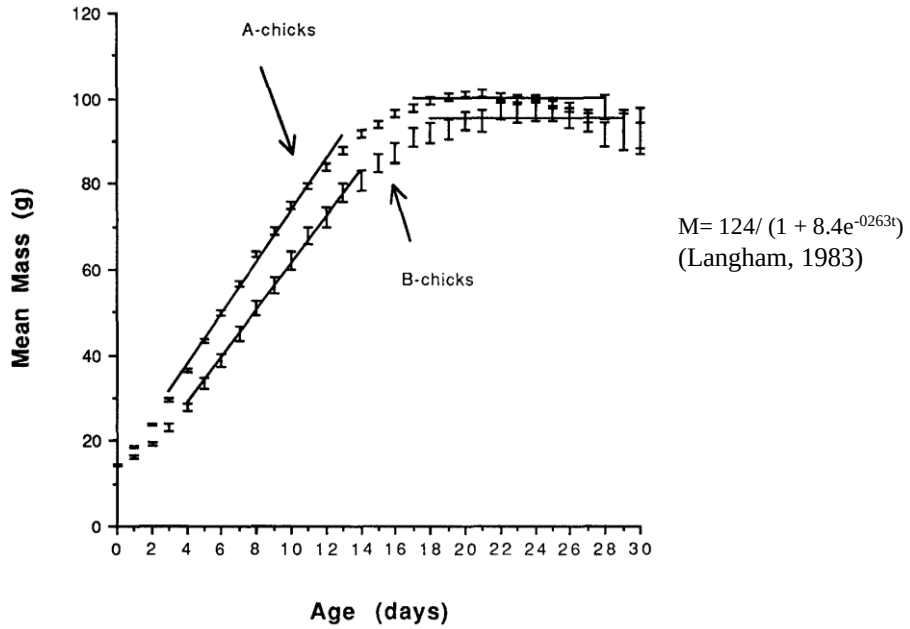


Figure 2.9 Composite growth data for A-chicks and B-chicks of Roseate Tern (Nisbet *et al.*, 1995)

2.2.3.2.4 Black Headed Gull

Parameters of BHGU chick growth curve (Figure 2.10) were taken form (Brandl and Nelsen, 1988; Ros, 1999; Eising *et al.*, 2001; Müller *et al.*, 2005): A = 300, ti = 12.5, k= 0.196

$$M = 124/ (1 + 12.5e^{-0.196t})$$

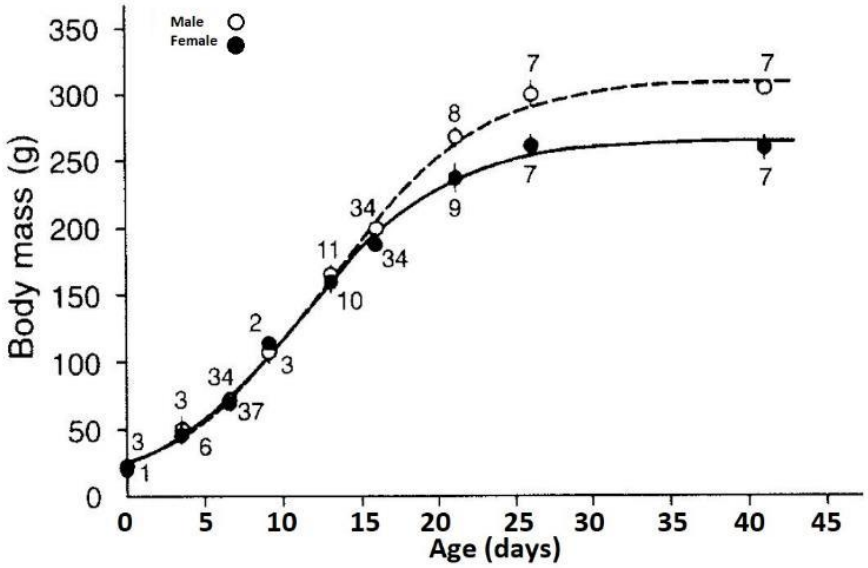


Figure 2.10 Development of body mass with age Black headed gull chicks (Ros, 1999)

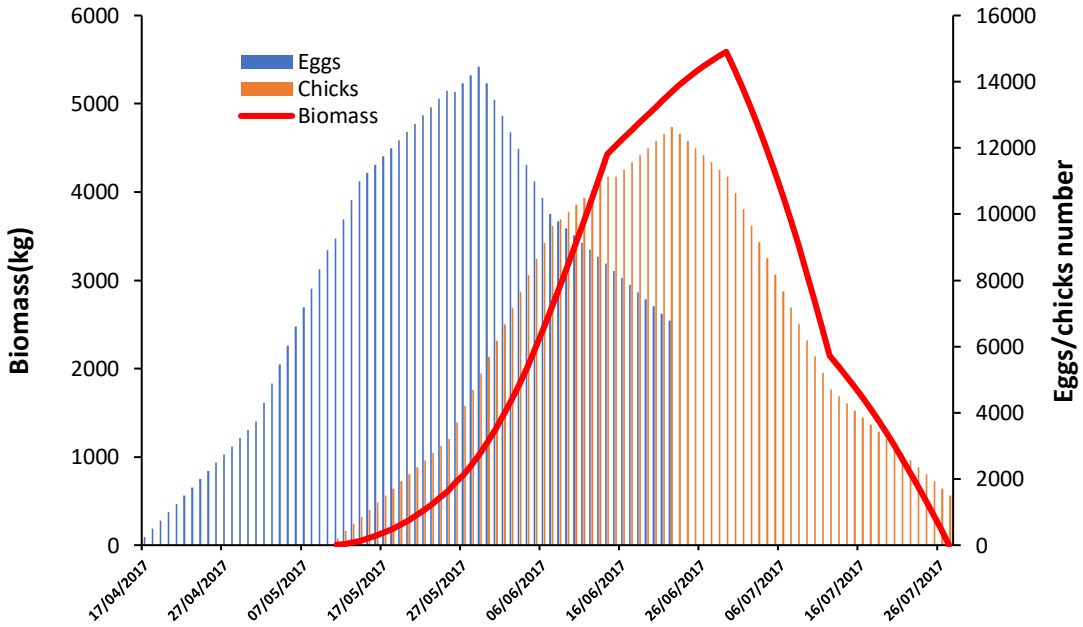


Figure 2.11 Example of estimated eggs, chicks, and chick biomass available during the breeding season for BHGU, 2017.

In this study, fledging age was set as 36 days for ST and BHGU, 23 days for CT and AT, and 29 days for RT in the biomass availability estimation, in view of the fact that chicks stay around the nests (Figure 2.11).

2.2.3.2.5 Puffin

In addition to predating displaced Puffin eggs and chicks, kleptoparasitism is the most common interaction between gulls and Puffins, where gulls attack adult Puffins as they return to the colony with fish to their nestlings (Finney *et al.*, 2001). In this study, by observing nesting activity and the presence /absent of pufflings, the season was categorised into three periods (0) No Puffin, (1) Puffin adults, (2) Puffin adults carrying fish to their nests. Generally, nesting activity was noted from 22 April onwards on the island. The population was on eggs by the first week of May. The first hatching chicks were discovered on the first week of June and foraging behaviour increased thereafter. The first young started fledging from early July and mass departure of adults occurred at the end of July.

2.2.3.2.6 Eider ducks

Weekly mean duckling numbers was calculated using data from the volunteer warden Hilary Brooker-Carey. The ducklings were counted by HB-C on the Coquet river and Amble Harbour. The dates of counts were shifted back by two days to account for the time taken for ducklings to travel from the island to the Coquet River (Flint *et al.*, 1998; Coulson, 1999; Hanssen *et al.*, 2002).

Table 2.2 Number of active nests of BHGU, ST, CT, AT, and RT in breeding seasons 2015, 2016, and 2017 (Davies and Morrison, 2015; Davies *et al.*, 2016; Davies *et al.*, 2017)

	BHGU			**ST**			**ST (South Colony)**			**CT**			**AT**			**RT**		
Breeding season	2015	2016	2017	2015	2016	2017	2015	2016	2017	2015	2016	2017	2015	2016	2017	2015	2016	2017
First egg seen date	16-Apr	17-Apr	17-Apr	29-Apr	08-May	02-May	01-Jun	01-Jun	01-Jun	08-May	13-May	10-May	10-May	12-May	09-May	18-May	17-May	16-May
Number of Pairs	4627	5348	5394	1300	998	1200	324	351	373	1160	1201	1257	1471	1490	1579	111	104	111
Mean Clutch Size	2.64	2.79	2.77	1.5	1.51	1.35	1.5	1.51	1.35	2.23	2.21	2.3	2	1.81	1.98	1.44	1.2	1.71
Productivity	1.27	0.97	0.86	0.65	0.65	0.65	0.65	0.65	0.65	0.47	0.6	1.7	0.59	1.39	0.6	0.92	0.88	1.5

- Weather conditions during the observation were obtained from The Centre for Environmental Data Analysis (MIDAS, 2018). Three weather elements were used in the analysis, mean wind speed and direction (was classified following “Beaufort wind force scale”), maximum wind gust speed and direction and the visibility (unit in “decametre”). Tide level (divided to falling /rising hourly), and total loafing Large Gulls were noted during the observation shifts.

2.2.4 Observation data analysis

Generalized linear mixed models (GLMMs) using R package, glmmTMB (Brooks *et al.*, 2017) which allows zero-inflated models to be fitted, running under R version 3.6.3, were used to analyse counts of LG activity over the RT colonies in three different years. The total number of loafing Large Gulls was standardized (to mean=0 and sd=1) before running the model. Similarly, biomass of available chicks of BHGU, RT, CT, AT and ST during the breeding season was summed, and standardized in the same way. Year was used as a random effect in all models. Explanatory factors were selected based on a review of the literature describing factors influencing LG foraging behaviour (Shamoun-Baranes *et al.*, 2011; Coulson, 2019) and their movement patterns (Carr and Lima, 2010; Suraci and Dill, 2012; Yoon *et al.*, 2014). Thus, fixed effects tested in the model were (1) tide levels and seasonal progression (day in year) because these factors might predict the frequency and LG movement from/to the reserve; (2) chick biomass availability and loafing LG numbers because prey availability and the numbers of predators might predict the extent of predation from LG, and (3) environmental parameters: mean wind speed, mean maximum wind gust speed, direction of maximum gust, precipitation amount, and visibility are mainly considered as those factor might have impact on the efficiency of LG hunting ability over the reserve or their mobility from/to the island.

Information Criterion (a measure of the quality of a statistical model) was used to assess model adequacy with model selection using Akaike Information Criterion AIC to rank possible models describing the relationship between the frequency of LG activity over the tern colony and other variables. The AICctab function in the "bbmle" package was used to compute IC tables from lists of Maximum likelihood estimation (mle) fits (Bolker, 2008; Bolker and R Development Core Team, 2020). P-values were obtained by Wald chi square tests of the full model. Change-point analysis with packages "changepoint", "zoo" and "changepoint.np" was applied to detect the change points in the total LG number over the study area.

2.3 Results

2.3.1 Counts breeding gull nests over reserve

The first gull survey in each of the last five years produced the highest count of active nests for the season (Table 2.3, Figure 2.12, Appendix 1, 2, 3, 4). Breeding Large Gulls were dominant in the north east part of the island towards the mid-east area. The mid-west and the south part of the island were almost totally free of nesting gulls (Figure 2.13, Figure 2.14, Figure 2.15, Figure 2.16).

2.3.1.1 Large Gulls survey and egg collection 2015

- The data were collected in this season by Pedro Rocha and Hannah Tilley (student placements) in a preliminary research project studying breeding Large Gull behaviour over the tern colonies (Davies and Morrison, 2015). 78 eggs from 29 active nests were found in the first egg collection (census day) on 8th June 2015. Three nests 1, 2 and 3 (with 3 eggs each) were kept for study purposes, whilst 69 eggs were collected from 26 active nests.

- Second egg collection found 36 eggs from 14 nests on 19th June 2015. 33 eggs were collected from 13 nests and nest 4 (with 3 eggs) was kept for the study purpose.
- Third egg collection found 29 eggs from 10 nests on 2nd July. 20 eggs were collected from 7 nests. Three nests 5, 6 and 7 (with 3 eggs each) were kept for the study purpose.
- Fourth egg collection found 19 eggs from 7 nests on 19th July. Three nests 8, 9 and 10 (with 3 eggs each) were kept for the study purpose. Then, fifth egg collection did not find any nests on 2nd August. Six fledged gull chicks for the entire season with productivity 0.67.

2.3.1.2 Large Gulls survey and egg collection 2016

- First egg collection found 74 eggs from 26 active nests on 8th June 2016. Ten nests with 29 eggs were kept for the study purpose whilst 45 eggs were collected from 16 nests.

- The Second egg collection found 21 eggs from 10 nests on 30th June 2016. Four eggs were collected from two nests.
- No more nests were found in third egg collection on 9th July. The final egg collection on 4th August found 8 eggs from 3 nests. All of them were kept to the end of the season. The total number of fledged gull chicks for the entire season was four Lesser Black-backed Gull chicks (3 ringed and 1 not ringed) with productivity 0.19 (Table 2.3, Figure 2.13, Appendix 1)

2.3.1.3 Large Gulls survey and egg collection 2017

- The first census occurred on 4th June 2017 found 28 eggs from eleven active nests. Only five LBBGU nests (15 eggs) were collected this season due to small population size and Large number of dud /predated nests.

  Eight nests (20 eggs) for Herring gulls were found on the first census day. According to the agreement with NE, one of HGU nests should be kept. However, the nest collection was deferred for two weeks to catch one HGU adult for ringing and GPS tagging.
- The second egg collection was conducted on 18th June 2017. Due to the noticeable decrease in the LBBGU nests, attempts were made to find more nests before this date which led to eight LBBGU nests and three HGU nests being located.
- On 2nd July, a third egg collection was undertaken, and a further four nests were found; no new nests were found after this date. Only four Lesser Black-backed Gull chicks from three nests (nests 24 /2 chicks; 29 /1chick; and 34 /1 chick) fledged successfully with productivity 0.22 (Table 2.3, Figure 2.14, Appendix 2)

2.3.1.4 Large Gulls survey and egg collection 2018

- Sixteen active LBBGU nests with 43 eggs from were found on the first census 8th June 2018. 16 LBBGU nests (44 eggs) were collected this season.

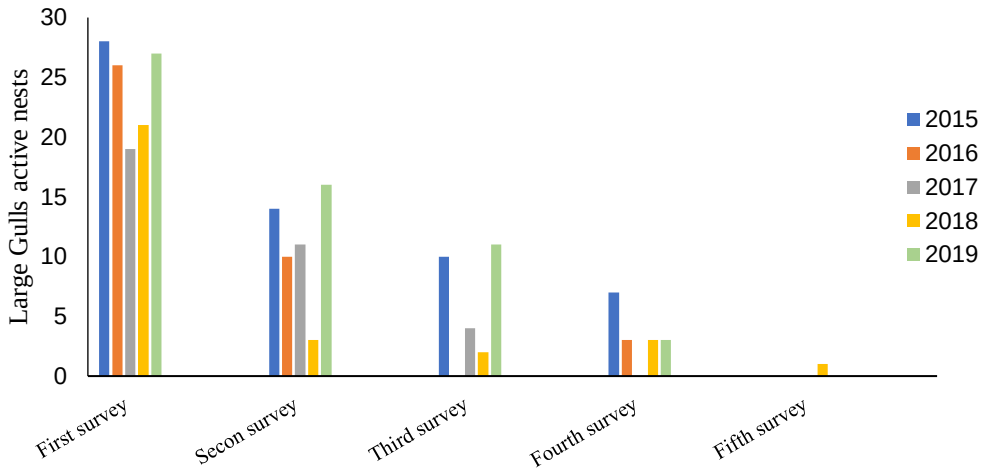


Figure 2.12 Total breeding Large Gulls surveys between 2015-2019 over Coquet Island

- Five nests (15 eggs) for Herring gulls were found on the first census day. One of HGU nests was kept for the study purpose. However, it was found abandoned on 21st June.
- Second egg collection found 9 eggs from 3 nests on 24th June 2018. Then, two nests (6 eggs), three nests (9 eggs) and one nest (3 eggs) were found during the third, fourth and fifth surveys, respectively. Six Lesser Black-backed Gull chicks fledged over the entire season (nests N8/1 chick; N15/2 chicks; and N12/3 chicks) with productivity 1.5 (Table 2.3, Figure 2.15, Appendix 3)

2.3.1.5 Large Gulls survey and egg collection 2019

- Twenty active LBBGU nests were found on the first census with 50 eggs. Only one nest (1 egg) out of the four study nests (12 eggs) fledged on 28th July then it was found dead on 4th August with productivity 0.25

  8 Herring gull nests were found in this season, seven nests (20 eggs) were found on the first census day and one with 2 eggs was found on the fourth survey. One HGU nest (3 eggs) was kept but the chicks were found dead on 20th June.
- Second, third and fourth surveys found 16 nests (38 eggs), 10 nests (24 eggs), 3 nests (7 eggs) respectively. All nest and eggs were destroyed on the site (Table 2.3, Figure 2.16, Appendix 4)

- Total area usage by Large Gulls for nesting, as indicated by the Kernel density map (Figure 2.17) was covering ≈ 51% of the plateau in 2002. However, Large Gulls nesting area was reduced to ≈ 30% of the plateau after applying control measures between 2015-2019 with decreasing the total nests number ≈ 95%.

Table 2.3 Breeding Lesser Black-backed Gull and Herring Gull on Coquet Island

Year	LBBGU NESTS	First Seen	EGGS	Clutch size	Productivity	HGU NESTS	EGGS	Clutch size	Productivity
2015	28	08/06/2015	76	2.67	0.33	1	2	2	0.0
2016	26	08/06/2016	72	2.85	0.19	1	2	2	0.0
2017	11	04/06/2017	28	2.57	0.22	8	20	2.45	0.0
2018	16	08/06/2018	43	2.8	1.2	5	15	3	0.0
2019	20	01/06/2019	50	2.43	0.25	7	20	2.75	0.0

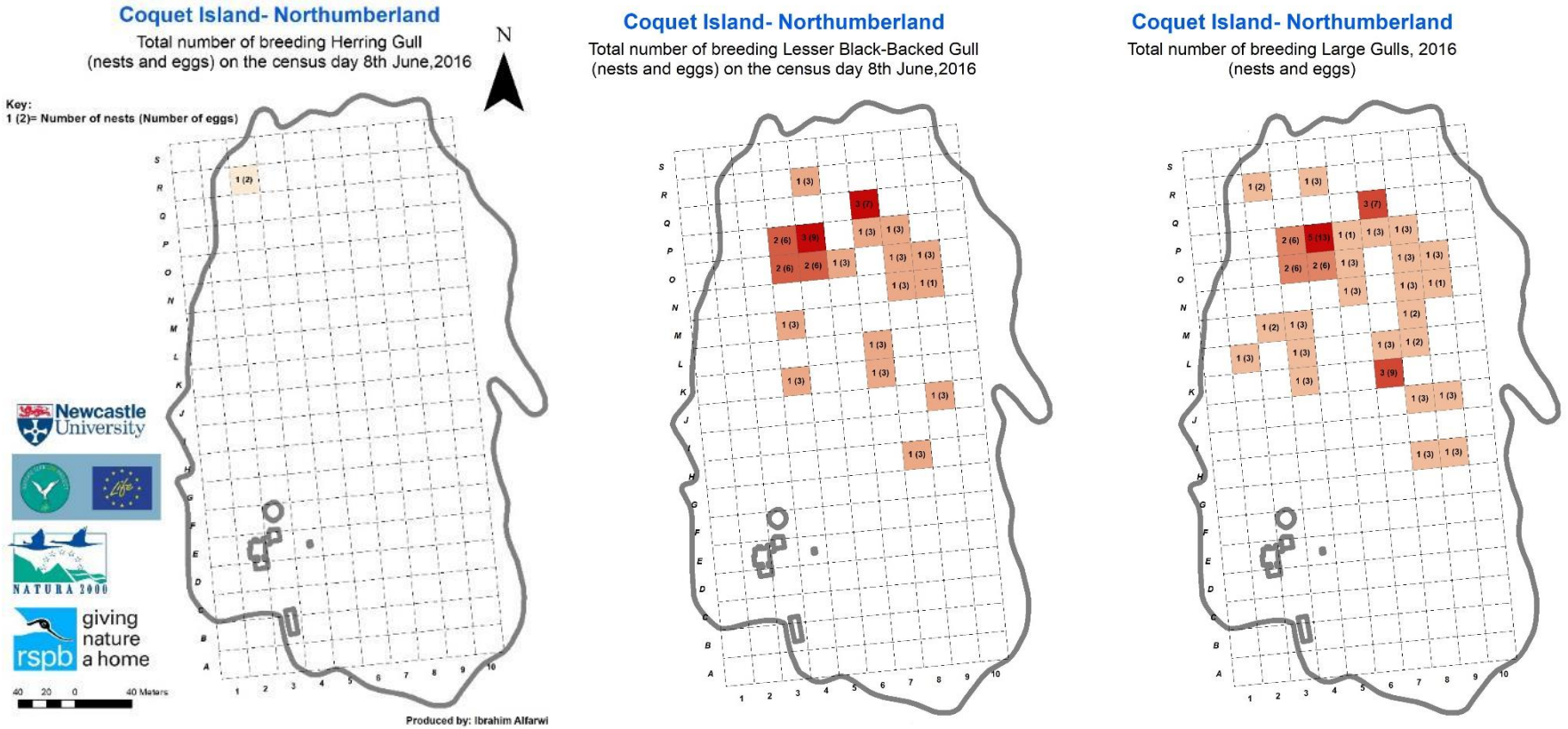


Figure 2.13 Breeding Large Gulls nests distribution over Coquet Island reserve – 2016

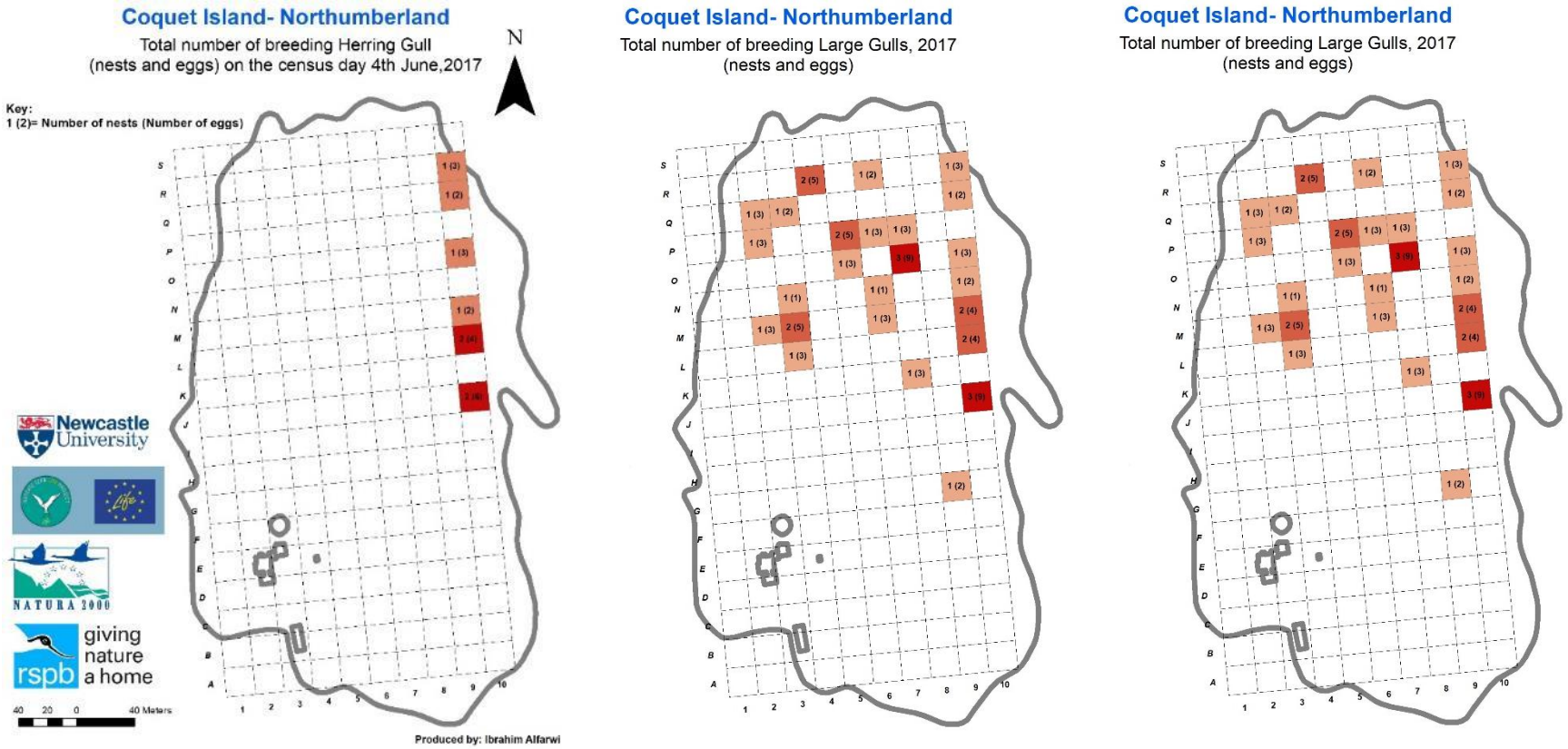


Figure 2.14 Breeding Large Gulls nests distribution over Coquet Island reserve – 2017

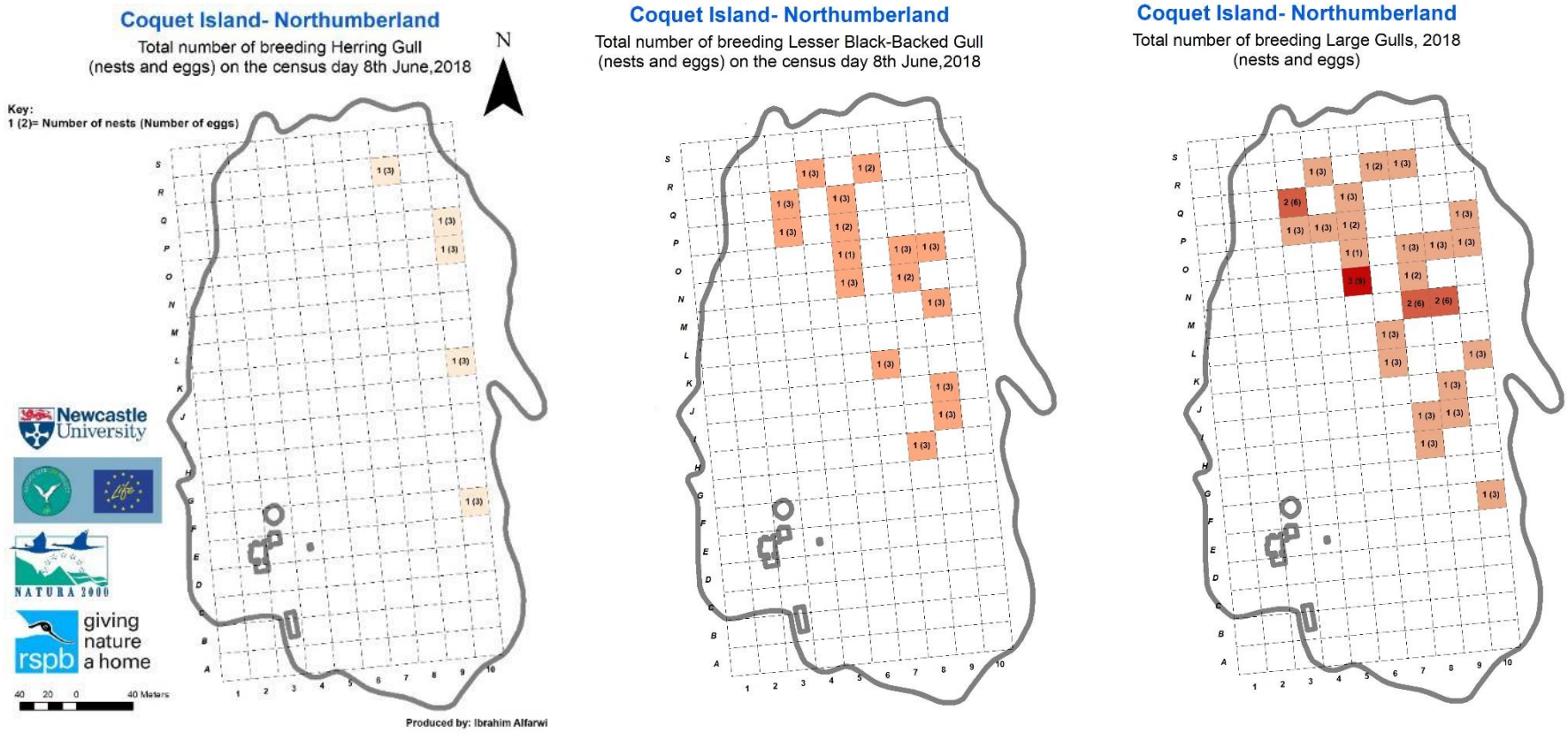


Figure 2.15 Breeding Large Gulls nests distribution over Coquet Island reserve – 2018

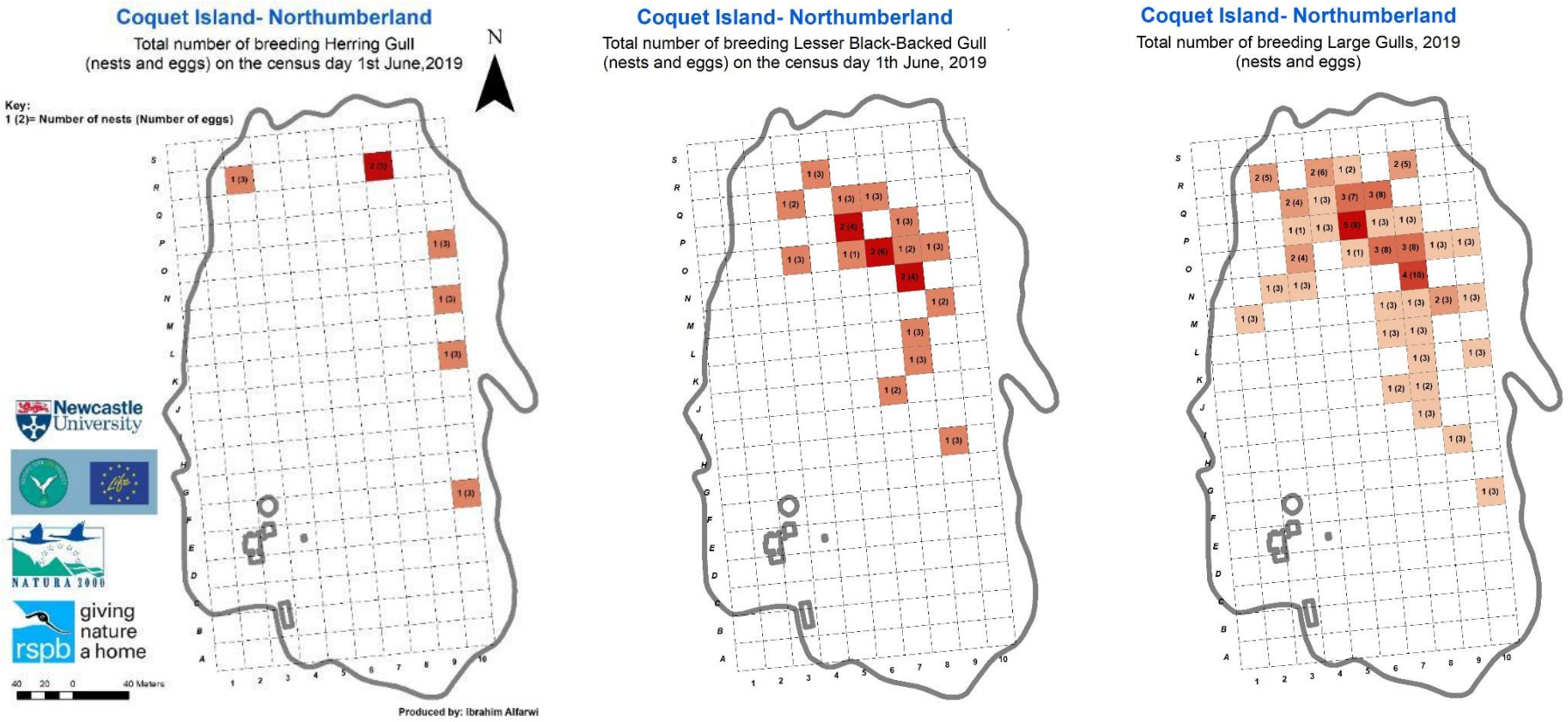


Figure 2.16 Breeding Large Gulls nests distribution over Coquet Island reserve – 2019

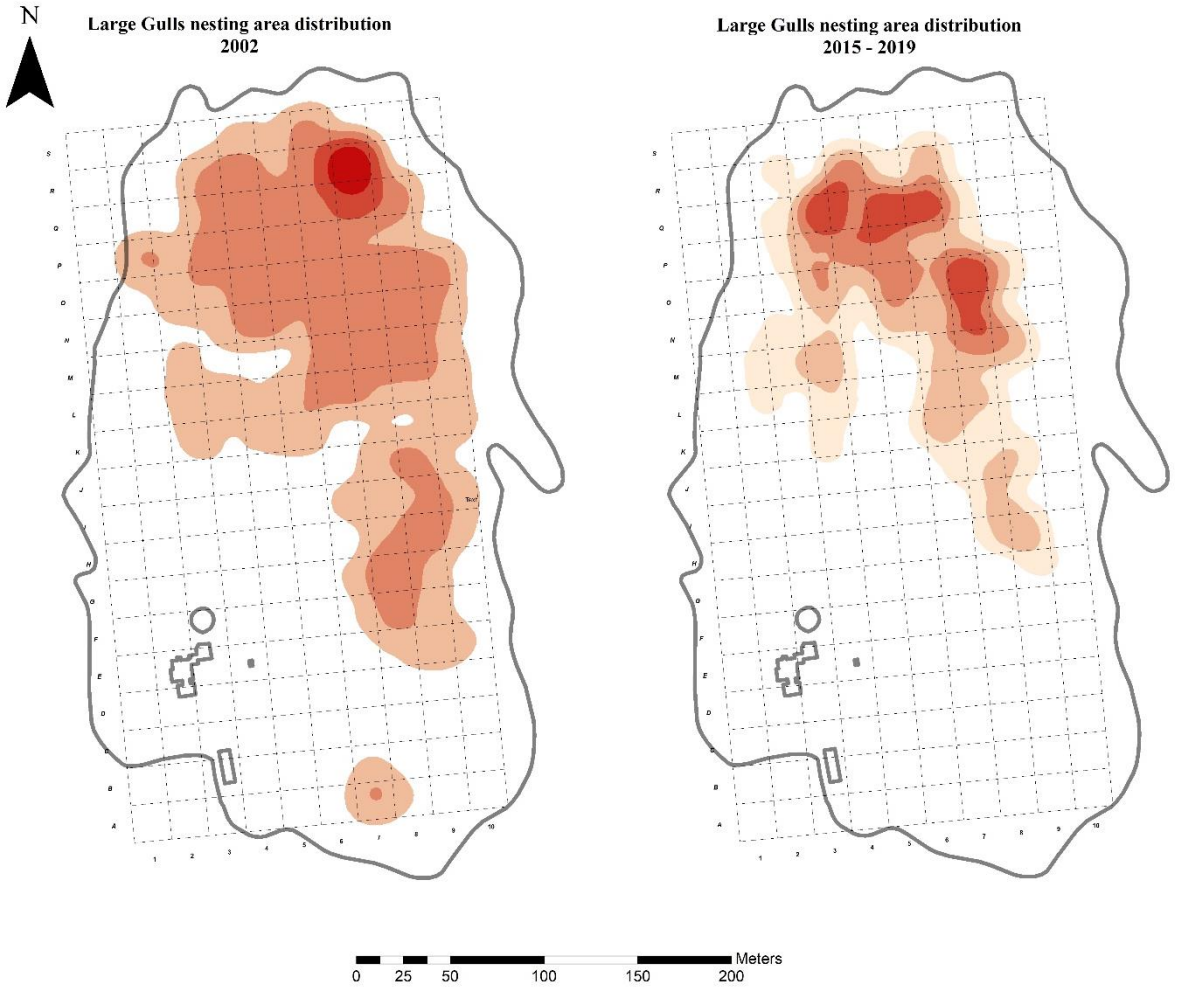


Figure 2.17 Kernel density shows nesting distributions for Lesser Black-backed Gulls on Coquet Island. LG breeding nests number and distribution showed no significant change during the study period with no attempts to nest close to tern colonies ($\chi 2 = 2.1069$, df = 2, p-value = 0.3487).

2.3.2 Study nests

2.3.2.1 Ringing the study gulls

In 2002 breeding season, 26 gulls were trapped out of 38 attempts (approximately 68%) with no abandoned nests as result of trapping (Fletcher *et al.*, 2002). The limitations on these first trapping procedures came from the trapping time availability, weather conditions (preferable calm and dry weather), nest locations and clutch size (preferable nest with 3eggs) (Fletcher *et al.*, 2002).

In 2014 breeding season, LBBGU pulli received green darvic C:10 - C:18 and HGU pulli received yellow 'Darvic' 4M6B (Davies and Morrison, 2014). In 2015 breeding season, 10 out of 19 attempts were successful (≈ 53%) but seven of those nests failed and the adults did not return to the nests (Davies and Morrison, 2015). Then, due to the high nest failure in 2016 breeding season, 21 Lesser Black-backed Gull and 1 Herring Gull (the number of nests simultaneously did not exceed five nests) were included in the study and left uncollected throughout the season. It is of note that many nests failed before being studied i.e., a before net was placed. Each Large Gulls nest had an adult ringed. Seven out of 22 attempts were successful in catching the Large Gulls adults in 2016 (≈ 32%)

Seven Lesser Black-backed Gull adult and 3 Lesser Black-backed Gull chicks were ringed over the 2016 season (Appendix 8). Three nests hatched successfully (1, 29 and 34). An adult Lesser Black-backed Gull from nest 14 was ringed on 8th June. The nest was enclosed throughout incubation. It raised one chick which was found dead (predated on 10th July)

An adult Lesser Black-backed Gull from nest 1 was ringed on 10th June. The nest was enclosed throughout its incubation. It raised one chick which was ringed on 9th July and the enclosure removed on 13th July. An adult Lesser Black-backed Gull from nest 20 was ringed on 19th July. However, the adults gull never returned to the nest. The eggs were cold and predated on 29th June.

An adult Lesser Black-backed Gull from nest 18 and 23 was ringed on 26th, 30th June and tagged with Mataki GPS logger (192, 199) respectively. The nests were not enclosed throughout its incubation. The chicks but were found dead 1st, 13th July.

Lesser Black-backed Gull from nest 29 received a BTO ring, a Darvic ring and Mataki GPS logger (200) on 11th July. The nest was enclosed throughout incubation. The enclosure was removed on 19th July after the chick and ringed with BTO ring and a Darvic ring. The adult was shot on 14th August because it was hunting at the Roseate Tern terrace during the observation from the jetty.

An adult Lesser Black-backed Gull from nest 32 was ringed and received Mataki GPS logger (196) on 20th July. However, the adults gull never returned to the nest. The chicks were found predated on 21st July. The final Lesser Black-backed Gull chick was ringed from nest 34 on 18th august. All the attempts to catch the adult failed on 14th July. The enclosure was removed on 21st August.

In 2017, two first attempts were successful but not in the next seven try-outs using walk-in trap and addition three failed times using whoosh net (≈ 18%). Three nests (nests 24 /2 chicks; 29 /1chick; and 34 /1 chick -7 eggs) out of the 18 study nests (44 eggs) fledged successfully. Last fledged chick for Lesser Black-backed Gull was ultimately ringed at nest 29. Finally, in 2018 breeding season only 3 nests (6 eggs) out of the 4 study nests (9 eggs) fledged successfully with no success in catching and ringing adults.

2.3.2.2 Tags

2.3.2.2.1 Mataki (Mataki-classic) tags

Ten Mataki tags were made available and it was planned to use 5 tags in 2016 breeding season and 5 tags in 2017. Four Mataki tags (Tag_192, Tag_199, Tag_200, Tag_196) were deployed in the 2016 on four breeding LBBGU adults captured using a whoosh net (see 2.2.1.2.1) and two (Tag_5, Tag_2) in the 2017 breeding season on two LBBGU subadults (fledged chicks) (Table 2.4). GPS tags were attached to LG at the start and middle of the breeding season to

cover the period when the tern eggs and chicks were available to LG. Data were received from 3 tags in 2016 because one adult did not return to the nest. The output of the GPS tags showed that the breeding Large Gulls visit different habitats including the mainland, urban area, fields, and freshwater lake. However, a key result was that LBBGU mainly used Coquet Island (more than 95% of the fixes were over the reserve during the GPS logging time) (Figure 2.21), with only a handful of individual trips going inshore. Nests 18 and 23 failed, nest 32 was deserted, but one chick from nest 29 fledged successfully. However, the tagged adult focussed on attacking the tern terrace at the end of July and was controlled on 14/08/2016 according to the management policy (Appendix 8).

Two Mataki tags were deployed on the fledged chicks in 2017 breeding season. One from nest 24 on 10th August, and the other one from nest 29 on 12th August. Tracking data for both fledged subadults showed them in the reserve during the logging period. The tagged chick from nest 24 was found dead on 15th August. This bird was in bad health, producing yellow/green guano the day before. The tagged fledged subadult from nest 29 was seen many times in the north east intertidal area until 20th August (Appendix 9).

Figure 2.18 LBBGU adult locations/ Nest 18 (Tag_192) from 26/06/2016 to 01/07/2016

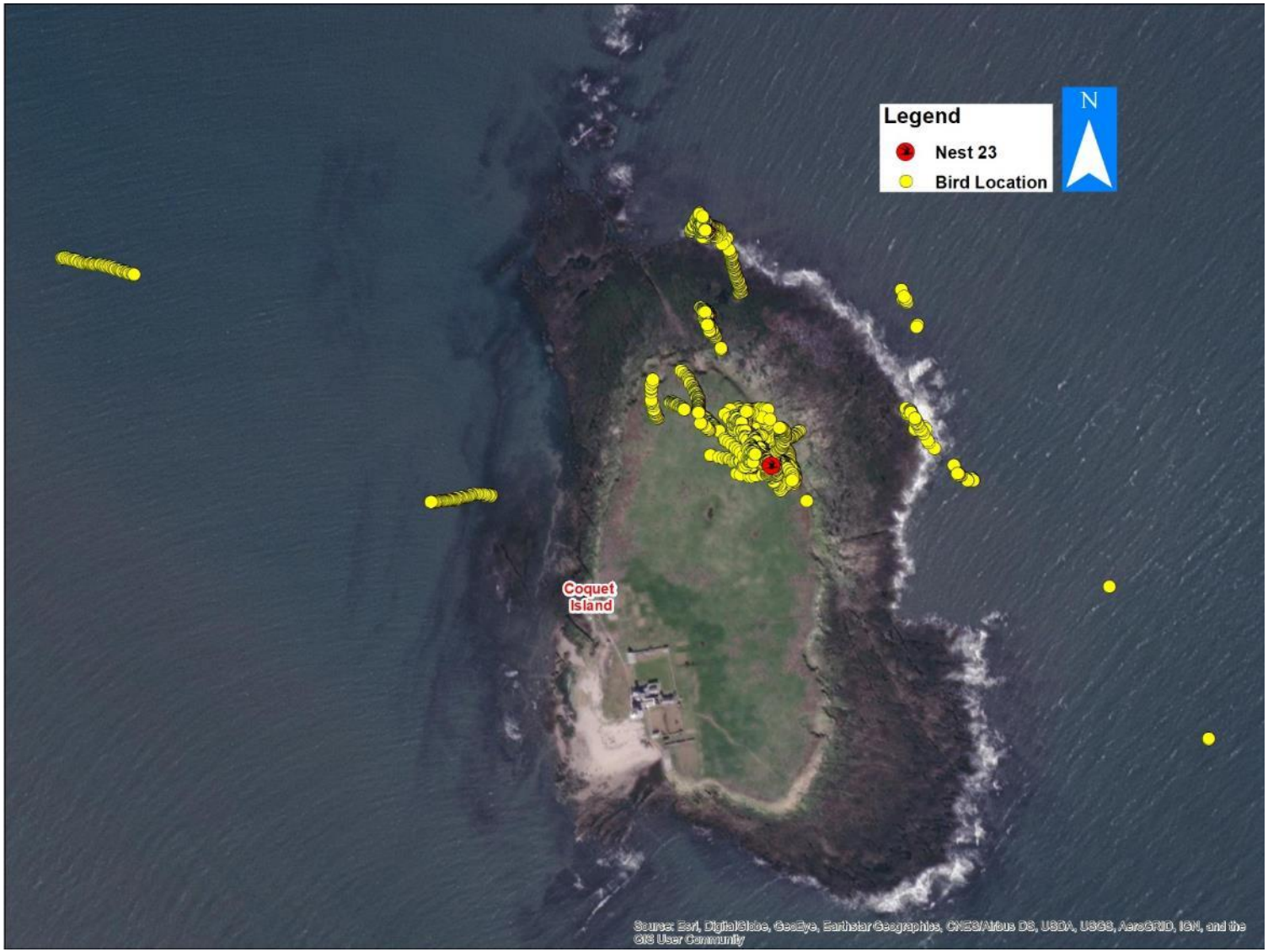


Figure 2.19 LBBGU adult locations/ Nest 23 (Tag_196) from 30/06/2016 to 03/07/2016

Figure 2.20 LBBGU adult locations/ Nest 29 (Tag_200) from 11/07/2016 to 17/07/2016

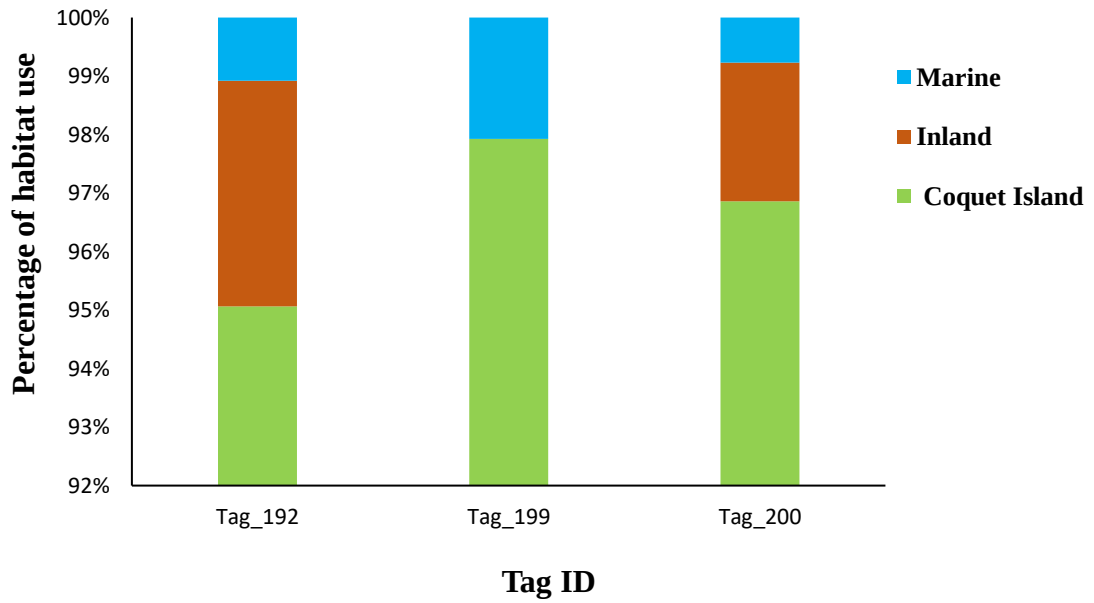


Figure 2.21 Percentage of fixes recorded in each habitat type from Mataki tags in 2016 breeding season

Table 2.4 Total number of fixes from each individual bird between tag deployment and last date of GPS logging

Nest No	GPS-Tag NO	Species	Age	Tagged date	Last logging date	Total number of fixes	Result
N18	192	LBBGU	AD	26/06/16	01/07/16	52555	Chick found dead on 1/07/2016
N23	199	LBBGU	AD	30/06/16	03/07/16	5255	Chick found dead on 13/07/2016
N29	200	LBBGU	AD	11/07/16	17/07/16	11649	1 rung Chick fledged (C:32) Adult was controlled on 14/08/2016 (C:30)
N32	196	LBBGU	AD	-	-	-	Nest failed: gull never returned to the nest
N24	5	LBBGU	CH	10/08/17	14/08/17	18635	Found dead on 15/08/2017
N29	2	LBBGU	CH	12/08//17	19/08/17	6624	Fledged on 07/08/2017, then caught in the intertidal area, ringed, tagged with GPS logger

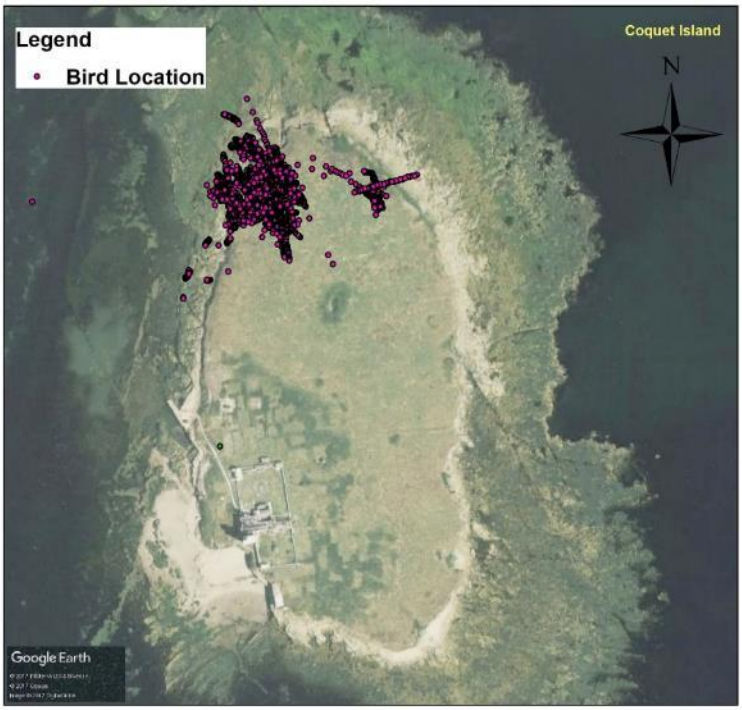


Figure 2.22 LBBGU subadult locations/ Nest 24 (Tag_5) from 10/08/2017 to 14/08/2017

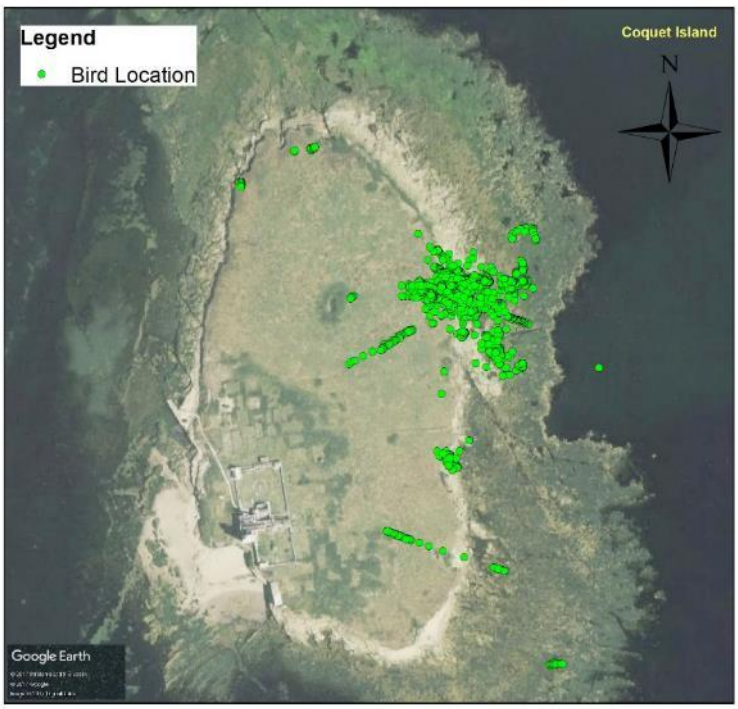


Figure 2.23 LBBGU subadult locations/ Nest 29 (Tag_2) from 12/08/2017 to 19/08/2017

2.3.2.2.2 Movetech tags

One incubating Lesser Black-backed Gull (Nest 20) and one Herring Gull (Nest 26) were captured with wire mesh traps placed over nests (see 2.2.1.2.2) and tagged with Movetech GPS-GSM (Tag_780, Tag_746) on 17th, 20th June 2017 respectively (Appendix 9, 12). Tags started logging from the second day of fitting them on the bird until 10th September 2017, 17th January 2018, respectively. Chicks in nest 20 and eggs in nest 26 were found predated on 28th June 2017. The last fix from the tagged LBBGU was over the reserve on 1st of July but then the tracking data showed the bird left the island and flew south with the last logging data obtained from the Birmingham area. However, HGU used the island habitat until 1st of August but then the tracking data showed the bird used inland fields in the coastal strip between Coquet Island and Farne Islands until the last tracking coordinates were obtained from the device over the sea 1 km off Druridge Bay.

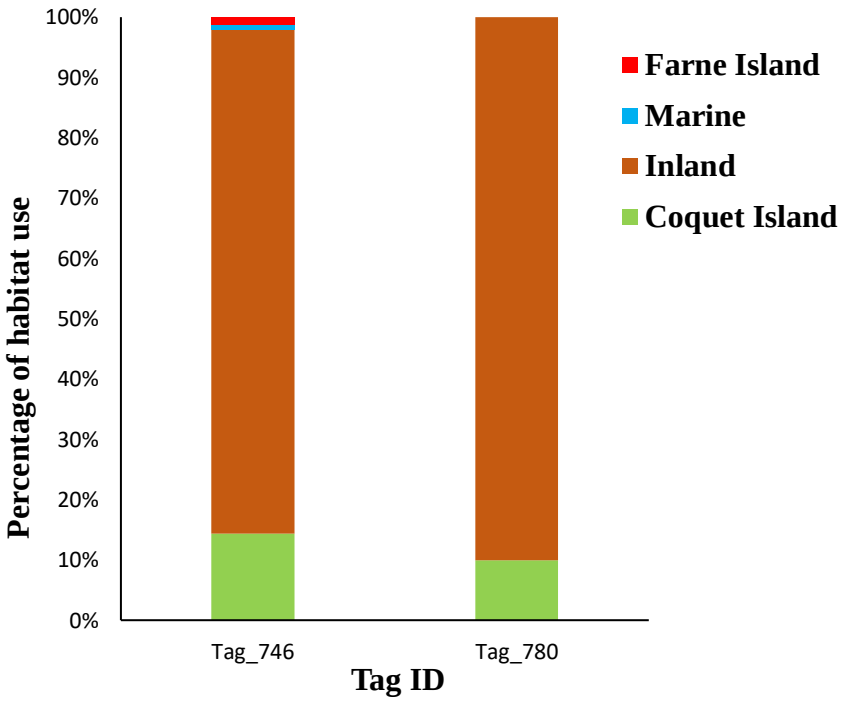


Figure 2.24 Percentage of fixes recorded in each habitat type from Movetech tags in 2017 breeding season

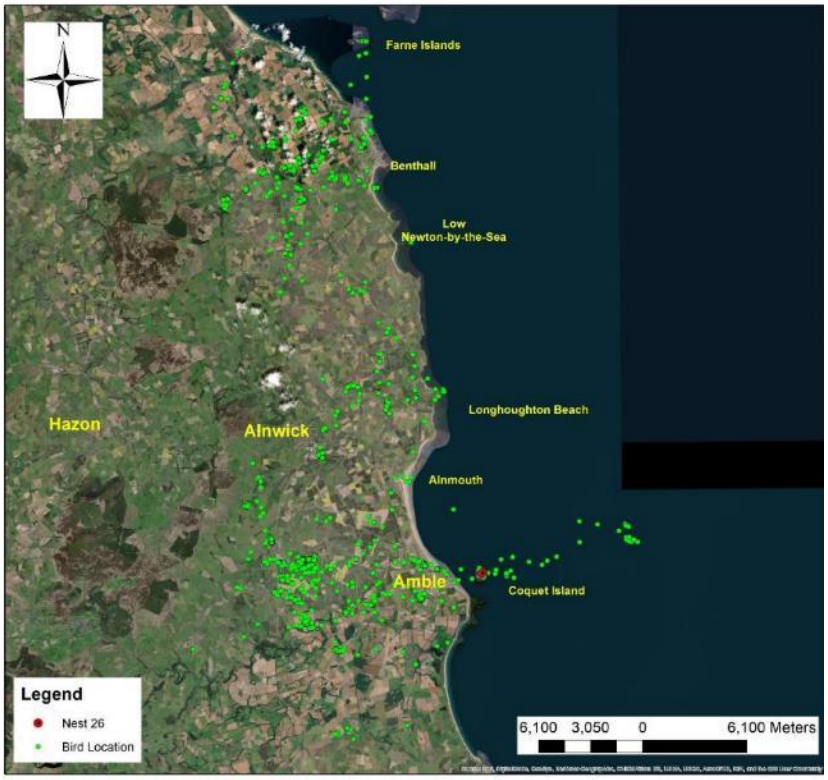


Figure 2.25 HGU locations / Nest 20 from (Tag_746) 18/07/2017 to 15/08/2017

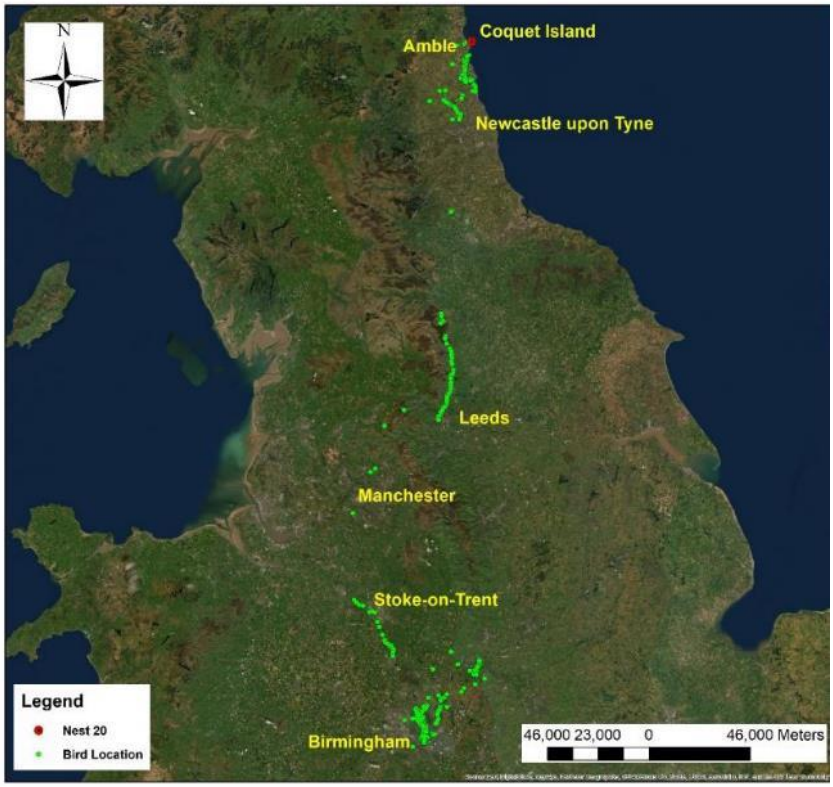


Figure 2.26 LBBGU locations / Nest 26 (Tag_780) from 21/07/2017 to 15/08/2017

The period of tagging breeding LG was designed initially to be at the start, middle and end of the RT breeding season, particularly to ensure that the RT chick hatching and fledging periods were covered. However, none of the location data from both of the tag types employed on adult or juvenile LG showed any spatial overlap with the main RT colony during 2016 and 2017 breeding seasons.

2.3.2.3 LG behavioral observation

Over the study period, 710 h of behavioural watches were conducted. These fell within the periods: 28th May – 9th August 2015; 8th May – 31st August 2016, and 17th May – 15th August 2017, with an average of 14.3, 18.75 and 19.6 h per week in each period, respectively.

2.3.2.3.1 The frequency of LG activity over the Roseate Tern colony

The total number of Large Gull foraging events over the study area decreased at the start of the breeding season after the LG egg collection mainly. Then, a notable increase in LG foraging events occurred at the end of the breeding season. LG activity was increased at the times of highest and lowest tide levels ($\chi 2$= 36.4782, df = 5, p-value < 0.001) on daily basis.

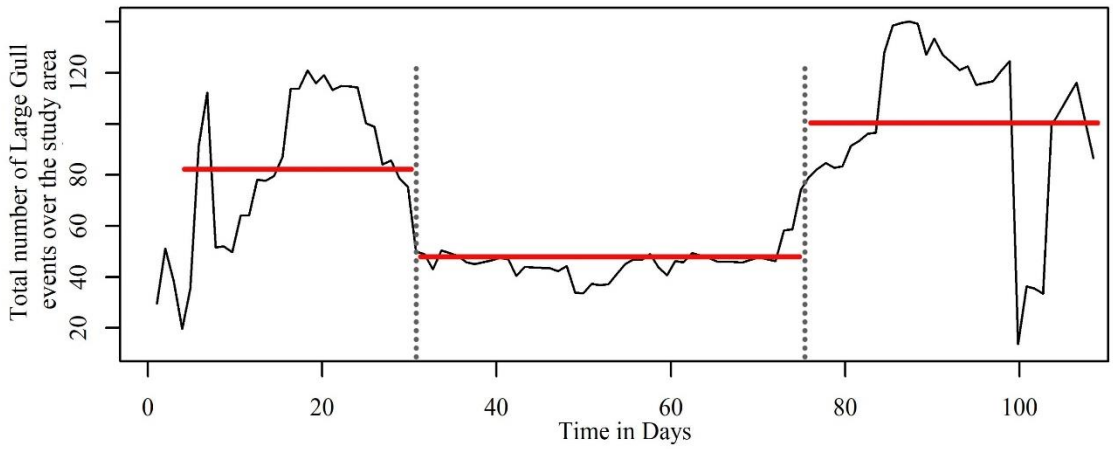


Figure 2.27 Two changing points (grey dotted line) were detected in the average number of the Large Gull events over the study area (red line) during the breeding season starting from 15th May to 25th August (Pettitt's test, with K=32 and K=72, p-value < 0.05)

Total number of LG foraging events were significantly lower over area **D** comparing with area **A**, **B** and **C** (χ^2= 887.92, df = 6, p-value < 0.001) (Figure 2.28). The highest proportion of the events over area **D** occurred at the end of breeding season. Whereas highest proportion of the events over area **A** and **B** occurred at the start and middle phase of the breeding season. Highest proportion of the events over area **C** started from the middle phase and of breeding season and continued to the end of the season. LG activities over the terrace were driven by combination of adult and subadult gulls. This combination changed significantly throughout the breeding season (χ^2= 121.52, df = 2, p-value < 0.001) (Figure 2.29); adults were active at the start of the season while subadults activities were more dominant during the middle phase of the breeding season and slightly more at the end of the season.

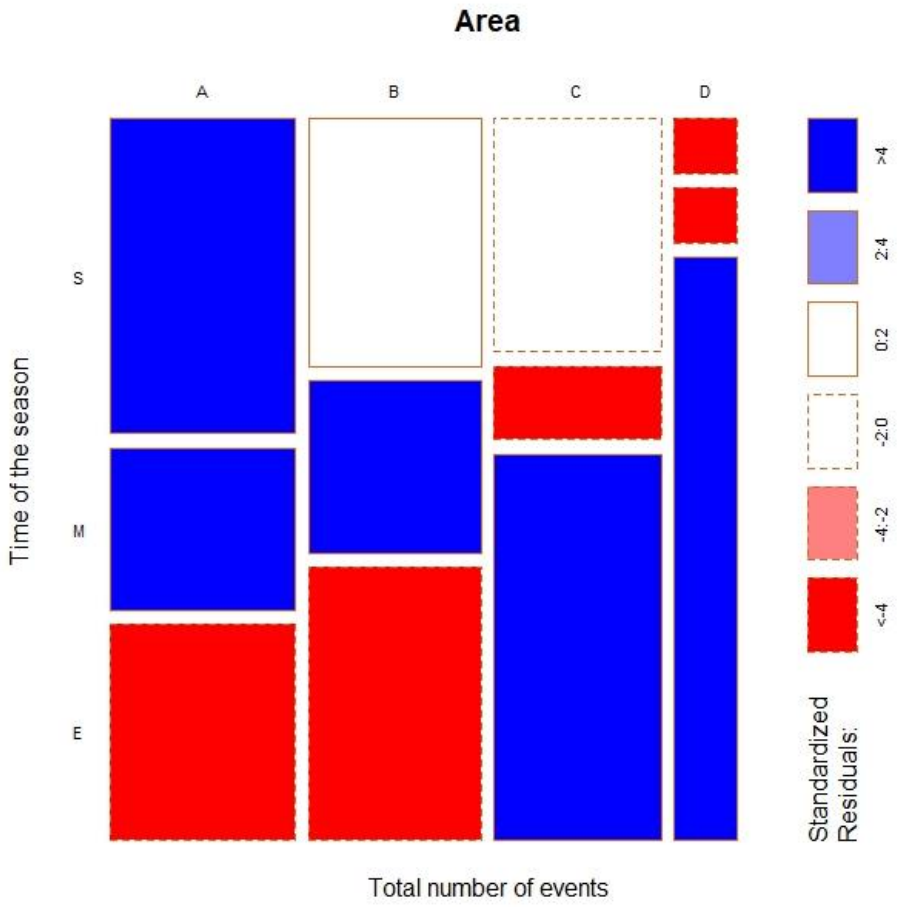


Figure 2.28 Mosaic plot of the LG event proportions over of four sections of the study area (**A, B, C, D**) during the breeding seasons 2016 and 2017 (S: first phase of the breeding season 15th May -10th June, M: middle phase of the breeding season 11th June -20th July, E: last phase of breeding season 21st July-15th August)

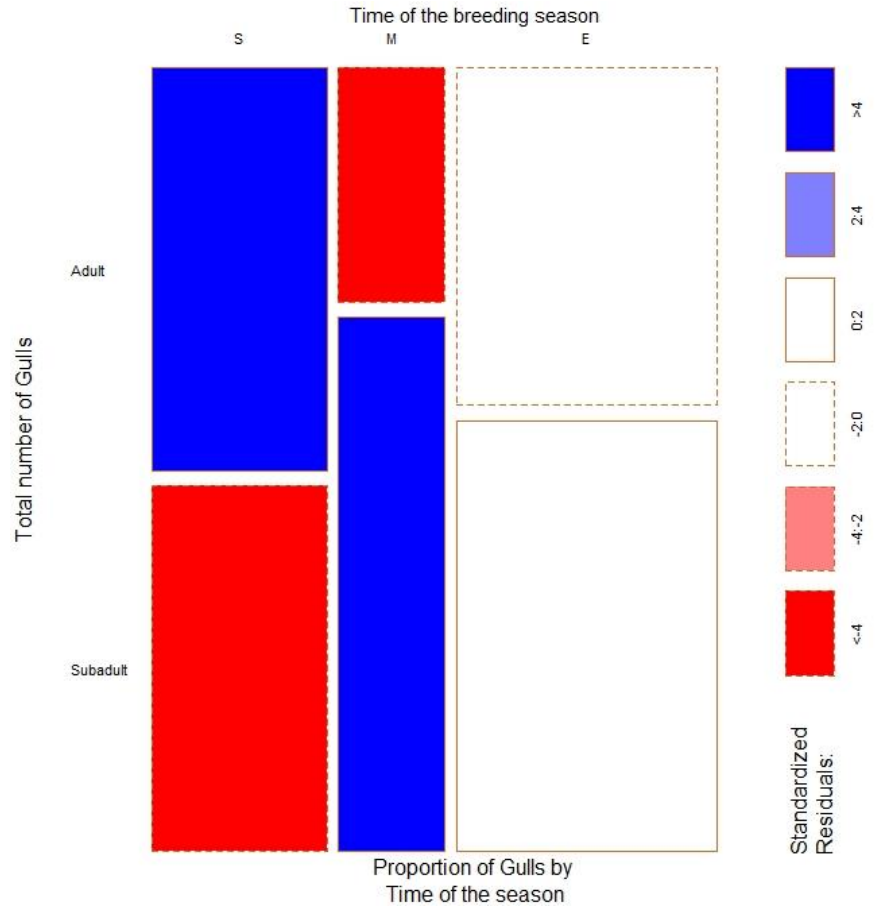


Figure 2.29 Mosaic plot of the LG age proportions over of during the breeding seasons 2016 and 2017 (S: first phase of the breeding season 15th May -10th June, M: middle phase of the breeding season 11th June -20th July, E: last phase of breeding season 21st July-15th August)

Two models out of 24 tested models within 10 ΔAICc points are shown in Table 2.5.

Table 2.5 Model selection based on ΔAICc <= 10

Mixed-effects Model: Expeditions ~	**AICc**	**ΔAICc**	**LL**
Fixed effects:			
DY * tide + RT.biom.std + biom2.std + tlg.std + tlg.std:tide	27860.08	0	-13908.03
DY * tide + RT.biom.st + biom2.std + tlg.std	27863.96	3.88	-13914.97
Random effects:			
(1 | year)			

Where:

Expeditions: LG numbers over the observation area
DY: Day in year
tide: Tide level
RT.biom.std: Available biomass of Roseate Tern chicks (standardized)
biom2.std: Available biomass of BHG, AT, CT, and ST chicks (standardized)
tlg.std: loafing Large Gulls (standardized)

Model.1 has the lowest AIC and therefore outperforms other models:

Expeditions= DY * tide + RT.biom.st + biom2.std + tlg.std + tlg.std:tide + (1 | year) **Model.1** (Table 2.6)

Table 2.6 Estimated regression parameters, standard errors, z-values and P-values for the top generalised linear mixed-effects model selected on the basis of AICc (Table 2.5)

Parameters	Estimate	Std.Error	P-value
(Intercept)	-1.0869477	0.5253413	0.038543 *
DY	0.0038231	0.0018643	0.040300 *
Tide falling level 2	0.2017696	0.5024621	0.688006
Tide falling level 3	1.1884694	0.4572812	0.009350 **
Tide rising level 1	0.9283543	0.463539	0.045204 *
Tide rising level 2	0.2702976	0.4523774	0.550171
Tide rising level 3	0.7577845	0.4904979	0.122363
Available biomass of Roseate Tern chicks (standardized)	-0.3382013	0.0259497	< 2e-16 ***
Available biomass of BHG, AT, CT, and ST chicks (standardized)	-0.0353655	0.0243337	0.146124
tlg.st	0.1704755	0.0479395	0.000376 ***
DY: Tide falling level 2	-0.0019987	0.0026481	0.450394
DY: Tide falling level 3	-0.007131	0.002416	0.003161 **
DY: Tide rising level 1	-0.0057589	0.0024055	0.016663 *
DY: Tide rising level 2	-0.0003544	0.0023207	0.878639
DY: Tide rising level 3	-0.00427	0.0025822	0.098199 .
tlg.std: Tide falling level 2	0.0567552	0.0754684	0.452027
tlg.std: Tide falling level 3	-0.1897037	0.0835995	0.023256 *
tlg.std: Tide rising level 1	0.0801864	0.0649964	0.217312
tlg.std: Tide rising level2	0.0468536	0.0560245	0.402982
tlg.std: Tide rising level 3	-0.0908079	0.0856355	0.288963

Analysis of Deviance for Model.1 showed that all fixed effects apart from the Available biomass of BHG, AT, CT, and ST chicks (standardized) contributed significantly to the probability of Expeditions over the observation area. (Appendix 11)

Predation activity of LG over the observation area increased significantly at the end of the season with the rising number of loafing Large Gulls on the reserve. However, LG activities over the observation area decreased with increasing availability of biomass of prey of other species (Figure 2.30).

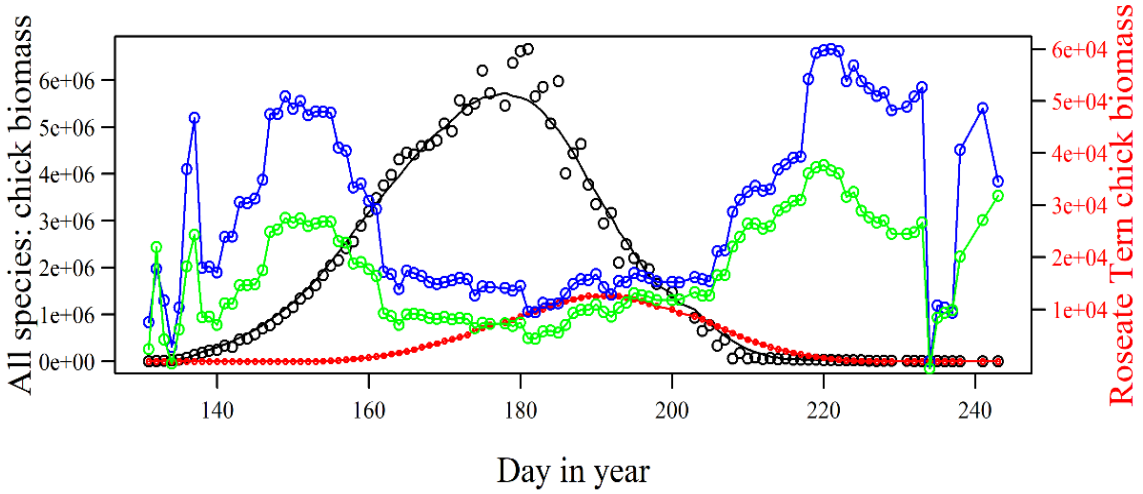


Figure 2.30 Changing of LG foraging activities over the RT colony on Coquet Island during breeding seasons 2015, 2016 and 2017. Red: Available biomass of Roseate Tern chicks (standardized), Black: Available biomass of BHG, AT, CT, and ST chicks (standardized), Green: LG number over the observation area, Blue: LG predation events over the observation area (Green and Blue are smoothed curves- 15 day running means)

2.4 Discussion

This study investigates seasonal changes in the predator-prey interactions between LG and the RT colony and the factors which drive or moderate these interactions. The statistical model which best explains the frequency of LG interactions with the RT colony suggests a high degree of seasonal dependence with predatory activity increasing towards the end of the breeding season driven by increase in the number of loafing LG in the intertidal area, with tidal state and availability of RT chick biomass having significant effects. The outputs of the tracking data indicate that breeding LG on the island may also use the island as part of their foraging territory, but there was no indication from the small sample of tracked birds that the RT colony itself was a particular target.

2.4.1 Changes of Large Gulls foraging activities over the Roseate Tern colony during the breeding season

This study suggests that the frequency of LG events over the RT colony increased towards the end of the breeding season and in relation to the number of loafing Large Gulls in intertidal areas, and was influenced by tidal state and decreased in relation to RT chick biomass availability (Table 2.6, Figure 2.30). LG activity was increased at the times of highest and lowest tide levels (Figure 2.27). These increases in LG activities linked to the tide level were most likely a daily interaction between the loafing LG and Tern colonies. During the falling tide, the LG attracted to the intertidal area for feeding and loafing overlapping with the study area where they are trying to feed on any approachable possible prey over the RT terrace. While during the rising tide, the reverse movement happened here, where shrinking the intertidal area pushed loafing LG to leave the island towards the mainland or different roosting areas overlapping again with the RT terrace (Enners *et al.*, 2018). On the other hand, with linked to the total number of loafing Large Gulls in the intertidal area, the frequency of this interaction becomes more noticeable at the end of breeding season resulted possibly from the waves of LG winter migration from the North Seas area to Spain, Portugal and north-west Africa are starting in late July and early August with using the island as a roost increasing the LG activities over the Terns colonies (Coulson, 2019). Moreover, which it might be the main factor attracting the LG to the study area, was the late establishing of Sandwich Tern sub-colony on the sandy south beach located in front of the RT main colony of the island. This ST sub-colony was noted for the first time in the 2013 breeding season, and the chicks fledging from this open, sandy colony were likely to be very desirable prey for the LG.

The available biomass of other possible prey (i.e., the BHG and chicks, other tern species and their chicks) did not improve significantly the prediction of LG activities over the RT colony (Appendix 11), this might have resulted from inaccurate presenting/or unrepresented other food sources in the suggested model (Kruuk, 1964; Parsons, 1971; Verbeek, 1977; Finney *et al.*, 2001; Donehower and Bird, 2008; Robertson *et al.*, 2015). However, a direct effect of

the presence of BHG chicks near RT colony in attracting LG was noticed during the observation period. When BHG chicks were nearly fledged their mobility increased and they often walked through the ST colony on the plateau near the RT north terrace, disturbing ST, CT, and RT in the process. As a result, on many occasions, LG were attracted to the disturbance as opportunist predators (Hernandez-Matias and Ruiz, 2003; Christina *et al.*, 2007; Robertson *et al.*, 2015; Coulson, 2019). Observations from the lighthouse confirmed previous reports of kleptoparasitism by LG on Puffins, and predation on Eider ducklings takes place over the plateau or the intertidal area during duckling departure (Evans *et al.*, 2000; Sheard *et al.*, 2004; Booth and Morrison, 2010; Davies and Morrison, 2014; Alfarwi *et al.*, 2018) and suggests that this might minimise LG activities over RT colony. However, it was not possible to estimate the available biomass of Eider ducklings or fish drooped from Puffins during this study. Therefore, they were excluded from the analysis.

2.4.2 Breeding gull foraging activity over the tern colonies during the breeding season

Although, some breeding LG were caught, colour-ringed, and marked on the head with temporary colour marks, it was difficult to distinguish them among other LG hunting over the tern terrace. This was because of the small number of ringed gulls, the rapidity of LG attacks which did not allow time to spot colour marks, and because some attacks were seen in low ambient light conditions. However, most of the ringed gulls were seen amongst the loafing gulls in the intertidal area, and some of these birds were amongst groups of LG moving between the mainland and the island suggesting that they might also have been among the LG active over the tern colonies (Figure 2.18, Figure 2.20). Two ringed breeding gulls were seen attacking the RT terrace: one LBBGU adult (Darvic ring /C:30/) and one fledged LBBGU chick (Darvic ring / C:29/) were spotted on the north RT terrace on 29/07/2016. The ringed LBBGU adult became specialist in hunting over the terrace and attacked the RT colony many times; therefore, it was controlled on 14/08/2016. Activities of the subadult over the RT colony were discouraged by human intervention and this bird was not seen again over the colony.

Attaching GPS tags to captured breeding gulls was essential to obtain objective data on the breeding LG movements. In addition to addressing the challenge of confirming that breeding LG were active in similar ways to LG loafing on and around the island, the obtained data covered unattended periods of the allocated observation shifts. Taking into consideration the low ground flying speed of LG (~5–10 $m \cdot s^{-1}$) (Shamoun-Baranes and Loon, 2006; Klaassen *et al.*, 2012) and the short distance between the main LG nesting area over the plateau and RT terrace (~ 300 meter), GPS devices were set to a high frequency of data logging. This places limits on the operating lifetime of the tag as a result of limited battery capacity. Mataki tags generated data with continuous logging for only approximately seven days whereas Movetech tags generated data for months, but with restricted logging periods of only three hours per day to allow the solar panels to recharge the device battery. To overcome the drawbacks of Mataki tags, the tags were deployed on different gulls over different periods during the breeding season with a combination of LG adults and recently fledged birds. Similarly, potential bias of the restricted logging time of Movetech tags was addressed by changing the three-hour logging periods to different times of the day every two weeks.

The GPS tags provided tracking fixes for short periods of data logging from a small number of tracked individual gulls. Apart from cost limitations of the tags, there were limits to the numbers of pairs allowed to breed on the island and the capture of suitable individuals was less successful than anticipated. Data available from successful tagging was then also limited by battery capacity of the devices in view of the high-frequency logging rates required by the study. In addition, when Movetech tags were used, the tagged gulls abandoned their nests shortly after tag deployment, resulting in less than 10% of the logging fixes over the reserve during the breeding season (Figure 2.24, Figure 2.25, Figure 2.26).

Nevertheless, the tracking data derived from Mataki tags gave a clear picture of the foraging movements of the breeding gulls. Data obtained from all Mataki tags showed that more than 90% of the logged fixes from the breeding tagged gulls overlapped with the reserve and

100 % of the logged fixes from the fledged gulls were over the reserve (Figure 2.21) during the period that tern eggs and chicks were available to LG. However, none of the tagged birds had GPS fixes over the RT colony. Although the RT terraces may be unattractive as hunting areas for LG because of the regular human activity along the path adjacent to the RT colony, because of the small sample of tagged birds it was not possible to conclude whether or not LG breeding on the island target the RT colony specifically as a source of prey. Overall, these outputs of the tracking data were comparable to the outputs of the pellet analyses (see Chapter 3) which suggest that prey types available on the island were an important component of the diet of LG breeding on the island. In other words, the results of marking and tagging the gulls were consistent with the hypothesis that the study area is included within the foraging area for the LG breeding on the island.

2.4.3 Large Gull predation activity over the microhabitats of tern colonies during the breeding season

Dividing the RT colony terraces area to four sections for observational work was driven by the differences in terrace features and the distribution of tern species over them (Evans, 2004; Weiser and Powell, 2011; Robertson *et al.*, 2015). Sections A and C were rocky and sandy intertidal areas, respectively; RT boxes were located in sections B (~25%) adjacent to the main ST colony, and D (~75%) was surrounded by the CT colony. LG foraging activities frequency changed significantly over observation area sections throughout the breeding season and section D experienced a lower proportion of the LG attacks overall (Figure 2.28). This might be linked to the extra protections for this section gained by having nest boxes sheltering the eggs, chicks and even the RT adults, and being surrounded by a defence buffer of CT (Burger and Gochfeld, 1988; Braasch *et al.*, 2014). Furthermore, this section is located near to the lighthouse near the wardens path to the island jetty and human activities along the path may act as a deterrent of attacks by LG. From a breeding season perspective, sections A and B were more exposed to LG foraging activities at the start of the breeding season, continuing to the middle phase (end of June to 20th July), but then LG activities over those two sections dropped

and started to build up over section C and D from the last week in July sustained to the end of the breeding season. This might be because sections A and B were closer to the LG roost and nesting area on the north of the island. Moreover, section B bordered the ST main colony on the plateau, and it was also the crossing path of departing Eider ducklings and BHG heading to section A and the intertidal area. These species would be attractive prey, inviting more gulls to hunt over those two sections at that time of the breeding season. For section C, the sandy section, this became the hot point for LG hunting activities from the last week of July (Figure 2.27). At this part of the season, Eider ducklings have left the island, BHG chicks fledged and Puffin have stopped bringing fish to feed their chicks. Moreover, and most likely, the presence of the late-established ST colony with slightly late hatching and fledgling chicks on this open sandy beach with no shelters was attractive and easy prey for loafing or breeding LG (Andrén, 1995; Davies and Morrison, 2013). Hence, despite extra protection measures over the RT colony, LG foraging activities increased over the main RT colony in section D at the end of the season. It was noticed that the LG trying to hunt over the terrace disregarding even active human disturbance applied by the observer. This might have resulted from age-related inexperience (Hand *et al.*, 1987; Bertellotti and Yorio, 2000), where most of the active gulls were first year subadults by the of end of July to the end of August (Figure 2.29).

2.4.4 Changing the frequency of Large Gulls foraging activities in response of LG control measures during the breeding season

Breeding LG on Coquet Island have been controlled with a combination of LG egg and nest destruction and adult disturbance since 2000 (Booth and Morrison, 2010), to reduce competition for nest sites with other species, particularly tern, which breed on the island. In this study, LG breeding nests number and distribution showed no significant change during the study period with no attempts to nest close to tern colonies. However, controlling top predators in many case studies has led to changes in both the abundance and behaviour of the predator (Brook *et al.*, 2012). This might be more noticeable when the controlled species has the ability to consume a wide range of marine and terrestrial foods such as with gull species (Hertel *et al.*,

2016; Shaffer *et al.*, 2017), where the high plasticity in foraging behaviour gives them the ability to switch to new types and sources of foods (Shaffer *et al.*, 2017; Enners *et al.*, 2018; JNCC, 2018; Coulson, 2019). In this study, collecting the eggs of breeding LG, the top predator in the reserve, had led to a noticeable decline in the frequency of LG foraging activities over the study area especially in the period after the first LG egg collection (first ten days in June) (Figure 2.27). It is possible that the systematic collection of LG eggs every two weeks, concurrently with the increasing availability of other food sources on the island, has contributed to keeping the frequency of LG foraging activities to a steady state until the next remarkable rising occurred in the last week of July (Figure 2.27). This might be considered, in addition to the LG tracking data outputs and re-sighted ringed gull records, as another indicator that LG breeding on the island also utilize the breeding area as a foraging territory.

2.5 Conclusion

The frequency of LG events over the RT colony increased towards the end of the breeding season with two major change points in the frequency of LG foraging activity. Firstly, a decrease in LG activity associated with the period after the first LG egg collection in the first ten days of June. Then, secondly, a remarkable increase in LG activity starting in the last week of July. This may have been a consequence of waves of HGU subadults fledged in Scotland moving to England following the coastline and/or LBBGU using the island as a stop-over during their migration from the North Seas to winter in Spain, Portugal, and north-west Africa. This is compatible with observations that the notable increase in the LG hunting activity approaching the end of the breeding season was mainly by sub-adult LG, which are documented to be the main components of the winter LG migration more than the adult LG.

The daily fluctuation in the frequency of LG foraging activity was associated with the times of highest and lowest tide levels when LG use the exposed intertidal area as an attractive roost for loafing. Important evidence that LG breeding on the island utilise the island as a food source was derived from the marked and tracked LG, coupled with direct sightings of hunting

activity by the breeding LG over the RT terrace. There were significant differences in the proportion of LG predation activity over the different microhabitat components of the RT colony area, where the covered section with nest boxes for RT (i.e., the main RT colony) received fewer LG predation events than the intertidal area in front of RT colony; this shows the success of existing management strategies and suggests that the RT nesting habitat, or even the intertidal areas in front of the colony, could be further manipulated or reconfigured to mitigate predation activity by LG.

Chapter 3 Combining dietary analysis techniques to assess Large Gull predation on small colony of Roseate tern

3.1 Introduction

Investigating animal diet composition is a key component of animal ecological studies (Wachter *et al.*, 2012). Dietary analysis provides important information on predator-prey relationships and is essential for assessing the threat of predators to rare prey species that may need to be protected (Napolitano *et al.*, 2008; Wachter *et al.*, 2012).

3.1.1 Avian diet analysis methods

There has been extensive research to gain knowledge of animal diets using different methods. Each has advantages and disadvantages (Lewis *et al.*, 2004; Steffens *et al.*, 2012) and can be generally separated into 'direct' and 'indirect' methods (Barrett *et al.*, 2007; McInnes *et al.*, 2016). Direct methods involve the observation of seabird nests during feeding of their young, or the foraging activities of individuals within the feeding habitat (Hall and Halliday, 1998; Kubetzki and Garthe, 2003). Examples of the use of direct methods include the studies of (Strong, 1914; Ansley, 1955; Burger, 1988) who conducted observations of gulls from hides or from a distance to obtain data on the composition of prey delivered to chicks in the nest; (Kotzerka *et al.*, 2010) who revealed the foraging strategies of Black-legged Kittiwakes using GPS telemetry, and (Soanes *et al.*, 2014; Lorentsen *et al.*, 2019) who showed annual variation, factors affecting the foraging behaviour of the European shag using GPS-loggers and time−depth recorders, while (Watanuki *et al.*, 2008; Evans, 2015) deployed cameras to study the prey captured by the European shag.

Indirect methods involve the collection of evidence from past feeding or predation events to infer the composition of diet. Examples of the use of indirect methods include (Kubetzki and Garthe, 2003; Bustnes *et al.*, 2010; Steenweg, 2010) who all collected prey remains, regurgitated pellets and faecal samples collected from gull colonies; (Harris, 1965; Mahoney and Jehl, 1985; Petry *et al.*, 2007; Kim and Oh, 2014) who analysed the stomach

contents of the black-browed albatross and gulls; and (Forero and Hobson, 2003; Bond and Jones, 2009; Ronconi *et al.*, 2014) who used stable isotope analysis to investigate seabirds diet. Indirect methods often provide large samples with little disturbance to the birds (Votier *et al.*, 2010). Samples can be preserved and accurately identified using different techniques, and collecting samples over time and space (Gong *et al.*, 2019) can give information on diet diversity and temporal and spatial shifts in foraging strategies. However, they can also result in incomplete or biased data because overestimation of prey species from which undigested material originated might occur as a result of physiological and behavioural differences of the predators consuming their prey (Steffens *et al.*, 2012). Another source of bias is that smaller prey may leave few remains relative to larger prey with hard components more resistant to digestion or environmental degradation. Direct observation, with the ability to see the prey delivered to the nest, is more beneficial (Gaglio *et al.*, 2017). This will enable the researcher to estimate the prey species, age, and size more accurately (Barrett *et al.*, 2007). In addition to diet information, the foraging frequency with feeding habits and foraging habitats could be revealed using these observation methods (Gaglio *et al.*, 2017). A small sample size is one of the associated disadvantages of these methods with required intensive labour and high costs (Zárybnická *et al.*, 2011). In general, no single technique provides a complete dietary description, but more complete diet and feeding behaviour description can be obtained by combining results from direct and indirect methods (Barrett *et al.*, 2007; Weiser and Powell, 2011).

3.1.2 Evidence of predation by diet analysis

The wide range of techniques used to study seabird diet are essential to estimate the energy and nutrition of food consumed by the adults and chicks, feeding habitat and prey choice, timing and frequency of foraging (Bolton *et al.*, 1993; Bukaciński *et al.*, 1998), providing information on the composition of consumed food in seabird foraging areas, and extending our knowledge of seabird adaptations to the marine environment and their position

in food web structures (Iverson *et al.*, 2007). Additionally, and in the context of wildlife conservation and biodiversity management, investigating seabird diet is a powerful tool for understanding the dynamics of predator–prey relationships and interactions of predators with their prey (Oro *et al.*, 2006; Drake *et al.*, 2011; Durant *et al.*, 2014). Hence, by determining predation effects on the prey population, measures could be designed and implemented to improve conservation management and reduce or avoid potential conflicts between the need to achieve the protection of rare species without compromising predator populations (Monaghan, 1992; Stapp, 2002; Caut *et al.*, 2008; Sanz-Aguilar *et al.*, 2009; Lewison *et al.*, 2012; Furness *et al.*, 2013). However, different techniques for studying seabird diets have their own limitations and biases (Barrett *et al.*, 2007) and there is no single reliable method that can be applied to obtain comprehensive quantitative information on predator diet (Duffy and Jackson, 1986; Barrett *et al.*, 2007).

The aim of this research study on Coquet Island was to address one of the most complicated conservation conflicts arising from the need to control protected predator species (breeding large gulls: Herring and Lesser Black-backed Gulls) which may consume protected prey (Roseate Tern) (Redpath et al., 2016). Although it is undoubtedly the case that individual gulls may predate on terns, the extent to which this is an issue for the Roseate Tern colony is difficult to measure. One of the aims of this project was to use different methods to assess prey choice by breeding large gulls (LG) on the reserve. Given the special circumstances of this case study i.e., the small population of Roseate Tern on the reserve (approximately 100 pairs occupying less than 2% of the total area of the reserve) compared to the population of more than 45,000 breeding seabirds on the island overall, two diet investigation methods were used: camera ‘trap’ observations and pellet analysis.

3.2 Material and methods

3.2.1 Surveillance cameras

Food-provisioning monitoring on avian nests using optical equipment or cameras installed at nest sites is one of the most cost-effective and reliable techniques for determining bird diet and quantifying nestling diet (Morrison *et al.*, 1990; Richardson *et al.*, 2009; Zárybnická *et al.*, 2011; Robinson *et al.*, 2015). Although the deployment of surveillance cameras at prey species nests can be an informative and accurate tool for identifying nest predators (Richardson *et al.*, 2009), predator monitoring at prey nests was not applicable in this study due to the restrictions in place to minimize disturbance of the Roseate Tern colony. Therefore, the camera traps and diet provisioning monitoring were used at the breeding LG nests.

3.2.1.1 Experiment design and preliminary camera recording test

3.2.1.1.1 Materials

- Camera (Bushnell Trophy Cam HD Aggressor) fixed to a wooden stand holder (60 cm high)
- Semi-rigid plastic garden fencing mesh, 20mm hole sizes (60 cm high) attached to hessian matting to help preventing LBBGU chicks escaping from the enclosure.
- Small toy attached to stick to move it in front of the camera stand.

A preliminary test for the camera sensitivity was done before the start of breeding in April 2016 to determine the optimal distance of the camera from the nest, with the aim of being able to record clear feeding events. To ensure that gull chicks were kept within the range of the camera until fledging, study nests were surrounded by low plastic garden fencing mesh approximately two days before predicted egg hatching dates. According to field notes by Wesley Davies, the warden assistant on the reserve at the time, during his previous attempts to keep LBBGU chicks in an enclosure to ring them before fledging, an enclosure of not less than 6-meter radius was recommended to give the parents enough space in the enclosure to be able to land on or beside the nest as otherwise there is a risk that they will abandon the nest site.

Taking this recommendation into account, an experiment to determine the maximum distance away that a targeted bird would trigger camera trap recording was conducted by moving a toy similar in size to a LBBG chick in front of the camera at different distances (Figure 3.1).

Figure 3.1 Testing the sensitivity of the camera trap to detect LBBG chicks

The preliminary test showed that the chicks should be within 6 m maximum and not less than 1 m from the camera site to trigger the recording (Figure 3.2). Therefore, two cameras were deployed on each nest to maximize coverage of the nest area by the camera field of view. Using this approach, two camera traps covered >70 % the active area around a large gull nest.

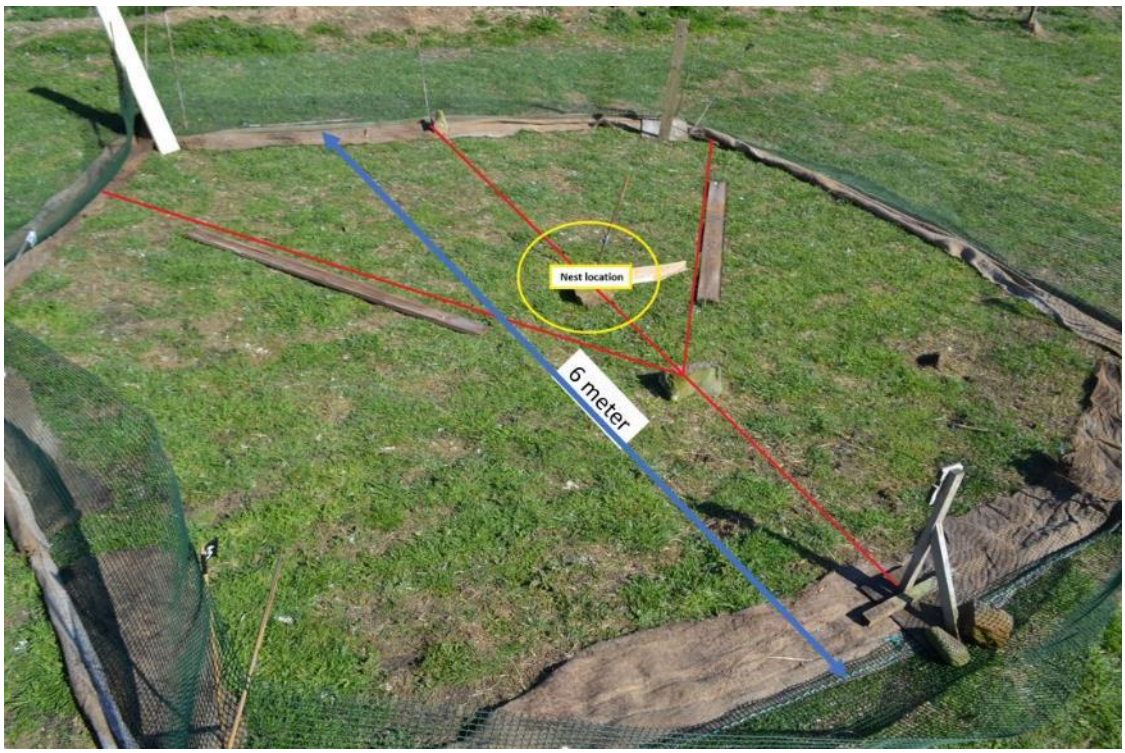


Figure 3.2 Determining the best camera trap location and the enclosure radius around LBBGU nest

3.2.2 Prey choice provisioning using camera traps

3.2.2.1 Method

Five LBBG nests were excluded from the LG control management plan for this research. These retained nests were located away from the tern colonies where they were judged to present minimum risks to the Roseate Tern colony. HGU nests were difficult to study because they mainly nested on the edge of the plateau where it was not possible to set an enclosure with camera traps. Study nests were monitored using camera traps from the first chick-hatching day. After finding and marking the allocated target nests, regular visits were made at one – three day intervals to determine the incubation stage of eggs (Walter and Rusch, 1997, Nol and Blokpoel, 1983, Liebezeit et al., 2007). As the day of egg hatching approached, the enclosures with two wooden stand camera holders were set around the nest two days before the potential hatching date. The purpose of establishing the enclosures at this time was to allow the LBBG parents to habituate to the new changes before hatching and to make sure that newly-hatched chicks only had a controlled space to wander.

Once hatching was confirmed, to each nest two motion-sensitive cameras were secured to the wooden stands. Cameras were programmed to take a 30-second video when motion was detected, at a rate of one video every 15 seconds. Cameras had infrared illuminators allowing video recording to take place under low ambient light conditions. Each camera was in place for 30 days approximately until the chicks are ready for fledging. The camera memory card and batteries were replaced by visiting the study nests at two-day intervals.

3.2.3 Pellet analysis

Identifying predator's prey by investigating prey remains in scats, pellets and/or stomach contents is an efficient method studying avian diet, (Barrett *et al.*, 2007; Howells *et al.*, 2018). Like birds of prey, LBBG and HG consume their prey whole but undigested hard parts of their prey such as feathers, shells and bones are regurgitated regularly in the form of pellets in 24 – 48 hours (Emslie and Messenger, 1991; Votier *et al.*, 2003). These can be collected around the nests and at accessible roosts on intertidal areas, giving an opportunity to assess their diet composition during the breeding season (Votier *et al.*, 2004; Steenweg *et al.*, 2011) and providing evidence of the predation activities of LG (Veitch *et al.*, 2016).

3.2.3.1 Pellet collections and storage

An intensive regime of pellet collection and clearance was conducted around the LBBGU nests and in intertidal area used by LG to assure that the pellets analysed were produced in the breeding period of the relevant study year. Pellets were collected during 2016 and 2017 starting from first LBBGU hatching chick (second week of June) to the end of the breeding season (last week in August). The pellets were collected from within a 4 – 6 m radius around each LBBG nest on the Island plateau (41 pellets from 7 nests in 2016 and 42 pellets from 6 nests in 2017) during each nest-check visit to the study LBBG nests. Pellets were also collected from intertidal large gull roosting areas on the SE, NE, and NW of the island after low tide on a weekly basis when weather conditions allowed.

592 pellets were collected in 2016, for analysis using morphological methods (Votier *et al.*, 2003). These were collected with bare hands by the researcher and volunteers, dried on the study island for several days before transfer to plastic bags for storage until the end of the season. They were then transferred to the Newcastle University and kept in the laboratory freezer (-20°C). In 2017, 351 pellets were collected for additional analysis with DNA metabarcoding methods. These pellets were collected by the researcher wearing latex gloves, stored in double-sealed plastic bags in a fridge at -5°C on the island, and transferred to a laboratory freezer (-20°C) at Newcastle University within 24 – 72 h of collection. The samples were collected carefully without touching the samples with bare hands or mixed with each other to avoid DNA contamination.

3.2.3.2 Pellet analysis using morphological methods

The composition of pellets was classified into 3 major dietary categories on the basis of prey contents: marine (fish and crab), mainland (mammal remains, human garbage and vegetation), and local (potential prey from Coquet Island). In addition to collecting pellets from the nesting area, prey carcasses around selected study nests were noted. Using field guides, research literature (Votier *et al.*, 2003; Votier *et al.*, 2004) and consulting with experts, prey items assigned to the potential prey from the reserve were identified to the finest possible taxonomic level based on feather colour and pattern, wing shape, or any hard-part remains (legs or bill).

3.2.3.3 Pellets analysis using molecular genetic analyses

This method was applied to the pellets collected in the 2017 breeding season. Because of the high cost of this method and time limits to achieve this research, only 137 pellets out of 309 pellets from the intertidal area and 26 pellets out of the 42 pellets from nests and plateau were selected for analysis, based on the presence of visible feathers. Pellets which mainly consisted of cleaning tissue, plastic, fish, and vegetation were excluded from DNA analysis.

3.2.3.3.1 DNA extraction

DNA extraction was carried out using a modular universal DNA extraction method (Mu-DNA) (S. Sellers *et al.*, 2018). However, different methods (Colosi and Schaal, 1993; Bello *et al.*, 2001; De Volo *et al.*, 2008; S. Sellers *et al.*, 2018) were used for sample grinding. Pellets were individually defrosted and processed for DNA extraction, one sample at a time to avoid cross contamination, and teased apart using sterilized disposable forceps (Taberlet and Bouvet, 1991). Two parts from the middle of each pellet were taken and each added to a new 5 mL tube prefilled with 15 g of sterile garnet (6 -7 mm) and with two stainless-steel grinding balls: 4 mm Diameter. Before use, the garnet and metal balls were washed and baked in a Carbolite High Temperature Box Furnace at 1000°C for 24 h (Colosi and Schaal, 1993; Karni *et al.*, 2013). One tube was saved in the laboratory freezer at -20°C and the other used for DNA extraction. The weight of each sample part varied depending on the size of each pellet, but the approximate average weight was 5 g. In the next stage, six samples were processed at the same time but on different laboratory tables; liquid nitrogen was added to each sample and after the liquid nitrogen evaporated all were inserted into the Geno/Grinder 2010 for 3 min at 1750 RPM. This stage was repeated twice. Then, the protocol of Mu-DNA was followed for the DNA extraction and purification, slightly modified by increasing Lysis solution 1 and Lysis 2 solution to 4400 µL and 1600 µL per sample, respectively. All extraction and purification buffer components are described in (Table 3.1) and referred to throughout by the names used in the table.

The extraction method was as follows: 4400 µL of Lysis solution 1 was added to each sample and vortexed briefly. Then, six samples were placed in Geno/Grinder 2010, with appropriate tube adapters, at speed 1750 RPM for 60 s to mix the powdered pellet and Lysis solution 1. Samples were then centrifuged at 4,000 x *g* for 1 min at room temperature to clear liquid from the tube lids. 1600 µL of Lysis solution 2 was added to each sample and vortexed to mix, followed by centrifugation at 4,000 x *g* for 1 min at room temperature. 1.5 mL of

supernatant from each sample was transferred to a fresh 2 mL tube and these were centrifuged at 10,000 x *g* for 1 min at room temperature. Finally, 500 µL of supernatant from each sample was transferred to a fresh tube and the remaining lysate stored at -20°C for future work.

3.2.3.3.2 DNA purification

200 µL of Protein flocculant was added to the 500 µL of supernatant from each sample, vortexed briefly, incubated on ice for a minimum of 10 min and then centrifuged at 10,000 x *g* for 1 min at room temperature. 500 µL of supernatant from each sample was transferred to fresh tube and 200 µL of inhibitor flocculant mastermix added. After centrifugation at 10,000 x *g* for 1 min at room temperature, 500 µL of supernatant from each sample was added to a fresh 2 mL tube containing 1000 µL of Binding solution and mixed by pipetting up and down. A silica spin column for each sample was filled with the above mixture, centrifuged at 10,000 x *g* for 1 min at room temperature, and the flow-through discarded. This step was repeated until all the mixture from each sample had passed through the relevant sample spin column. Fresh Wash solution (400 µL) was added to each column and the flow-through after centrifugation at 10,000 x *g* for 1 min at room temperature discarded. DNA was eluted from the columns into fresh collection tubes by adding 200 µL of Elution buffer directly to each silica filter membrane and centrifugation at 10,000 x *g* for 1 min at room temperature.

Table 3.1 Chemical components, and concentrations, were used during DNA extraction and purification based on Mu-DNA method

Component	Contents	Solution concentration	pH
Lysis solution 1	Guanidine thiocyanate	147 mM	9.0
	Trisodium phosphate	228 mM	
	Sodium chloride	26 mM	
	1 M Tris HCl	67 mM	
	0.5 M EDTA	27 mM	
Lysis solution 2	Aluminium ammonium sulphate dodecahydrate	90 mM	-
	Sodium dodecyl sulphate (SDS)	1.25 %	
Protein flocculant	Ammonium acetate	5 M	-
Inhibitor flocculant 1	Aluminium ammonium sulphate dodecahydrate	180 mM	-
Inhibitor flocculant 2	Calcium chloride dihydrate	204 mM	-
Binding solution	Guanidine HCl	5.5 M	-
Wash solution	Ethanol	80 %	-
Elution buffer	Tris hydrochloride	10 mM	8.0

3.2.3.3.3 DNA amplification (PCR)

A 'next-generation' sequencing approach was applied in this step using nested-tagging DNA metabarcoding, described in (Pompanon *et al.*, 2011; Kitson *et al.*, 2019). The primer pair mICOIintF and jgHCO2198, designed by (Leray *et al.*, 2013), was modified by (Kitson *et al.*, 2019). With the justified primers from (Kitson *et al.*, 2019), 6 out of 12 forward primers and 4 out of 8 reverse primers were used for Polymerase Chain Reaction (PCR1) in this study. In addition, unique primer tags were also used for positive and two negative controls (one for DNA extraction and one for PCR1) (Appendix 14). The samples were distributed across a 96-well PCR plate (each plate contained 27 primer combinations), keeping an empty well between

samples to minimize the chance of contamination. The primer tag combinations were then replicated on seven PCR plates (Appendix 15).

PCR1 was carried out using a Techne™ 5PrimeG Gradient Thermal Cycler with the following conditions: 45 cycles (95°C for 15 s, 51°C for 15 s and 72°C for 30 s) in 25 μL reactions using a high-fidelity Taq mastermix (MyFi Mix Bioline), 2 μL of template DNA and 0.88 μL of each primer. A drop of mineral oil was added to each reaction to avoid contamination between wells, and PCR plates were sealed with plastic film.

3.2.3.3.4 Normalisation of sample concentrations and Sequencing

The DNA concentrations of all samples in each plate were equalised with the aim of equalising the sequencing read depth across all samples. Solid Phase Reversible Immobilization (SPRI) beads were used to normalise DNA sample concentration; magnetic bead solutions were made following the method of (Hosomichi *et al.*, 2014). Then, all samples from one PCR1 plate (i.e., 27 samples) with 27 primer combinations were pooled into one PCR tube forming the pre-library (seven pre-libraries in total). Then, PCR1 inhibitors were removed using the protocol of (Vo and Jedlicka, 2014) before running PCR2 with the following conditions: 12 cycles (95°C for 30 s, 72°C for 30 s and 72°C for 3 min) in 25 μL reactions using a high-fidelity Taq mastermix (MyFi Mix Bioline), 2 μL of template DNA and 1.1 μL of each primer. The justified primers for this step were taken from (Kitson *et al.*, 2019): seven of 12 forward primers and seven of eight reverse primers were used in this study for PCR2. In addition, unique primer tags were also used for negative controls see (Appendix 14). PCR2 was followed by removing the PCR2 inhibitors using same protocol as for PCR1(Vo and Jedlicka, 2014). Finally, the concentrations of each of the seven libraries were quantified on a Qubit 3.0 using the Invitrogen dsDNA HS Assay Kit, then diluted to 20 ng/ μL DNA concentration (Appendix 16) and sequenced in an Illumina MiSeq using V3 run (2 x 300 bp), loaded at 20 pM with 10% PhiX by the Nuomics DNA sequencing research facility, Northumbria University, UK. Illumina

MiSeq outputs were processed to identify the taxonomic assignment using a custom analysis pipeline for metabarcoding data: METABEAT v0.97.7. (Kitson *et al.*, 2019).

3.2.3.3.5 Agarose gel electrophoresis

PCR1 and PCR2 reaction products were analysed on 2% agarose gels in 0.5 x TBE buffer at 100 V for 65 min by loading 2 µL of template DNA with 2 µL bromophenol blue loading dye. Gels were stained with ethidium bromide (3 µL/100 mL) and DNA visualised using UV light. A molecular weight marker (EasyLadder I, Bioline) with 5 regularly-spaced bands, ranging from 100 bp to 2000 bp (Figure 3.3), was used for DNA-length calibration (Appendix 17)

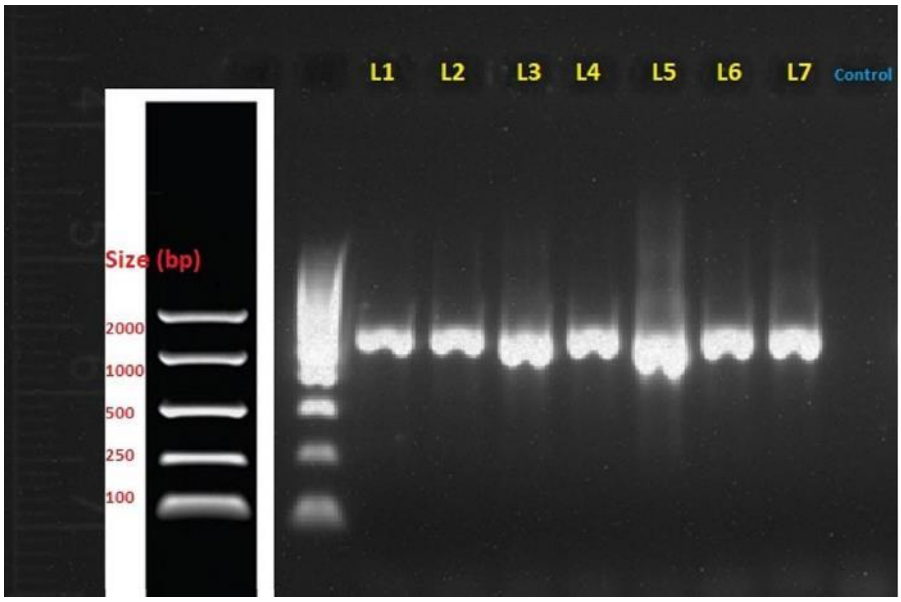


Figure 3.3 An image of a gel post electrophoresis for 7 libraries. The gel was exposed to UV light and the picture taken with a gel documentation system, Negative control (nuclease-free water) in last well showing no band.

3.3 Results

3.3.1 Prey delivery recorded by surveillance cameras

Feeding events for seven LBBG nests on Coquet island were recorded using camera traps in the 2016 breeding season. Around 135 hours were recorded from all seven nests. Only 94 (0.6 %) feeding events were obtained from those total event footages. Taxonomic Class of prey was the finest identification level possible using surveillance cameras (Table 3.2, Figure 3.4)

However, 41 collected pellets from the same videoed nests showed a wide variety of prey taken by the breeding gulls (Table 3.3). Moreover, Tern species were recorded in five of the collected pellets with approximately 30% of the pellets containing 'local' prey items. Additionally, the carcasses of 21 Arctic tern adults and 6 Common tern adults were found around the same nests; a notable feature of these carcasses was that the pectoral muscles had been eaten.

Table 3.2 Prey items delivered to chicks extracted from the camera footages from 7 LBBG nests

Nest No	Species	Total feeding events	Fish	species	Unknown prey	Feeding outside of the camera's field of view
N1	LBBG	15	8	Unknown	4	3
N2	LBBG	18	8	Unknown	8	2
N3	LBBG	12	3	Unknown	5	4
N4	LBBG	10	5	Unknown	5	0
N5	LBBG	11	6	Unknown	-	5
N6	LBBG	8	2	Unknown	1	5
N7	LBBG	20	3	Unknown	2	15

Figure 3.4 LBBG chick with fish supper (Footage by Bushnell Trophy Cam HD Aggressor 21/06/2016)

3.3.2 Pellet content from morphological analysis

Table 3.3 Pellets contents, collected from 7 LBBG nests, 2016 breeding season

Nest No	Species	Pellet	Fish	Feather	Fur and Hair	Vegetation	Prey Species
N1	LBBG	7	3	2	0	2	Puffin
N2	LBBG	3	1	0	2	0	Vole spp
N3	LBBG	6	0	5	1	0	1 Puffin, 1 Arctic Tern, 3 Tern spp, unidentified mammal
N4	LBBG	7	2	2	3	0	Puffin, unidentified mammal
N5	LBBG	6	5	0	0	1	-
N6	LBBG	10	6	3	1	0	2 Tern spp, Eider duck, unidentified mammal
N7	LBBG	2	0	1	0	1	unidentified feather

Largest number of collected pellets per month was in July in both breeding seasons 2016 and 2017 (Figure 3.5)

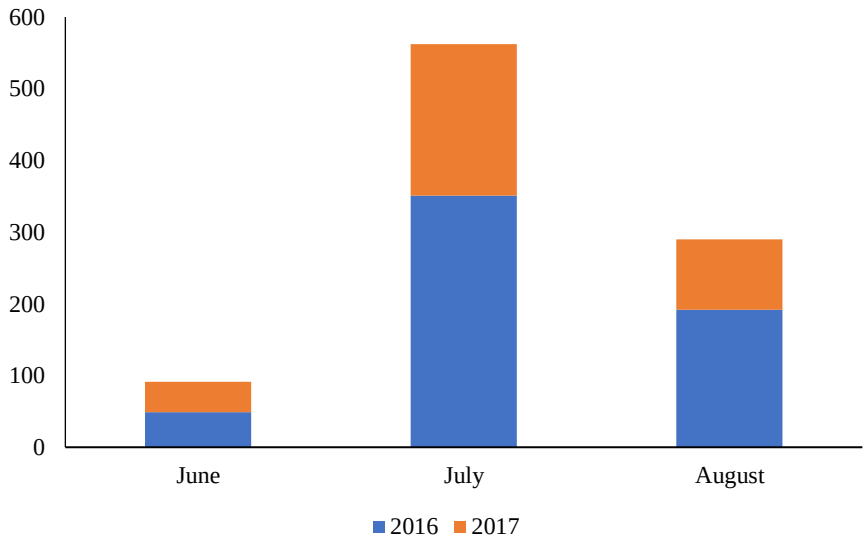


Figure 3.5 Number of pellets collected on each calendar month, per year

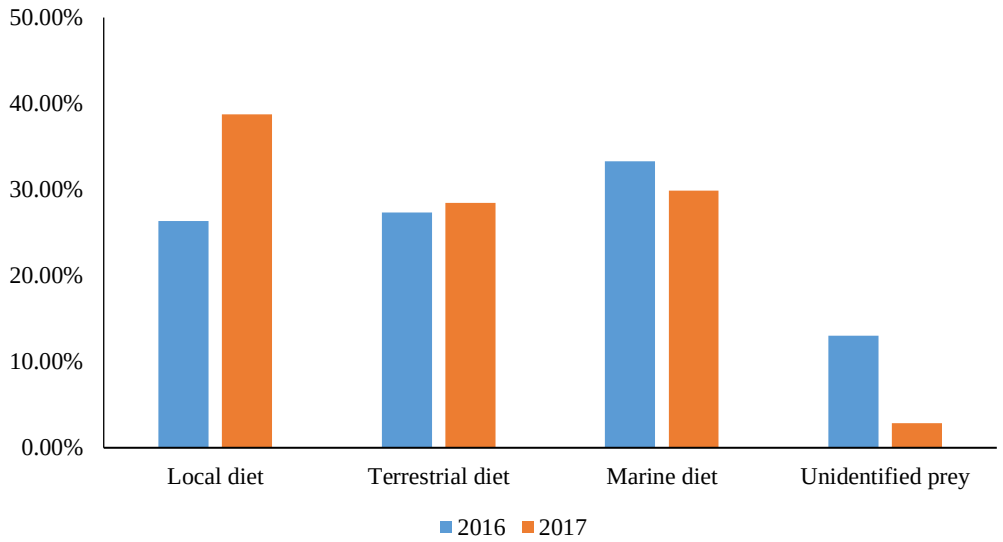


Figure 3.6 Percentage of diet types in the pellets

Table 3.4 Total numbers of LG pellets by dietary classification collected in two breeding seasons 2016 and 2017, including unidentified bird prey and vegetation

	2016		2017	
Local diet	**Pellet NO**	**%**	**Pellet NO**	**%**
Puffin	90	15.20%	104	29.63%
Tern species	27	4.56%	20	5.70%
Eider	6	1.01%	4	1.14%
BHG	33	5.57%	8	2.28%
Terrestrial diet				
Mammal remains	17	2.87%	25	7.12%
Human garbage	21	3.55%	7	1.99%
Junk food	9	1.52%	8	2.28%
Vegetation	115	19.43%	60	17.09%
Marine diet				
Fish	153	25.84%	73	20.80%
Crab	44	7.43%	32	9.12%
Unidentified diet				
	77	13.01%	10	2.85%

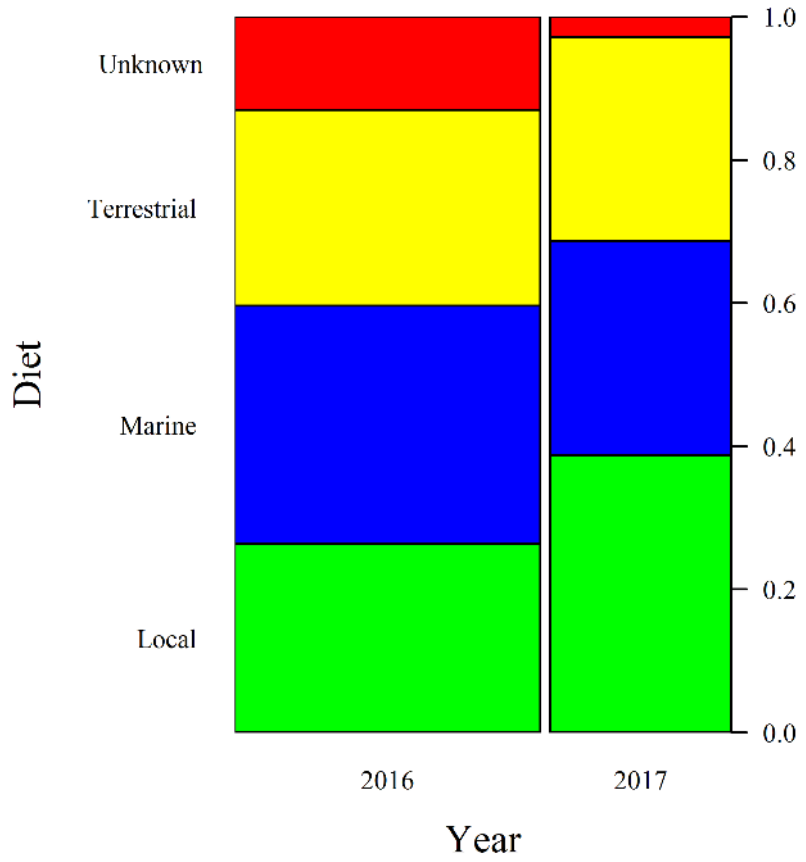


Figure 3.7 Frequency of diet types in the pellets collected on Coquet Island

Table 3.5 The percentage of diet type obtained from different sources obtained from breeding and roosting HGU and LBBGU on Coquet Island

	2016		**2017**	
	Roosting LG	**Breeding LG**	**Roosting LG**	**Breeding LG**
Local diet	24.3%	2.0%	37.3%	1.4%
Terrestrial diet	25.5%	1.9%	20.8%	7.7%
Marine diet	30.4%	2.9%	27.1%	2.8%
Unidentified diet	12.8%	0.2%	2.8%	0.0

Statistical analyses were performed using contingency tables, Chi-squared test and McNemar's test for categorical data. Although data were collected from birds breeding on the same colony, there were significant differences between breeding seasons in the proportions falling within each dietary category in the collected pellets from nest sites and roost area (χ^2=10.698, df=3, P<0.05; Table 3.4, Figure 3.6). Therefore, pellets from each season were analysed separately to

compare the pellet components between the intertidal area and the nests. In the 2016 breeding season, local diet formed a similar proportion of the pellets collected from nests and intertidal areas (χ^2=4.816, df=3, P=0.088). However, pellets representing a local diet formed a substantially smaller proportion of pellets collected from the nests in the 2017 breeding season compared to pellets collected from the intertidal zone (χ^2=36.476, df=3, P=0.0001). Conversely, the majority (approximately 8%) of the pellets from nests in 2017 represented a terrestrial diet (Table 3.5).

3.3.3 Pellet analysis using molecular genetic analyses

Gel electrophoresis showed a success rate of 78% of all samples on PCR1 reactions and 100 % tagging success of all PCR2 reactions with no evidence of contamination neither between samples nor between the libraries (Figure 3.3, Appendix 17).

The results of processing Illumina MiSeq outputs were filtered on the following basis:

- No repetitive or unusual DNA reads were found in the negative controls, therefore no need to put thresholds for the DNA reads in samples.
- A high or low number of DNA reads is not representing the prey biomass in the sample. Therefore, if a sample, for example, showed high reads of Fungi DNA and low reads of Puffin reads, Fungi will not be considered dominant in the sample, similarly for the LG reads.
- LG DNA was not assigned as prey because it might be coming from the predator (eater) itself, unless it was confirmed morphologically (which it was not the case in all samples), and it was always considered an environmental contaminant.
- Fish or seafood was not included in the selected pellets; therefore, it was always considered an environmental contaminant.
- Genus taxonomy level was considered as an acceptable level to determine the food sources especially with the "Microtus & Puffin"

An exact McNemar's test determined that there was a statistically significant difference in the proportion of samples identified to the “Species” taxonomic level using DNA metabarcoding method comparing to the pellet’s morphological assessment (McNemar's χ^2=4.816, df=1, P= 0.00001).

21.5% of total analysed samples using DNA metabarcoding technique gave unexpected DNA reads or no reads and only 15% success detecting Tern spp out of the 13 morphologically confirmed Tern spp presence in the pellets, 95% of unidentified prey was solved by using DNA combined with morphological method (Figure 3.8)

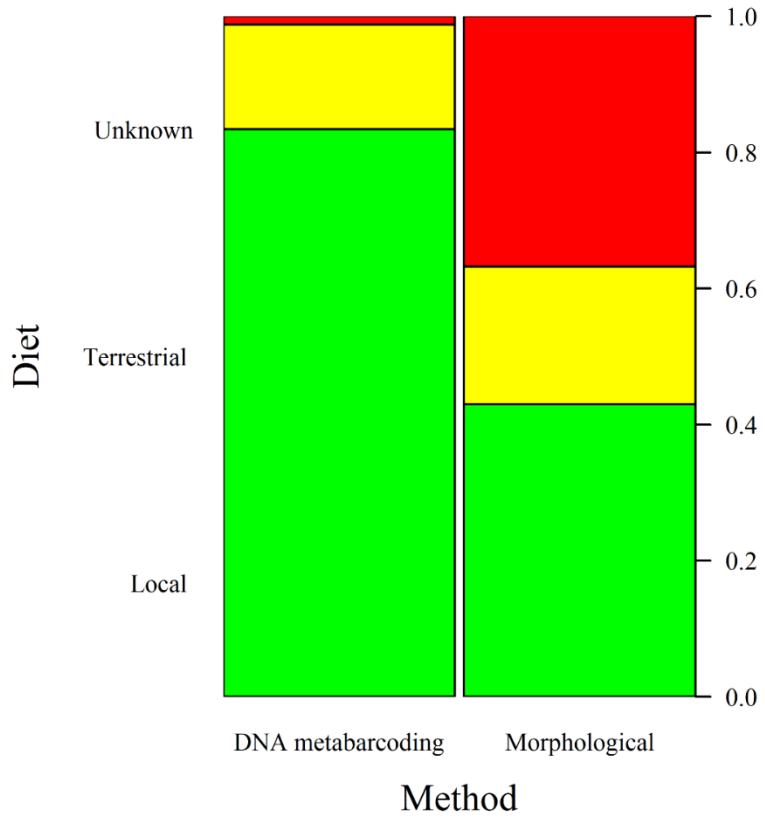


Figure 3.8 Proportion of identified diet types resulted using DNA metabarcoding and morphological assessment methods

3.4 Discussion

For this study, the use of trail cameras was found to be impractical for determining prey delivery to nestlings. Conversely, combining the molecular technique of 'next-generation' DNA sequencing (NGS) with morphological examination of prey remains in pellets was a powerful tool for dietary analysis. There was direct evidence for LG predation on some of the tern species nesting on Coquet Island, and this implies that RT too would be at risk.

3.4.1 Knowledge Gained from Video-Monitoring Large Gull Nests

Ecology has been dramatically revolutionized by utilizing camera traps to studying animal behaviour, their relationship to their environment, in providing evidence of the presence of very rare species (Rovero and Zimmermann, 2016), and observing wildlife without disturbance in natural habitats (Kucera and Barrett, 2011). Although the initial use of camera trapping was focused primarily on studying medium and large-sized mammals because the detection system was not sensitive enough to trigger recording of small sized animals including birds, with advances in the camera detection system, this technique has now been used extensively in avian ecology studies (O'Brien and Kinnaird, 2008) with wide range of implications in avian habitat management, research, and monitoring. Cameras are most commonly used to study adult behaviour (Thorsen *et al.*, 2004; Tremblay *et al.*, 2014), feeding ecology and activity budgets (van Veen, 2003; Tremblay *et al.*, 2005), and nest predators (Zegers *et al.*, 2000; Tornberg and Reif, 2007; Lynch *et al.*, 2015).

3.4.1.1 Prey identification, bias, and limitation of using surveillance cameras in surveillance cameras

From a conservation perspective, investigating nest predation and identifying nest predators was one of the first widespread uses of remote photography and video surveillance, enabling an evidence-based approach to wildlife management for reducing and mitigating nest predation (Thompson III and Ribic, 2012).

According to most of the published literature (Tornberg and Reif, 2007; O'Brien and Kinnaird, 2008; Ellis-Felege and Carroll, 2012; Moeller *et al.*, 2018), camera traps provide valuable

knowledge about avian dietary composition with the ability to identify most prey delivered to the nest to Species taxonomic level. Additionally, although most wildlife research studies based on the use of camera traps suffer from small sample sizes, such studies have minimized the biases inherent in only using physical signs at nests for identifying predator species responsible for predation events. However, in this present study, prey item identification in the video footage was not generally informative other than describing the frequency of chick feeding events. This might be linked to what Steenweg *et al.* (2011) and Garthe *et al.* (1999) found in their research where LG adults feds on higher trophic levels whereas the main food delivered to their chicks was high-energy content and easily-digestible prey, mainly krill and mackerel with (>60%, >20% respectively). This might be the reason why none of the recorded videos showed bird or mammal prey have been given to the chicks making fish most of the identified delivered prey to the chicks. Collected prey remains and pellets from the same videoed nests showed a wide range of prey choices with precise confirmed prey species most likely. This failure of camera-trap methodology to characterize the diet of LG chicks adequately may have resulted from a combination of different factors:

- Large Gull Nestling behaviour:

It was not possible to record all the chick feeding events due behaviours at the nest. This has resulted from the high mobility of the chicks from the first hatching day. Therefore, with limitations in viewing all angles of the nest, the detectability of prey delivered to the chicks was very low.

- Camera aspects:

In addition to the camera resolution and focal length not being high enough to show prey type clearly, many studied nests failed because the parents abandoned the nests after setting up the cameras. This may have resulted from the large size of the camera and the possibility that the nesting bird was disturbed by the presence of the camera (Richardson *et al.*, 2009; Ellis-Felege and Carroll, 2012). Furthermore, the regular visits to the nest required to replace the camera

batteries and download data increased the pressure on studied nests leading to nest failure (Stake and Cimprich, 2003).

- LG nestling habitat:

LG establish their nests in the grass-camouflaged habitat on Coquet Island with Puffin nesting burrows frequently present within the LG nest enclosures. This led to the cameras frequently being triggered inappropriately, draining the batteries, filling the memory card, and with the vegetation also frequently blocking the camera view.

3.4.2 Large Gull diets on Coquet Island

Studies of seabird diets have categorized LG as generalists in their food choices at a population level, describing HG and LBBG as omnivores and scavengers, (Bicknell *et al.*, 2013; Gyimesi *et al.*, 2016; Coulson, 2019). Although LBBGU and HGU nesting habitat varies between coastal and urban colonies, LG diet studies have shown a wide range of food sources (Table 3.6). The present study revealed a similar variation in food sources utilized by LG either breeding or roosting on Coquet Island (Table 3.4,Table 3.5). LG pellets collected in 2016 breeding season were analysed morphologically; in 2017 pellets were collected under more rigorous conditions primarily for the purpose of investigating LG diet using DNA analysis and as a result the number of pellets collected was 60% less than in 2016. Nevertheless, the dietary components fell into the same four categories (Table 3.4, Figure 3.6).

Contrary to the previous season, in 2017 the diet of breeding LG (collected pellets from LG nests) showed that they used mainly terrestrial food sources (Table 3.4, Table 3.5). This could be biased from the low number of successful studied nests (only three LBBGU nests fledged successfully) reducing the pellet sample size. The high rate of failed and predated LBBGU nests in 2017 breeding season may have been linked to the presence of three subadult Great Black-backed Gulls (GBBGU) over the plateau during the breeding season. It was clear from observations from the lighthouse and the LBBGU surveys that GBBGU subadults were predating LBBGU nests or causing nests to be deserted.

Table 3.6 The percentage of food type obtained by HGU and LBBGU at the same colonies in Netherlands (Camphuysen, 2013)

Source of food	Lesser Black-backed Gull	Herring Gull
Marine	87%	23%
Intertidal	3%	74%
Terrestrial	32%	23%
Human waste, landfill, etc.	6%	13%

3.4.3 Indirect evidence of Large Gull predation on Roseate Tern on Coquet Island

When providing evidence of predation by studying the predator diet, it is vital to know the limitations of different methods of dietary examination in providing sufficient information on the identity of prey remains reliably and efficiently (Oehm *et al.*, 2017). Choosing an appropriate method is critical in studies to detect or quantify predation when the prey species forms a small proportion of the available prey (Osterback *et al.*, 2013).

In this study it was not expected to find irrefutable evidence of LG predation on dozens of very protected Roseate tern colony among of thousands of other available preys alike and alternative easier prey catching on Coquet Island, in the intertidal area, from the sea or the close mainland. However, finding clear sign of a proxy predation indicator i.e., the presence of tern species as a component of the diet of breeding LG, indicates that RT are also at risk of predation.

Three methods have been used in this research to gain more knowledge of the breeding LG diet during the breeding season aiming to gain a better understanding of LG-RT relationship cycles, especially with respect to predation pressure. Firstly, video/photography can be an important tool to determine the identity of predators or prey (Ellis-Felege and Carroll, 2012; Thompson III and Ribic, 2012), and camera trapping has provided the most complete description of the diet of raptors (Lewis *et al.*, 2004). However, LG on Coquet Island were not easily sampled by camera traps in the grassland breeding habitat (see 3.4.1.1) Therefore, as an alternative, the

analysis of pellets and prey remains at LG nests was considered to be the best approach for a comprehensive characterisation of the diet of LG breeding on Coquet Island. Morphological assessment of the collected pellets and prey remains was very informative in terms of outlining the food sources and prey choice. Moreover, it provides clear evidence of predation on tern species by finding their remains in the collected pellets. However, it also needs to be borne in mind that LG are also scavengers and the remains of terns in the pellets could have come from carcasses killed by other predators such Peregrine *Falco peregrinus* or Sparrowhawk *Accipiter nisus*. Nevertheless, clear evidence of direct predation on tern species came from the carcasses of freshly-killed tern species around the study LG nests and the LG intertidal roosting area.

3.4.4 Expansion of DNA metabarcoding as a tool for studying the trophic interactions

Predator diet analysis which relies on the preservation of the diagnostic hard parts of prey remains can limit taxonomic resolution and introduce bias (Yoshikawa and Osada, 2015). Thus, using only morphological methods can be problematic for establishing the diets of avian generalist consumers (Steffens *et al.*, 2012). DNA-based analyses provide an objective and less-biased method for assessing the diets of generalist predators, potentially overcoming many of the limitations introduced by other techniques because digested prey can be identified using short DNA sequences from diagnostic gene regions and prey identification can be achieved in the absence of diagnostic hard remains (S. Sellers *et al.*, 2018; Kitson *et al.*, 2019). This will improve prey detection rates and taxonomic resolution in dietary analysis (Horswill *et al.*, 2018). In this study, 95% of unidentified prey was solved using DNA in combination with morphological analysis. This is a powerful illustration of the benefits of using a combination of techniques to detect and identify prey of generalist predators.

In 2017 breeding season, recent advances in molecular NGS techniques were used to resolve the inability to identify prey morphologically in the LG diet (Kaunisto *et al.*, 2017). This ability to use DNA-based approaches in diet analysis overcame some limitations in identifying prey type (McInnes *et al.*, 2016; Oehm *et al.*, 2017). One technical limitations of

using DNA metabarcoding methods to study predator diet is the inability to estimate prey biomass (Mariano-Jelicich and Favero, 2006). Problems related to the amplification of predator DNA or other nontargeted species in the sample are solvable by the ability to design specific primers targeting species of interest, and occurrence correction factors can be used to estimate roughly the relative abundance of prey in the sample (Mariano-Jelicich and Favero, 2006; Leray *et al.*, 2013). In this case study on a generalist, omnivore, and scavenger predator, it was challenging to determine whether the species identified in the pellet samples were predated by the LG or scavenged corpses. However, combining the DNA metabarcoding analysis with morphological assessment of food choice and prey remains around nests reduced this uncertainty and gave confirmed evidence of predation on tern species on Coquet island. Therefore, it is recommended to use a combination of molecular, biochemical and morphological techniques to overcome such uncertainty when studying generalist predators (Barrett *et al.*, 2007; Horswill *et al.*, 2018).

3.5 Conclusion

As in this study, the utilization of camera surveillance techniques to study different bird species in different ecosystems has shown similar limitations for identifying all food items to fine-scale taxonomic levels, and 20–40% of food items across all observed deliveries can remain unidentified, depending on the species and species habitat (Takagi and Akatani, 2011; Schroeder *et al.*, 2013; Robinson *et al.*, 2015). Thus, surveillance cameras at LG nests on Coquet Island had substantial limitations for determining prey choice in the context of assessing predation pressure. Using molecular NGS techniques together with morphological analysis of LG pellets on Coquet island showed that a wide range of prey types were present in the diet with no difference between the diet of breeding or roosting LG. Direct evidence of predation on tern species from these pellet analyses and the presence of prey remains around LG nests suggests that Roseate Terns are also at risk from LG predation.

Chapter 4 Laser hazing to reduce Large Gulls predation on Coquet Island

4.1 Introduction

Interactions between predators and prey has not been framed in a completely satisfactory mathematical model (Nicholson, 1933; Krausman and Leopold, 2013; Ellis *et al.*, 2020). Hence, the effects of predation on prey population dynamics still provoke controversy between two ecological dogmas with respect to whether such effects are regulatory or limiting factors (Nicholson, 1933; Gese and Knowlton, 2001; White, 2001; Blackshaw and Petrovskii, 2007). Predator removal is promoted by game and livestock managers. Thus, this form of intervention has been adopted as a useful tool for conservation and wildlife managers to reduce the impact of predation pressure, and is supported by many studies showing that removing predators or limiting their actions has a remarkably positive effect on populations of the predated species (Rollins, 2004; Gibbons *et al.*, 2007).

In recent decades in the UK, numbers of some birds of prey species have declined; simultaneously, some of their predator populations have increased, suggesting a link between predation and declines in prey population (Gibbons *et al.*, 2007). Consequently, with many scientific studies supporting both ecological dogmas (Gese and Knowlton, 2001), a conflict has been emerging regarding the procedures, results, and values of predator control practice as a tool to maintain the biodiversity (Yoakum, 2008).

4.1.1 Non-lethal alternatives for predation management

Two theories of predator control are relevant in this context: first, the top down (predator-driven) theory encompasses removal or exclusion of predators using lethal or non-lethal means. Secondly, the bottom up (prey-driven) approach includes habitat management, diversionary feeding and conditioned taste aversion (Côté and Sutherland, 1997; Rollins, 2004; Smith *et al.*, 2010b; Williams *et al.*, 2012). However, with respect to policies for predator control, there are clear conflicts over whether to use lethal or non-lethal methods and if these

should be aimed at controlling or total eradication of the predators. Effective predator control comes at a high cost with respect to resources, time and associated animal welfare issues, but the benefits are not guaranteed (Smith *et al.*, 2010b).

Although using non-lethal high-technology tools in wildlife management may be complicated, costly and not completely effective in reducing predation rates, it can be more preferable than lethal methods to prevent or reduce ecosystem damage (Blackwell *et al.*, 2002; Shivik *et al.*, 2003; Wildlife Services, 2010). Additionally, applying lethal predator controls is more difficult when the predator itself is of critical conservation status. Thus, in such cases non-lethal controls can be used to maintain the biodiversity of which the predator is an integral component (Williams *et al.*, 2012).

In the light of these issues, wildlife conservation bodies in the UK are keen to encourage more research on habitat restoration and non-lethal practices, particularly new technological approaches to ecosystem management, to reduce predation, rather than lethal predator control (Gibbons *et al.*, 2007; Baker. and Moore., 2011; DEFRA, 2018; Pacheco, 2018). Royal Society for the Protection of Birds (RSPB) have adopted advances in technology to improve wildlife management (Gibbons *et al.*, 2011; RSPB, 2012). However, there is a clear need for scientific evidence to understand and test the effectiveness of new methods as management tools (Gibbons *et al.*, 2007; Mathur, 2017; Pacheco, 2018). In this context, the Conservation Science department of the RSPB are coordinating a trial across several nature reserves, working with site staff and researchers, of the laser hazing technique as a non-lethal tool to discourage predators. RSPB aims from this experiment to determine the responses of the targeted species to the laser hazing practice, and ultimately assess the effectiveness of this practice in terms of productivity of the protected species.

The trial has two parts: firstly, to deter 'problem' species from settling to nest near to a colony of a species of higher conservation concern (SETTLEMENT intervention). Secondly, to reduce

predation by 'problem' species on a species of higher conservation concern (PREDATION intervention).

4.1.2 Study area and conservation status

Coquet Island is, a seabird reserve, managed by RSPB (see 1.5.2) was one of the most appropriate sites to start the laser hazing trial. This is because, firstly, Coquet Island gives the platform to apply both intervention types where the predators (Large Gull species) mainly, Herring Gull *Larus argentatus* and Lesser Black-backed Gull *L. fuscus* and their prey (tern species) are breeding on the island, and, secondly, the reserve presents one of the most complicated conservation conflicts by the need to control a protected predator which consumes protected prey (Redpath et al., 2016). This conflict creates the need to use non-lethal technologies to solve the dilemma (Shivik, 2004; Scopel and Diamond, 2017). Lastly, the breeding LG populations on the island were historically controlled by using all the predator tradition applications (Morrison and Allcorn, 2006) leading to have a certain range of LG nests starting breeding on the island each season. Thus, this will give us a chance to compare this range of breeding attempts after applying the laser hazing technology to scare the LG instead of the traditional scaring applications.

4.1.3 Laser hazing experiment objective

Assess the efficacy of the innovation in the current or novel non-lethal predation mitigation strategies, based on scientific evidence, is needed to encourage the adoption of the application by the decision makers (Scasta *et al.*, 2017). Integrating effective non-lethal methods to protect tern colonies is an essential step towards achieving a win-win relationship between predators and their prey on Coquet Island.

The objective of this study was to examine experimentally the effects of laser hazing as a non-lethal method for controlling LG settlement and breeding on Coquet Island. This was accomplished by applying the technique during LG settlement in nesting territories (March to mid-April: settlement intervention), before tern species arrived back to the island, and then at

the end of the season when terns are exposed to LG predation directly (last week in July to end of August: predation intervention).

4.2 Method

4.2.1 Equipment

An Aerolaser Handheld (Figure 4.1) produced by Bird Control Group (BCG; Delft, The Netherlands) with a green laser beam (532 nm; 500mW) was used for hazing the LG- (Appendix 18) (BCG, 2017). Binoculars (8.5x42 W B), Scope (ATS STS 80 HD), Camcorder.

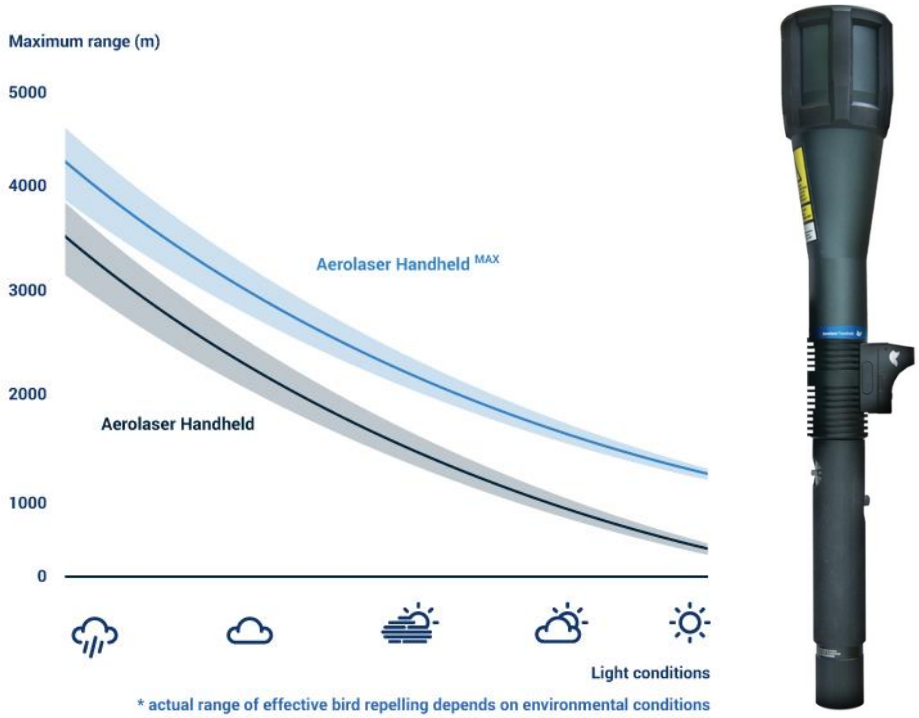


Figure 4.1 Range for effective bird dispersal depends on Local environmental conditions from (BCG, 2017)

The experiment was implemented in two phases on Coquet Island for two seasons 2017 and 2018 between (5th March -15th April) and then from (25th July – 1st September). The target in phase one was to control the breeding LG number (settlement) whereas the second phase was to control the predation rate (predation).

Phase one was divided to three periods: firstly, laser hazing for two weeks while wearing a Hi-Viz jacket. Then, two weeks scaring by human disturbance activities wearing the Hi-Viz jacket without laser hazing, followed by two weeks laser hazing. The tests were applied three times per day: early morning (dawn), midday and early evening (dusk).

Taking into consideration the effective range of the Aerolaser (Figure 4.1), at the beginning of the season, when it was possible to walk over the island plateau because the other breeding species (Puffin, Black-headed gull, Eider duck and the Terns) had not yet arrived, the observer monitoring position was from the closest point in the north of the island. Later in the season, when other breeding species had arrived, the monitoring positions were the roof of the cottage next to the lighthouse and the jetty.

The observer hid or walked slowly (to avoid scaring them in advance of using the laser) towards the observation point before using the laser. This was done so that the LG in the roosting area could be counted before using the laser so that the response of LG to the laser beam alone could be assessed. Environmental factors (weather conditions) and events (fishing boats, airplanes... etc.) during the observation period were recorded.

To avoid the possibility of causing eye damage to the targeted birds, the laser hazing process was done following the Aerolaser supplier's recommendations by slowly moving the laser beam dot on the ground towards roosting LG (Figure 4.2, Figure 4.3)

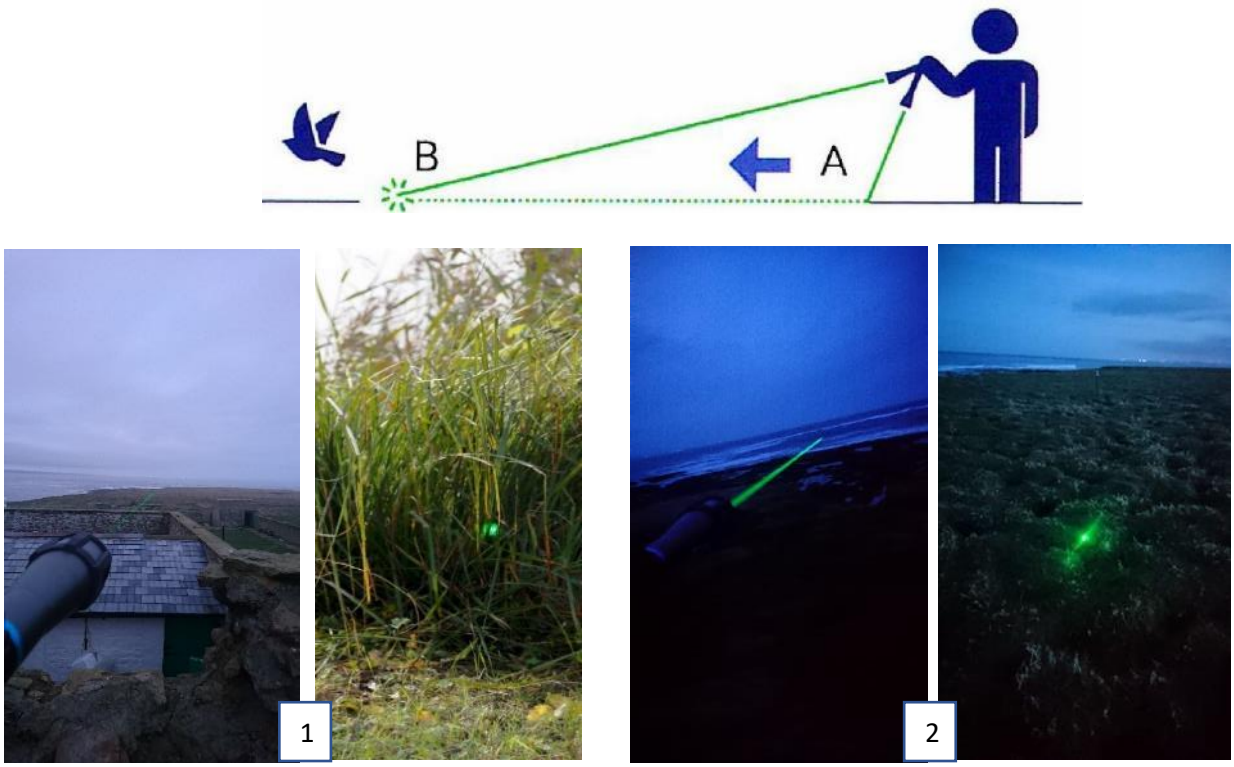


Figure 4.2 Move the laser dot from point A (the applicant) to B (bird breeding/roosting area) (BCG, 2017)
1-Morning hazing 2- Evening hazing

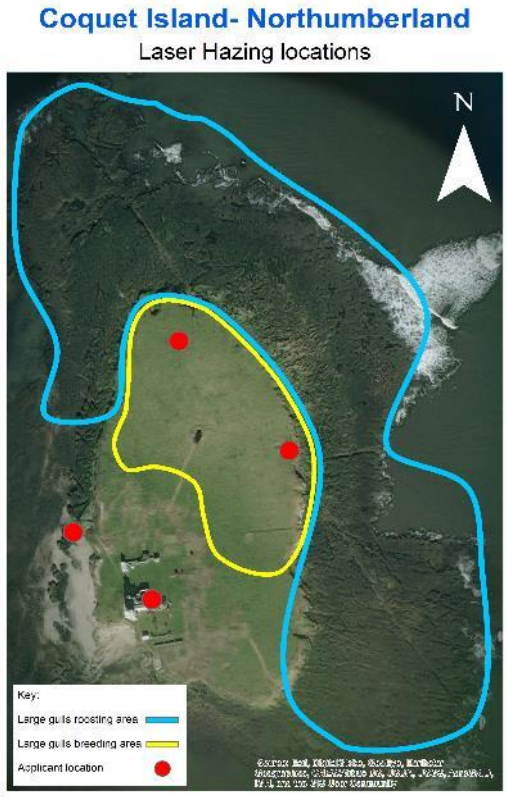


Figure 4.3 Large Gulls Breeding and roosting area on Coquet Island with applicant location

- Weather conditions during the laser hazing application were obtained from The Centre for Environmental Data Analysis, Boulmer weather station, Northumberland (MIDAS, 2018) (Appendix 19). Three weather elements were used in the analysis, mean wind speed and direction (wind speed unit "knot" and the unit of direction "degree"), maximum wind gust speed and direction and the visibility (units in "decametre"), observer location, distance to the targeted LG area, the number of LG Before hazing (LGB) and responses of the LG to laser hazing were categorized as described in (Appendix 22).

4.3 Data analysis and results

The field experiment was designed to show when the laser hazing is effective (success) or non-effective (no success) in scaring the LG. Therefore, a binomial model would be the most appropriate method of data analysis (Burnham, 2002; Richards, 2008; Seltman, 2018) to assess the Efficacy of the Laser Hazing (ELH). ELH was defined as binary possible outcomes (0= non-effective;1= effective) by combining two variables:

- First variable was defined using equation 1 and 2. This indicates the percentage **R**eduction of the number of roosting **LG** after laser hazing (RLG). The LG were counted before applying the laser treatment and then counted again after 30 then 60 minutes:

$$RLG\_30 = -1 * ((LNA\_30\_ LGB) / LGB) * 100) \quad (1)$$

And

$$RLG\_60 = -1 * ((LNA\_60\_ LGB) / LGB) * 100) \quad (2)$$

Where: RLG_30 is the reduction in LG after 30 minutes, RLG_60 is the reduction in LG after 60 minutes, LGB is the number of LG **B**efore hazing, LNA_30 is the number of LG remaining **A**fter 30 minutes of hazing, LNA_60 is the number of LG remaining **A**fter 60 minutes of hazing. The frequency distributions of RLG_30 and RLG_60 showed that values were most likely to be either 0 % (no effect) or 100 % (maximum effect) (Figure 4.4 - Appendix 20-2, 20-3, 20-4). Therefore, it was transformed to two categories (success or no success) where 1 = partial or complete success where RLG_30 or RLG_60) > 0, and 0 otherwise.

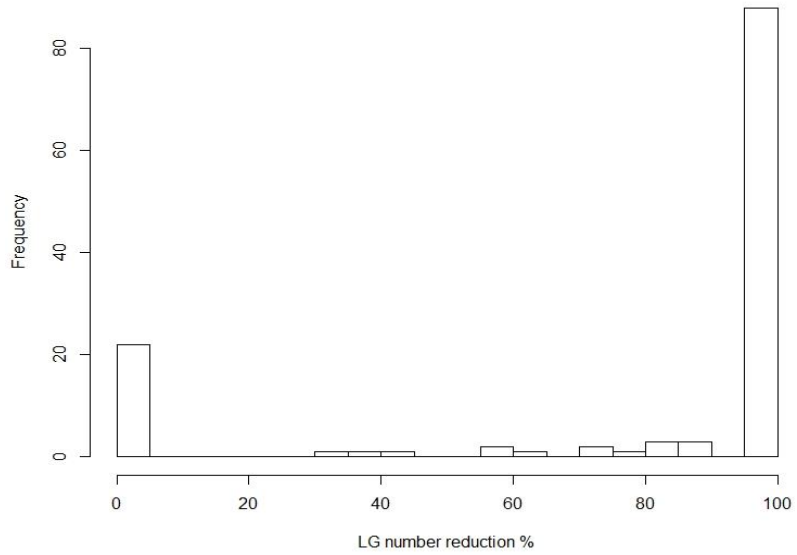


Figure 4.4 Frequency of LG number reduction (as a percentage) after 30 minutes of laser hazing

- A second variable was created based on the total time of laser hazing (TTL). Where it was considered success when TTL =< 15 seconds (TTL_15). This threshold was chosen based on the total time of applying most of the traditional scaring methods (Appendix 20-1) but in addition is justified by the data distribution because the majority of TTL times used to achieve efficacy was <16 seconds.
- Finally, ELH was created by combining RLG_30 or RLG_60 with TTL_15 where:

  ELH =1 when RLG and TTL_15 = 1 or 0 otherwise.

  - To reduce the effect of outliers, data where the LG number (LGB) over the roosting area were <= 200 individual birds was used in the analysis (Appendix 20-5).

There was significant difference for success events vs failure events between the categories of time of the day (TOD) (p-value = 2.59e-08; two tailed Fisher's exact test). However, with the ELH threshold settings used no success events were recorded in midday sessions, and as a consequence factors that might affect success at the midday level of TOD cannot be assessed. The morning and evening sessions are characterised by low ambient light compared to midday, and when the proportion of successes are compared between these two levels of the ambient light there is a significant difference (p-value = 2.036e-08 two tailed Fisher's exact test)

implying that ambient light levels may be an important factor in hazing success. To assess other factors that may affect hazing success in a binomial logistic regression analysis, data from midday sessions were therefore excluded.

Since the dependent variable for ELH is a discrete success/failure (1/0) quantity, the ordinary linear Probability Model can be used to fit binary outcomes. However, since the linear probability model is heteroskedastic and may predict probability values anywhere between 0 and 1 range, the logistic regression model was used to determine which/whether variation in the measurement variable influencing the probability of success laser hazing with two predicted ELH values 0 and 1. An information-criterion approach was used to rank all models. Then, AIC model selection was used to distinguish among a set of possible models describing the relationship between the efficacy of laser hazing and all other variables. AICctab command in the "bbmle" package was used to compute IC tables from lists of mle fits (Bolker, 2008; Bolker and R Development Core Team, 2020).

Binomial logistic regression analysis was undertaken of the Efficacy of the Laser Hazing (ELH) depending on conditions during the experiment period. ELH was the dependant variable (0= non-effective;1= effective), with time of the day (tod), mean wind speed (m_w_s) and direction(wd), maximum wind gust speed (mgs) and direction (gd) and the visibility (vis), observer location (ol), distance to the targeted LG area(dis), the number of LG Before hazing (LGB) as model predictors. All combinations of model predictors were run (23 models) and ranked according to AICctab. Model.2 with ΔAICc <2 is presented in (Table 4.1).

ELH= time of the day (tod)+ maximum wind gust speed (mgs) Model. 2

Table 4.1 Estimated regression parameters, standard errors, z-values and P-values for the glm presented in selected model IC-based approach

Parameters	Estimate	Std.Error	z value	P-value
(Intercept)	1.71391	0.84985	2.017	0.0437 *
todmo	-1.06949	0.62783	-1.703	0.0885 .
max_gust_speed	-0.07714	0.03552	-2.172	0.0299 *

Then, a Hosmer Lemeshow approach was used to implement goodness of fit test for the top ranked model (Lele *et al.*, 2019). We found that our model appears to fit well because we have no significant difference between the model and the observed data (GOF test, χ^2= 8.2464, df = 8, p-value > 0.05). Although the chosen model contains two explanatory variables, an ANOVA test showed that tod does not make a significant contribution to the ELH (p-value = 0.3). Thus, only 1 out of the 8 predictors are significantly associated to the outcome, which was the maximum wind gust speed (p-value = 0.02). The coefficient estimates of the variable max_gust_speed = -0.07714, which is negative. This means that an increase in wind speed will be associated with a decreased probability of ELH to be effective in scaring LG (Figure 4.5). Using the same procedures with the ELH response after 60 minutes showed seven models with low AIC value. However, only Model. 2 contains a variable which contributed significantly to the model (p=0.0425), again, this was max_gust_speed with negative coefficient = -0.07. We found that this model appears to fit well because we have no significant difference between the model and the observed data (GOF test, p-value is above 0.05) (Appendix 21)

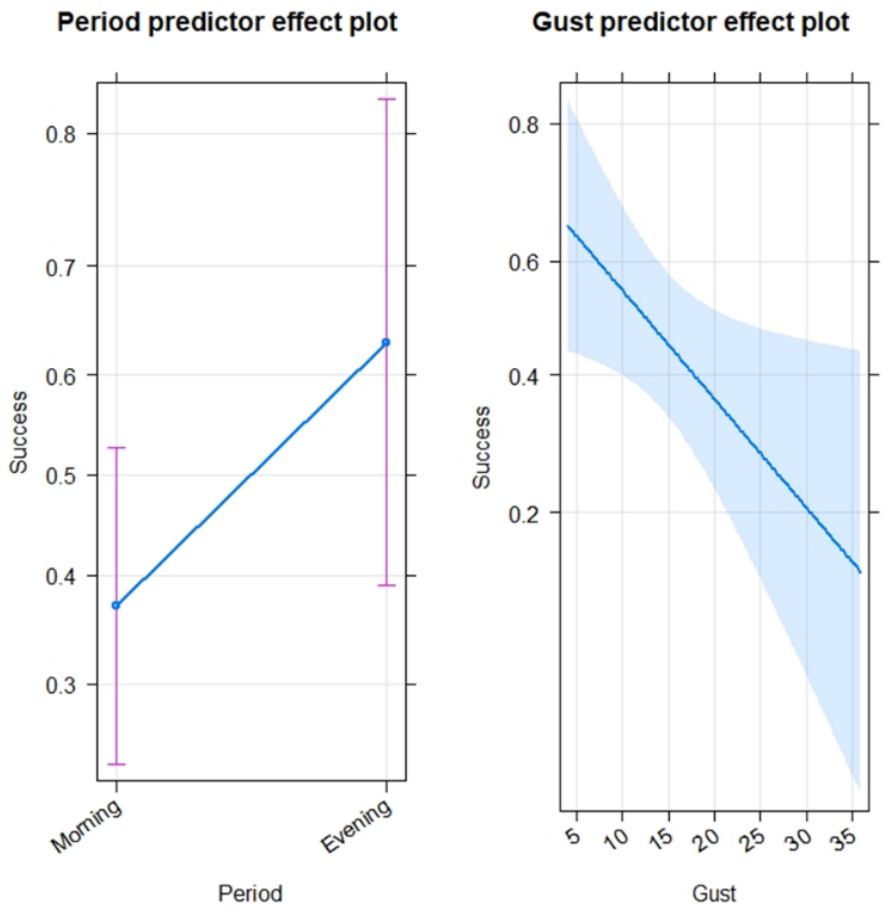


Figure 4.5 ELH after 30 minutes

- **Assessment of the Laser hazing effectiveness between years:**

Kruskal-Wallis Test was conducted to compare the effectiveness of using old LG control methods and laser hazing on the total number of LG nesting over the reserve plateau (TLGN). There was a weak difference in the mean of TLGN between the controlled /uncontrolled seasons (p-value = 0.05) with no significant difference between the applied methods (p-value > 0.05)

4.4 Discussion

This research study is among the first to investigate the effects of laser hazing as a non-lethal method for controlling LG settlement and breeding on Coquet Island and to determine the best environmental conditions to use it with maximum efficacy. Here, I aimed to assess the laser hazing effectiveness by creating a measurable variable by combining the laser treatment time with LG number before and after the laser hazing. The results highlight the best time and weather conditions to control LG successfully using laser hazing.

Unexpectedly, most effective factor on the laser hazing outcome was strong wind which seemed to act as a deterrent for the targeted LG to fly away during or after the laser treatment. It is unlikely that the wind had any effect on Laser beam strength. Rather than being a discouragement to a bird that had noticed the laser-beam spot, it is also possible that wind strength made the spot less visible to targeted birds because the targeted LG spent more time with their eyes closed or heads tucked under their wing as a result of windy condition, a strategy to reduce energy consumption (Ferretti *et al.*, 2019).

The field observations on Coquet, similar to (Blackwell *et al.*, 2002), showed that the laser hazing was more effective at a time of the day with low ambient light levels (i.e. early morning, early evening comparing with and midday). Hence, in low light ambient level caused by the fog or cloudy days (i.e., visibility), the laser hazing might be more effective. However, in the light of the nature of the reserve, field tests could not meet standard experimental design protocols. Therefore, it was not possible to include a control plot or replicate the experiment during the field trial in the same season (M.L.Richmond *et al.*, 1979). With the short time to conduct the experiment, the sample size of the data was small. Data available for hazing at midday were very limited and to avoid bias had to be excluded from the analysis; consequently, it was not possible to test the effect of ambient light levels on laser hazing efficacy.

In previous seasons, the application of traditional disturbance techniques has limited the extent of LG breeding to the north part of the island, with, on average, approximately 40 active nests throughout the breeding season. Applying laser hazing alone has maintained the extent of LG breeding to the same range.

Assessment of laser hazing effectiveness on mitigating the predation over the Tern colonies was not possible due to the following circumstances:

First, it was not possible to chase the flying predator with the laser beam and maintain the standard of animal welfare according to the standard usage criteria.

Secondly, the colony warden needs to act quickly to scare the attacking gull. Therefore, (**A**ctive **H**uman **D**isturbance) AHD was achievable quicker than the using the laser gun.

Thirdly, it was noticed at the end of the season, most of the predation attempts were by subadult LG which were unconcerned by the laser beam did not respond to laser hazing. In addition, the laser gun was not available at the end of the second season to repeat the experiment during predation phase.

4.4.1 Pros and Cons of laser hazing

There are few recent research studies investigating or recommending the use of laser hazing, particularly on LG in a conservation context (Blackwell *et al.*, 2002; Bishop *et al.*, 2003; Sutherland *et al.*, 2019). Similar to those few studies, these research findings found the same strengths and weaknesses of using the laser application to disperse the LG with respect to the low power demand in use, accuracy over distance, and usage practicality. Moreover, the silence of laser devices makes them an effective tool in wildlife management to target key species and avoid causing disturbance to other presence species. Additionally, it has the ability to disperse LG roosting on sea water.

The main disadvantage of a laser is that it is less effective, or even ineffective, in bright ambient light. Therefore, successful use is likely to be restricted to dusk and dawn, or with in low visibility conditions (foggy and cloudy days). Moreover, it is less effective on LG in windy weather (from our trial experiment in Coquet Island). Additionally, especially in conservation management, and although it can target certain species in misty weather conditions the protected non-target species can also be scared by the laser beam (from our trial experiment in Coquet Island). Furthermore, specialised training and regulation is required to use laser devices, and the equipment is fragile, expensive, and cannot be used in rainy weather unless it was waterproofed, which adds to the costs (Bishop *et al.*, 2003).

4.5 Conclusion

In conclusion, the results presented here support the use of laser technology in wildlife conservation as a non-lethal tool to discourage the presence of predators. Prey populations could be enhanced by removing predator actions or controlling the predators if prey population is at a lower level than their ecosystem carrying capacity (Côté and Sutherland, 1997; Gese and Knowlton, 2001; Smith *et al.*, 2010b; Williams *et al.*, 2012). One study in the UK found that numbers of terns and small gulls on gravel islands declined despite the attempted control of LG. (Williams *et al.*, 2012). However, our research study showed that applying such control measures kept the breeding LG over Coquet island within acceptable limits; this contributes to maintaining the Roseate Tern colony and facilitates longer-term recovery and population increases (Morrison and Allcorn, 2006; Davies and Morrison, 2015; Alfarwi *et al.*, 2018).

The Coquet Island management plan contains two approaches to protect the Roseate tern colony: (1) top down (predator-driven) and the (2) bottom up (prey-driven). A combination of lethal and non-lethal control practices was used on Coquet Island historically because some individual LG learn to focus their hunting interests on the RT colony terraces and for Coquet Island is probably the best management strategy (Morrison and Allcorn, 2006).

4.5.1 Recommendation

- Clearly, no one method is a panacea to control predators. Thus, laser devices cannot be used as the sole method for controlling breeding LG, but should be complemented and integrated with other scaring techniques to achieve maximum effectiveness (White, 2001; Blackwell *et al.*, 2002; Bishop *et al.*, 2003; Morrison and Allcorn, 2006; Sutherland *et al.*, 2019).
- To be successful, laser hazing should be applied in low light ambient, low visibility, calm weather.
- It is preferable to deploy lasers that pose little risk of eye damage to humans or birds (laser Class-II and Class-III B categories)(Blackwell *et al.*, 2002).

- Applying the laser hazing from a high vantage point especially targeting LG roosting over rocky area.
- An automated, fixed-position laser system would likely prove a safe and effective enhancement of LG management efforts at Coquet Island reserve.
- Laser hazing was not possible during rainy weather conditions; therefore, it would be preferable to use a waterproof laser gun.
- On Coquet Island, it is recommended to repeat laser hazing sessions several times in the evening period because during this time the gulls arrive continuously from the mainland to roost over the intertidal area. However, this will be possible just at the start of the season (first three weeks of March) because the other species will be present later and the laser beam will disturb these other species too.
- If the predators are targeted from a long distance, it is better to have the laser gun on the stable balanced tripod during the hazing process. This is because small movements of the laser device will move the laser light spot far from the targeted area and the motion of the laser light point will be too fast for the gulls to notice it. Using binoculars will be very useful in such cases, allowing the operator to focus the laser light point near to the targeted gulls.
- Finally, one point to highlight, is that habituation is a common problem with all scaring devices (Blackwell *et al.*, 2002; Bishop *et al.*, 2003). Laser hazing can be used for the control of a wide range of bird predators, but some species will habituate to the product quickly, as is the case with most scaring measures (Bishop *et al.*, 2003; Werner and Clark, 2006). However, we have noticed that a LG distress call alert produced by the targeted gulls on laser hazing causes the whole LG flock to leave the area. This suggests that the other individuals in the flock would have responded to the alert call not to the laser itself. Therefore, targeting different individuals at different times and in different areas may delay or reduce habituation.

4.5.1.1 Further questions and future work

1. Closing the gaps in knowledge on laser hazing as a bird deterrent demands well-designed field experiments to its effectiveness as a tool for conservation and wildlife management.
2. Additional field research, with long term and replicated experiments, including adding control plots where possible within the same season or between different seasons, is needed to determine laser hazing effectiveness for repelling LG and assess the habituation rates.
3. Long-term assessments need to be undertaken to ensure that there is no risk of ocular damage.

Chapter 5 General discussion

5.1 Overview

5.1.1 Large Gull nest competition space over Coquet Island

There is cumulative evidence that LG force tern species to move from preferred nesting habitat to lower quality or inappropriate nesting areas, for example intertidal areas where they will be exposed to frequent tidal flooding (O'Connell and Beck, 2003; Cadiou and Fortin, 2010). In this study area, the seabird nesting seabird distribution over the reserve has changed since the 1970s. Common and Roseate Tern used to breed on the north part of Coquet Island but relocated their nesting area to the south part of the reserve near the lighthouse in the 1997 breeding season, and this may have been driven by the pressure of LG nesting on the north part of the reserve (Lidstone-Scott, 1997; Morrison *et al.*, 1998; Morrison and Allcorn, 2006); here, the greater size of LG and the fact that they prospect the nesting area before terns arrive on the island gives them an advantage for winning the competition for nest space (Cadiou and Fortin, 2010).

5.1.2 Large Gulls predation pressure on Coquet Island

Large Gulls prey on all tern life stages, eggs, chicks, and adults, either directly or by kleptoparasitism to steal fish from adult terns returning to the colony to feed their nestlings (Donehower *et al.*, 2007; Pon and Morettini, 2009; Cadiou and Fortin, 2010; Capoulade *et al.*, 2010; Jacob and Capoulade, 2010; Morrison, 2010). All annual Coquet Island management reports documented the predation events by LG over tern nesting areas, including the RT terraces, throughout the breeding season; this highlights LG as the major top predator in this seabird colony (Cooter, 1990; Lidstone-Scott, 1997; Morrison *et al.*, 1998; Morrison and Allcorn, 2006; Davies and Morrison, 2014).

5.1.3 Roseate Tern conservation measures on Coquet Island

In the light of threats to the RT population on Coquet Island, the conservation managers adopted two approaches to reduce degradation of the RT colony and accelerate the recovery of this threatened species in the UK (Capoulade *et al.*, 2010). Both approaches started before the breeding season and continued throughout the breeding season. The first approach was to enhance the nesting habitat for this species by providing shelter boxes on a prepared terrace in the area used by RT (Morrison, 2010). Those terraces were paved with interlocking slabs and covered with a bed of shell shingle to be used as nest materials because observations showed that RT use shell fragments to form their nests (Morrison and Gurney, 2007). In addition, the vegetation cover around the lighthouse, including the RT terraces, was managed (removed) to create suitable plots for nesting Common, Arctic and Sandwich tern surrounding the RT colony. This approach minimized competition for nest spaces between Puffins and terns and increased RT resilience to bad weather. Furthermore, surrounding RT boxes by a buffer zone of Common Terns provide RT eggs, chicks and the adults an enhanced natural defence barrier against predators (Morrison, 2010). Grey Seals were prevented accessing the plateau by closing the gully with a stone wall. Human disturbance was minimized by restricting pleasure boats to staying not more than 10 min opposite the RT terrace area and by not allowing visitors to land. Such provisions can be enforced by the legal protection provided to RT by being listed on Schedule 1 on the Wildlife and Countryside Act 1981. In addition, RT terraces were afforded 24 hours/day protection against egg theft and unauthorised intrusion by operation of a CCTV system with night watches in place throughout the breeding season.

The second approach was a control program to discourage LG from nesting over the plateau. This started in early March before the start of the breeding season i.e., before the arrival of the Puffins, Terns, Black-headed Gulls, and Eiders, to mitigate the expanding LG nesting territory. This discouragement program varied from direct active human disturbance (by staff walking over the plateau wearing hi-visibility jackets forcing LG to leave the reserve) to using

a gas gun, various pyrotechnics, electronic distress-callers, and, more recently, laser hazing. LG surveys were conducted over the island every two weeks during the breeding season to collect LG eggs and remove LG nests. Finally, the wardening team is licensed by Natural England to apply lethal control of any LG adults which develop a preference for hunting over the RT terraces.

5.2 Main findings of thesis

This study, using an integrative evidence-based approach (Stevens, 2012), aimed to enhance our understanding of the LG-RT interaction cycle by determining the biological and ambient factors which affect this cycle (Abrams and Ginzburg, 2000). Thus, this study frames in Chapter 2 some influential variables in a model demonstrating how LG foraging events correlate with changes in those variables during the breeding season. The model showed a general trend of increasing the LG predation events frequency towards the end of the breeding season. This increase was probably attributable to the migration of immature LG at that time of the year (Coulson, 2019). The exposed intertidal area at low tide forms an attractive roost for LG coming from the nearby mainland or other coastal LG colonies. Thus, the low and high tide levels were associated with higher frequencies of LG foraging events over the RT terraces linked to the arrival or departure of LG with respect to the intertidal roost area (Enners *et al.*, 2018).

The results support the efficacy of RT habitat manipulation practices in successfully mitigating not just predation attacks over the terrace but the frequency of LG predation event in general (Morrison and Gurney, 2007). However, the notable increase of the LG predation events over the RT terraces at the end of the breeding season, despite the presence of shelter boxes, might be explained by the predominance of inexperienced immature LG at that period of the breeding season. The study also suggested that the late-established colony of Sandwich Terns on the sandy south beach creates attractive prey for LG with eggs and chicks exposed to predation attacks on this open beach (Fuchs, 1977; Stienen and Brenninkmeijer, 2002; Stienen,

2006), and this is a factor which will increase the interest and presence of LG over the adjacent RT terraces.

This study provides evidence of that LG breeding on the island also use the reserve as part of their foraging territory. The outputs of the tracking data are entirely compatible with the outputs of the pellet analyses (see Chapter 3) which showed a high utilization of available prey from the reserve. Furthermore, the study showed a remarkable decline of LG predation events over the RT colony in the periods after LG egg/nest destruction, suggesting that breeding LG contribute to LG predation events over RT terraces.

During the long period of controlling breeding LG on the island since 2000, the re-sighting of LG marked by colour ringing in previous seasons re-nesting and breeding again on the island confirms, to a large extent, the necessity to continue LG disturbance methods and egg removal for deterring LG from competing with nesting terns on Coquet Island (Booth and Morrison, 2010; Cadiou and Fortin, 2010). Finally, in Chapter 4, the study shows that applying non-lethal Laser technology, for the first time in a wildlife conservation context in the UK, was a practical and effective method giving similar outputs to the traditional methods of discouraging LG from nesting on the island (Booth and Morrison, 2010) (see 5.1.1 Roseate Tern conservation measures on Coquet Island). The study provides preliminary guidance for the optimal usage of the Laser gun in terms of time of the day, time of the breeding season, weather conditions, and from where/how to deploy it on Coquet Island.

5.3 Conflict of interest in Roseate Tern conservation management, reason, and solution

In accordance with the results of Cadiou and Fortin (2010), this combination of both approaches of RT conservation management has led to a steady increase in recovery of the RT population in parallel with reduction of the number of nesting Large Gulls from 233 pairs in 2000 to 26 pairs in 2020 (Morrison *et al.*, 2000; Morrison, 2010; Kinchin-Smith and P.G.Morrison, 2020). However, a conflict with continuing the LG control policy arose when the conservation status of the HGU moved to the Red and LBBGU to the Amber categories.

There is insufficient knowledge of the LG population in the UK and its distribution between urban and coastal LG breeders, and unknown drivers of the decline of LG predominantly in coastal and island populations (Mitchell *et al.*, 2004; Balmer *et al.*, 2013; Eaton *et al.*, 2015; Davis *et al.*, 2018; JNCC, 2020; Natural England, 2020). Graham *et al.* (2005) suggest in their review of human–predator-prey conflicts, that it is difficult to assess such conflicts within a single reliable or consistent framework. For Coquet Island, where both prey and predator are threatened, none of the alternative possible solutions, for example, the translocation of LG nests, diversionary feeding, or LG nest compensation (Captive-Release), to solve this conflict are applicable for maintaining the LG population naturally in the bird assemblage on Coquet Island (Graham *et al.*, 2005; Karanth *et al.*, 2013). Therefore, where the nature of the predator-prey relationship itself connects to complex variables, and with the recommendation of most authorities in the literature to examine more than one factor to understand the dynamics of predator-prey relationship accurately, collecting informative data across a range of cases and habitats are needed to solve such conflicts (Graham *et al.*, 2005; Karanth *et al.*, 2013).

This study highlights some underlying mechanisms effecting LG predation events over a RT colony (Abrams and Ginzburg, 2000; Stevens, 2012) and on the basis of these results a solution to resolve the conservation dilemma of how to maintain effective conservation of the RT colony while maintaining a major top predator represented in the bird assemblage on Coquet Island may be achievable (Sutherland *et al.*, 2019). LG select their nesting territory and start establishing their nests over the island before the arrival of breeding terns (Cadiou and Fortin, 2010; Morrison, 2010). These breeding LG will increase their predation activity to feed their chicks until fledging stage during a period of maximum prey availability on the island (Hand *et al.*, 1987; Burger, 1988; Drent *et al.*, 1992; Bustnes *et al.*, 2010; Coulson, 2019). Thus, allowing some of these very early nesting LG to breed successfully will lead to low predation risk on the RT colony for the following reasons: firstly, those LG will fledge during/or just before the high peak of the breeding season at time when the majority of RT will be at the incubation phase

inside their boxes. Secondly, this will be at the peak of available biomass of other possible prey (BHGU eggs and chicks, Eider eggs and ducklings, the eggs and chicks of other tern species, and kleptoparasitism on Puffins) will take most of the predation pressure. Thirdly, the aggressive behaviour of Common Terns will be at a maximum by that time, giving RT extra protection (Braasch *et al.*, 2014). In addition, the 24 hour/day protection operation system will be in place to discourage predation attempts at the RT colony. Apart from allowing a some early LG pairs to nest successfully, continuing subsequent discouragement of new LG pairs nesting later throughout the breeding season will maintain the LG population at a sustainable level appropriate for a successful mixed-seabird breeding colony as conducted since 2000 (Morrison, 2010).

5.4 Management Implications

The results of this study provide a rational, evidence-based approach to conservation and shows how biodiversity can be enhanced while addressing the concerns of different stakeholder views in the conservation community. The study emphasizes the efficacy of deploying both bottom-top and top-bottom approaches to conservation management. Thus, allowing some LG to breed successfully at the start of the breeding season on Coquet Island together with targeted LG nesting discouragement and predation control and other, positive conservation measures, will limit the threat to expansion of the RT population. This study showed the efficacy of deploying the Laser hazing in discouraging LG to breed on the Island and suggests adopting the Laser gun alongside with other non-lethal tools in conservation operations in the reserve.

Additional positive conservation measures would comprise an extension of guarding to the RT terrace at the end of the breeding season, especially by regular active human disturbance by wardening staff. In addition, providing a series of chick shelters for Sandwich tern chicks within and on the boundary of the main Sandwich tern colony on the plateau, near to the edge

of area **B**, and on the boundary of Common and Arctic tern colony outside the gardens area, may be beneficial to retain a defence buffer zone.

5.5 Limitations of the study

The sample size of studied breeding LG nests was small due a number of factors, probably largely relating to the years of nest discouragement experienced by LG trying to breed on the island:

- It was difficult trap birds on the nest. The breeding LG on Coquet Island showed a high level of stress and awareness of any nest environment modifications made in the preparation of catching sessions. Moreover, although the observer and assistant were well hidden at the cliff at either side of the Island, nesting adults avoided returning to incubate. In other words, the gulls appear to have learnt to associate observer presence on the roof, human activity over the plateau, and the presence of net poles around the nest with the catching process which made them alert and discouraged incubation activity as long as the observer was on the roof. On the other hand, when the vegetation cover became longer, one of the gull parents used the posts over the plateau as vigilance position most of the time and the targeted nest was not visible to the observer on the roof to give the signal for triggering the catching net at an appropriate time.
- A High rate of failure in nests retained for the study: breeding LG frequently abandoned the nest site after surrounding the nest with the enclosure and surveillance cameras.
- The consequential small sample size of LG tracking data in terms of the number of tagged adults with Movetech GPS-GSM or Mataki Tags and in terms of the short logging time limited by battery lifetime with Mataki GPS tags.

- The nature of working in the reserve, with the priority of avoiding disturbance to tern colonies, which restricted the observer conducting some observations especially during bad weather conditions or collecting LG pellets systematically.
- Laser gun was not waterproof which limited deploying Laser hazing during rainy weather.

5.6 Conclusion

Ecologists have long appreciated the need to quantify the factors affecting the predation rates of generalist top predators and the predator-prey relationship dynamics of seabirds (Jones, 2013). To understand this phenomenon, we aimed to provide data to develop a model which could be used to predict the effects of predation of breeding LG on the RT colony. Whilst the sample data size on breeding LG on Coquet Island was relatively small there was a high degree of consistency with respect to the conclusions which could be drawn from different data types, particularly in respect of diet and foraging activity revealed by different methods of pellet analyses and tracking data. From the data and insights gained from this study, it will be possible to develop a theoretical modelling framework of RT population trajectories which can incorporate predation risk under different LG management strategies, alongside other environmental parameters such as forage-fish availability and climate change at local and regional levels.

Appendices

Appendix 1 Large Gulls census and collection dates 2016

Grid	Nest found NO	Species	First Seen date	Nests found on Census day	Eggs found on Census day	Eggs No	Predated – Failed- Collected- Fledged date	Predated	Failed	Collected	Fledged
R5	1	LBBGU	15/05/2016	1	3	3	13/07/2016				1 (2 chick)
N8	1	LBBGU	17/05/2016	1	3	3	08/06/2016			1	
N9	1	LBBGU	17/05/2016	1	1	1	12/06/2016		1		
O5	1	LBBGU	17/05/2016	1	3	3	08/06/2016			1	
P5	1	LBBGU	17/05/2016	1	3	3	07/07/2016		1		
P7	1	LBBGU	17/05/2016	1	3	3	08/06/2016			1	
Q7	1	LBBGU	17/05/2016	1	3	3	12/06/2016		1		
H8	1	LBBGU	20/05/2016	1	3	3	08/06/2016			1	
J9	1	LBBGU	20/05/2016	1	3	3	08/06/2016			1	
O4	1	LBBGU	20/05/2016	1	3	3	13/07/2013		1		
O8	1	LBBGU	20/05/2016	1	3	3	12/06/2016		1		
M4	1	LBBGU	22/05/2016	1	3	3	16/06/2016		1		
O9	1	LBBGU	22/05/2016	1	3	3	22/05/2016			1	
P8	1	LBBGU	22/05/2016	1	3	3	22/05/2016			1	
P4	1	LBBGU	05/06/2016	1	3	3	08/06/2016			1	
P5	2	LBBGU	05/06/2016	2	6	6	08/06/2016			2	
Q7	2	LBBGU	05/06/2016	2	4	4	25/06/2016		2		
O4	1	LBBGU	07/06/2016	1	3	3	16/06/2016		1		
O5	1	LBBGU	07/06/2016	1	3	3	08/06/2016			1	
P4	1	LBBGU	07/06/2016	1	3	3	08/06/2016			1	
K4	1	LBBGU	08/06/2016	1	3	3	08/06/2016			1	
K7	1	LBBGU	08/06/2016	1	3	3	08/06/2016			1	
L7	1	LBBGU	08/06/2016	1	3	3	29/06/2016		1		
O6	1	LBBGU	08/06/2016	1	3	3	08/06/2016			1	
L2	1	LBBGU	19/06/2016			3	09/08/2016				1 (1 chick)
P5	1	LBBGU	19/06/2016			3	18/07/2016		1		

P5	1	LBBGU	20/06/2016			2	01/07/2016		1		
P6	1	LBBGU	20/06/2016			1	01/07/2016		1		
N6	1	LBBGU	26/06/2016			3	21/07/2016		1		
H9	1	LBBGU	30/06/2016			3	04/08/2016		1		
K7	1	LBBGU	30/06/2016			3	30/06/2016			1	
L4	1	LBBGU	30/06/2016			3	30/06/2016			1	
M3	1	LBBGU	30/06/2016			2	21/08/2016				1 (1 chick)
M8	1	LBBGU	30/06/2016			2	22/07/2016		1		
J8	1	LBBGU	18/07/2016			3	10/08/2016		1		
L8	1	LBBGU	22/07/2016			2	10/08/2016		1		
K7	1	LBBGU	04/08/2016			3	15/08/2016		1		
Total	39			26	74	107		0	19	17	3

Grid	Nest found NO	Species	First Seen date	Nests found on Census day	Eggs found on Census day	Eggs No	Predated – Failed- Collected- Fledged date	Predated	Failed	Collected	Fledged
R3	1	HGU	22/05/2016	1	2	2	23/06/2016		1		
Total	1			1	2	2			1		

Appendix 2 Large Gulls census and collection dates 2017

Grid	Nest found NO	Species	First Seen date	Nests found on Census day	Eggs found on Census day	Eggs No	Predated – Failed- Collected- Fledged date	Predated	Failed	Collected	Fledged
P8	1	LBBGU	10/05/2017	1	3	3	08/06/2017		1		
O8	1	LBBGU	26/05/2017	1	3	3	18/06/2017	1			
R5	1	LBBGU	04/06/2017	1	3	3	18/06/2017			1	
Q3	1	LBBGU	04/06/2017	1	2	3	18/06/2017	1			
P7	1	LBBGU	04/06/2017	1	2	3	18/06/2017		1		
P3	1	LBBGU	04/06/2017	1	2	3	18/06/2017		1		
O6	1	LBBGU	04/06/2017	1	3	3	18/06/2017	1			
O8	1	LBBGU	04/06/2017	1	3	3	18/06/2017	1			
N4	1	LBBGU	04/06/2017	1	1	1	18/06/2017	1			
M3	1	LBBGU	04/06/2017	1	3	3	08/06/2017			1	
K8	1	LBBGU	04/06/2017	1	3	3	08/06/2017			1	
P6	1	LBBGU	08/06/2017			2	28/06/2017		1		
R7	1	LBBGU	11/06/2017			2	28/06/2017	1			
R5	1	LBBGU	11/06/2017			2	28/06/2017		1		
Q4	1	LBBGU	11/06/2017			2	09/08/2017				1 (2 Chicks)
M4	1	LBBGU	11/06/2017			3	11/06/2017			1	
M4	1	LBBGU	18/06/2017			2	18/07/2017		1		
M7	1	LBBGU	18/06/2017			3	07/08/2017				1 (1 Chicks)
O8	1	LBBGU	18/06/2017			3	08/07/2017		1		
P6	1	LBBGU	02/07/2017			1	08/07/2017	1			
N7	1	LBBGU	02/07/2017			3	08/07/2017	1			
L4	1	LBBGU	02/07/2017			3	02/07/2017			1	
G9	1	LBBGU	02/07/2017			2	19/07/2017				1 (1 Chicks)
Total	23			11	28	59		8	7	5	3

Grid	Nest found NO	Species	First Seen date	Nests found on Census day	Eggs found on Census day	Eggs No	Predated – Failed- Collected- Fledged date	Predated	Failed	Collected	Fledged
J10	1	HGU	10/05/2017	1	3	3	08/06/2017			1	
J10	1	HGU	12/05/2017	1	3	3	08/06/2017			1	
R10	1	HGU	18/05/2017	1	3	3	13/06/2017			1	
O10	1	HGU	04/06/2017	1	3	3	16/06/2017			1	
Q10	1	HGU	04/06/2017	1	2	2	18/06/2017			1	
M10	1	HGU	04/06/2017	1	2	2	18/06/2017			1	
L10	1	HGU	04/06/2017	1	2	2	18/06/2017			1	
L10	1	HGU	04/06/2017	1	2	2	08/06/2017			1	
J10	1	HGU	09/06/2017			3	18/06/2017			1	
N10	1	HGU	16/06/2017			2	28/06/2017	1			
M10	1	HGU	16/06/2017			2	20/06/2017			1	
Total	11			8	20	27		1	0	10	0

Appendix 3 Large Gulls census and collection dates 2018

Grid	Nest found NO	Species	First Seen date	Nests found on Census day	Eggs found on Census day	Eggs No	Predated – Failed- Collected- Fledged date	Predated	Failed	Collected	Fledged
H8	1	LBBGU	17/05/2018	1	3	3	08/06/2018			1	
R7	1	LBBGU	24/05/2018	1	2	2	17/06/2018			1	
P6	1	LBBGU	24/05/2018	1	2	2	17/06/2018			1	
O8	1	LBBGU	24/05/2018	1	3	3	17/06/2018			1	
N6	1	LBBGU	24/05/2018	1	3	3	24/07/2018				1 (1 chick)
R5	1	LBBGU	08/06/2018	1	3	3	24/06/2018	1			
Q4	1	LBBGU	08/06/2018	1	3	3	10/07/2018	1			
Q6	1	LBBGU	08/06/2018	1	3	3	17/06/2018		1		
P4	1	LBBGU	08/06/2018	1	3	3	26/07/2018				1 (3 chick)
O6	1	LBBGU	08/06/2018	1	1	1	17/06/2018			1	
O9	1	LBBGU	08/06/2018	1	3	3	24/06/2018			1	
N8	1	LBBGU	08/06/2018	1	2	2	24/07/2018				1 (2 chick)
M9	1	LBBGU	08/06/2018	1	3	3	08/06/2018			1	
K7	1	LBBGU	08/06/2018	1	3	3	08/06/2018			1	
I9	1	LBBGU	08/06/2018	1	3	3	08/06/2018			1	
J9	1	LBBGU	08/06/2018	1	3	3	08/06/2018			1	
Q4	1	LBBGU	17/06/2018			3	24/06/2018	1			
N6	1	LBBGU	24/06/2018			3	28/06/2018	1			
P5	1	LBBGU	24/06/2018			3	28/06/2018		1		
M8	1	LBBGU	30/06/2018			3	30/06/2018			1	
I8	1	LBBGU	01/07/2018			3	09/07/2018			1	
L7	1	LBBGU	12/07/2018			3	12/07/2018			1	
M8	1	LBBGU	12/07/2018			3	12/07/2018			1	
M9	1	LBBGU	12/07/2018			3	12/07/2018			1	
N6	1	LBBGU	24/07/2018			3	24/07/2018			1	
Total	25			16	43	70		4	2	16	3

Grid	Nest found NO	Species	First Seen date	Nests found on Census day	Eggs found on Census day	Eggs No	Predated – Failed- Collected- Fledged date	Predated	Failed	Collected	Fledged
F10	1	HGU	17/05/2018	1	3	3	18/06/2018			1	
P10	1	HGU	24/05/2018	1	3	3	21/06/2018		1		
O10	1	HGU	24/05/2018	1	3	3	18/06/2018			1	
R8	1	HGU	08/06/2018	1	3	3	17/06/2018			1	
K10	1	HGU	08/06/2018	1	3	3	18/06/2018			1	
Total	5			5	15	15		0	1	4	0

Appendix 4 Large Gulls census and collection dates 2019

Grid	Nest found NO	Species	First Seen date	Nests found on Census day	Eggs found on Census day	Eggs No	Predated – Failed- Collected- Fledged date	Predated	Failed	Collected	Fledged
H9	1	LBBGU	01/06/2019	1	3	3	01/06/2019			1	
J7	1	LBBGU	01/06/2019	1	2	2	01/06/2019			1	
K8	1	LBBGU	01/06/2019	1	3	3	01/06/2019			1	
L8	1	LBBGU	01/06/2019	1	3	3	01/06/2019			1	
M9	1	LBBGU	01/06/2019	1	2	2	01/06/2019			1	
N8	1	LBBGU	01/06/2019	1	2	2	01/06/2019			1	
N8	1	LBBGU	01/06/2019	1	2	2	01/06/2019			1	
O4	1	LBBGU	01/06/2019	1	3	3	01/06/2019			1	
O6	1	LBBGU	01/06/2019	1	1	1	01/06/2019			1	
O7	1	LBBGU	01/06/2019	1	3	3	20/06/2019		1		
O7	1	LBBGU	01/06/2019	1	3	3	12/07/2019		1		
O8	1	LBBGU	01/06/2019	1	2	2	01/06/2019			1	
O9	1	LBBGU	01/06/2019	1	3	3	28/07/2019		1		
P6	1	LBBGU	01/06/2019	1	2	2	01/06/2019			1	
P6	1	LBBGU	01/06/2019	1	2	2	01/06/2019			1	
P8	1	LBBGU	01/06/2019	1	3	3	25/06/2019	1			
Q4	1	LBBGU	01/06/2019	1	2	2	01/06/2019			1	
Q6	1	LBBGU	01/06/2019	1	3	3	01/06/2019			1	
Q7	1	LBBGU	01/06/2019	1	3	3	01/06/2019			1	
R5	1	LBBGU	01/06/2019	1	3	3	01/06/2019			1	
R5	1	LBBGU	15/06/2019			3	15/06/2019			1	
Q4	1	LBBGU	15/06/2019			2	15/06/2019			1	
Q6	1	LBBGU	15/06/2019			3	15/06/2019			1	
Q6	1	LBBGU	15/06/2019			1	15/06/2019			1	
Q7	1	LBBGU	15/06/2019			2	15/06/2019			1	
Q7	1	LBBGU	15/06/2019			3	15/06/2019			1	
P7	1	LBBGU	15/06/2019			3	15/06/2019			1	
P6	1	LBBGU	15/06/2019			1	15/06/2019			1	

P5	1	LBBGU	15/06/2019			3	15/06/2019			1	
O7	1	LBBGU	15/06/2019			2	15/06/2019			1	
N8	1	LBBGU	15/06/2019			3	15/06/2019			1	
N3	1	LBBGU	15/06/2019			3	15/06/2019			1	
M2	1	LBBGU	15/06/2019			3	15/06/2019			1	
M9	1	LBBGU	15/06/2019			1	15/06/2019			1	
L7	1	LBBGU	15/06/2019			3	15/06/2019			1	
J8	1	LBBGU	15/06/2019			2	15/06/2019			1	
P6	1	LBBGU	16/06/2019			1	16/06/2019			1	
I8	1	LBBGU	16/06/2019			3	16/06/2019			1	
M7	1	LBBGU	02/07/2019			3	02/07/2019			1	
N4	1	LBBGU	02/07/2019			3	02/07/2019			1	
N8	1	LBBGU	02/07/2019			3	02/07/2019			1	
O8	1	LBBGU	02/07/2019			3	02/07/2019			1	
P4	1	LBBGU	02/07/2019			1	02/07/2019			1	
P6	1	LBBGU	02/07/2019			2	02/07/2019			1	
Q5	1	LBBGU	02/07/2019			3	02/07/2019			1	
R6	1	LBBGU	02/07/2019			2	02/07/2019			1	
M8	1	LBBGU	16/07/2019			3	16/07/2019			1	
O8	1	LBBGU	16/07/2019			3	16/07/2019			1	
O4	1	LBBGU	16/07/2019			1	16/07/2019			1	
Total	49			20	50	119		1	3	45	

Grid	Nest found NO	Species	First Seen date	Nests found on Census day	Eggs found on Census day	Eggs No	Predated – Failed- Collected- Fledged date	Predated	Failed	Collected	Fledged
F10	1	HGU	01/06/2019	1	3	3	01/06/2019			1	
K10	1	HGU	01/06/2019	1	3	3	01/06/2019			1	
M10	1	HGU	01/06/2019	1	3	3	01/06/2019			1	
O10	1	HGU	01/06/2019	1	3	3	01/06/2019			1	
R3	1	HGU	01/06/2019	1	3	3	01/06/2019			1	
R8	1	HGU	01/06/2019	1	2	2	01/06/2019		1		
R8	1	HGU	01/06/2019	1	3	3	20/06/2019			1	
R3	1	HGU	02/07/2019			2	02/07/2019			1	
Total	8			7	20	22		0	1	7	0

Appendix 5 Whoosh net full specifications

Two leading poles 130cm length green colour

1pc of a knotted net 130x130cm, white colour, mesh size 100x100mm, with rubber ropes

2pc of trigger stabile parts

4pcs of metal pins for fixing of the net and rubber ropes

Pull cord (75m

Whoosh net trap over herring gull nest – 2016

Appendix 6 Walk-in trap full specifications

This trap was made of Galvanised wire (with wire thick 0.9mm and mesh 50x50mm). Therefore, it is lightweight and can be folded and carried by one person. The trap was in the same described model by (Meissner, 1998) with some modified dimensions. The entrance was formed by cutting down the edge of the mesh and bended inside forming funnel shape. The edges of the cut were folded and make it face the outer side of the trap to avoid causing any injury for the birds when it is trying to escape. The directions of the entrances were made in different direction to avoid giving the bird easy escape from the trap

middle The trap was placed on a nest in which eggs were being incubated, and when possible, the funnel-entrances were placed on a gull's potential paths of nest-entry(Weaver and Kadlec, 1970)

Multiple traps were set up over 3-4 nests at the same time. The targeted nests were chosen depending on the nest location. The nest location should be approachable clearly by the applicant with easy way to run quickly towards the trap in case of success catching. The traps were sat up and the applicant hide behind the cliff underneath camouflage cover. If we could not catch the birds within 45 minutes, the catching session was cancelled, and the trap was removed to allow the gull to return

Walk-in trap with funnel-shape entrance over Nest 24 - 2017.

Appendix 7 Large Gulls Ringed -2015

Nest	Grid	Ring date	Species	Age	BTO	D.Colour	D.Number	Eggs	T.head (mm)	Wing (mm)	Weight (g)	Temp.Mark	Result
1	P8	28/05/15	LBBGU	AD	GP94735	GREEN	C:00	3	122.9	435	1009	–	3 rung chicks fledged (C:02; C:03; C:04)
2	P7	03/06/15	LBBGU	AD	GP94736	GREEN	C:01	3	121.2	427	840	–	Nest failed: gull never returned to the nest
3	P7	07/06/15	HR	AD	GP94737	YELLOW	4M7B	3	117.4	420	900	–	Nest failed: gull never returned to the nest
1	P8	28/06/15	LBBGU	PULLUS	GP94738	GREEN	C:02	–	–	–	–	–	Chick released on 28 June; recaptured on 2 July
1	P8	28/06/15	LBBGU	PULLUS	GP94739	GREEN	C:03	–	–	–	–	–	Chick released on 28 June
1	P8	28/06/15	LBBGU	PULLUS	GP94740	GREEN	C:04	–	–	–	–	–	Chick released on 28 June
4	P6	28/06/15	LBBGU	AD	GP94711	GREEN	C:05	3	108.4	389	750	Blue line on head	Nest failed: eggs warm on 30 June; enclosure set on 30 June; gull never returned to enclosed nest
5	P7	01/07/15	LBBGU	AD	GP094712	GREEN	C:06	3	123.8	431	989	Blue line dots on head	Nest succeeded: enclosure set open on 10 July; 3 chicks went missing after 28 July
6	Q6	03/07/15	LBBGU	AD	GP94713	GREEN	C:07	3	123.9	424	941	Blue chest line	Nest failed: enclosure set open on 10 July; Eggs cold on 15 July; eggs predated on 17 July
7	N3	04/07/15	LBBGU	AD	GP94714	GREEN	C:08	3	126	432	998	Two blue stripes on head	Nest failed: gull never returned to the nest; C:08 spotted flying above the nest on 6 July
8	Q7	15/07/15	LBBGU	AD	GP94715	GREEN	C:09	3	114.9	394	705	Blue 'X' on head	Nest failed: gull never returned to the nest
9	I9	17/07/15	LBBGU	AD	GP94716	GREEN	C:20	2+1C	125.3	439	995	Blue line on head	Nest failed: gull never returned to the nest; Chick found dead on 19 July
10	G9	22/07/15	LBBGU	AD	GP94717	GREEN	C:21	3	112.5	414	708	Blue spot on chest	Eggs warm on 6 August
10	G8	08/09/15	LBBGU	PULLUS	GP94718	GREEN	C:22	-	-	-	-		
10	G8	08/09/15	LBBGU	PULLUS	GP94718	GREEN	C:23	-	-	-	-		

Appendix 8 Large Gulls Ringed -2016

Nest	Grid	Ring date	Species	Age	BTO	D.Colour	D.Number	Eggs	T.head (mm)	Wing (mm)	Weight (g)	Temp.Mark	Result	GPS-Tag NO
N14	P5	08/06/16	LBBGU	AD	GP94720	GREEN	C:24	3	119	432	825	Blue stripe on head	Chick found dead on 10/07/2016	-
N1	R5	10/06/16	LBBGU	AD	GP94721	GREEN	C:25	3	123.2	430	908	No mark	1 rung Chick fledged (C:29)	-
N20	Q7	19/06/16	LBBGU	AD	GP94722	GREEN	C:26	2	102	425	900	Blue mark on the head	Nest failed: gull never returned to the nest	-
N18	P5	26/06/16	LBBGU	AD	GP94723	GREEN	C:27	3	125.3	401	785	Blue ears	Chick found dead on 1/07/2016	192
N23	O4	30/06/16	LBBGU	AD	GP94724	GREEN	C:28	3	111	439	767	Blue band behind the bill	Chick found dead on 13/07/2016	199
N1	R5	09/07/16	LBBGU	PULLUS	GP94725	GREEN	C:29	-	96.7	241	710	No mark	Chick released on 13/07/2016	-
N29	L2	11/07/16	LBBGU	AD	GP94726	GREEN	C:30	3	105.9	404	661	Blue ring around the bill	1 rung Chick fledged (C:32) Adult was shot on 14/08/2016 (C:30)	200
N32	N6	20/07/16	LBBGU	AD	GP94727	GREEN	C:31	3	The biometric were not recorded because the Gull was very exhausted			Green colour behind the head	Nest failed: gull never returned to the nest	196
N29	L2	06/08/16	LBBGU	PULLUS	GP94728	GREEN	C:32	-	95.6	216	570	No mark	Chick released on 09/08/2016	-
N34	M3	18/08/16	LBBGU	PULLUS	GP94729	GREEN	C:33	-	93.0	216	545	No mark	Chick released on 21/08/2016	-

Appendix 9 Large Gulls Ringed -2017

Nest	Grid	Ring date	Species	Age	BTO	D.Colour	D.Number	Eggs	T.head (mm)	Wing (mm)	Weight (g)	Temp.Mark	Result	GPS-Tag NO
N6	R5	15/06/17	LBBGU	AD	GP94730	GREEN	C:34	3	113.2	403	833	No mark	Nest collected on 18/06/2017	-
N12	O10	16/06/17	HGU	AD	GP94701	GREEN	C:35	3	135	402	776	No mark	Nest collected on 16/06/2017	-
N26	N10	17/06/17	HGU	AD	GP94702	GREEN	C:36	2	119.2	386	913	No mark	Eggs found predated on 28/06/2017	BTO-746
N20	P6	20/06/17	LBBGU	AD	GP94703	-	-	2	116.8	407	799	No mark	Chicks found predated on 28/06/2017	BTO-780
N34	G9	19/07/17	LBBGU	PULLUS	GP94704	GREEN	C:37	-	-	-	-	No mark	Escaped from the enclosure on 05/07/2017 then caught in the intertidal area, ringed and released on 19/07/2017	-
N24	Q4	01/08/17	LBBGU	PULLUS	GP94705	GREEN	C:38	-	-	-	-	No mark	Fledged on 09/08/2017	-
N24	Q4	01/08/17	LBBGU	PULLUS	GP94706	GREEN	C:39	-	-	-	786	No mark	Fledged on 09/08/2017, then caught in the intertidal area, tagged with GPS logger and released on 10/08/2017- Found dead on 15/08/2017	Mataki-5
N29	M7	12/08/17	LBBGU	PULLUS	GP94707	GREEN	C:40	-	-	-	743	No mark	Fledged on 07/08/2017, then caught in the intertidal area, ringed, tagged with GPS logger and released on 12/08/2017	Mataki-2

Appendix 10 Large Gulls Ringed -2018

Nest	Grid	Ring date	Species	Age	BTO	D.Colour	D.Number	Eggs	T.head (mm)	Wing (mm)	Weight (g)	Temp.Mark	Result
N15	N8	24/07/18	LBBGU	PULLUS	GP94708	GREEN	C:41		109	263	800	No mark	Fledged
N15	N8	24/07/18	LBBGU	PULLUS	GP94709	GREEN	C:42		11	290	800	No mark	Fledged
Unknown	M8	24/07/18	LBBGU	PULLUS	GP94710	GREEN	C:43	-	108	323	650	No mark	Fledged

Appendix 11 Analysis of Deviance Table (Wald chi-square tests)

Response: Large Gulls number over the observation area			
	chi-square	Df	**P-value**
(Intercept)	4.2809	1	0.0385431 *
Day in year	4.2052	1	0.0403002 *
Tide level	10.6962	5	0.0577476 .
Available biomass of Roseate Tern chicks (standardized)	169.8583	1	< 2.2e-16 ***
Available biomass of BHG, AT, CT, and ST chicks (standardized)	2.1122	1	0.1461244
tlg.std	12.6455	1	0.0003765 ***
DY: Tide level	15.8701	5	0.0072250 **
tlg.std: Tide level	14.4875	5	0.0127921 *

Appendix 12 GPS TAGS

Mataki-Classic

Latest Firmware: V5.4.4
Size: 44 x 21.75mm
Weight: approx. 10g
Radio Base Frequency: 868MHz (Europe)/916MHz (USA)
Max. transmit power (at antenna): 10mW (+10dBm)
Battery (not supplied): 3.6V Lithium-Ion
Log capacity: 932066*
Features:
Battery voltage sensor
GPS position
Light sensor
Accelerometer
Temperature/Pressure Sensor
Current Consumption (typical):**
Sleeping: 30µA
GPS Module: 26mA**
Radio: 19mA***

** During acquisition, tracking current is ~20mA; PA6B GPS on PCBs prior to V5.3 takes ~48mA(Acq), 37mA(Trk)

*** When receiving

Movetech GPS-GSM tags:

This GPS-GSM device weighs < 20 g with battery and solar panel built-in. The robust, waterproof 3D-printed housing comes as standard with attachment points for a 3-point backpack system. Includes accelerometer and temperature sensors as standard and sampling schedules are fully flexible and changeable, even after deployment.
Standard dimensions - 57.5mm x 26.5mm x 14.5mm
All data is pushed from 6.2.2. Movetech servers automatically to Movebank.

Appendix 13 Movetech GPS-GSM tags procedures

This is part of a wider PhD study conducted by Ibrahim Alfarwi on the effects of breeding Large Gulls on Roseate Tern population. The permit states: up to ten, 18-23g Movetech GPS-GSM (wing loop/thoracic weak link body harness) fitted on adult LBB & Herring Gull (project ref 17-49) - breeding on Coquet Island.

Mark 1

Bird/Mark	1
Nest	26
Trap Method	Walk-in
Latitude	55.335808
Longitude	-1.5376
Tag deployed by	Wesley Davies
Assist	Ibrahim Alfarwi
First egg seen	16/06/2017
Species	HGU/Adult
# Eggs	2
Animal/GPS Tag	746
Logger weight	20g
BTO ring	GP94702
Darvic ring colour	Green
Darvic ring	C:36
Darvic ring weight	2.87 g
Harness weight	3.45g
Total mark weight	26.32g
Total % of bird weight	2.88%
Bird weight	913 g
Wing length	386mm
Total Bill/ head	119.2mm
Culmen	50.9mm
Gonydeal	17.6mm
Samples collected	Feather
Date caught	17/06/2017
Time caught	15:55
Time released	16:50

Notes

Three traps were installed for 30 minutes, and this was the only bird caught. Fitting was straight forwards as per training. There was no difference in length between the left and right straps. The bird took off easily once freed and flew to the sea with the customary quick ‘shake’. The first received track data showed the bird returning to the nest.

Mark 2

Bird/Mark	2
Nest NO	20
Trap Method	Walk-in
Latitude	55.336079
Longitude	-1.538895
Tag deployed by	Wesley Davies
Assist	Ibrahim Alfarwi
First egg seen	08/06/2017
Species	LBBG/Adult
# Eggs	2
Animal/GPS Tag	780
Logger weight	19 g
BTO ring	GP94703
Darvic ring colour	N/A
Darvic ring	N/A
Darvic ring weight	N/A
Harness weight	3.93g
Total mark weight	22.93 g
Total % of bird weight	2.87 %
Bird weight	799g
Wing length	407mm
Total Bill/ head	116.8mm
Culmen	50.3mm
Gonydeal	16.3mm
Date caught	20/06/2017
Time caught	17:25
Time released	18:20

Notes

Four traps were installed for 30 minutes, and this was the only bird caught. Fitting was as per training – with one mm difference between the left and right sides of the straps.

The release was ‘unfortunate’. The bird flew confidently as normal – but chose to shake/adjust in front of two passing sub adult GBBGUs. They took this as an indicator of weakness and attacked. A third GBBGU joined them a chase – swooping the tagged bird. It took four minutes before they realised there was no issues with the tagged bird (which evaded all attacks), and let it go about its business. The first data back from this logger showed it sitting back on its nest.

Appendix 14 Illumina Barcoding primers (Leray)

Reverse primers

Rev Tag	Tag name	pre-adapter	Sequencing primer sequence
TAGATCGC	N501	GTCTCGTGGGCTCGG	AGATGTGTATAAGAGACAG
CTCTCTAT	N502	GTCTCGTGGGCTCGG	AGATGTGTATAAGAGACAG
TATCCTCT	N503	GTCTCGTGGGCTCGG	AGATGTGTATAAGAGACAG
AGAGTAGA	N504	GTCTCGTGGGCTCGG	AGATGTGTATAAGAGACAG
GTAAGGAG	N505	GTCTCGTGGGCTCGG	AGATGTGTATAAGAGACAG
GCAGCGTA	DNAp	GTCTCGTGGGCTCGG	AGATGTGTATAAGAGACAG
CTGCGCAT	PCRp	GTCTCGTGGGCTCGG	AGATGTGTATAAGAGACAG
GAGCGCTA	n1	GTCTCGTGGGCTCGG	AGATGTGTATAAGAGACAG
CGCTCAGT	n2	GTCTCGTGGGCTCGG	AGATGTGTATAAGAGACAG

Forward primers

Fwd Tag	Tag name	pre-adapter	Specific locus primer
TCGCCTTA	N701	TCGTCGGCAGCGTC	GGWACWGGWTGAACWGTWTAYCCYCC
CTAGTACG	N702	TCGTCGGCAGCGTC	GGWACWGGWTGAACWGTWTAYCCYCC
TTCTGCCT	N703	TCGTCGGCAGCGTC	GGWACWGGWTGAACWGTWTAYCCYCC
GCTCAGGA	N704	TCGTCGGCAGCGTC	GGWACWGGWTGAACWGTWTAYCCYCC
AGGAGTCC	N705	TCGTCGGCAGCGTC	GGWACWGGWTGAACWGTWTAYCCYCC
CATGCCTA	N706	TCGTCGGCAGCGTC	GGWACWGGWTGAACWGTWTAYCCYCC
GTAGAGAG	N707	TCGTCGGCAGCGTC	GGWACWGGWTGAACWGTWTAYCCYCC
GCAGCGTA	DNAp	TCGTCGGCAGCGTC	GGWACWGGWTGAACWGTWTAYCCYCC
CTGCGCAT	PCRp	TCGTCGGCAGCGTC	GGWACWGGWTGAACWGTWTAYCCYCC
GAGCGCTA	n1	TCGTCGGCAGCGTC	GGWACWGGWTGAACWGTWTAYCCYCC
CGCTCAGT	n2	TCGTCGGCAGCGTC	GGWACWGGWTGAACWGTWTAYCCYCC

Illumina MiSeq Adapter primers- Reverse

Rev Tag	pre-Adapter	Primer name	Combined sequence
TAAGGCGA	GTCTCGTGGGCTCGG	MiSeq_Adapter2_N701	CAAGCAGAAGACGGCATACGAGATTAAGGCGAGTCTCGTGGGCTCGG
CGTACTAG	GTCTCGTGGGCTCGG	MiSeq_Adapter2_N702	CAAGCAGAAGACGGCATACGAGATCGTACTAGGTCTCGTGGGCTCGG
AGGCAGAA	GTCTCGTGGGCTCGG	MiSeq_Adapter2_N703	CAAGCAGAAGACGGCATACGAGATAGGCAGAAGTCTCGTGGGCTCGG
TCCTGAGC	GTCTCGTGGGCTCGG	MiSeq_Adapter2_N704	CAAGCAGAAGACGGCATACGAGATTCCTGAGCGTCTCGTGGGCTCGG
GGACTCCT	GTCTCGTGGGCTCGG	MiSeq_Adapter2_N705	CAAGCAGAAGACGGCATACGAGATGGACTCCTGTCTCGTGGGCTCGG
TAGGCATG	GTCTCGTGGGCTCGG	MiSeq_Adapter2_N706	CAAGCAGAAGACGGCATACGAGATTAGGCATGGTCTCGTGGGCTCGG
CTCTCTAC	GTCTCGTGGGCTCGG	MiSeq_Adapter2_N707	CAAGCAGAAGACGGCATACGAGATCTCTCTACGTCTCGTGGGCTCGG
CGAGGCTG	GTCTCGTGGGCTCGG	MiSeq_Adapter2_N710	CAAGCAGAAGACGGCATACGAGATCGAGGCTGGTCTCGTGGGCTCGG

Illumina MiSeq Adapter primers- Forward

Fwd Tag	pre-Adapter	Primer name	Combined sequence
CTCTCTAT	TCGTCGGCAGCGTC	MiSeq_Adapter1_S502	AATGATACGGCGACCACCGAGATCTACACCTCTCTATTCGTCGGCAGCGTC
TATCCTCT	TCGTCGGCAGCGTC	MiSeq_Adapter1_S503	AATGATACGGCGACCACCGAGATCTACACTATCCTCTTCGTCGGCAGCGTC
GTAAGGAG	TCGTCGGCAGCGTC	MiSeq_Adapter1_S505	AATGATACGGCGACCACCGAGATCTACACGTAAGGAGTCGTCGGCAGCGTC
ACTGCATA	TCGTCGGCAGCGTC	MiSeq_Adapter1_S506	AATGATACGGCGACCACCGAGATCTACACACTGCATATCGTCGGCAGCGTC
AAGGAGTA	TCGTCGGCAGCGTC	MiSeq_Adapter1_S507	AATGATACGGCGACCACCGAGATCTACACAAGGAGTATCGTCGGCAGCGTC
CTAAGCCT	TCGTCGGCAGCGTC	MiSeq_Adapter1_S508	AATGATACGGCGACCACCGAGATCTACACCTAAGCCTTCGTCGGCAGCGTC
CGTCTAAT	TCGTCGGCAGCGTC	MiSeq_Adapter1_S510	AATGATACGGCGACCACCGAGATCTACACCGTCTAATTCGTCGGCAGCGTC
TCTCTCCG	TCGTCGGCAGCGTC	MiSeq_Adapter1_S511	AATGATACGGCGACCACCGAGATCTACACTCTCTCCGTCGTCGGCAGCGTC

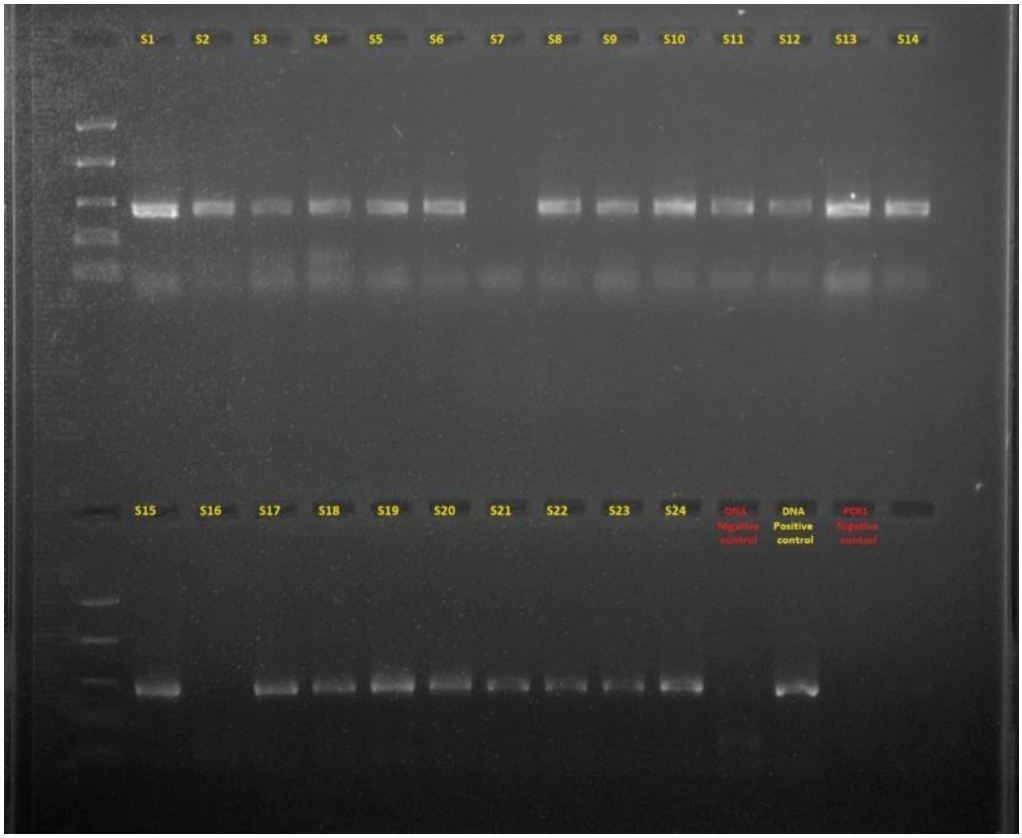
Appendix 15 Library design

Primer combinations	1	2	3	4	5	6	7	8	9	10	11	12
A	S1		S5		S9		S13		S17		S21	P+1
B												
C	S2		S6		S10		S14		S18		S22	N-1
D												
E	S3		S7		S11		S15		S19		S23	
F												
G												
H	S4		S8		S12		S16		S20		S24	N-2

Appendix 16 Library concentration through the normalisation process

	Library concentration after normalization (ng/ul)	Library concentration after PCR1 size selection (ng/ul)	Library concentration after PCR2 size selection (ng/ul)
1	2.61	18	54
2	2.46	17.7	55
3	3.65	24	56
4	1.06	9	47.7
5	2.34	16.4	59
6	1.45	10.5	47.7
7	1.13	7.4	58

Appendix 17 An image of a gel post electrophoresis for Library 1



An image of a gel post electrophoresis for Library 1. The gel was exposed to UV light and the picture taken with a gel documentation system, 2 Negative controls (nuclease-free water) in are showing no band, one positive control showing band successfully.

Appendix 18 The technical specifications of the Aerolaser Handheld

Technical specifications

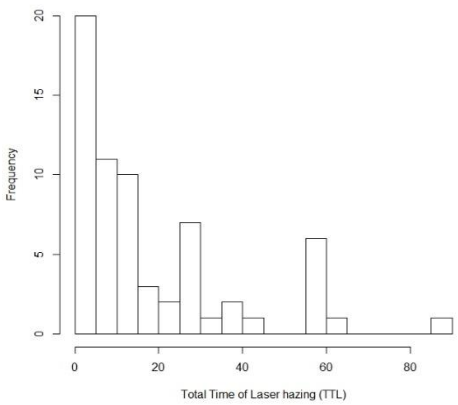
Laser class	**3B**
Laser beam colour	**Green**
Service life laser source	**5000 hr**
Battery laser	**1 x 18650 Lithium Ion battery**
Battery scope	**1 x CR2032 battery**
Battery lifetime	**3 hr (continuous use)**
Operating temperature	**-5°C to +45°C**
Relative humidity	**0% to 95%**
Storage temperature	**-20°C to +50°C**
Dimensions	**500 x 65 x 90 mm (L x W x H)**
Weight	**1000 gr**

Appendix 19 Weather data

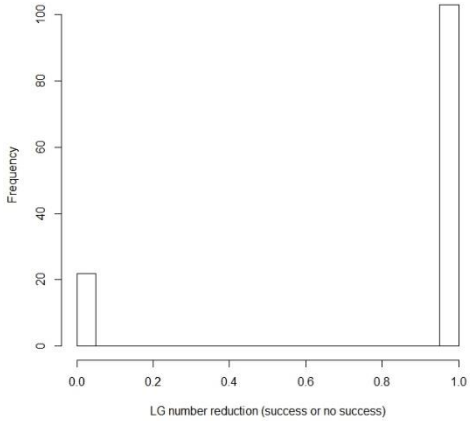
Weather station name	BOULMER
src_id	315
Geographic area:	NORTHUMBERLAND
Latitude (decimal degrees):	55.4208 (WGS 84 value: 55.4208)
Longitude (decimal degrees):	-1.59966 (WGS 84 value: -1.60126)
Grid ref:	NU 253141 (Easting: 425338 Northing: 614178)
Grid ref type:	OS
Postcode:	NE66 3
Elevation:	23 meters
Drainage stream:	COASTAL
Hydrological area ID:	220
Station start date	1975-01-01
Station end date	Current

Appendix 20 Laser Hazing data preparation

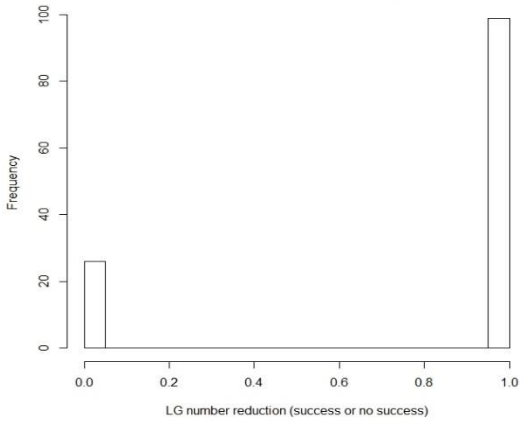
1



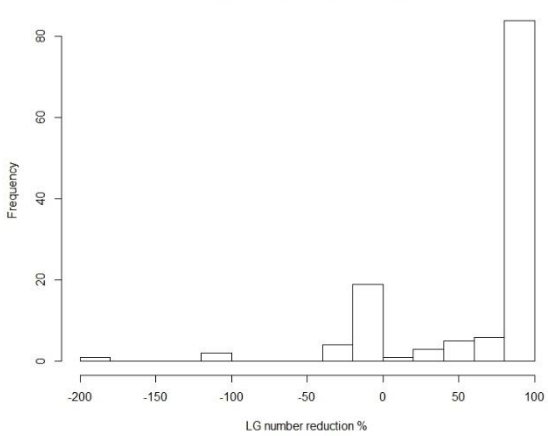
2



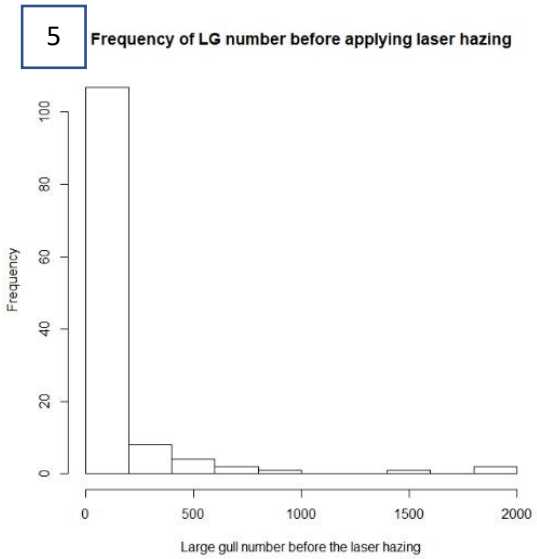
3



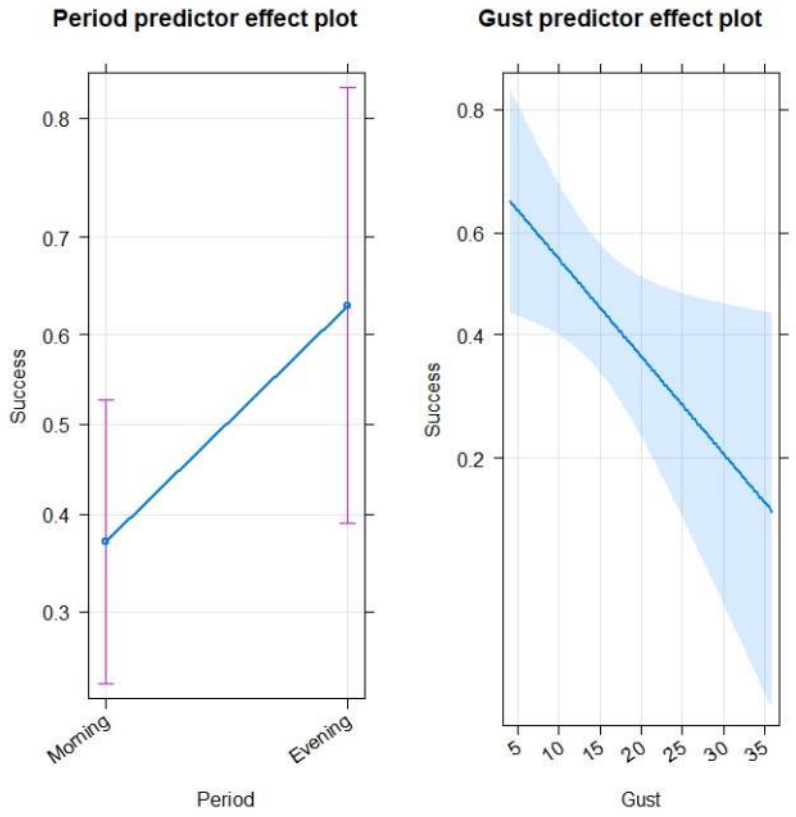
4



5



Appendix 21 ELH after 60 minutes



Appendix 22 Laser data form

Date	**Tide**	**Weather: use standard codes**	**Applicant place: Roof, Jetty or Plateau**	**Targeted area: Plateau or intertidal**			**Targeted LG species**		**Another species present**	**Hi-Viz Jacket YES/ NO**
Time	**LG No.**	**Treatment time**	**Alert, Yes or No, %**	**Number**	**Flew, Yes or No, %**	**Number. and directions**	**left island, Yes or No, %**	**Number**	**return to island immediately , Yes or No, %**	**Number**
8:00 AM										
8:05 AM										
8:10 AM										
8:15 AM										
8:20 AM										
8:25 AM										
8:30 AM										
8:35 AM										
9:00 AM										

Observer name	**Note**

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