Master's thesis

An Analysis of
Common Guillemot *Uria aalge* Chick Diet
Atlantic Puffin *Fratercula arctica* Productivity and Great Skua *Stercorarius skua* Diet on Mingulay, Outer Hebrides

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An Analysis of Common Guillemot Uria aalge Chick Diet, Atlantic Puffin Fratercula arctica Productivity and Great Skua Stercorarius skua Diet, on Mingulay, Outer Hebrides
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Declaration

I hereby confirm that I am the sole author of this thesis and it is a product of my own academic research.

Student's name

Abstract

Mingulay hosts nationally important congregations of several seabird species. Regular seabird monitoring has recently been established, and this study aimed to improve the current state of knowledge for three species. The study investigated common guillemot *Uria aalge* chick diet, great skua *Stercorarius skua* diet, and conducted an Atlantic puffin *Fratercula arctica* productivity study and census count.

Sandeel stocks around the UK are changing, due to both fisheries and climate change. As a keystone species, the impacts of these changes are complex, and common guillemot chick diet acts as an indicator of sandeel availability. This study found that chick diet on Mingulay consists mainly of sandeels and gadoids. Later in the season, the proportion of sandeels in chick diet decreased, while gadoids increased significantly. Gadoids are the predominant alternative prey type, and if sandeel availability declines as a result of climate change then common guillemot chick survival could suffer, as gadoids are of lower nutritional value.

Great skua diet was analysed to collect baseline data that can allow the impacts of increasing population and a reduction in fisheries discards to be understood. This study found seabird remains in 88% of pellets analysed, suggesting that great skuas on Mingulay predate heavily on other seabirds. The impact on black-legged kittiwakes is particularly concerning, as this species is suffering long-term decline on Mingulay, as well as nationally.

The census and productivity study of Atlantic puffins at Mingulay Bay identified 893 Apparently Occupied Burrows in early June. This figure is consistent with recent census counts, and suggests that the population is stable. Puffin productivity was calculated as 0.594 ± 0.153. This figure suggests that 2014 was a successful season for puffins on Mingulay, compared to 2013 when productivity was 0.158 ± 0.164.

These studies can contribute to management decisions on Mingulay; as part of a long-term dataset, the studies can reveal trends in dietary composition, predation impacts and breeding success. This data can indicate whether prey availability is changing, and whether climate change and fishing effort are having a detrimental impact on Mingulay's seabirds. This will allow appropriate management decisions to be taken on a local scale; such as controlling fishing effort, discards, and marine developments. Long-term data can help to inform the island's protective designations, and highlight the importance of large scale climate change mitigation alongside data from various other colonies around the UK.

For my mum, Doreen Lawrence
Without whose support and guidance this couldn’t have been possible
Thank you for believing in me whenever I didn’t

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Acronyms

AOB	Apparently Occupied Burrow
AON	Apparently Occupied Nest
AOT	Apparently Occupied Territory
CFP	Common Fisheries Policy
DSR	Daily Survival Rate
EAA	Ecological Assessment Area
EIA	Environmental Impact Assessment
EU	European Union
Ha	Hectares
HRA	Habitats Regulation Appraisal
IUCN	International Union for Conservation of Nature
JNCC	Joint Nature Conservation Committee
NTS	National Trust for Scotland
SAC	Special Area of Conservation
SNH	Scottish Natural Heritage
SPA	Special Protected Area
SSSI	Site of Special Scientific Interest
SST	Sea-surface Temperature

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1 Background and Introduction

1.1 Mingulay

The island of Mingulay / Miùghlaigh (56° 48' N, 7° 38' W) is the second largest of the Bishop’s Isles, located on the southern tip of the Western Isles (or Outer Hebrides) in north-west Scotland. The island has been owned and managed by the National Trust for Scotland (NTS), since 2000.

Mingulay is 911ha in size (Scottish Natural Heritage, 2005), and on its western coast hosts some of Scotland’s highest sea cliffs, rising to 210 metres. The island is predominantly covered by maritime grassland (JNCC, 2001), and is host to a number

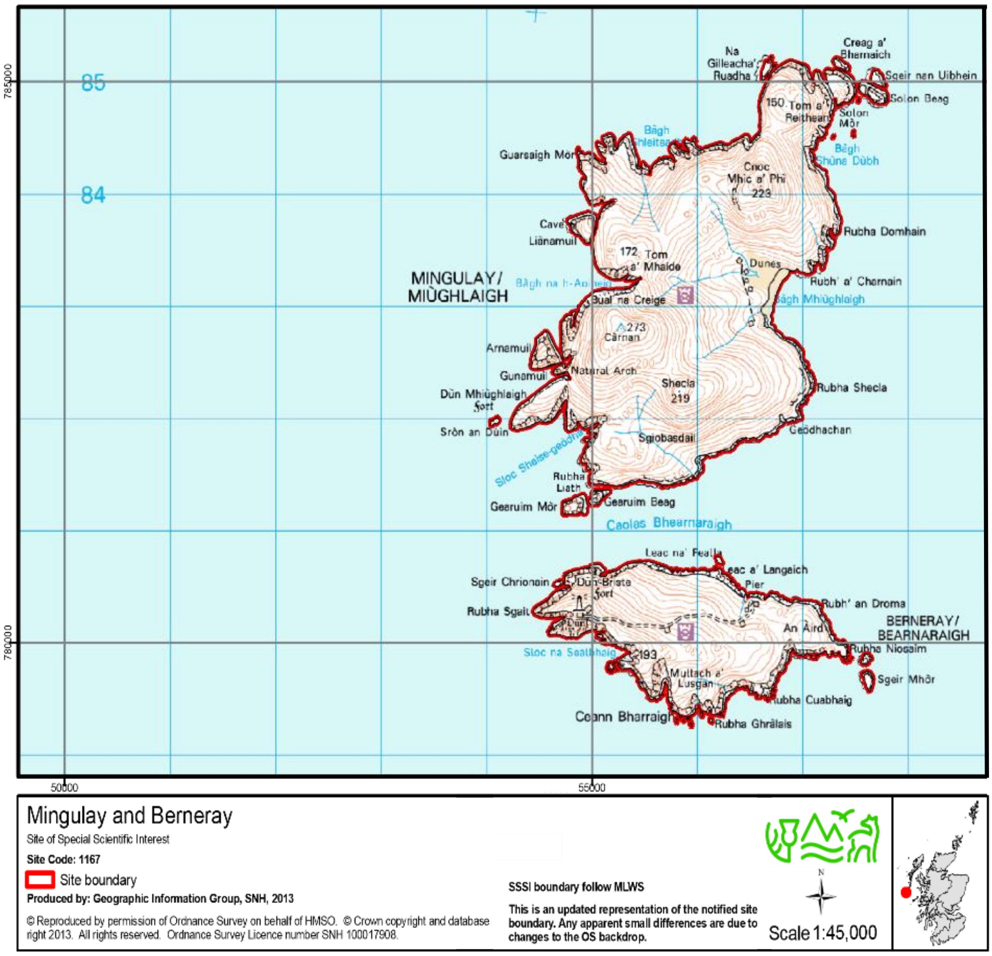


Figure 1: Mingulay and Berneray SSSI Boundary

of seabird species, supporting breeding populations of national and European importance. Partly on account of Mingulay's breeding seabird assemblage, the whole island has been designated as a Site of Special Scientific Interest (SSSI) since 1975 (Figure 1) (SNH, n.d.), and a Special Protection Area (SPA) since 1994. The SPA was further extended to include a marine component in 2009 (Figure 2) (Scottish Natural Heritage, 2009a).

The island is of historic importance, with evidence of human habitation since Neolithic times (Buxton, 1995). The village area is located on the east of the island, behind Mingulay Bay, and during the 19th Century its population grew rapidly, peaking at 164 people in 1883. In the following years the population declined, and evacuation of the island began in 1907. The last residents left in 1912 (Buxton, 1995). After its abandonment the island was used for sheep grazing by various crofters until it was sold by the Barra Head Isles Sheep-stock Company in 2000, and the island is now held in trust by the National Trust for Scotland (Scottish Natural Heritage, 2009a). The sheep were subsequently removed from the island, and in 2013 the Old Schoolhouse (seen in

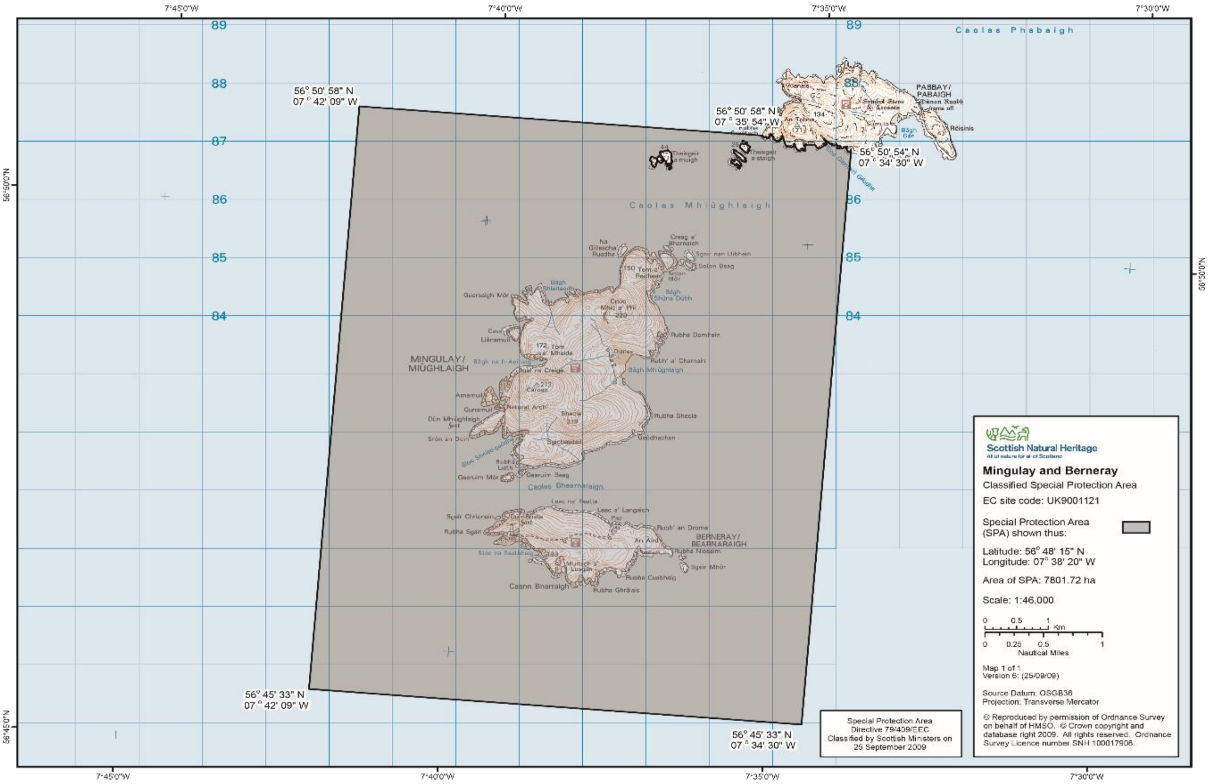


Figure 2: Mingulay and Berneray SPA Boundary.

Figure 3) was restored in order to facilitate research. A seabird monitoring programme has since been initiated by NTS (Dunn, 2013 & 2014).

Figure 3: The Old Schoolhouse, located on the south side of Mingulay Bay (Photo credit: Sarah Lawrence).

Seabirds of various species, and their eggs were harvested by the islanders as a staple food source each year in unknown numbers, though on some occasions 2000 common guillemots were recorded to be taken in one day (Buxton, 1995). The harvest decreased throughout the 19th Century, and finally seabird-fowling ceased when the island was evacuated (Buxton, 1995). Throughout the 20th Century, seabird monitoring and census data on Mingulay has been collected with varying degrees of effort and regularity; census data was collected in 1964-65, 1985, 1994, 1998, and since 2003 (excluding 2004, 2005 & 2007) (Dunn, 2013). Productivity data is not available prior to 2013. For certain species, such as the Atlantic puffin, it is difficult to draw long-term trends from the earlier census data due to its irregularity and the possibility that census methods were not consistent, but the data since 2003 shows short-term trends from the whole-colony population census. The intensive productivity monitoring that has occurred since 2013 is still in its infancy, and due to the long life history of seabird species, it is necessary that long-term monitoring continues into the future. This will allow productivity and population trends to be better understood, as breeding productivity over time can act as an indicator of the current state of regional seas, as well as providing an early indication of future population changes. For example, a known period of poor productivity in the present could explain decreasing breeding populations when those fledglings reach maturity several years in the future (Scottish Natural Heritage, 2012).

Long-term monitoring is important because the UK is obliged under the Ramsar Convention and the EC Birds Directive (79/ECC/409) to provide information on the state of breeding seabird populations. This obligation is administered by Scottish Natural Heritage (SNH), which conducts Site Condition Monitoring of designated sites in Scotland. The Seabird Monitoring Programme, run by the Joint Nature Conservation Committee (JNCC), is also active at seabird colonies throughout the UK (Walsh *et al*. 1995). Annual intensive monitoring by NTS on Mingulay can make a contribution to Scotland's seabird monitoring obligations, as the island's SSSI and SPA notifications are partly due to its important breeding seabird populations.

Nationally important breeding populations of the following seabird species are present on Mingulay (percentage of the UK population shown in parentheses): northern fulmar *Fulmarus glacialis* (2%), common guillemot *Uria aalge* (3%), black-legged kittiwake *Rissa tridactyla* (2%), Atlantic puffin *Fratercula arctica* (0.9%) and European shag *Phalacrocorax aristotelis* (2%), as well as a razorbill *Alca torda* population of European importance (2% European population, 12% UK population) (Scottish Natural Heritage, 2009b).

1.2 Seabird Threats

On a global scale, 43% of seabird species are considered by the IUCN (International Union for Conservation of Nature) to be either Globally Threatened, Critically Endangered or Near Threatened, and 47% of seabird species globally are thought to be experiencing population declines (Croxall *et al.* 2012). There are several major threats to which these declines can be attributed, including commercial fisheries, pollution, habitat degradation, human disturbance and predation by invasive species (Croxall *et al.* 2012). None of the breeding seabird species recorded on Mingulay fall into the above IUCN categories, but some species have experienced population decline in the last 30 years. The black-legged kittiwake *Rissa tridactyla* has suffered population declines at colonies around the UK, partially as a result of a decrease in sandeel availability; since the species is a sandeel specialist (Wanless *et al*. 2005).

Conversely, some 17% of seabird species globally are increasing in population size (Croxall *et al.* 2012). One reason for this trend is the ability of certain species to successfully exploit human activities; for example, great skua *Stercorarius skua* populations in Scotland have increased by 26% between 1985-88 and 2002 (Mitchell *et al*. 2004). This increase is at least partly due to the large quantity of fisheries discards that are available to these generalist predators (Votier *et al.* 2004a). The increase in great skua populations has been implicated in the decline of other seabird species, as great skuas frequently predate on seabirds (Votier *et al*. 2004a). Changes to the Common Fisheries Policy (CFP), mean that a landing obligation (or discard ban) is being phased in to EU fisheries. This legislation will be phased in from late 2014 onwards, and is due to be complete by 2019 (European Commission, 2015). This reduction in fisheries discards raises concerns that great skua diet may switch towards seabird prey, and this could present a threat to seabird communities, particularly black-legged kittiwakes (Votier *et al.* 2004a).

Of the main issues that are threatening seabird species worldwide, several may be applicable to the seabird colonies present on Mingulay. The island does not currently host any invasive species that could predate on seabirds; rabbits were introduced to the island after its evacuation, as a food source for the visiting shepherds (Buxton, 1995), but they are not thought to detrimentally affect the breeding seabirds. Nevertheless, biosecurity of the island is a consideration (Dunn, 2014), as Mingulay is regularly visited by tourist boats. This means that the accidental introduction of harmful invasive species such as rats is a concern, although this has not happened so far.

Human disturbance is also considered a threat to seabird populations in some parts of the world; and on a local scale, Mingulay is a destination for day-trippers, yachts, and rock climbers in the summer. Direct disturbance to breeding birds is therefore possible, but with just one licensed boat operator, visitor numbers remain low. Visitors usually remain close to Mingulay Bay in the east of the island, which is far from the majority of breeding seabirds, with the exception of the Mingulay Bay puffin colony. Disturbance by rock climbers on the west of the island is a threat that is minimised through engagement with the climbing community, who avoid cliffs that are populated with seabirds – both through consideration and practicality.

The remaining global threats to seabird species are intertwined; commercial fisheries, pollution and habitat degradation. One of the greatest emerging threats is that of anthropogenic climate change, which has contributed to a rise in sea-surface temperatures (SST) across the North Atlantic. In waters surrounding the UK, SST have risen by between 0.1°C and 0.5°C per decade in the 30 year period 1983-2012 (Dye *et al.* 2013). On the west coast of Scotland – where Mingulay is located – data from the Tiree Passage showed that SST cooled in the early 1980s, followed by a period of strong warming from 1986 – 1990. Warming SST have generally continued into the 21st Century, along with marine air temperatures, which have been rising at between 0.2°C and 0.4°C per decade on the west coast of Scotland (Dye *et al*. 2013).

The impacts of climate change on breeding seabirds in the UK are very complex; direct effects include the possible increase of seabird 'wreck' events – when there is a large-scale beaching of dead birds. These could become more frequent as a result of the increased frequency and intensity of extreme weather events, and some species are particularly vulnerable to this threat, such as the European shag *Phalacrocorax aristotelis* (Frederiksen *et al.* 2008).

Many of the impacts of climate change on seabirds are likely to be indirect, and come as a result of changes throughout the trophic system. Simplistically, as sea temperatures change, variations within the thermocline, halocline, pycnocline and ocean currents can influence the frequency and distribution of nutrient upwelling (Doney *et al*. 2012). These oceanographic changes are complex and challenging to predict, but they can often be observed at higher trophic levels. The resulting changes to nutrient availability can affect the production of plankton, one of the main food sources for forage fish. Depending on the oceanographic conditions, forage fish populations may vary in their phenology and recruitment from year to year; influencing the success of top predators such as seabirds (Lauria *et al*. 2013).

Understanding the ways in which anthropogenic climate change is influencing marine systems, and its future impacts on ecology and human activities is a global challenge.

It is difficult to approach the issue on a local or regional level, but seabirds can provide an early insight into its impact on marine ecosystems, since they are easily accessible during the breeding season and are sensitive to changes in the marine environment. Long-term trends in seabird populations and productivity can act as indicators of ecosystem health, improving the understanding of the ways in which anthropogenic threats are affecting the marine environment (Piatt *et al*. 2007).

In order to understand the impacts of climate change on seabirds and their environment, diet has been identified as an important area for further study. Grémillet & Boulinier (2009), identify "*linking seabird distribution patterns to those of their prey*" as a research priority in order to understand the wider ecological context of changes in population and productivity due to climate change. A global study by Lewison *et al*. (2012) identified 6 broad research topics as priorities in order to improve the conservation and management of seabirds. Trophic dynamics and the community roles of seabirds were identified as a priority, with seabird diet and prey availability deemed as an important and reliable indicator of trophic shifts. Another global assessment of priority actions in seabird conservation was by Croxall *et al*. (2012). This study also highlighted anthropogenic climate change as a research priority; "*especially effects on the distribution of prey species*". The assessment suggested that further research into this field may allow management actions to be developed.

It is evident that seabird diet will play an increasing role in developing an understanding of the way in which climate change influences marine ecosystems. A long-term diet study has been established with this objective on the Isle of May, off the east coast of Scotland (CEH, n.d.), and diet studies have recently begun at seabird colonies around the UK. Less data has been collected from colonies on the west coast, so Mingulay is an ideal location to study seabird diet in order to build an understanding of prey fish availability on a national scale.

Since intensive monitoring on Mingulay has only recently been initiated, this is also an opportunity to better understand seabird diet and dynamics on the island, so that well-informed management decisions can be made. This may be particularly useful in the case of future marine development proposals in proximity to the island, which are a real possibility. Scotland is set to increase its production of renewable energy, and Marine

Scotland have identified several potential sites for offshore wind energy generation on the west coast. A potential offshore wind site "W1" was identified directly south of Mingulay in 2011, and a license was initially issued for an offshore wind farm, the Argyll Array, which is south of Tiree and to the south-east of Mingulay (Scottish Development International, 2011). This development was halted in 2013, but ScottishPower Renewables believe that the Argyll Array could still be a viable site for development in the future (ScottishPower Renewables, 2013). It is therefore important to understand the state of nearby seabird colonies, so that the impact of any future developments can be assessed and managed.

1.3 Introduction

The objective of this study is to conduct additional research into the breeding seabird colonies on Mingulay in order to better understand their current state and long-term trends. This information is required in order to contribute to the requirements of the EC Birds Directive, and to improve the National Trust for Scotland's understanding of the seabird colonies at their properties.

The three main areas of study are as follows:

1. Common guillemot chick diet study
2. Great skua diet study
3. Atlantic puffin census and productivity study

These studies can contribute towards future management decisions regarding the seabird colonies on Mingulay by providing information to the National Trust for Scotland and other interested parties such as SNH and the JNCC. As part of long-term trend data, the research could be used to inform decisions regarding the island's protected status, as well as other issues that may be relevant to Mingulay's seabird colonies in the future, such as offshore developments and fisheries.

Each of these topics has been chosen with the challenges facing Mingulay's seabird colonies in mind. The common guillemot chick diet study was chosen in order to understand local forage fish availability, and to begin monitoring the impact of changing prey distributions as a result of climate change. The great skua diet study will provide baseline data so that the impact of the impending fisheries landing obligation can be monitored; and this will allow the extent of great skua predation on smaller seabird species to be assessed. The collection of puffin census and productivity monitoring will allow the current state of this difficult-to-monitor species to be better understood on Mingulay.

The following paper presents each of these three studies individually, with their respective research aims, methodologies, results and discussions. Finally, recommendations and conclusions for each study will be presented.

2 Common Guillemot Diet Study

2.1 Introduction

The research problem addressed by this study is the threat of changing forage fish availability (specifically sandeels) to common guillemot chick diet, as a result of climate change.

This study aims to explore the following research questions:

1) Which prey types are present in the diet of common guillemot *Uria aalge* chicks on Mingulay?
2) Is there a seasonal variation in dietary composition?
3) What are the management implications of changing prey availability on Mingulay?

Research aims 1) and 2) will be addressed in relation to the 2014 chick rearing period. Research aim 3) will be discussed more broadly, with reference to the results of the study. Due to the nature of the research methodology, and the data collection period being limited to one field season, it will not be possible to assess whether – or to what extent – prey availability and fish stocks locally are changing over time. However, the study will serve as baseline dietary data for Mingulay, and act as a starting point towards understanding the impacts of a threat that is not yet well studied on the west coast of Scotland. Long-term monitoring to explore changing dietary composition as an indicator of forage fish availability will allow a better understanding of climate change impacts on seabirds, on the marine environment as a whole, and on the human industries reliant upon it.

2.1.1 Study Species

The common guillemot *Uria aalge* (hereafter 'guillemot') is the largest and most abundant species of auk found in the UK; characterised by its dark brown–black upperparts, white chest, slender pointed bill, and occasionally its bridled morph which has a white eye-ring. Guillemots do not nest-build, instead breeding on wide, flat cliff ledges and on top of stacks; where they lay a single egg onto bare rock, soil or guano (Birkhead, 1977), as seen in Figure 4. The species often breed in very large, dense colonies, and breeding productivity is higher where there is a greater density of birds (Mitchell *et al*. 2004). At between 15-35 days of age, the still flightless 'jumplings' fledge to sea, where the male parent continues to feed the chick for several weeks (Hjernquist *et al*. 2012). Therefore the period of time when chick diet can be viewed and monitored from land is limited to approximately 1 month – which is generally mid-June to mid-July on Mingulay, as seen from recent productivity monitoring (Dunn, 2013).

Figure 4: Breeding guillemots at the study site E2 on Mingulay (Photo credit: Sarah Lawrence).

2.1.2 Background and State of Knowledge

Around the UK coastline, the proportion of different prey types present within guillemot chick diet can vary considerably between colonies. Sandeel populations are localised, varying between regions; and adult guillemots travel tens of kilometres from their breeding site to forage whilst provisioning, so the prey groups that are fed to chicks are an indicator of these localised fish stocks (Wanless *et al*. 2005). Information on chick diet from multiple seabird colonies can be used to indicate changes in prey distribution and predator-prey dynamics, which are an issue of ongoing interest due to the declining availability of sandeels (Anderson *et al.* 2013). Understanding chick diet can also help to explain trends in seabird population size over time, and allow possible management solutions to be identified (Visser & Both, 2005).

Sandeels are the prey item most commonly fed to chicks by guillemots in UK waters, and are an important part of chick diet due to their high energetic value. Guillemot productivity is directly influenced by sandeel availability, and in years when fewer sandeels are available, chick growth and survival rates are lower (Rindorf *et al*. 2000). Two other prey groups are predominant in guillemot chick diet; clupeids, which are generally of good nutritional value, and gadoids, which have a comparatively poor energetic value due to their low lipid content. Snake pipefish *Entelurus aequoreus* are occasionally recorded as an additional group, but due to their very low energetic value and rigid structure (making them difficult for chicks to swallow) they are infrequently provisioned when alternatives are available (Harris *et al.* 2008). The breeding seabirds on Mingulay are thought to be largely dependent on sandeels when provisioning to their chicks, and a significant decline in the sandeel population would be likely to have a detrimental impact on their breeding success (Scottish Natural Heritage, 2009b).

Guillemots are single-prey loaders, so the quality and size of prey brought back to the chick can critically affect its survival and growth (Wanless *et al*. 2005). Adults usually make between 1 – 3 foraging trips per day, but can adapt their behaviour by increasing foraging effort when prey availability is low (Wanless *et al*. 2005). This can maintain chick survival, though not sufficiently to compensate for a lack of high quality prey (Rindorf *et al.* 2000), and can have a negative impact on adult condition as well as increasing the risk of chick predation while parents are absent during foraging trips (Wanless *et al*. 2005).

Evidently, a decrease in sandeel availability would reduce guillemot productivity on Mingulay, and in the UK generally, but the impact of their decline would be far reaching. Sandeels are a forage fish that support many other species of seabirds during the chick-rearing period and throughout the year. Other species that are dependent on them include seals (Furness, 2002) and cetaceans such as the harbour porpoise (Macleod *et al*. 2007). They are a keystone species, and form an important trophic link between the zooplankton on which they feed, and predator species at higher trophic levels such as cod and herring. Within the last 20 years, sandeels, used in fishmeal, have been the target of a major industrial fishery that at one point was the largest single-species fishery in the North Sea (Wanless *et al.* 2005). Thus, as well as ecological impacts, a continuing decline in sandeel stocks could have a financial impact on North Sea fisheries. Some commercially fished species also predate on sandeels, so a sandeel decline could be detrimental to other commercial fisheries around the UK (Heath *et al*. 2012).

The cause of sandeel decline is thought to be two-fold; partially as a result of both climate change and commercial fishing, and the North Sea sandeel fishery has contributed to the poor breeding success of kittiwakes on the east coast of Scotland (Frederiksen *et al*. 2004). Sandeel populations on the Atlantic west coast of Scotland are not well studied, and sandeel grounds are fewer in number there than within the North Sea region. Sandeels were the target of a directed industrial fishery in the west of Scotland previously, but this fishery has now ceased to exist and no catch has been taken since prior to 2008 (Scientific, Technical and Economic Committee for Fisheries, 2014). Although the licensing of a resumed sandeel fishery is still possible (MacInnes, 2014), the state of the stock is unknown, and no increase to the catches in this region are advised until there is evidence that the stock can be fished sustainably (Scientific, Technical and Economic Committee for Fisheries, 2014). At least one sandeel ground is known close to the Mingulay and Berneray SPA, and there are notable records of sandeel grounds in the north of the Western Isles (SNH, 2012). Less is known about the state of sandeel stocks on the west coast of Scotland than those on the east coast bordering the North Sea.

Anthropogenic climate change is also causing changes in sandeel populations around the UK. Sandeels lay their eggs on the seabed during the winter, with planktonic larvae emerging between January and May, before their juveniles settle into areas of sandy seabed in the summer months (Arnott & Ruxton, 2002). During these months, they form large schools throughout the water column by day; which is when they are predated by many species, including chick-rearing seabirds and human fisheries. Climate change is causing temperature increases within UK waters (Anderson *et al.* 2014), and warmer temperatures cause a reduction in sandeel recruitment. Sandeel populations at south-west North Sea latitudes (such as the Western Isles) are particularly vulnerable to the warming impacts of climate change, as they live at the southern limit of their distribution. This means they are exposed to the extremes of climatic variation within their range (Arnott & Ruxton, 2002). Changes in environmental conditions are also suggested to be a cause for sandeel size decreasing significantly in the North Sea over the past 30 years. This change is detrimental to predators such as guillemots as the energy content of each prey item is lower, which can affect breeding success (Wanless *et al*. 2004). Changing temperatures and ocean currents may also cause the zooplankton that sandeels feed on to shift their distribution northwards (Heath *et al.* 2009). Sandeels have been linked to a plankton regime shift that has been measured in the North Sea since the 1980s, but the species is non-migratory, and due to their strict association with the sandy substrates in which they lay their eggs and burrow at night, they would be unable to adapt their distribution with changing sea temperatures (Heath *et al*. 2012).

Seabirds in general can be used as useful indicators of many oceanic processes that are otherwise difficult to observe; such as pollution, climate change and heavy metal accumulation (Newman *et al.* 2007). There are many processes and variables influencing the state of sandeel populations; among them are weather, temperature, ocean currents, fishing pressure and top-down / bottom-up influences. Some of these factors can be affected by climate change, but it is very difficult to measure and understand exactly what is influencing changes within marine systems, and how they are occurring (Heath *et al.* 2009).

It is clear that sandeel populations have been changing within the last 30 years, and that their decline could have an impact on the whole marine ecosystem (Wanless *et al*. 2004). This illustrates the importance of collecting long-term datasets that can help to understand the underlying and hidden factors contributing to changes in their populations (Frederiksen *et al*. 2007). Using guillemot chick diet as an indicator of sandeel availability is an easily replicable way of seeing how sandeel populations change over time across the whole British coastline. Guillemots feed mid-water so they predate on sandeels when they are present within the water column during the day (Anderson *et al.* 2014). Since sandeels are their main prey type, the proportion of sandeels within chick diet is a reliable indicator of sandeel availability year-on-year.

Located on the west coast of Scotland, Mingulay and the Outer Hebrides are categorised within the Celtic Seas OSPAR Monitoring Region III, which includes the whole western coast of the UK from Cornwall in the south-west to Cape Wrath in north-west Scotland. Mingulay also falls on the border between Regional Seas Monitoring Region 6, “Minches and Western Scotland”, and Regional Seas Monitoring Region 7 “Scottish Continental Shelf”, which extends further east than the OSPAR boundary to include Orkney, Fair Isle and Shetland (Defra, 2005). These regions – particularly the Regional Seas – aim to act as an appropriate scale to inform management decisions within their region once ecological assessments have been compiled. However, their boundaries have been defined using biogeographic features, which may not act as effective boundaries for monitoring mobile species such as seabirds and their prey.

Cook *et al*. (2011) used seabird census data to identify regions within which population trends varied consistently. They identified only two Ecological Assessment Areas (EAAs) for guillemot populations, the boundaries of which lie at Cape Wrath in the north, and the Isle of Wight in the south. The main difference between this identified region and that of the Regional Seas is that Orkney, Fair Isle and Shetland are not located within the same EAA as Mingulay, as their population trends were more consistent with east coast populations. This distinction between the islands of northern Scotland and their ecological boundaries is relevant as guillemot diet has been studied for a number of years on Shetland and other northern islands (Heubeck, 2009). The EAAs identified suggest that changes in these guillemot colonies may not be consistent with those in the Western Isles (as may be suggested by the Regional Seas boundaries).

The majority of published and long-term studies on the subject of guillemot diet in Scotland have been focused on east coast populations that border the North Sea, which have different oceanic conditions and external pressures to those seen on the west coast and in the Western Isles. Guillemot diet is well studied on the Isle of May in the Firth of Forth, as well as on Shetland. Recently, data has been collected from guillemot colonies on other islands around the UK, including Handa Island, Lunga and Colonsay, each on the west coast of Scotland (Anderson *et al*. 2014), and these provide baseline information to give a comparison of chick diet on a larger scale. The need for further study on the west coast is still apparent, since sample sizes are small compared to east-coast data. Guillemot chick diet has been studied on St Kilda, which lies 64 kilometres to the west of the Bishop's Isles (Buxton, 1995), but a dietary study on Mingulay can contribute the first baseline data for this part of the region.

If guillemot diet continues to be monitored on Mingulay in future breeding seasons, this study could contribute to a long-term dataset that would allow local trends in dietary composition caused by anthropogenic climate change to be understood. Monitoring dietary composition over a period of years could help to explain changes in the productivity of guillemots and other sandeel-dependant species on the island such as kittiwakes. The study could also be used to inform management locally, for example, if changes in fishing pressure occurred, several years of dietary data could indicate whether fishing effort is affecting seabird breeding success, and action could be taken. On a larger scale, the data could be used in collaboration with monitoring from other colonies to build a picture of the way in which sandeel populations around the UK are changing over time.

2.2 Methodology

2.2.1 Study Location

The study site identified as being most appropriate for this dietary study was sector E2, located in the north of Mingulay. The site was chosen for its congregation of guillemots within 30 metres of an accessible vantage point, from where feeding activity could be accurately viewed. Sector E2 is shown in Figure 5, and feeding activity was viewed from a set observation point in the adjacent Sector E3. Other study sites on Mingulay were considered – including Sectors D2 and G4 (Figure 5) which both host congregations of guillemots – but these sites were rejected on account of their distance from appropriate vantage points and difficulty of access.

The observation point was located approximately 30 metres from the study site, and was directly opposite E2, allowing good visibility of guillemots on ledges of various heights. The study site is shown in Figure 6, and further photographs of the study site

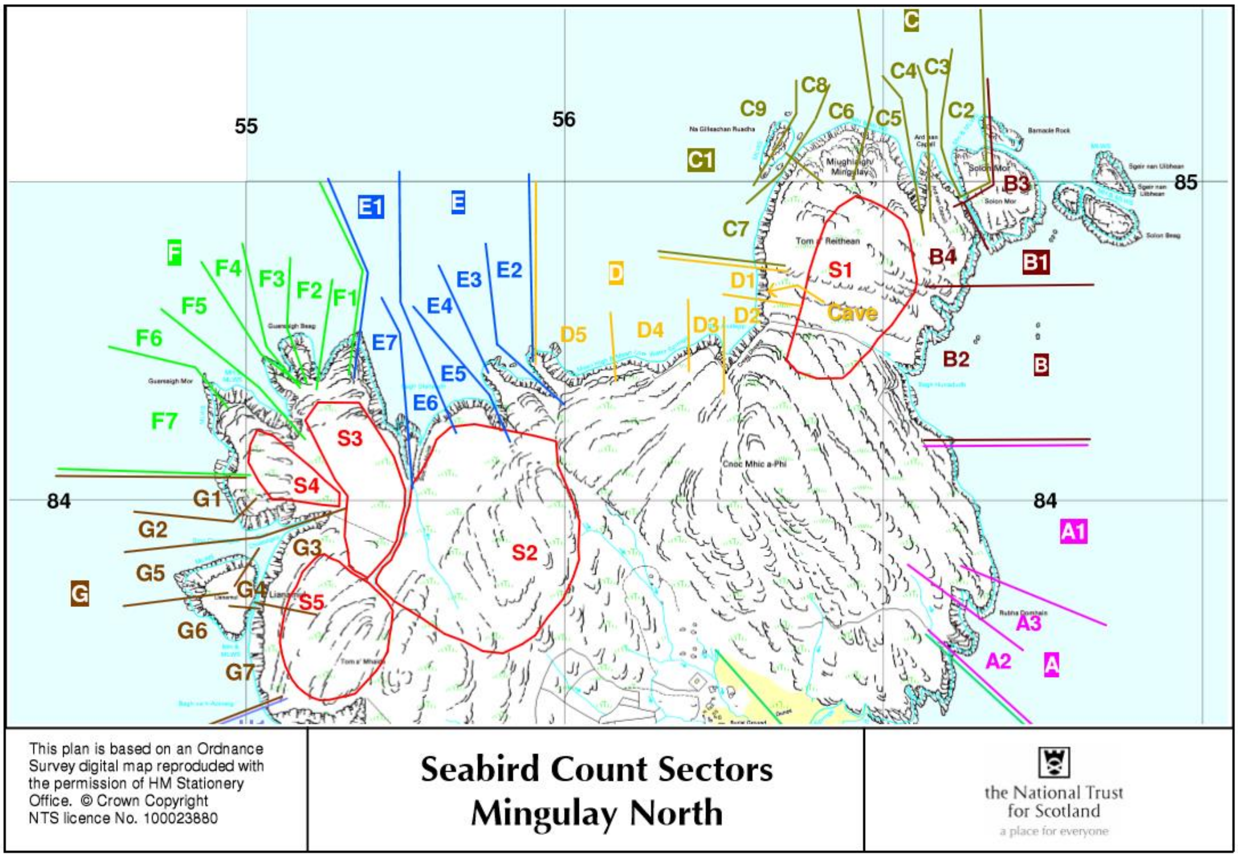


Figure 5: Mingulay North Seabird Count Sectors: showing study site E2

can be found in Appendix 1. The study site, E2, consists of a rock wall with sloping ledges of various widths on which the guillemots breed. The site is sheltered to the south by the island, and to the west by the small peninsula of E3/E4, so fish-carrying adults could be easily identified as they approached from the north.

Figure 6: The study site at E2, as seen from the observation point on E3 (Photo credit: Sarah Lawrence).

Figure 7: A young guillemot chick being predated by a greater black backed gull at the study site E2 (Photo credit: Sarah Lawrence).

During the whole-island census of guillemots conducted in 2014, 11,729 individuals were counted on Mingulay. Sector E2 lies in the part of the island with the greatest concentrations of guillemot presence (Dunn, 2013), and other species present on E2 included razorbill, kittiwake, fulmar, shag and puffins. Greater black-backed gull *Larus marinus* and great skua *Stercorarius skua* regularly entered the colony at E2 and predated on chicks of various species during monitoring (Figure 7).

2.2.2 Chick diet

Using 8x42 binoculars, birds were scanned as they approached the colony and individuals carrying fish were identified and followed until arrival at their breeding site. The use of a telescope for more accurate identification was considered, but binoculars allowed a faster reaction to approaching guillemots, without compromising the accuracy of identification. As they landed, guillemots spread their wings to provision the fish to their chick, and this allowed a short period of time for the fish to be identified and the size of the prey item classified.

The first chick was observed on the 17th June 2014, and two-hour watches were conducted during the day throughout the chick rearing period. Most observations (90%) were made between 11.00 – 16.00 BST in fine weather conditions, and usually two two-hour watches were taken each day, with a short break in between. Observations began on the 27th June and ended on the 24th July 2014. Data was not collected at the very beginning and end of the chick rearing period due to the low frequency of provisioning during these periods (fewer than 50% of the average rate of observations per hour were seen on the final day of data collection). Data was not collected during periods of bad weather, due either to low-lying cloud cover or heavy rain, which impeded visibility of incoming guillemots as well as causing the study site to become slippery and hazardous.

Each fish observed was identified and classed into one of the following categories: sandeels, clupeids, gadoids, other known prey (e.g. snake pipefish) and ‘unknown’. Visual examples of these species classifications are seen in Appendix 2. Fish were also classified by size, using guillemot bill length as guidance (“1” = 1 bill length). Any birds that landed a fish without provisioning the item were assumed to be non-breeders or failed breeders and these fish were classed as display items, which were excluded from analysis. During the observations, some feeds were not recorded due to several parents approaching the study site simultaneously, and other feeds were unrecorded due to ‘crash-landing’ parents, where the feeding was too rapid to allow identification of the fish. Data was also collected on environmental conditions including temperature and precipitation each day. An example of the data recording form, provided by Professor Sarah Wanless of the Centre for Ecology and Hydrology, can be found in Appendix 3.

2.3 Results

Research question 1:

Which prey types are present in the diet of common guillemot *Uria aalge* chicks on Mingulay?

Over the whole data collection period, from the 27th June – 24th July, 1092 prey items were classified (excluding display items) over 54 hours 41 minutes (one 2-hour observation period was aborted due a rapid decline in weather conditions).

Chick diet was dominated by gadoids and sandeels (most probably lesser sandeels *Ammodytes marinus*), followed by clupeids, as seen in Figure 8, and this is shown in Table 1. A very small number of fish could not be identified, and these were classed as 'unknown'. The ratio of gadoids: sandeels: clupeids observed was 1.22 **:** 1 **:** 0.63. No snake pipefish were observed during the season.

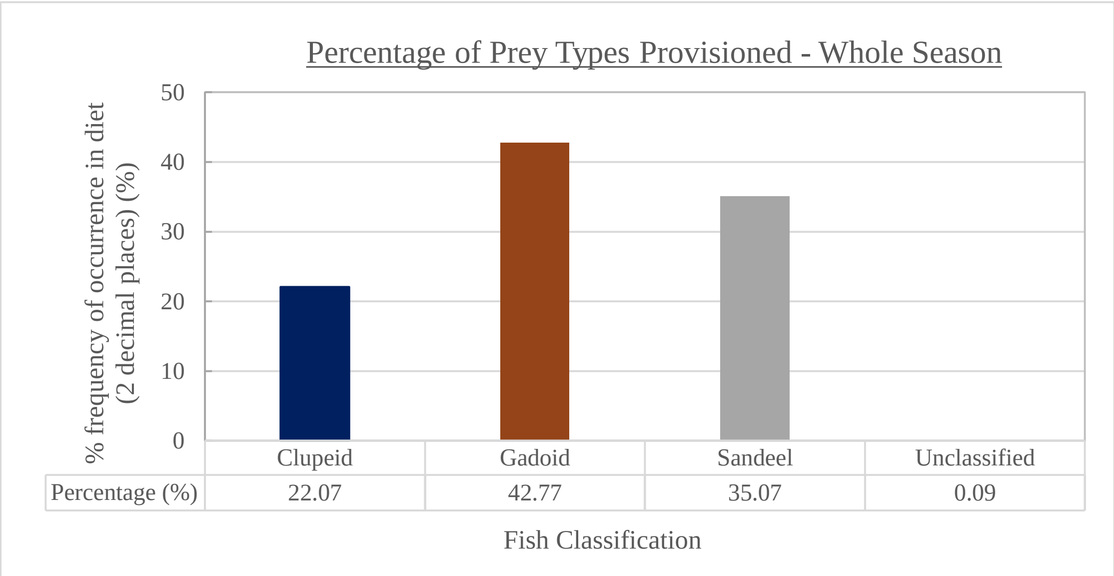


Figure 8: Percentage of each prey type provisioned during the whole observation period.

Table 1: The number and type of prey items provisioned to guillemot chicks in 2014

Prey Type	Total Number (n)	% of Total Prey Items (2 decimal places)
Clupeid	241	22.07
Gadoid	467	42.77
Sandeel	383	35.07
Unclassified	1	0.00
Total number of prey items provisioned	**1092**	

From 1st – 24th July, each fish that was observed was classified by prey type, and its size was ranked relative to guillemot bill length. A total of 829 prey items were classified by size within this period. Bill length was used as an appropriate scale, as it allowed a comparable estimate of prey size to be collected. Fish were placed in one of three size categories: 'small' or '1' for fish that were of the same length as the guillemot's bill. Only 5 fish were considered to be markedly smaller than '1' bill length across the whole observation period (4 gadoids and 1 sandeel), and since this size class was extremely small, those prey items were categorised alongside 'small' prey items. Fish of 1.5 bill lengths were classed as 'medium', and fish that were '2' bill lengths in size (or larger), were classed as 'large'.

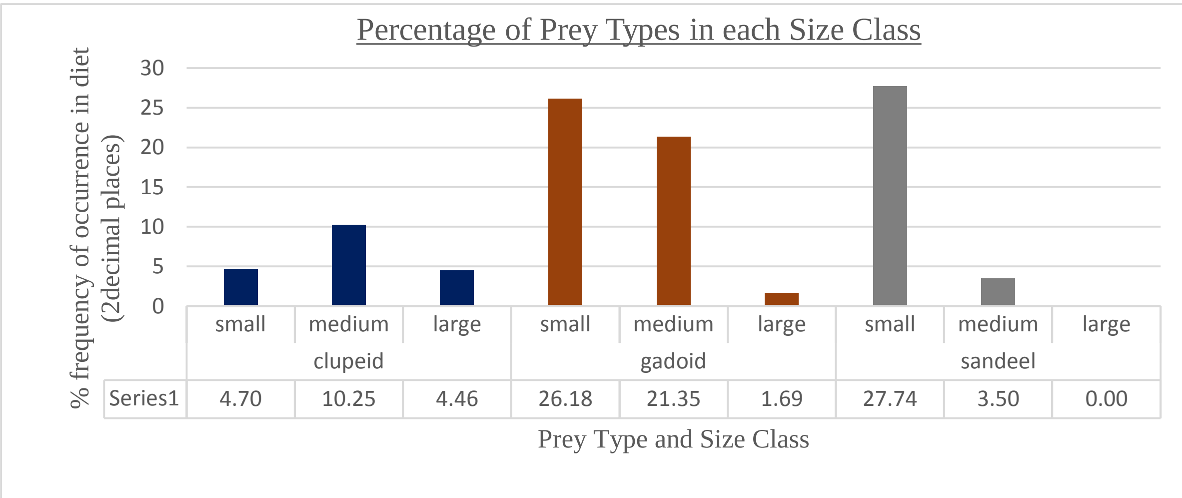


Figure 9: Percentage of prey provisioned within each size class.

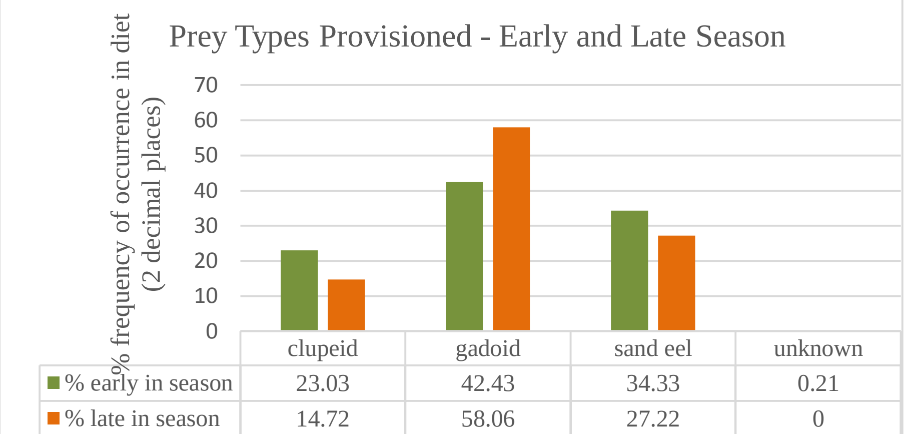
Between 1st July – 24th July, small sandeels dominated guillemot chick diet, comprising 27.74% of all prey provisioned. Small gadoids were the next most frequent prey item, comprising 26.18%, and medium gadoids also contributed a large percentage of total prey items at 21.35%, as seen in Figure 9.

Research Question 2:

Is there a seasonal variation in dietary composition?

It is possible that seasonal variation in prey availability or a change in feeding preferences may mean that there is an intra-seasonal variation in the prey species and size that are provisioned to chicks. For example, a very small, young chick may be unable to eat an extremely large fish, so parents may select against large specimens in the early stages of the chick rearing period. Therefore, seasonal variation in dietary composition was tested for using a χ^2 test.

The prey types provisioned early and late within the observation period were compared. All prey observed from the 1st – 24th July were classified by their size relative to guillemot bill length. As before, overall, gadoids were the most frequent prey type, followed by sandeels and then clupeids (both early and late in the season). However, the frequency of gadoids provisioned increased from 42% between the 1st and 11th July, to 58% between the 12th and 24th July. The frequency of sandeels and clupeids both decreased slightly, as seen in Figure 10. There was statistically significant variation between the frequency of each prey type in chick diet early and late in the feeding period; $\chi^2 = 20.62$, df = 2, $P > 0.01$.



	clupeid	gadoid	sand eel	unknown
% early in season	23.03	42.43	34.33	0.21
% late in season	14.72	58.06	27.22	0

Figure 10: Percentage frequency of occurrence in diet of each prey type, early and late in the chick feeding season.

In further χ^2 tests, intra-seasonal variation was broken down into fish size classes as well as prey type. As illustrated in Figure 11, small sandeels comprised 31.13% of chick diet early in the season, which decreased to 23.33% later in the season. Yates' Correction for Continuity was applied to a χ^2 test, which showed that there was no significant variation in the proportion of each sandeel size class provisioned early and late in the observation period; adjusted $\chi^2 = 1.460$, df = 1, $P < 0.05$ (Table 2). Small decreases were observed in each clupeid size class between the early and late observation period (Figure 11), so a χ^2 test was applied in order to test the significance of this variation. There was no statistically significant variation in the proportion of each clupeid size class provisioned early and late in the observation period; $\chi^2 = 1.909$, df = 2, $P < 0.05$.

The proportion of small gadoids in chick diet increased from 19.40% early in the observation period, to 35% later in the season (Figure 11). A χ^2 test showed with 95% confidence that there is a statistically significant association between the provisioning frequency of gadoids early and late in the observation period; $\chi^2 = 9.041$, df = 2, $P >$ 0.05 (Table 2). The results of the χ^2 test confirm that a higher than expected proportion of small gadoids were provisioned to chicks later in the observation period.

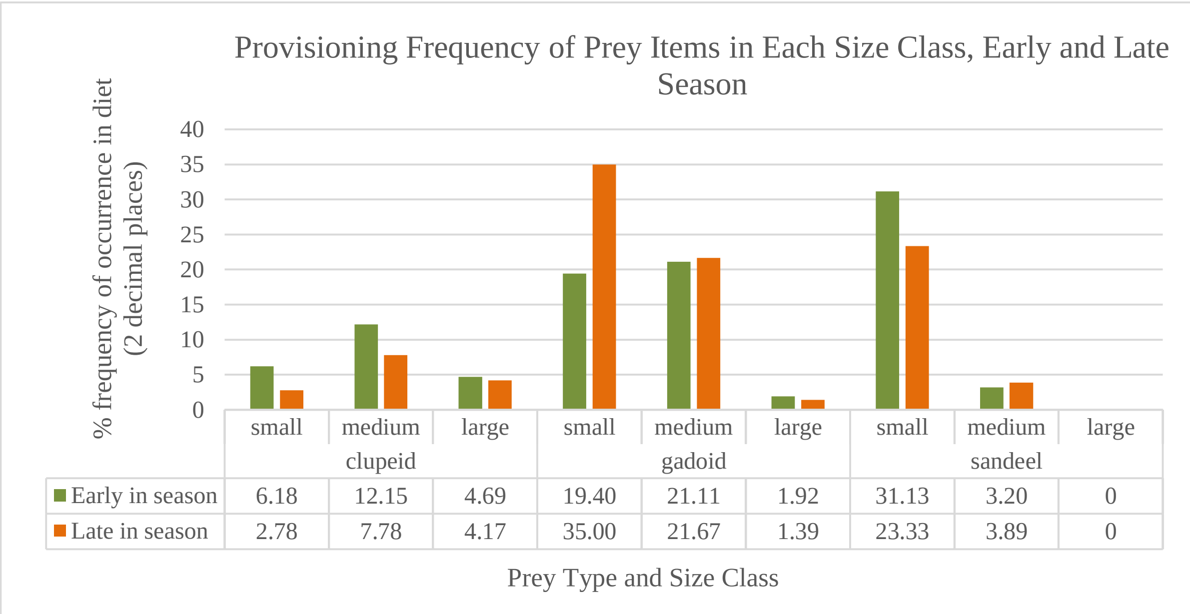


Figure 11: Percentage frequency of occurrence in diet of prey types in each size class, early and late in the chick feeding season.

Table 2: Prey composition across the whole observation period, and the results of Chi-Square tests exploring the relationship between a) chick survival at E2 and the whole island, b) seasonal variation in prey composition, and c) seasonal variation in the size of each prey type.

Prey Composition	
Observation date range (n)	27.06.2014 - 24.07.2014 (28)
No. sandeel *(% of total)*	383 (*35.07%*)
No. gadoids *(% of total)*	467 (*42.77%*)
No. clupeids *(% of total)*	241 (*22.07%*)
No. unclassified *(% of total)*	1 (*0.00%*)
Total Prey Items	1092
Whole island census (individuals)	11,729

a) Breeding Productivity

—— Chi-Square Test ——

— chick survival between E2 and the whole-island —

	Productivity rate ±SE	Chicks surviving ≥ 15d	Chicks surviving < 15d	Totals
Whole island	0.462 ± 0.046	204	238	442
Seabird count sector E2	0.536 ± 0.087	67	58	125
		271	296	567

Adjusted $\chi^2 = 2.168$ df = 1, P < 0.05

b) Seasonal Variation

—— Chi-Square Test ——

— proportion of each prey type, early and late in season —

	01.07.2014-11.07.2014 (early observation period)	12.07.2014-24.07.2014 (late observation period)	Totals
No. sandeel *(% of total)*	161	98	259 (*31.24%*)
No. gadoids *(% of total)*	199	209	408 (*49.22%*)
No. clupeids *(% of total)*	108	53	161 (*19.42%*)
Totals	468	360	828 (+ 1 'unclassified' item)

$\chi^2 = 20.62$ df = *2, P > 0.01*

—— Chi-Square Test ——

c) Prey Size

— size difference in each prey type, early and late in season —

	Sandeel (*'large' omitted from χ^2 test*)				Gadoid				Clupeid			
	Small	Medium	Large	Totals	Small	Medium	Large	Totals	Small	Medium	Large	Totals
01.07.2014 – 11.07.2014 (early observation period)	146	15	0	161	91	99	9	199	29	57	22	108
12.07.2014 – 24.07.2014 (late observation period)	84	14	0	98	126	78	5	209	10	28	15	53
Totals	230	29	0	259	217	177	14	408	39	85	37	161
	Adjusted $\chi^2 = 1.460$, df = 1, $P < 0.05$				$\chi^2 = 9.041$, df = 2, $P > 0.05$				$\chi^2 = 1.909$, df = 2, $P < 0.05$			

Research question 3: What are the management implications of changing prey availability on Mingulay?

While it is not possible to draw conclusions about the links between diet and productivity from just one season of diet monitoring, it should be noted that several years of monitoring data would allow for exploration of a connection between diet and productivity on Mingulay.

The overall productivity of guillemots on Mingulay in 2014 was 0.462 ± 0.046 fledged young per pair of breeding adults (Dunn, 2014). Productivity at the chick diet study site of E2 was slightly higher, at 0.536 ± 0.087 (Dunn, 2014), but there was no significant difference between E2 and the island's overall productivity rate; $\chi^2 = 2.168$, df = 1, $P < 0.05$ (Table 2). Productivity in 2014 was higher than recorded during 2013 (mean 0.289 ± 0.0917) (Dunn, 2013), and diet is a possible contributor to that change.

2.4 Discussion

The results showed gadoids and sandeels to be the prey type most frequently provisioned by guillemots at Sector E2 on Mingulay. Sandeels are usually the most abundant prey type provisioned by adults when they are available as they have a high lipid content and energetic value that is beneficial to chick growth and survival. The presence of a large proportion of gadoids within the diet is likely to be a reflection of suboptimal sandeel availability surrounding Mingulay, as gadoids are of lower energetic value, and are therefore a less desirable prey type than sandeel or clupeids.

In most guillemot colonies that have been studied in the UK, chicks feed predominantly on sandeels, with a secondary prey type becoming more abundant in chick diet when sandeel availability is low. The secondary prey type is usually either gadoids or clupeids, and the results of this study show gadoids to be the secondary prey type on Mingulay. Research has shown that the secondary prey type of guillemots varies according to latitude. At lower latitudes in the UK, clupeids are often the predominant alternative to sandeels, as observed at Bempton Cliffs, St Abbs Head, the Isle of May and Ramsay Island (Anderson *et al*. 2014). At colonies in higher latitudes, such as Fair Isle and Sumburgh Head, Shetland, gadoids are generally the predominant alternative to sandeels (Anderson *et al.* 2014). Due to Mingulay's location at a high UK latitude, it is unsurprising that gadoids were the predominant alternative prey type observed. Anderson *et al.* (2014) showed the variation in prey types provisioned at colonies around the UK, and also highlighted the need for more dietary monitoring in order to build a useful picture of sandeel availability around the UK. Some of the data included in Anderson *et al.* (2014) came from a single year of monitoring, and was not representative of guillemot chick diet in the longer term. For example, the study showed snake pipefish as dominating chick diet on St Kilda, although this prey type was only recorded for a very short period of time from 2006 – 2008, and is certainly not representative of long-term prey availability on the island. Dietary monitoring has since continued annually on St Kilda, a remote archipelago west of Mingulay, and in recent years chick diet generally comprises of 40-50% sandeels, 25-30% clupeids, and ~20% gadoids (Prior, 2011, 2012, 2013).

If the abundance and distribution of sandeels around the UK does change as a result of climate change, the results of this study suggest that guillemot diet on Mingulay would shift to become dependent on gadoids as their main prey type. As previously explained, gadoids are generally of lower nutritional value to chicks due to their low lipid content when compared to sandeels and clupeids. This means that an increase in the provisioning of gadoids could result in slower rates of chick growth and survival. Guillemot colonies that are predominantly dependent on clupeids as an alternative food source may be able to cope better with a decline in sandeel availability, because clupeids are of a similar energetic value to sandeels.

When looking at within-season changes in prey type (as shown in Figure 10), the results suggest that the proportion of sandeels in chick diet was lower in the second half of the observation period. While the proportion of sandeels in chick diet declined, the proportion of gadoids increased significantly. This shows that as the season progressed, gadoids became an increasingly important component of chick diet. This is thought to be as a result of decreased sandeel availability later in the season; and correlates with the phenology of sandeel populations. Adult sandeels retreat back to the seabed later in the season during June and July, burrowing into the sandy substrates in which they spend most of the year. This means that sandeels are less abundant within the water column, and less available to adult guillemots, which generally feed mid-water (Anderson *et al*. 2014).

The increased frequency of gadoids within chick diet may also be due to an increase in gadoid abundance later in the season. Densities of juvenile gadoids in western Scotland are generally highest during late summer and autumn, however, certain species are most abundant at various times of the year. Juvenile cod are often most abundant in May, saithe in July, and pollack from September – January (Kamenos *et al*. 2004). It is therefore possible that both gadoids and sandeels were readily available early in the breeding season, and that optimal foraging by adult guillemots resulted in the preferential feeding of energetically high sandeels to chicks. The within-season changes of prey type observed on Mingulay are consistent with those observed at other guillemot colonies around the UK (Anderson *et al*. 2014).

When the varying sizes of prey types were analysed, the most frequently provisioned prey item across the whole season was small sandeels. Since guillemots are single prey-loaders, the size class of prey provisioned to chicks is important because larger items indicate higher quality (Anderson *et al.* 2014). The majority of sandeels and gadoids observed on Mingulay were classed as 'small' – which is defined as being approximately equal in length to the guillemot's bill. The majority of the remaining prey items were classed as 'medium' in length, which was defined as approximately equal to 1.5 bill lengths. These size definitions were subjective and at risk of observer bias (Anderson *et al.* 2014). Observations were 'standardised' across the season since there was only one observer who defined each prey item on the same scale, minimising potential bias. Nevertheless, bias is a possible issue in classifying prey lengths since 'small', 'medium', and 'large' by the definition used are perhaps not equal to the average 'small', 'medium' and 'large' sandeel, and this may explain why a normal distribution of size observations is not seen for sandeels within figure 11. There is further potential for bias because prey items are categorised according to their size in relation to the bill whilst the majority of the fish is obscured within the bill. This means that the head of the fish may be held at different depths within the guillemot's mouth, making it difficult to assess its true size.

Prey type identification was straightforward with the aid of the Centre for Ecology and Hydrology (CEH) identification guide (Appendix 2). Additional photographs and ongoing research into prey type appearance and identification meant that prey items were classified with some confidence. Despite this, it would have been beneficial to verify species by collecting and identifying dropped fish, which could confirm the species of sandeel that is seen on Mingulay. Unfortunately this was not possible due to the topography of the study site. Due to the speed with which prey items were delivered to chicks within the colony, it was not possible to collect photographs of reasonable quality for identification. This would have added additional confidence and verification to the study.

Since gadoids comprised a large proportion of chick diet, species specific identification would be beneficial in order to better understand guillemot chick diet on Mingulay. Unlike observations of clupeids – which are most usually sprat at the species level, there are several potential gadoid species that could be provisioned. In the short time available to identify prey, identification at the species level was not possible, but through personal observation, several different gadoid species were provisioned. Guillemots have been known to feed their chicks young whiting *Merlangius merlangus*, saithe *Pollachius virens* or cod *Gadus morhua* (Anderson *et al*. 2014) so it is possible that some of these species were present within chick diet on Mingulay.

3 Great Skua Diet Study

3.1 Introduction

The population of great skuas *Stercorarius skua* on Mingulay is increasing (Dunn, 2014), and the impact of their predation on smaller seabird species is not known. Great skua populations are thought to have been artificially increased through the ready availability of fisheries discards as a food source (Votier *et al*. 2004a). With the quantity of fisheries discards due to decrease as a result of changes to the Common Fisheries Policy, there is a risk that great skuas may become more reliant on other seabird species as a food source.

Great skua diet on Mingulay has not previously been monitored, so this study will serve as an initial assessment of the species' feeding preferences on the island. The research problem addressed in this study is the threat of increasing great skua predation on other seabird species on Mingulay, particularly black-legged kittiwakes and auks.

The study will explore the following research question:

1. To what extent does the great skua colony on Mingulay predate on other seabird species?

This research question will result in data showing the proportions of each food group that are found within great skua diet on Mingulay. This will allow an understanding of how important seabirds are as prey to the island's great skuas.

This study will act as baseline data, showing the extent of great skua predation upon other seabird species prior to the discard ban. Such an understanding can allow the impact of the discard ban to be understood, and this will inform future management decisions regarding the great skua population. An increase in predation on species such as black-legged kittiwakes (henceforth 'kittiwakes') could pose a threat to their future success on Mingulay.

3.1.1 Study Species

The great skua *Stercorarius skua* is a large, speckled brown skua with broad white wing flashes, seen in Figure 12a. The species breeds across Iceland, Norway, the Faroe Islands and the north of Scotland, where they nest on coastal moorland in large, scattered colonies (Furness, 2010). They usually lay one or two speckled olive brown eggs within grass-lined nests (Figure 12b); the species is highly territorial and aggressively defensive of its nest site. Approximately 60% of the species' Apparently Occupied Territories (AOTs) are located in Scotland, where their population increased by 26% between 1985-1988 and 2002 (Mitchell *et al.* 2004). Great skuas are kleptoparasitic predators, feeding on prey scavenged from other seabirds, as well as shoaling fish, small seabirds and fishery discards – particularly during winter months (Votier *et al*. 2004a).

Figure 12: a) A great skua in flight. b) A great skua nest and egg on Mingulay (Photo credit: Sarah Lawrence).

3.1.2 Background and State of Knowledge

In recent decades, an abundant source of food for great skuas has been fish discarded from fishing vessels, which are thought to have contributed to an increase in the species' population (Votier *et al*. 2004a). The impending discard ban (or 'landing obligation') in the EU is likely to make discarded fish a less easily accessible food source for great skuas (Bicknell *et al*. 2013). Another food source exploited by the species are lipid-rich shoaling fish such as the sandeel, which are declining as a result of climate change (Votier *et al*. 2008). These declines raise concerns that great skuas may switch their feeding behaviour to rely more heavily on the predation of small seabird species.

This dietary study was prompted by the rapid growth in the breeding population of great skuas present on Mingulay. The first pair of great skuas were recorded on the island in 1979, rising to five pairs in 1985 (Rennie, 1988). The population continued to grow, with 43 Apparently Occupied Territories (AOTs) recorded in 2003 (Dunn, 2013), 71 AOTs in 2012, and most recently 117 AOTs recorded in 2014 (Dunn, 2014). The rapid colonisation and increase in the population of great skuas present on Mingulay presents a concern that predation by great skuas may be detrimental to other breeding seabird species on the island. Auks and kittiwakes are known prey items of great skuas, and the impact of their predation on kittiwakes is a particular concern.

Kittiwake populations across the UK have been declining in recent years (Mitchell *et al.* 2006), and the colonies on Mingulay have echoed these declines. Mingulay hosts 2% of the UK's kittiwake population (Scottish Natural Heritage, 2009b), with 2,875 Apparently Occupied Nests (AON) recorded in 2014. This figure represents a decline of 42% since 2003, and an estimated decline of 71% since 1949, when between ~8,000 to ~10,000 pairs of kittiwakes are thought to have been present on the island (Dunn, 2014).

Great skuas are thought to have contributed to severe declines in kittiwake populations at some colonies in Scotland. One of the most notable kittiwake declines has occurred in Shetland, where there has been over a 90% decrease in the number of AONs since 1980, with local extinction of some colonies – which predation by great skuas is thought to be partly responsible for (Scottish Natural Heritage, 2013).

The declines observed in kittiwake populations are also thought to be associated with oceanographic changes caused by climate change, as warmer winters cause a reduction in sandeel recruitment, and therefore a decrease in prey availability, which reduces their breeding success (Frederiksen *et al*. 2004). Commercial fisheries have caused a reduction in prey availability that is associated with poor survival and breeding success of kittiwakes, and together these two factors are thought to have played an important part in the species' decline (Wanless *et al.* 2010).

As stated, the population of great skuas present on Mingulay has steadily increased whilst the kittiwake population steadily decreased during the past 40 years. This correlation does not necessarily imply that great skua predation is the cause of the initial decline observed in kittiwakes. The pressure of declining forage fish availability affects both species, but unlike kittiwakes, great skuas are generalist predators, able to adapt and switch their feeding behaviour according to food availability. Kittiwakes are a sandeel specialist, so they are less able to respond to changes in prey availability caused by climate change (Wanless *et al*. 2005). Therefore, as kittiwake populations decline in response to reduced shoaling fish availability, great skuas may be responding to shoaling fish and discard declines by increasing their predation of smaller seabirds including kittiwakes (Votier *et al*. 2004a).

Such a change in the diet of great skuas is not unlikely; research has shown a direct link between the reduction of shoaling fish and fishery discards with an increase in seabird predation by great skuas (Votier *et al*. 2004a). The result of this dietary change is that kittiwake populations are subject to both top-down and bottom-up regulation (Votier *et al.* 2008); with the low abundance of forage fish reducing their breeding success at the lower trophic levels, while predation by great skuas is further reducing their populations from above.

Recent reforms to the Common Fisheries Policy (CFP) mean that it will no longer be permitted to discard catches of quota fish species. A landing obligation will be phased into fishing practice from late 2014 onwards, and by 2019 this obligation will apply to fisheries across the EU (European Commission, 2015). These reforms to the CFP will be beneficial to the marine environment, as they will reduce the quantity of waste from within the fishing industry. They may have some positive impacts for seabirds, such as reducing the number of birds caught as bycatch in fishing gear, and reducing the unnaturally high numbers of generalist scavengers that have thrived since discards have been a readily available food source (Bicknell *et al.* 2013). However, in the short-term, scavengers may begin to adapt to the reduced availability of discards by switching to alternative food sources, such as seabirds. If such a switch in great skua diet was observed on Mingulay, this could be harmful to the island's already declining kittiwake population.

3.2 Methodology

3.2.1 Study Location

Mingulay's great skua colonies are widespread across the west of the island, and are most concentrated in sectors S3-S5 in the north-west. The samples collected within this study were taken from seabird sectors S2, S3, and S5, as seen in Figure 5. Samples were collected from these locations due to their proximity to the study site of the Guillemot Diet Study, E2.

3.2.2 Diet

Great skuas regurgitate pellets, containing the indigestible remains of their diet. At two points within the breeding season (05.07.2014 and 28.07.2014), great skua pellets were collected from a random sample of AOTs. A total of 59 pellets were collected from 26 AOTs (13 on each date). Since great skuas are highly territorial, each pellet could be attributed to a particular nest site, so it could safely be assumed that several pellets collected within a territory belonged to the same pair of breeding individuals. This allowed the general dietary preferences of each territory to be established, since some great skuas are specialist feeders on certain food types. Once the pellets were collected, their contents were analysed and categorised by type; auk, other seabird, goose barnacle, egg, fish, or other/unknown. All otoliths (ear bones of fish, which can allow identification at the species level) were removed from pellets and stored to allow more specific identification of the fish species consumed.

3.3 Results

Research Question 1:

To what extent does the great skua colony on Mingulay predate on other seabird species?

From a sample of 26 AOTs, pellets were collected early and late within the breeding season. In total, a sample of 59 pellets were collected. Seabird remains were identified in 88.5% of the AOTs sampled (including those containing both fish and seabird pellets), with the remaining 11.5% of AOTs containing pellets comprising only of fish-based remains.

The prey types identified within pellets included auks, kittiwakes (‘other seabirds’), several fish species, and rabbits. One pellet contained rabbit remains in the form of fur and bones. Notably absent from the analysis were pellets containing the remains of goose barnacles, which are commonly found in skua diet at some other colonies.

Feathers from auks and kittiwakes were found in many pellets – although in some cases it was difficult to identify their remains to the species level. Due to the similarities between kittiwake and Northern fulmar feathers, these pellets were classed as ‘other seabird’, though it is likely that kittiwakes accounted for the majority of these. In most cases, pellets contained only feathers, which meant that identifying auk remains to the species level was rarely possible. In a small number of pellets, auks could be identified to the species level by the presence of their bill; one razorbill was identified, and three guillemots – two of which were chicks.

Eggshell fragments were present in 18% of pellets from the initial collection early in July, but in none from the second collection later in the month. This is likely as a result of availability, since the majority of species’ eggs had hatched by the second collection. Of the 6 pellets containing eggshell, 2 were identified as guillemot eggs due to their blue-green colour; while the others were cream / brown but could not be identified due to the similarities in colour between razorbill, kittiwake and great skua eggshells.

The percentage of each prey type found overall from each AOT within the initial pellet collection is illustrated in Figure 13, and from the second collection in Figure 14.

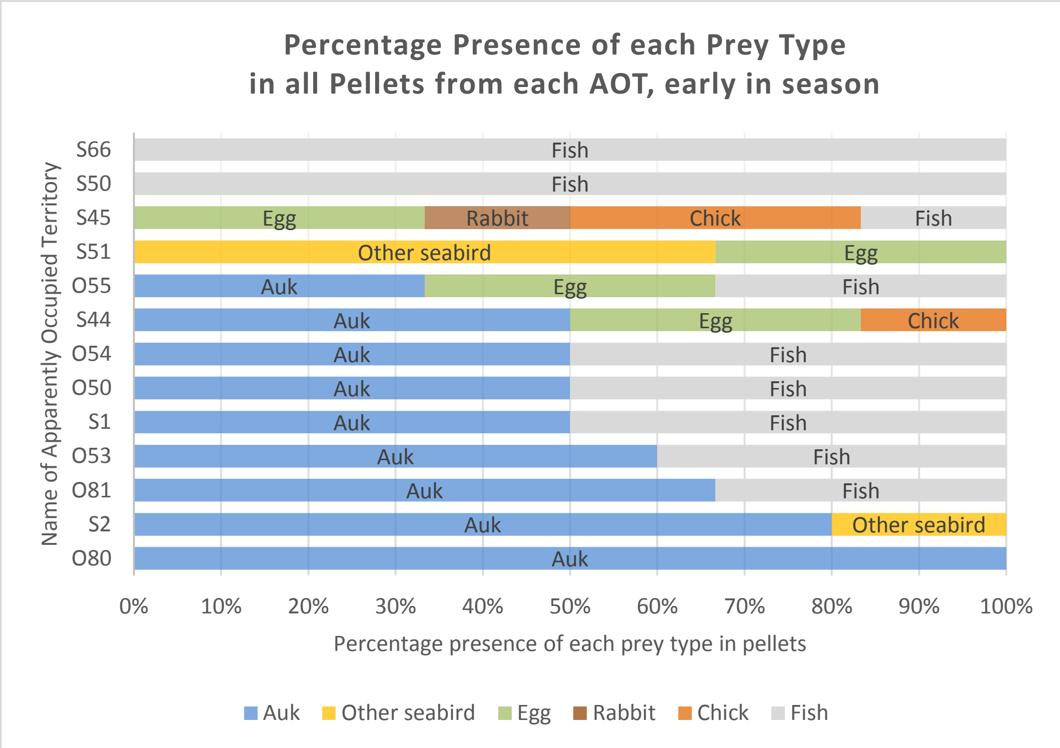


Figure 13: The percentage presence of each prey type in all pellets from each AOT (early in the 2014 season). The name of each AOT represents the name of its GPS mark from the 2014 census count of great skua AOTs.

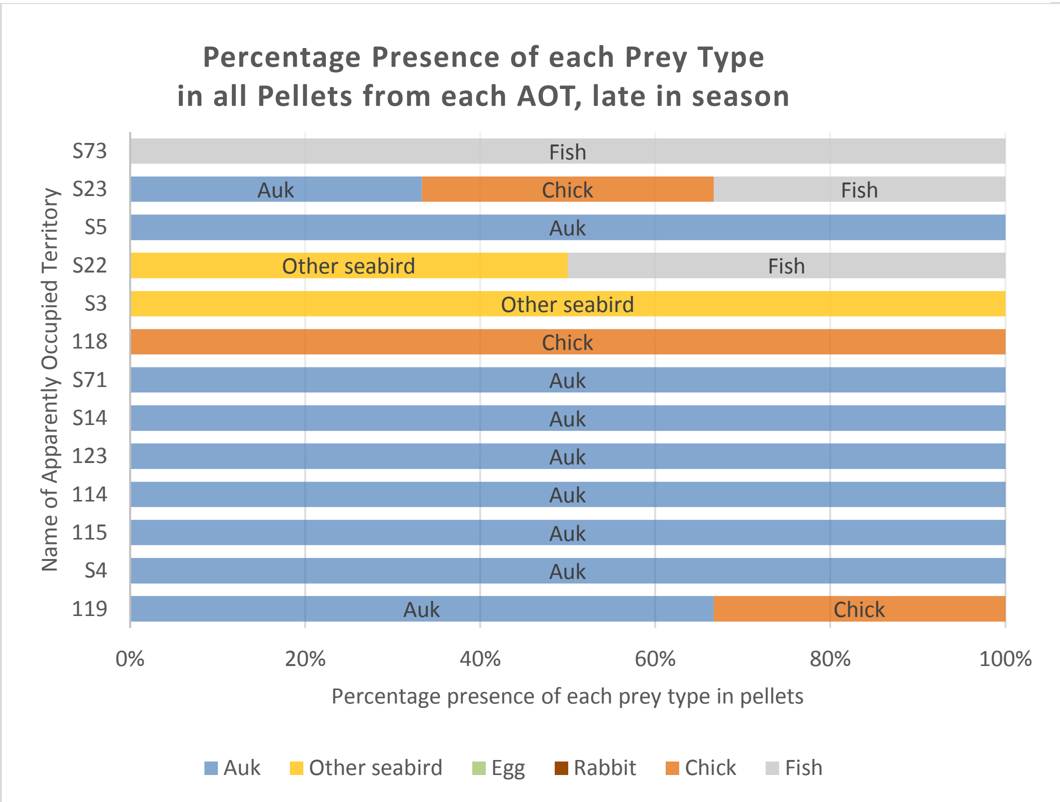


Figure 14: The percentage presence of each prey type in all pellets from each AOT (late in the 2014 season). The name of each AOT represents the name of its GPS mark from the 2014 census count of great skua AOTs.

As Figures 13 and 14 show; seabirds were the most frequent prey type found within great skua pellets. While the results suggest that auks are the predominant prey type, this category includes three species on Mingulay; Atlantic puffins, razorbills and common guillemots.

The results also showed that fish were more regularly found in great skua diet early in the season, though due to the small sample size, it is not possible to test whether there is a statistically significant intra-seasonal change in great skua diet. It is possible that the quantity of fish within great skua diet was under-represented in the results of this study, because, due to their non-fibrous consistency, fish-based pellets disintegrate more easily – particularly if there has been a period of bad weather. All pellets were collected following dry weather in order to minimise this bias, but it is still possible that fish formed a larger proportion of great skua diet than is represented within the results. Research into the efficiency of pellet analysis by Votier *et al.* (2001) suggests that when sandeel and sprat are consumed by great skuas, pellets are not produced. Some fish species such as herring and mackerel have very small, easily digestible otoliths, and are often under-represented within pellet analysis, which presents a further possibility that more fish was consumed by great skuas than this dietary analysis suggests (Votier *et al*. 2003).

Otoliths were collected from all pellets for more specific identification. Identification of otoliths was attempted, and in some pellets a large number of small otoliths, thought to be sandeel, were identified. Several fish species were certainly present within the pellets that were collected; however, due to a lack of expertise, it was not possible to identify otoliths to the species level with any degree of certainty. All otoliths collected within this study have been retained in case their identification may contribute to further study – if they belong to demersal fish species, it is probable that the fish were scavenged from discards, since great skuas are surface plungers and unable to catch demersal species.

The results showed that seabird prey (including eggshell and chick remains) was found in 88% of all pellets collected. The frequency of chick remains increased from 9% in the first collection to 20% in the second, which could be indicative of the increased availability of large chicks as the season progressed. Of the seabird-containing pellets, 11% contained both seabird and fish remains, since great skua pellets do not necessarily represent a single meal. However, it is possible that some of the fish remains found in pellets alongside seabird remains represented a recent meal of the seabird prey item. For these reasons, it is very difficult to quantify the amount of seabird prey that was taken by great skuas, or produce a representative proportion of seabird prey within the diet from this sample of pellets.

Although the sample size was low, and would ideally have been larger in order to allow a greater degree of confidence in the results, observations from the guillemot diet study site suggest that ongoing predation effort by skuas occurred at sector E2. Unfortunately the frequency of great skua predation efforts was not recorded, but the species was observed attempting predation of auks and kittiwakes at E2 on a daily basis (Figure 15a). The successful predation of a kittiwake chick from sector E2 was observed on 01.07.2014, as seen in Figure 15b, so there is no doubt that some great skuas were actively predating on kittiwake chicks. It could be beneficial to record great skua predation effort alongside any future monitoring of guillemot chick diet.

Figure 15: a) A great skua predating on a kittiwake chick at sector E2. b) A great skua with a kittiwake chick (Photo credit: Sarah Lawrence).

The small sample size was a limitation to this study, which would have ideally included a larger sample of AOTs. It would have been beneficial to sample the same AOTs at several points within the breeding season in order to understand how the dietary preferences of great skuas changes throughout the season, and to better understand whether certain breeding pairs specialise in particular food types. In addition to sampling actively breeding skuas, a sample of pellets from the club site (where non-breeding individuals are found) would have been beneficial, as non-breeding individuals can exhibit different feeding behaviour. The difficulty of accurately identifying prey to the species level was a particular challenge to this study, especially since the predation of kittiwakes is a concern on Mingulay, and the lack of otolith identification was a major limitation. Nevertheless, the results suggest that the majority of great skua diet on Mingulay consists of seabirds, their chicks and eggs.

3.4 Discussion

The results show that great skua diet sampled on Mingulay comprised heavily of seabirds, their chicks and eggs. This confirms that a substantial level of predation on smaller seabird species is occurring on Mingulay, but the diet of great skuas does show variation, and skuas are also feeding from other sources such as fish. Great skuas can exhibit dietary specialisation, though usually only a small number feed exclusively on other seabirds (Votier *et al*. 2007). It is not possible to confirm that individual birds are seabird specialists on Mingulay due to the limited data collected in this study. However, seabird specialist skuas are known to defend feeding territories, so it is possible that this behaviour occurs on Mingulay (Votier *et al.* 2004b).

Seabird specialists have been found to have larger clutch volumes and hatch chicks of better condition than those not specialising in seabirds. This could be a result of their spending less time foraging due to their proximity to their food source, and because the fittest individuals in the population are able to defend high quality seabird feeding grounds (Votier *et al.* 2004b). This could mean that although the number of birds specialising in seabird prey is low, there is still a consistent predation effort by those individuals that are able to defend a feeding territory. In Shetland, around 5% of the breeding population are seabird specialists, and these individuals take just 30% of all seabird prey consumed (Votier *et al.* 2004c), with the majority being taken opportunistically by generalist individuals (Votier *et al*. 2007). Despite this, the ability of seabird specialists to predate even on the least accessible seabird prey meant that these individuals accounted for all of the kittiwakes that were predated upon during monitoring in Shetland (Votier *et al*. 2004c). It would be useful to understand whether similarly targeted foraging is occurring and influencing kittiwake declines on Mingulay.

There are many factors influencing the predation of seabirds by great skuas, among which is colony size. It has been found that in larger great skua colonies, the percentage of seabird prey within the diet is lower. This is thought to be because per-capita access to seabirds is lower at larger colonies (Votier *et al*. 2007), though the actual pressure of predation on seabirds may not be reduced. Since Mingulay's great skua colony is continuing to grow, this information is relevant as it suggests that there may be a maximum level of seabird predation. This is a result of the territorial and kleptoparasitic behaviour of great skuas themselves – as the population of great skuas increases, so does the density of individuals feeding upon other seabirds. This results in more competition and aggression between individuals, reducing the benefit and profitability of seabirds as prey items (Votier *et al.* 2007).

Nevertheless, the impending changes to the CFP that will phase a landing obligation into Scottish fisheries are likely to result in increased competition for seabird prey, as a result of the reduction in readily available discards. It is uncertain how reliant the great skua colonies on Mingulay are on discards as a food source, but the results suggest that fish are not a large part of their diet. The west coast of Scotland hosts fewer commercial fisheries than the east, which borders the heavily fished North Sea. It is therefore possible that west coast great skua colonies are less reliant on discards in the first place, and that the new landing obligations will pose less threat of great skua diet switching to seabirds than it does in colonies bordering the North Sea region. This could be the case, since at other west coast colonies including Handa Island (Jones *et al*. 2008) and St Kilda, the occurrence of seabird prey in great skua diet is higher than at colonies such as Foula, Shetland which borders the North Sea (Furness, 1997). However, fish do form part of great skua diet on Mingulay, so there is still a threat that predation on seabirds could increase – and since fish-based pellets disintegrate more easily that those from seabird prey, it is possible that they have been under-represented within this study (despite all AOTs being thoroughly searched for pellets).

Islands in other parts of Scotland have experienced similarly rapid colonisation and population growth of great skuas in the last 50 years; an example is St Kilda, 64km to the west of Mingulay. Great skuas were first recorded on St Kilda in 1963, and in 2014, 270 AOTs were recorded (Prior, 2014), which represents a slight decline in the population since the initial period of rapid growth (Miles, 2010). Great skua diet on St Kilda consists of a high component of seabird prey, which is a cause for concern since the island hosts internationally important congregations of several species (Phillips *et al*. 1999), in particular the Leach's storm-petrel *Oceanodroma leucorhoa*, of which 94% of the population in the UK and Ireland breeds on St Kilda.

Despite the large amount of predation by great skuas on St Kilda, the majority of Leach's storm-petrels predated upon are thought to be non-breeding individuals. This is, of course, a positive indication for the longevity of the breeding population under increased predation, but it does raise concerns that the impact of great skua predation may be concealed until a decline in recruitment to the breeding population occurs in the future. It has been speculated that the same situation may be true for breeding kittiwakes on St Kilda, since, in 2008 an estimated 1,174 kittiwakes were consumed – which would represent 61% of the AONs (each representing 2 individuals) identified that year. It seems unlikely that the breeding population could continue under this level of predation, so non-breeders may have been subject to much of that predation (Miles, 2010). From the results of this study, it is of course not possible to know whether there is any predation bias towards breeders or non-breeders on Mingulay. However, it may be important to consider that there could be concealed declines in the non-breeding populations of auks and kittiwakes, which also relieve the pressure on breeding populations.

A large extent of the great skua population increase on St Kilda is thought to be as a result of immigration from other colonies (Phillips *et al*. 1999), and it is certainly possible that immigration has also contributed to Mingulay's rapid population expansion. Although the west coast of Scotland does not host the same scale of fisheries as the east coast that borders the North Sea, and therefore prey-switching by resident great skuas may be less of a concern, it is possible that immigration could cause predation to increase. When the availability of discards and sandeels from commercial fisheries around Shetland declined in the past, great skuas from colonies in Shetland are thought to have been among the individuals that migrated to St Kilda (Phillips *et al.* 1999). With even more rapid and substantial declines in discards anticipated due to the new landing obligations, the possibility that juveniles are willing to migrate to more suitable colonies to breed raises concerns that the number of great skuas could continue to increase rapidly in future years. If individuals from other colonies – particularly those where great skuas are reliant on fisheries discards, migrate to colonies where there is less intra-specific competition for seabirds as prey such as Mingulay, the consequences for small seabird species on the island could be very concerning.

On other colonies that have experienced a recent and rapid colonisation of great skuas, their populations have been seen to eventually plateau and stabilize to a relatively consistent size (Votier et al. 2004a). This pattern of growth since colonisation has been seen on St Kilda, and it is possible that great skua population growth on Mingulay will stabilize when intra-specific competition for seabird prey becomes too high, or when the colony density becomes too high to provide suitable nest sites. The latter seems unlikely to occur soon, since further suitable habitat exists on Mingulay, and on neighbouring Berneray, where only 5 AOTs were recorded in 2014 (Dunn, 2014). The breeding productivity of great skuas on Mingulay remains low, and was calculated as 0.215 ± 0.127 in 2014. This figure is higher than the 0.021 ± 0.021 found in 2013 (Dunn, 2014). This, combined with the ongoing occurrence of immigration by skuas into western Scotland, suggests that immigration into the breeding population may pose the greatest risk of increasing predation to seabirds on Mingulay. Continuation of dietary monitoring would allow the impacts of the increasing great skua population on Mingulay to be better understood – particularly in light of the changing discards legislation.

4 Atlantic Puffin Census and Productivity Study

4.1 Introduction

This study will explore the following research questions:

1) What is the population of the Mingulay Bay puffin colony?
2) What is the productivity of puffins breeding at the Mingulay Bay colony?

4.1.1 Study Species

The Atlantic puffin (hereafter 'puffin') is a small species of auk, approximately 18cm tall and between 350 – 600g in weight. It is easily distinguishable in the summer by its black and white plumage, orange feet and characteristic tall, flattened bright orange and red bill (Harris & Wanless, 2011), as seen in Figure 16. The puffin is the second most common British seabird, generally breeding in burrows on grassy cliff-tops or in natural holes in the cliff face. Most populations are located on isolated islands, as is the case of the puffins breeding on Mingulay, which is located 20 kilometres south of the nearest inhabited island, Barra (Dunn, 2013).

Figure 16: Atlantic puffins at the Mingulay Bay study site (Photo credit: Sarah Lawrence).

4.1.2 Background

The SPA designated at Mingulay was extended in 2009 to include a marine component (Figure 2), which aims to protect species that are dependent on the marine environment, and their feeding grounds (Malcolm *et al.* 2012). All of the seabird species mentioned within this document fall into that category, but the Atlantic puffin is one species for which less census and productivity data exists. Since Mingulay is an SPA and SSSI, it is important that such data is collected in order to inform its protected status. In 2012, a report was commissioned by Marine Scotland to identify population trends of breeding populations on SPAs. The report concluded that insufficient data existed to plot trends in the Atlantic puffin populations across Scottish MPAs, including Mingulay (Malcolm *et al*. 2012).

Since Scotland hosts 80% of the EU's puffin population (Mitchell *et al.* 2004), the collection of breeding population data on Mingulay is important as it can contribute to the understanding of trends over time. Trend data can be used as a component of Environmental Impact Assessments (EIA) and Habitats Regulation Appraisals (HRA) used to inform potential developments. For SPAs with marine components, such potential developments may include offshore wind, wave and tidal schemes. If such a scheme were to be mooted near to the Mingulay & Berneray SPA, then regular population and trend data would be advantageous as it would allow risk assessments and management decisions to be made with a higher degree of certainty (Malcolm *et al*. 2012).

The puffin is a charismatic species that contributes to a 'sense of place' for many people in Scotland (RSE, 2012). The puffin's intrinsic value and contribution to national identity is certainly motivation to build on the existing breeding population data on Mingulay, to allow for their future conservation. This intrinsic value of biodiversity is recognised within the European Union (EU) vision for 2050: "*European Union biodiversity and the ecosystem services it provides – its natural capital – are protected, valued and appropriately restored for biodiversity's intrinsic value and for their essential contribution to human wellbeing and economic prosperity, and so that catastrophic changes caused by the loss of biodiversity are avoided"* (EU Commission, 2011).

The importance of intrinsic value and the EU vision for 2050 are in line with the environmental principles of the National Trust for Scotland, which manages the island. The NTS Biodiversity Policy Aim states that: "*The Trust will act to conserve biodiversity on its land and properties and will promote biodiversity conservation in Scotland*", and their environmental policy recognises a "*responsibility to protect and care for the environment of Scotland for the benefit of all*." (National Trust for Scotland, 2011). The conservation aims of the National Trust for Scotland provide further motivation to monitor the puffin breeding population in order to better inform management decisions.

4.2 Methodology

4.2.1 Mingulay Bay Census

A census count was conducted at the Mingulay Bay Puffin colony, which is located at monitoring sector Q2 (Figure 17) between the 11th and 15th June 2014. Mingulay Bay hosts the most accessible puffin colony on the island, but certainly does not represent puffin numbers on the island as a whole. Two other accessible puffin colonies exist on Mingulay, located on Dun Mingulay (sector L1) and the Promontory of Arnamul (sector J4). Ideally, the census would have occurred slightly earlier in the season, from early to

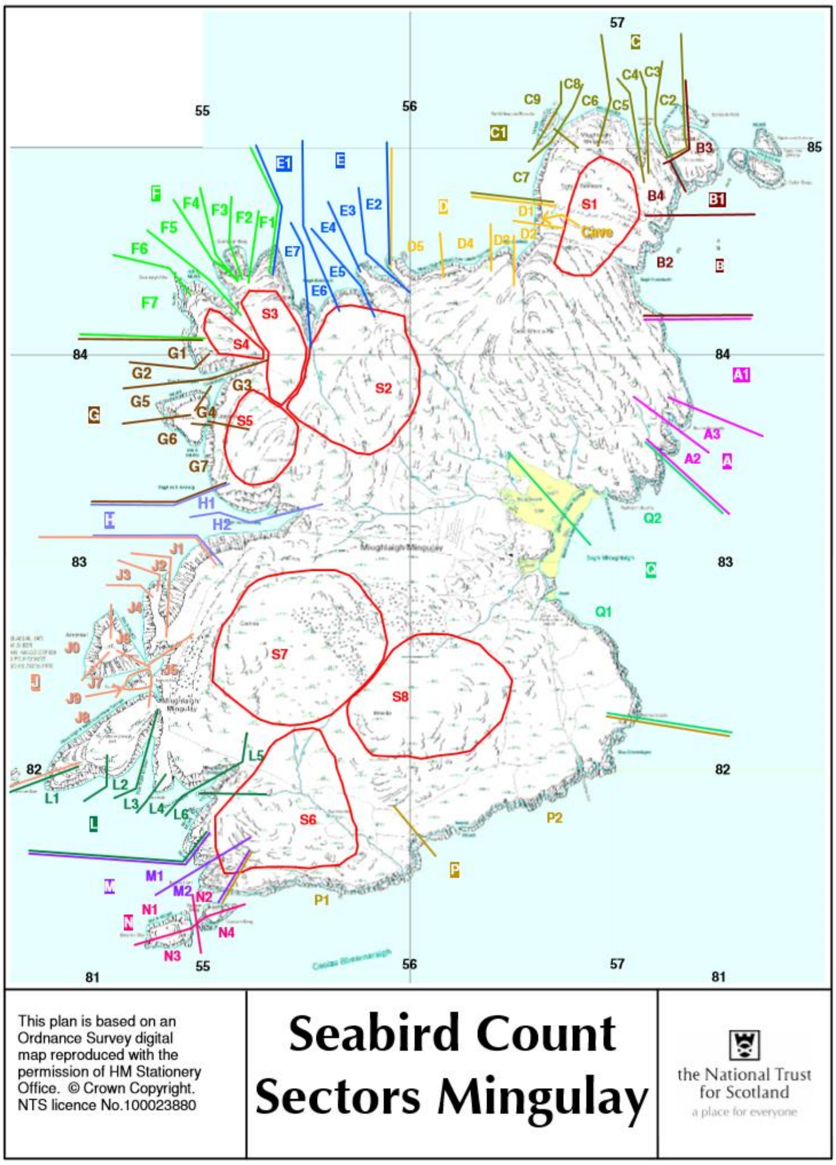


Figure 17: Seabird count sectors for the whole island, featuring sector Q2 on the north side of Mingulay Bay.

mid-May – as suggested within the Seabird Monitoring Handbook (Walsh *et al*. 1995). However, counts taken before August are still deemed acceptable, and these dates are in line with census counts taken in other years (28th May and 21st June 2012, and 23rd June 2011).

The census units used were 'Apparently Occupied Burrows' (AOBs), and due to the small area of the Mingulay Bay colony, a full census was carried out. This method of assessing the number of AOBs by counting all the burrows in a colony is the preferred approach due to its accuracy (Harris & Wanless, 2011), but is rarely possible due either to constraints of access, safety or time. The Mingulay Bay puffin colony is easily accessible; located mainly on a grassy slope, and steeper, rocky slopes with thick vegetation at the boundaries of the colony (as seen in Figure 18). Due to the ease of its access, one person could safely count the AOBs over several days; and due to the timing of the guillemot chick rearing period, there was sufficient time available to complete each area of study without compromising the other.

Figure 18: The Mingulay Bay puffin colony is located on a grassy slope with steeper rocky areas (Photo credit: Sarah Lawrence).

The limits of the census area are defined in Figure 19. The colony was segmented using rope to define its boundaries, and using these boundaries as a guide, each segment of the colony was carefully walked, counting each AOB as it was encountered. AOBs were identified as defined within the Seabird Monitoring Handbook (Walsh *et al*. 1995):

"*Apparently occupied burrows are characterised by signs of regular use, such as fresh digging, hatched eggshells, or fish in the entrance. Rabbit burrows are usually larger, usually have much soil outside, and often have droppings at the entrance and conspicuous runs through the vegetation leading away.*"

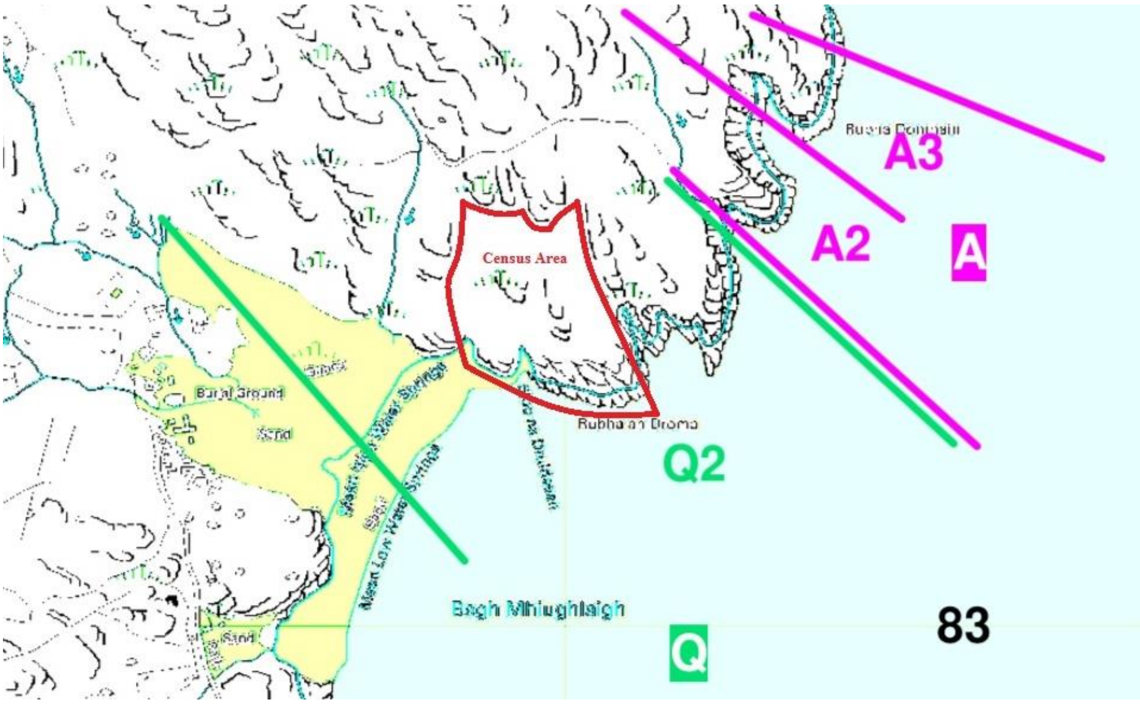


Figure 19: The boundaries of the puffin census area.

4.2.2 Productivity Study

To assess the productivity of the Mingulay Bay puffin colony, productivity-monitoring method 1 – staked burrows – from the Seabird Monitoring Handbook (Walsh *et al*. 1995) was used.

This method is appropriate to Mingulay due to the nature of the colony; which is accessible, with burrows that are in soil, and no Manx shearwaters are present on the island:

1. A series of burrows, dispersed throughout the colony, were identified from the 7^{th} – 10^{th} June 2014.
2. A bamboo cane (~50cm long), was gently pushed into the burrow using an arm, and eggs were felt-out with the stick on the floor of the nest chamber (the incubating puffin moves off the egg).
3. A video borescope was used alongside bamboo canes in order to identify burrows containing an egg.
4. A bamboo cane was staked outside each burrow where an egg was felt or observed.
5. The burrows were re-checked on the 18^{th} June, 7^{th} & finally 27^{th} July towards the end of the season, and successful nests were determined. A successful nest is identified by "*feeling the chick, finding the chick's latrine at the first bend of the burrow, or searching for moulted down among the nest-lining*".

A total of 25 burrows were identified as containing eggs, and these burrows were staked with bamboo canes for later re-checking. The burrows were staked in early June, which is later than recommended within the Seabird Monitoring Handbook, but perhaps the greatest challenge was the number of burrows identified; 25, as the recommended sample size for a puffin productivity study is 100 burrows. The small sample size means that the results – while still an indicator of productivity at Mingulay Bay – should be treated with caution.

Identifying an adequate number of active burrows was a major constraint to this study, as the majority of burrows that were visited were very long, containing a number of bends and large rocks. This made it difficult for either an arm, a bamboo cane or the (approximately 1 metre) video borescope to reach the nest chamber within. The video borescope, however, was of great use in identifying the final 25 burrows, and allowed a greater degree of certainty of their active occupation than the bamboo canes alone. Figure 20 shows a puffin within its nest chamber, as captured by the video borescope.

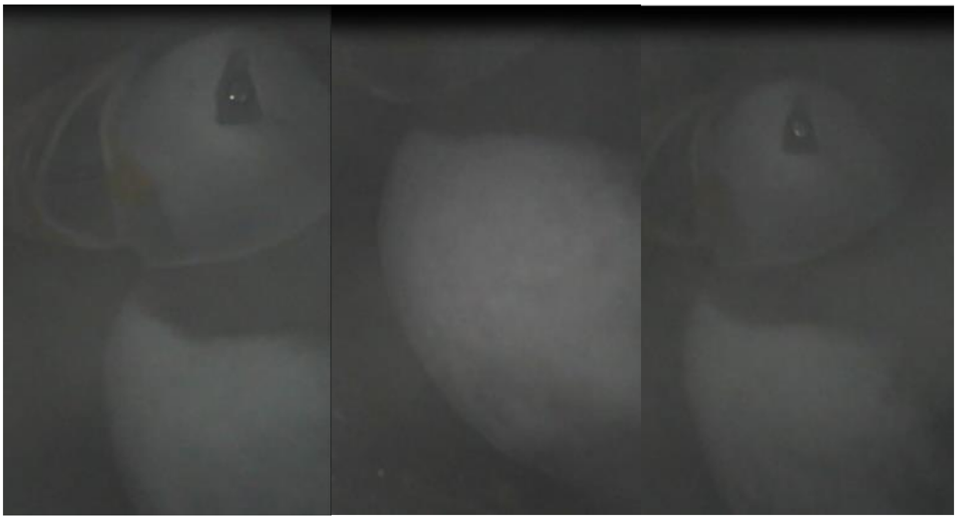


Figure 20: Puffin seen within its burrow using the video borescope (Photo credit: Sarah Lawrence).

4.3 Results

4.3.1 Mingulay Bay Census

Research Question 1:
What is the population of the Mingulay Bay puffin colony?

The number of Apparently Occupied Burrows counted within the boundaries defined within Figure 11 was 893 burrows.

Each AOB was identified in line with the Seabird Monitoring Handbook guidelines (Walsh *et al*. 1995), and the final figure should be treated as an approximation of the number of occupied burrows at the Mingulay Bay colony.

4.3.2 Productivity Study

Research Question 2:
What is the productivity of puffins breeding at the Mingulay Bay colony?

Of the 25 initially staked burrows, 24 burrows were re-found, allowing the presence or absence of a chick to be determined. The one 'lost' burrow is not included in the calculation of productivity.

Puffin productivity was calculated according to the recommended method 'Productivity Monitoring Method 1' within the Seabird Monitoring Handbook, and a successful nest was defined as one where either; the chick could be felt in the nest, a latrine was identified at the first bend of the burrow, or moulted down was identified among the nest-lining.

The productivity rate is expressed as "*the number of chicks present divided by the total number of burrows re-found where presence or absence of a chick was determined"* (Walsh *et al*. 1995).

Table 3: Puffin Productivity Rate and estimated DSR at Mingulay Bay (Q2)

	2013	2014
Re-found burrows	19	24
Successful nests	3	17
Productivity rate	0.158 ± 0.164	0.708 ± 0.182
Days of nest exposure	-	1133
Daily Survival Rate	-	0.994
Breeding period (days)	-	84
Adjusted productivity rate	-	0.594 ± 0.153

Puffin productivity at the Mingulay Bay puffin colony was calculated as 0.708 ± 0.182 (Table 3), which is higher than the 0.158 ± 0.164 recorded in 2013 from a comparable sample size of 19 burrows (Dunn, 2014). Due to the small sample size, the high productivity rate recorded of 0.708 ± 0.182 should be considered with caution, but nevertheless this figure does suggest that Mingulay's puffin population has experienced improved breeding success in 2014.

Mayfield's correction for exposure was applied to the data, since the productivity rate calculated at 0.708 ± 0.182 does not account for early losses prior to the identification of active burrows, nor for mortalities that may occur following the final observations (Mayfield, 1961). The estimated Daily Survival Rate (DSR) over the study period (with 1133 days of nest exposure) was 0.994. With a breeding season length of 84 days, the adjusted productivity rate at the Mingulay Bay puffin colony is estimated as 0.594 ± 0.153 (Table 3).

4.4 Discussion

4.4.1 Mingulay Bay Census

The census count of puffins in Mingulay Bay recorded 893 AOBs. Each AOB represents a breeding pair of puffins, so the estimated number of breeding birds at the Mingulay Bay colony is approximately 1,786 birds in 2014. It is possible that some human error meant that burrows were 'missed' within the undergrowth, despite the census being thorough and methodical. As the breeding season progresses, immature ‘non-breeding’ puffins arrive at the colony, sometimes inhabiting unoccupied burrows. It is possible that these individuals may have caused some false AOBs to be counted; but this should not significantly impact the census count, since it was undertaken relatively early in June. Studies have shown that puffin census counts are consistently underestimated, so it is likely that the census count at Mingulay Bay is a conservative estimate (Calvert & Robertson, 2002).

The number of puffins recorded on Mingulay has varied wildly in the years that it has been collected. Due to their nesting habitat, it is very difficult to obtain an accurate count of puffins. Various methodologies have been used to estimate puffin populations over the years. This makes it not only difficult to have confidence in the number of puffins recorded, but also casts doubts over the trends in population size that have been observed; since even a standardised methodology with flaws of accuracy can succeed in showing annual trends if it is consistently applied.

Intermittent attempts have been made to estimate puffin populations on Mingulay in the past, but due to their nesting habitat, it is very difficult to obtain accurate population counts, and various different monitoring methods were used. For this reason, it is not possible to estimate trends in the puffin population on Mingulay prior to the recent monitoring at Mingulay Bay. Census counts at the Mingulay Bay sample plot (Q2) over the last 3 years have shown a similar number of AOBs to the 893 recorded in 2014, which suggests that puffin populations have remained stable in recent years.

There were some limitations to the 2014 census count, including the inability to conduct the census slightly earlier in the season, when AOBs could be identified with more confidence due to the decreased chance of non-breeding individuals being present within the colony. The difficulty of identifying active burrows with a high degree of certainty, and the possibility of some inaccessible or unseen burrows is also a limitation, although this is an ongoing challenge at puffin breeding colonies in general.

Although the census represented a thorough count of AOBs at the Mingulay Bay puffin colony, there are two other accessible colonies on the island, located at Dun Mingulay and the Promontory of Arnamul. Breeding puffins are also present in scattered numbers at other locations around the island, and it would have been advantageous to conduct a census of these areas in order to reach the best possible estimate of puffin population numbers for the island.

4.4.2 Productivity Study

The adjusted productivity rate calculated for puffins at the Mingulay Bay colony was 0.594 ± 0.153, higher than the 0.158 ± 0.164 calculated during the 2013 season. The increase in productivity suggests that the 2014 breeding season was successful for puffin colonies on Mingulay. Other puffin colonies on the west coast of Scotland have also recorded high rates of productivity during the 2014 breeding season, such as St Kilda, which has been suffering a long term decline in breeding success (National Trust for Scotland, 2014).

Undoubtedly the greatest limitation to this study was the small sample size of 24 burrows. The sample size recommended in the Seabird Monitoring Handbook is 100 burrows, so 24 burrows was not ideal. The small sample size means that the productivity rate recorded should be treated with caution, as a 'best estimate' since no further burrows could be suitably identified.

A possible solution could be to attempt identifying further occupied burrows for a productivity study on Dun Mingulay and the Promontory of Arnamul, as well as Mingulay Bay. This would mean that a larger overall sample size could be achieved, which would allow the final productivity rate to be calculated with a greater degree of confidence and reliability. It would also mean that the productivity rate was representative of puffins across the island, since the colonies may experience different pressures that affect their breeding success. For example, the puffin colony at Mingulay Bay is regularly visited by groups of day-trippers during the summer months, and it is possible that they could influence breeding success. Equally, the puffins at Dun Mingulay and the Promontory of Arnamul on the west of the island are in closer proximity to great skua territories, and may be more vulnerable to predation. There is not currently any evidence to suggest that these pressures do affect puffin productivity on Mingulay. However, with both tourism and great skua populations increasing on the island, it could be beneficial to better understand the state of puffin population dynamics.

5 Recommendations and Conclusions

5.1 Guillemot Diet Study

The most important recommendation that can be drawn from this study is that dietary monitoring should be continued annually in future monitoring seasons. A long-term study of chick diet on Mingulay would reveal a greater variety and depth of knowledge than one season of data alone can produce. Continuation would allow a better understanding of the way in which chick diet and sandeel availability is changing over time. If chick diet over a series of years was known then it would be possible to see how prey availability on Mingulay affects guillemot productivity, and could help to explain trends in productivity of other species such as kittiwakes.

On a larger scale, continuing to collect dietary data would add to the current knowledge of guillemot chick diet as an indicator of prey availability on the west coast of Scotland, which is currently lacking in data compared to the east coast and North Sea region. Since nationally important congregations of the UK's breeding seabird populations are resident in the Western Isles, it can only be beneficial that the region is better represented in studies of seabird diet and prey availability.

A substantial number of hours were spent collecting dietary data for this study, but in future monitoring seasons this may not always be possible. Monitoring could be continued on a smaller scale in order to provide some dietary data when time and resources are limited. The study site at E2 is visited regularly by the island's Seabird & Marine Ranger (approximately every three days) throughout the breeding season as part of productivity monitoring. The feasibility of spending an extra 1-2 hours at E2 on some of these days in order to collect guillemot diet data could be explored, as this would produce a reasonable quantity of data and allow trends in prey availability across the season to be observed.

If the study were to be continued annually, then it is recommended that some effort be made to verify the fish species that are observed. This would ideally be through the collection of dropped fish samples; though since collection of samples is unlikely to be feasible, collection of photographic verification should be attempted.

A potential change to the methodology used would be to conduct watches of selected guillemot chicks' diet over a set period of time. From this data an average feeding rate could be calculated, which would allow tracking of changes in parental effort according to prey availability, and therefore a better understanding of guillemot productivity in relation to diet could be established.

In terms of management implications, the findings of the guillemot chick diet study are interesting, since they suggest that gadoids are the alternative prey type of guillemots in the Western Isles. The lower nutritional value of gadoids when compared to sandeels and their other possible alternative, clupeids, means that if a reduction in sandeel availability occurred, chick survival and growth rates could suffer. Anthropogenic climate change is the most probable cause of sandeel decline in the region – and practical management on a small and immediate scale would of course not be possible to counteract this. However, if changes in sandeel availability were identified in the future, this data could be useful as part of long-term monitoring to advise changes to fishing effort in the region. The data could also be used to inform management decisions regarding the protected areas surrounding Mingulay, particularly the marine component of the SPA, as it illustrates the seabird's dependence on sandeels as a food source, and shows that clupeids are not widely available as a comparatively high-energy prey item.

This study has met its research aim to establish the prey items and seasonal variation within the diet of common guillemot chicks on Mingulay. Immediate management implications cannot be drawn from this study, due to its short time-frame and the global nature of the greatest threats to guillemot prey. However, if the identified recommendations for further study are embedded into the regular monitoring programme on Mingulay, then the influences of climate change and SST on Mingulay's seabirds can be tracked over time. This may allow mitigation measures to be developed, and would provide much needed evidence of climate change impacts, providing an incentive for national or European level climate change mitigation that could slow the observed trends in SST.

5.2 Great Skua Diet Study

It is recommended that dietary monitoring of great skuas on Mingulay is repeated regularly, in order to understand the impact of predation upon other seabird species. It is important that monitoring should be repeated prior to the discard ban being fully implemented in 2019, as this will allow any impacts of the ban to be monitored. It is evident that seabird prey forms a large part of great skua diet on Mingulay, but a greater effort should be made to identify the otoliths found within pellets, since this data could reveal the extent to which great skuas are feeding on demersal fish species that are often obtained from fisheries discards. Due to the small sample size within this study, it is not possible to quantify the impact of predation by great skuas upon other seabirds, and long-term monitoring would reveal annual changes in great skua diet.

If the study is continued in future breeding seasons, then it is recommended that a larger sample size is collected, to ensure that the results are representative of the colony as a whole. While a relatively large area of the skua colonies on the north of Mingulay are represented within this study, it would be beneficial to collect samples from the colony on the south of the island in seabird monitoring sectors S6, S7 and S8 (Figure 17), since it is possible that their diet may differ in its composition.

The implementation of a larger scale study would allow the collection of a larger sample of pellets across the whole season. Using the GPS points collected during the annual census and productivity study, it would be possible to collect pellets from a chosen sample of AOTs several times throughout the season, since they are regularly visited during productivity monitoring. This would mean that the changing diet of each AOT could be better understood throughout the whole season, revealing changing pressures upon great skuas' seabird prey. For instance, there may be more predation upon seabirds later in the season – as the results of this study suggests may be the case. If a large sample of pellets was collected, then it would be possible to apply a correction factor to the data, and obtain results that are more representative to the true proportions of each prey type within great skua diet (Votier *et al*. 2001).

It is not possible to draw management implications from this study, due to its small scale and data limited to one season. Only from long-term dietary monitoring, as well as the population and productivity monitoring that is currently in place, can it be understood whether predation by great skuas is a factor driving the declines in other species such as the kittiwake. The large amount of seabird prey found within this study suggests that this is a possibility, and that further monitoring would be worthwhile. If future monitoring were to confirm that great skuas are causing continued declines on the island, as elsewhere, the options for management are very limited. The great skua itself is Amber listed as a bird of conservation concern (Mitchell *et al*. 2006), and despite recent population increases, the great skua remains globally rare due to its limited distribution within Europe. Implications for great skua management were considered on St Kilda as a result of predation on the internationally important species that breed there. Culling was considered as an option to reduce the amount of predation on other vulnerable seabirds, but this option is unfeasible for several reasons, not least the great skuas own protected status. Artificially reducing the population of great skuas is unlikely to be effective, since this would encourage further migration to the island, potentially disrupting recruitment at other colonies, so this option would be unlikely to relieve predation pressure on other species (Phillips *et al.* 1999).

If the implementation of the discard ban is found to cause predation by great skuas to increase beyond levels that are sustainable for other seabird species, then it may be possible to reduce great skua predation on a local scale. This could be achieved by reducing discards at a slower rate, and implementing better protection for seabirds in other ways, such as by reducing mortality through bycatch or designating their feeding grounds as Marine Protected Areas. Ensuring that local sandeel grounds have adequate protection could help seabird species such as kittiwakes by increasing food availability, which could increase their breeding productivity. Great skuas also feed on forage fish such as sandeels, so increasing the recruitment to these stocks locally could reduce the quantities of seabird prey in great skua diet (Votier *et al*. 2004). The waters surrounding Mingulay are already designated as an SPA, and the East Mingulay SAC has recently been designated, affording more local protection to seas surrounding the island. The East Mingulay SAC protects a cold-water coral reef complex, which acts as a valuable spawning ground for some species, so the seabird colonies on Mingulay may benefit from the designation of this SAC in the future (Henry *et al.* 2013).

5.3 Atlantic Puffin Census and Productivity Study

It is recommended that a census count of puffins is repeated annually, and that an effort should be made to include puffins in the whole-island census count if possible. Conducting a census of puffin populations is time consuming and can only ever result in a broad estimate of puffin numbers. Nevertheless, including the other areas of the island that are well populated by puffins, such as Dun Mingulay and the Promontory of Arnamul in the count of AOBs would result in the most accurate possible estimation of their numbers.

Repeating a thorough count of AOBs within the fixed sample plot at Q2 on an annual or 5-yearly basis would allow a more accurate estimation of puffin trends to be collected, as, since the historic data has not been collected using a consistent methodology or section of the island, it is difficult to know the true fluctuations of puffin populations over the years.

It is also recommended that a productivity study should be repeated annually. Ideally, a larger sample size should be included in future productivity studies, in order to improve their reliability and accuracy. However, it is difficult to identify suitable burrows on Mingulay due to their length and rocky nature, so this may not be possible. The feasibility of conducting a productivity study on Dun Mingulay and the Promontory of Arnamul should be investigated. This would allow a larger sample size to be achieved for the island as a whole, and thus a more accurate productivity rate could be obtained. Understanding population dynamics at each of the accessible puffin colonies on the island would also be beneficial as it would mean that changes between each colony could be observed, rather than using a productivity rate from just one colony as a proxy for the whole island.

The logistics of implementing puffin monitoring on a larger scale would be time consuming and most probably require two people for the western colonies, due to the challenge of accessing these sites. These factors should be considered when assessing the feasibility of increasing puffin monitoring alongside the established monitoring of other species.

It is not possible to draw direct management suggestions from this study, due to the small sample size, the limited trend data and the complexity of factors influencing changes within puffin populations. However, it is important to continue, and increase the scope of puffin monitoring into the future, so that the natural and anthropogenic factors influencing population changes can be understood.

Perhaps one of the more important reasons to understand puffin population trends is the ongoing threat of marine developments such as aquaculture and renewable energy. The planning of such developments would certainly be influenced by seabird populations locally, and their impacts could only be understood in relation to long-term trend data prior to development.

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Appendices

Appendix 1: Photographs of the study site, E2

Figure 21: The direction from which prey-carrying guillemots return to E2. The cliff to the right of the picture is the study site E2, sheltered from the west by E3 (seen left). (Photo credit: Sarah Lawrence)

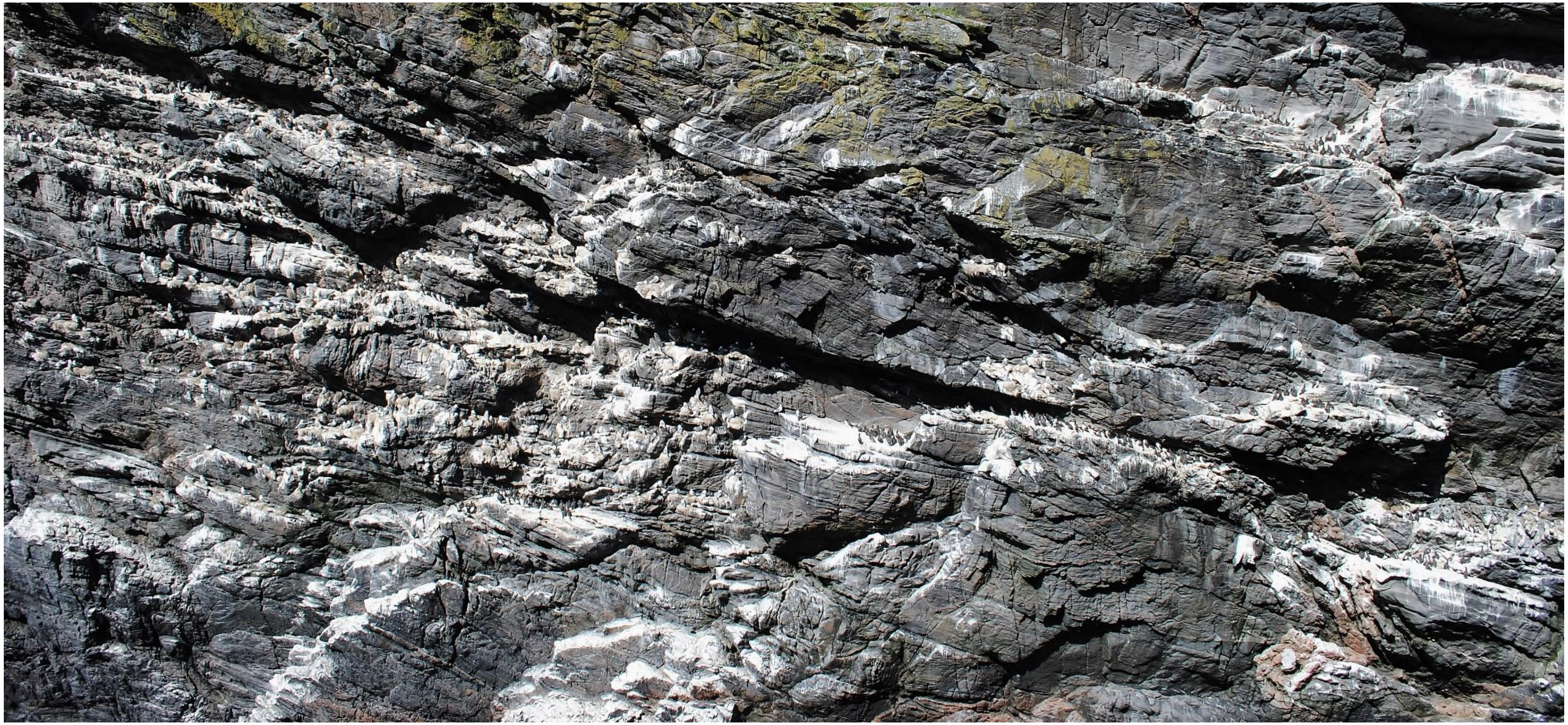


Figure 22: Wide view of the study site E2. (Photo credit: Sarah Lawrence)

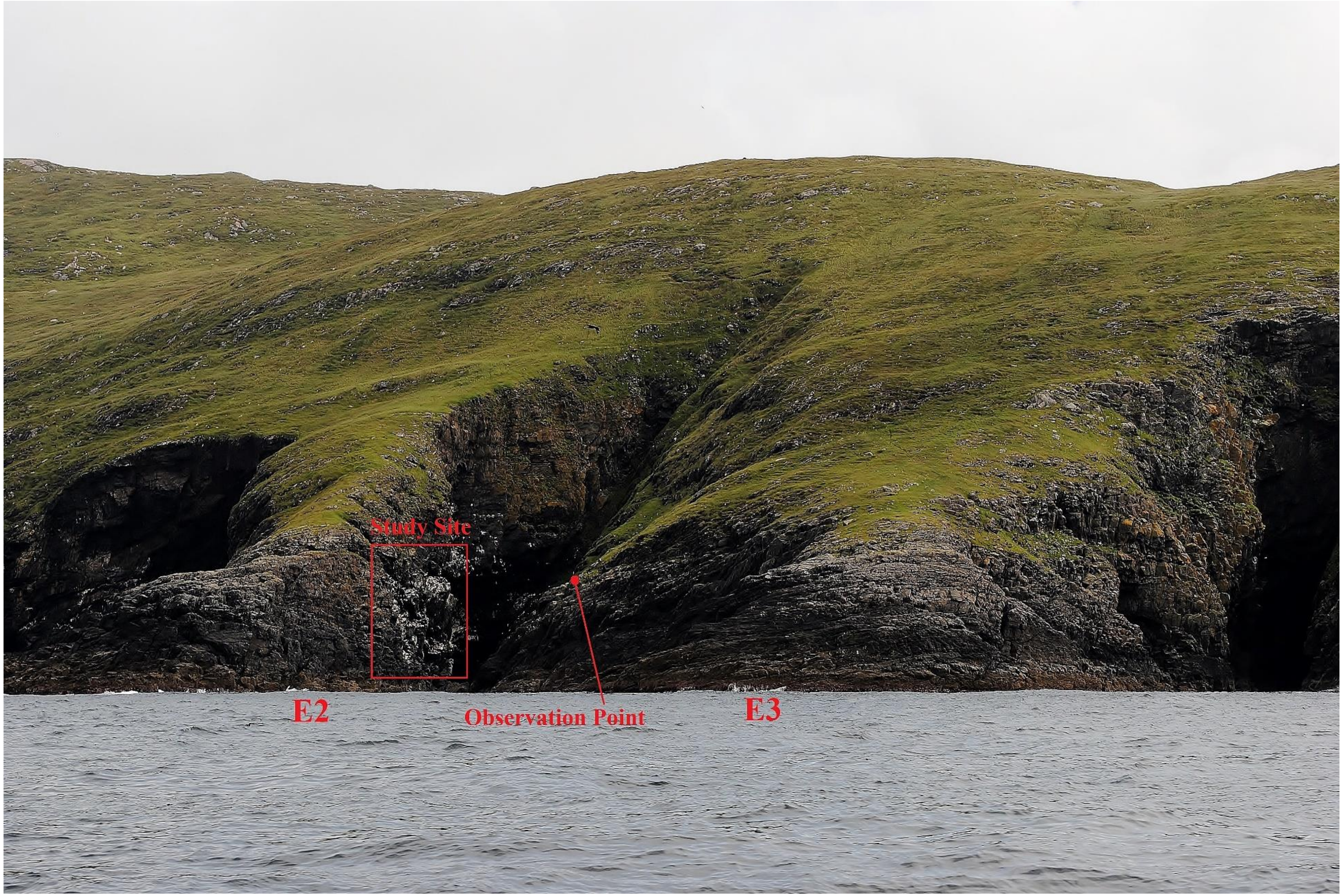
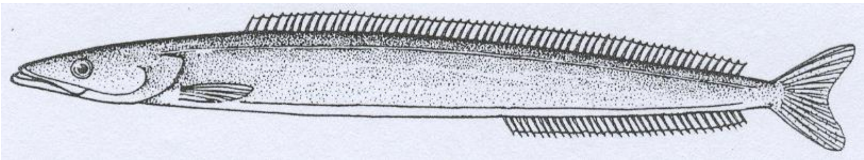


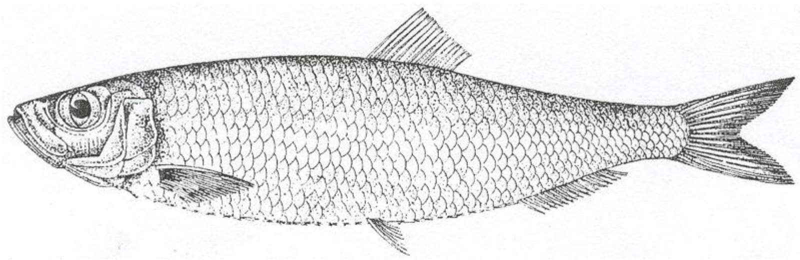
Figure 23: View of the study site E2 and its location from sea. (Photo credit: Sarah Lawrence)

Appendix 2: Identification Guide to Fish Prey of Guillemots

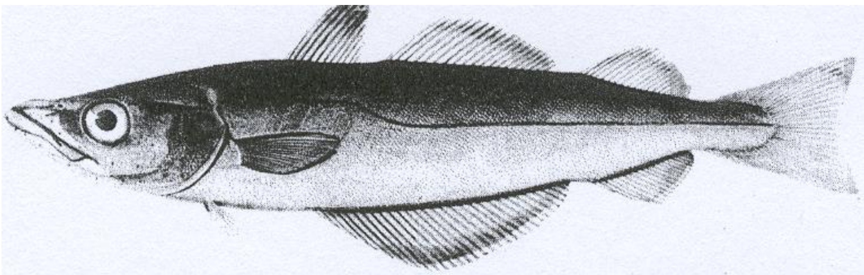
Sandeel: silvery and elongate, usually has a somewhat floppy appearance. Small rounded tail fin.



Clupeid: blue or silvery and noticeably deeper bodied and more rigid than sandeel. Tail long and noticeably forked.



Gadoid: rusty brown or greenish above, dirty white below. Chunky appearance, large square-ended (slightly forked) tail fin.



Pipefish: Mottled or barred brown and beige. Elongate appearance, but noticeably rigid despite this owing to bony plates. Some species lack the tail fin.

Guillemot colony: this would make a good group to follow. All the birds are incubating, note their ‘humpback’ posture

Guillemot colony: another example of an ideal group for monitoring. Again most of the birds are incubating but the fourth bird from the right is the off duty mate of the incubating bird in front of it. Note its much more upright posture.

Two guillemots with clupeids. Note the deep bodied appearance even from a ventral view and long, distinctively forked tail. These are display fish, clearly the birds do not have chicks. Looking at display fish is a good way to get identification experience.

Guillemot carrying a sandeel. Note thin "bootlace" appearance and small rounded tail fin.

Guillemot carrying a gadoid. Note pink colour, chunky body and blunt tail end. Normally guillemots carry fish length ways in the bill but small fish such as this are sometimes held crosswise.

Appendix 3: Guillemot Diet Recording Form

Colony	
Observer	
Start time	
Form number	

Date	
Weather	
End time	
Of	

Time	Fish Species	*Chick/Display*

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