

THE GEOGRAPHY OF DIET:  
DIVERSITY IN DIET AND FORAGING BEHAVIOR IN HERRING GULLS (*LARUS*  
*ARGENTATUS*) ACROSS ATLANTIC CANADA

By

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## ABSTRACT

Changes in food availability are thought to be the primary driver of Herring Gull (*Larus argentatus*) species decline, but empirical evidence linking gull diet to population dynamics is lacking. First, I test the ability of new GPS tracking technology to provide representative data on Herring Gull movement, analyzing the effect of tag deployment on adult behavior and reproductive output. I found that effects were short-term. Secondly, I analyze data from GPS tags deployed on Herring Gulls at two colonies in the Bay of Fundy, Canada, and combine results with those from a more established diet methodology, stable isotope analysis. I found that variation in individual foraging strategy is high, but colony-level differences in diet and foraging location do emerge. This study provides the foundation for understanding how differences in individual foraging strategy may lead to variation in individual reproductive success and the ability to adapt to a changing environment.

## **DEDICATION**

For John Anderson, friend and mentor, who seems to have decided I am worth the trouble. Also for the gulls, which have brought me to many beautiful and ghastly places, and which always remind me that life is fundamentally real and miraculous.

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## Chapter 1: Introduction

Herring Gulls (*Larus argentatus*) are among the most widely recognized seabirds in eastern North America. Naturalists, scientists, and wildlife managers have observed Herring Gulls for as long as these birds are likely to have colonized that coastline, and the resulting wealth of knowledge about them makes Herring Gulls an ideal study species to investigate questions of population biology and ecology in a changing landscape.

Like all seabirds, gulls rely on islands with protection from predators to raise their young (Pierotti and Good 1994). However, unlike most seabirds, gulls are well adapted to foraging and resting in terrestrial environments during all seasons (Clark et al. 2016). In trying to model gull diet and population dynamics, it is important to note changes in the terrestrial and marine environments, both of which are affected by natural changes and changes in human activity.

The Gulf of Maine (Fig. 1.1) has large, shallow areas uniquely influenced by strong tidal currents and coastal inputs, producing one of the world's most rich and diverse marine biota (Parker 2012). From 2005 to 2015, sea surface temperatures in the Gulf of Maine warmed faster than 99.9% of the global ocean (Pershing et al. 2015). This warming, combined with a highly intensive fishing industry, has caused widespread changes to the entire marine food web from phytoplankton to top predators such as cod (*Gadus morhua*; Pershing et al. 2015). As highly visible top predators, marine-dependent seabirds such as terns (*Sterna* spp.) and Atlantic Puffins (*Fratercula arctica*) have been used as biological indicators to monitor bottom-up changes occurring in the Gulf of Maine (Diamond and Devlin 2003, Boyd et al. 2006, Gaston et al. 2009). Since gulls are unique among seabirds in their success in accessing terrestrial resources, changes in

measures like reproductive success and adult survival are likely to lag in gulls compared to other marine-dependent indicator species. However, a potentially big and rapid shift in what and where gulls eat should be detectable in generalist feeders like gulls. If, as I will discuss in the following section, gull populations are declining system-wide, it is an indication that those coarser measures like reproductive success and adult survival may ultimately be affected. Long-term changes in food availability is the current hypothesis for what is primarily driving the current gull decline, but many factors other than diet may also contribute to population change of a species. The aim of this thesis is to lay the foundation for an empirical test of the link between changing food resources and population decline in the generalist Herring Gull.

### **A century of population change**

After a half-century of rapid population expansion, Herring Gulls in eastern North America plateaued in number in the 1980s and have declined steadily since (Drury 1973, Nisbet et al. 2013, Anderson et al. 2016a). A similar pattern of population rise and fall has been observed in Europe, where the last decades' decline has been severe enough to list Herring Gulls with an Endangered status in the United Kingdom (Nager and O'Hanlon 2016). In eastern North America, gull population expansion was attributed to two changes: improved species protection under the Migratory Bird Treaty of 1917 which prevented recreational and plume hunters from shooting gulls and other birds; and year-round, easy access to abundant food resources including open landfills and fisheries discards, especially in the winter months when many high-latitude species are vulnerable to starvation (Kadlec and Drury 1968, Horton et al. 1983, Goodale 2001). Between the

1970s-1990s, most open landfills were closed in favor of centralized and monitored solid waste parks and transfer stations, and the fishing industry in northeastern North America faced a series of fisheries stock collapses and responding industry regulation changes (Wilhelm et al. 2016). Current management of the Herring Gull population in Canada and the United States is based on the notion that the past rise and current decline in regional Herring Gull numbers is due primarily to changes in food availability (USFWS 2005, Cotter et al. 2012). This implies that the gull population decline from the 1980s onward was to be expected since it coincided with decreasing anthropogenic food subsidies (i.e. garbage and fisheries discards), and implicitly predicts that the gull population would stabilize to a lower carrying capacity within several generations. The relationship between food and animal abundance is demonstrated in other avian species (White 2008), so this hypothesis a reasonable place to start testing for causes of Herring Gull decline.

However, experimentation should be carried out to test these correlative observations (Romesburg 1981), especially because there are two potential issues in this interpretation of the most recent Herring Gull decline. First, until recently, the literature lacked studies that quantify changes in diet at a regional scale over time. Recent literature is synthesized below and should be used to reevaluate prior interpretations of what drives changes in Herring Gull population size. Secondly, diet is only one life history component contributing to population structure, and these other factors may interact with changes in diet to worsen or alleviate the severity of a regional population change. Not only is the link between diet and Herring Gull population change lacking empirical testing, other factors such as predation, human disturbance, and climate change have been scarcely considered as potential contributors to the current gull decline. As has been

demonstrated in another taxon, suites of factors may combine in a multitude of ways at local levels to create the more uniform population decline observed at a regional scale (Campbell Grant et al. 2016). That the Herring Gull decline has happened regionally for more than 30 years, long after many of the changes to landfills and fisheries went into effect (Mittelhauser et al. 2016), suggests that factors other than food may be contributing to the decline.

### **Long-term shifts in Herring Gull diet**

Written life history accounts of the Herring Gull exist back to the early 19th century, before systematic population censuses were conducted (Anderson et al. 2016b). These accounts, in addition to subsequent quantitative studies, provide robust descriptions of species nesting habitat, diet, and behavior. As a species, gulls are broadly identified to be “generalist scavengers” (Craig et al. 2015), for observation has been consistent over the last century that gulls consume a wide variety of prey including everything from fisheries discards, sewage, and live crustaceans to dead ducks, hare, and insects and seeds (Bent 1921, Tinbergen 1953, Pierotti & Good 1994). Though gull diet is still generalist, recent publications worldwide emphasize a shift towards reliance by *Larus* spp. on human-generated food sources (Yoda et al. 2012, Washburn et al. 2013, Blight et al. 2015, Hobson et al. 2015, Bond 2016, Gyimesi et al. 2016). Possibly related to this new reliance on anthropogenic food, researchers have also noticed a marked increase in the number of urban nesting rooftop gulls (Perlut et al. 2016, Rock et al. 2016) despite the overall decline in the number of nesting pairs (Nisbet et al. 2013, Nager & O’Hanlon 2016, Wilhelm et al. 2016).

Optimal foraging theory predicts that individuals will adopt feeding strategies that maximize caloric intake while minimizing the amount of energy required to obtain those calories (Schoener 1971, Pyke et al. 1977, Stephens et al. 2007). Newer iterations of the theory incorporate ideas such as complex information theory (Krebs 1974, Bayer 1982, Mock et al. 1988, Giraldeau and Caraco 2000, Stephens et al. 2007), the influence of risk on the forager's strategy (Lima and Dill 1990, Houston et al. 1993, Sherratt 2003, Allard 2006, Kiorboe and Jiang 2012), and the way in which foragers deal with variable or patchy environments (Monaghan et al. 1986, Stephens et al. 2007). Foraging theory may also be used to predict environmental conditions in which generalist or specialist strategies are more profitable. McCleery and Sibly (1986) theorize about individual specialization in Herring Gulls, considering variability in the availability of food resources at different periods of time.

Data show that anthropogenic food sources may increase colony productivity by providing a plentiful, predictable source of calories. This has been confirmed at colonies close to landfills (Pons 1992, Weiser and Powell 2010, Steigerwald et al. 2015) and fisheries discards (Hunt 1972, Oro et al. 1995, Goodale 2001, Furness 2003). Although anthropogenic food types tend to benefit gulls, they are not universally beneficial. Some studies (Ramano et al. 2006, Grémillet et al. 2008) have found evidence supporting the Junk Food Hypothesis that attributes decreased reproductive success to the lower nutritional value of novel food types as compared to the birds' historical marine prey. Coulson (2015) also suggests that the role of landfills in the expansion of the U.K. gull population may be significantly overstated, and that botulism from food at landfills may have damaged the population more than it benefited it.

## **Linking diet to population change**

As a species, Herring Gulls are generalist scavengers, but individuals within the species often specialize on only a few prey types (McCleery and Sibly 1986, Pierotti and Annett 1991, Spear 1993, Guillemette and Brousseau 2001). Specialization on varied prey types may, in turn, create variation in individuals' foraging behaviors, patterns of movement, nest attendance, and reproductive success. For example, gulls specializing on anthropogenic food sources adjust their feeding trips to the times of day or week when those anthropogenic resources are most readily available (McCleery and Sibly 1986, Monaghan et al. 1986, Yoda et al. 2012, Ceia et al. 2014). Widespread shifts in one or more of potential prey types would therefore affect each type of specialist differently.

## **Thesis overview**

Recently developed GPS technology makes it possible to investigate the relationship between individual foraging strategy and reproductive success in greater detail than ever before. Doing so may clarify the link between the widespread changes in Herring Gull diet and the widespread changes in the number of nesting Herring Gulls that have already been observed. To lay the foundation for such a study, I conducted fieldwork at two of the largest Herring Gull colonies in Atlantic Canada and at a third colony in Maine. Chapter 2 tests the reliability of GPS tags to deliver accurate information about off-colony movements by studying the effect of GPS tag attachment on Herring Gull behavior and reproductive output. Chapter 3 combines geographic data from GPS tags with dietary isotope sampling to quantify gulls' use of anthropogenic food sources in the Bay of Fundy. A chapter of general discussion follows.

## **Description of study colonies**

### *Great Duck Island, Maine*

Great Duck Island (44.146°N, 68.250°W) is a relatively isolated, 90ha island located 20 km offshore from Bar Harbor, Maine (Fig. 1.1.1). Most of the island is jointly owned by The Nature Conservancy and the State of Maine, and is managed for conservation purposes. Additionally, 0.4ha of the north end of the island are privately owned and are site to the landowner's summer house, and College of the Atlantic (COA) owns property in the south and around the eastern boathouse. COA has had an active ecological station on Great Duck Island between Jun.-Aug. since 1998, meaning that there is a continuous presence on the island by 4-8 researchers during the peak of the seabird breeding season.

Approximately one-third of the island interior is a mature stand of White Spruce (*Picea glauca*) where farmers in the mid-19th century cleared the forest for pasturage. By 1890, the lighthouse at the southern tip of the island was under construction, and a new stage in history of the island began. The Lighthouse Service was a civilian organization that maintained lights and fog bells (later: foghorns) for communication to boat traffic along the coast before the U.S. Coast Guard took responsibility at the outbreak of World War II. The Service kept one Head Keeper, two Assistant Keepers, and their families on the south end of Great Duck Island after the completion of the lighthouse in 1890. Host to some “3,400 birds” with another “2,200 birds” on neighboring Little Duck (Dutcher 1903), Great Duck Island was likely one of the few sizable Herring Gull colonies in the eastern United States at the time. The Head Keeper was therefore paid by the Thayer Fund of the American Ornithological Union to protect gulls there from persecution by

people and wildlife (Anderson 2017). Herring Gulls along the U.S. east coast increased dramatically between the early 1900s and the 1970s (Drury 1973), and by the 1940s population control measures were being taken. Eggs were oiled on Great Duck Island 1943-1946. Following 1946 there were no systematic counts of the gull colony until 1985, but the Great Duck Island colony appears to have remained <1,000 pairs until it started increasing in the 1990s. The colony on Great Duck Island has continued to increase despite a 30% decline in the statewide population over the past 30 years (Table 1.1; Allen et al. 2012, Mittelhauser et al. 2016).

In addition to Herring Gulls, there are approximately 50 nesting pairs of Great Black-backed Gulls (*Larus marinus*), Common Eiders (*Somateria mollissima*), and two of the largest colonies of Black Guillemot (*Cephus grylle*) and Leach's Storm-petrel (*Oceanodroma leucorhoa*) in Maine. One pair of Bald Eagles (*Haliaeetus leucocephalus*) has sporadically nested at the north end of Great Duck Island, and eagles, particularly juveniles, have been an increasing source of stress and chick mortality for Herring Gulls on the island (Anderson 2017). Snowshoe Hare (*Lepus americanus*) are the only mammals that permanently inhabit Great Duck Island. There was a report of otter (*Lontra canadensis*) activity in 2013, but no mammalian predators were captured in the COA summer crews' trapping efforts and no patterns of egg or chick predation were observed that would have implicated a ground predator such as otter.

#### *Kent Island, New Brunswick*

Kent Island, (44.581°N, 66.756°W) is an 80ha island at the southern edge of the Grand Manan archipelago, New Brunswick, at the mouth of the Bay of Fundy (Fig.

1.1.2). Bowdoin College has run a scientific station (BSS) on Kent Island continuously since 1935, making it one of the longest running field stations in North America. BSS is known for its Leach's Storm-petrel research, but studies have also focused on gulls, migrant songbirds, meteorology, and other aspects of island ecology.

In the 1930s and 1940s, Kent Island was one of the largest Herring Gull colonies in the Gulf of Maine and Bay of Fundy, host to some 20,000 pairs or more, and probably served as a source for the expansion of gull population eastward and southward during that period (Cannell and Maddox 1983). By 1983, the colony was down to 5,000 nesting pairs, and even further to 1,400 by 1989 (Hébert 1989; Table 1.1). Hébert (1989) speculates that egg collection by Grand Manan locals may have been a primary cause of the decline. The latest estimates (Ronconi and Wong 2003, R. Ronconi unpub. data 2015) show the gull population rebounded slightly sometime after Hébert's study, but may be declining again with the provincial population (Wilhelm et al. 2016). Like Great Duck Island, Kent Island is relatively isolated from the mainland, and Bald Eagles are a likelier threat to breeding gulls than ground predators.

#### *Brier Island, Nova Scotia*

Brier Island (44.275°N, 66.345°W) is a 1,500ha island in southwestern Nova Scotia (Fig. 1.1.3). It is separated from the mainland by two narrow (<1.5 km), fast-moving tidal passages to the north, and is bordered by St. Mary's Bay to the east and the Bay of Fundy to the west. The village of Westport is home to just over 200 year-round residents, and is clustered around the wharf on the northeast side of Brier Island. Nature

Conservancy Canada owns the entire southern third of Brier Island (485 ha), and manages it as a nature preserve by encouraging only low-impact recreational activities.

Herring Gulls, Great Black-backed Gulls, Common Eiders, and Double-crested Cormorants (*Phalacrocorax auritus*) nest in various sub-colonies around Brier Island and Peter's Island, a small island immediately northeast of Brier Island in Petit Passage. The number of Herring Gulls nesting in the Brier Island colony has grown significantly in the past half century, primarily due to the creation of habitat in Big Meadow Bog, the protected center of Brier Island. In 1958-1959, a former landowner dug three deep ditches along the length of the Big Meadow Bog with the goal of draining it (Toms 2015a). Gulls subsequently moved from sub-colonies on the periphery of Brier Island to pockets of newly dried land in Big Meadow Bog (Toms 2015a). The population in Big Meadow Bog grew from 0 in 1970 to over 2,400 by 2013 (Toms 2015b). At a total colony size of 5,100 breeding pairs, Brier Island is now the largest Herring Gull colony in Atlantic Canada (Table 1.1).

Because Brier Island is inhabited by people and is located so close to the mainland, more mammalian predators live here than on a typical seabird island. Dogs (*Canis lupus familiaris*), coyotes (*Canis latrans*), local egg collectors, mustelids (e.g. mink), as well as Bald Eagles, have been observed depredating gulls nesting on Brier Island. It may be for this reason that the number of gulls nesting in Big Meadow Bog, which is protected by dense and scrubby vegetation, grew so rapidly once habitat became available due to drying.

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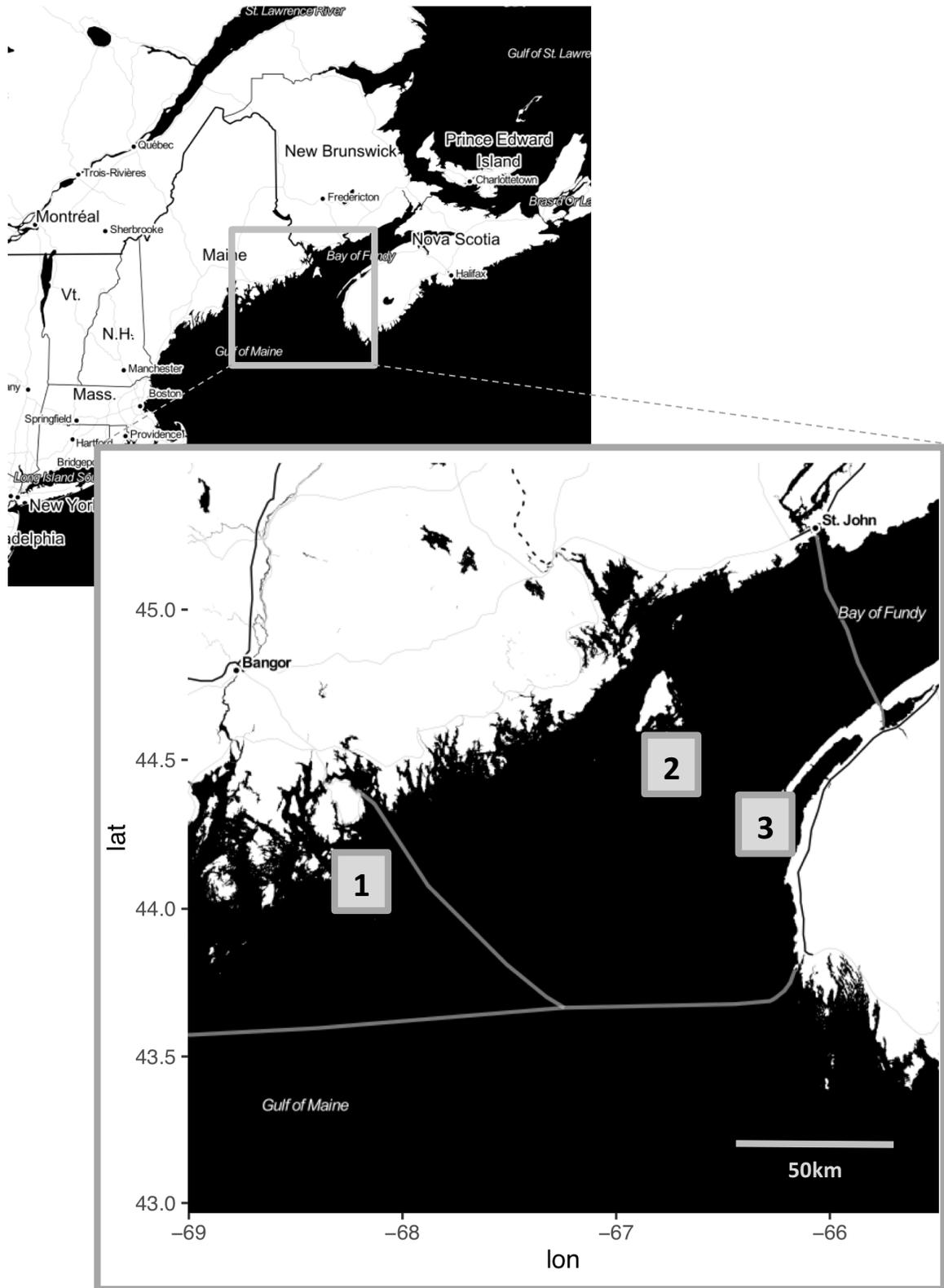
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**Table 1.1.** Rounded estimates of breeding pairs of Herring Gulls at study colonies and associated regions, 1940-2016. Arrows denote trends over the timeframe specified by the light gray box (2001-2008 to Present, “10-year Trend”) and the bold box (1977-1987 to Present, “30-year Trend”). See individual references for full description of survey methods.

Location	Year	No. Pairs	10-year Trend	30-year Trend
Great Duck Island, ME	1940 <sup>a</sup>	600		
	1972 <sup>a</sup>	100		
	1985 <sup>b</sup>	700		
	1999 <sup>c</sup>	800		
	2005 <sup>c</sup>	1,000		
	2010 <sup>c</sup>	1,100		
	2016 <sup>c</sup>	1,400	↑	↑
ME (regional total)	1977 <sup>d</sup>	26,000		
	1995 <sup>e</sup>	35,800		
	2008 <sup>f</sup>	24,300		
	2013 <sup>f</sup>	21,500	↓	↓
Kent Island, NB	1940 <sup>g</sup>	25,000		
	1983 <sup>h</sup>	5,000		
	1989 <sup>i</sup>	1,400		
	2001 <sup>j</sup>	5,900		
	2015 <sup>k</sup>	4,000	↓	↓
NB (regional total)	1986 <sup>l</sup>	6,000		
	2002 <sup>l</sup>	2,400		
	2010 <sup>l</sup>	3,100	↑	↓
Brier Island, NS	1987 <sup>m</sup>	4,200		
	2016 <sup>n</sup>	5,100	NA	↑
NS (regional total)	1986 <sup>l</sup>	28,600		
	2002 <sup>l</sup>	10,000		
	2010 <sup>l</sup>	8,700	↓	↓

<sup>a</sup>Drury 1973; <sup>b</sup>Folger and Wayne 1986; <sup>c</sup>J. Anderson unpub. Data; <sup>d</sup>Erwin and Korschgen 1979; <sup>e</sup>USFWS 2010; <sup>f</sup>Mittelhauser et al. 2016; <sup>g</sup>Gross 1940; <sup>h</sup>Cannell and Maddox 1983; <sup>i</sup>Hébert 1989; <sup>j</sup>Ronconi and Wong 2003; <sup>k</sup>R. Ronconi unpub. Data; <sup>l</sup>Wilhelm et al. 2016; <sup>m</sup>Cotter et al. 2012; <sup>n</sup>B. Toms unpub. Data

**Figure 1.1.** Map of study colonies, including (1) Great Duck Island, Maine, USA, (2) Kent Island, New Brunswick, Canada, and (3) Brier Island, Nova Scotia, Canada.



**Chapter 2: Tag attachment affects hatching but not chick rearing in  
Herring Gulls (*Larus argentatus*)**

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## **Abstract**

With recent advances in technology, GPS tracking has rapidly become prominent in seabird research. The effect that trapping and tagging has on birds is specific to the species and the methods used, but documenting these effects is critical for both the protection of animal welfare and for gauging the scientific rigor of the GPS data collected. In this study, we deployed GPS tags (17 g, leg-loop harness attachment) on adult Herring Gulls on Brier Island, NS (n=27), Kent Island, NB (n=14), and Great Duck Island, ME (n=6). At each location, we monitored all nests with a tagged adult, a set of procedural control nests where gulls were trapped and handled but not tagged, and a set of control nests where no adult birds were trapped or handled. We found that nests of tagged gulls suffered lower hatch success compared to procedural control nests, but that (excluding failed nests) there was no difference in chick growth rate or chick survival to Day 21. We suggest that egg loss at nests of tagged individuals was likely due to atypical behavior in the 0-48 hours after tag attachment. This atypical behavior, where birds loafed at the edge of the colony instead of attending their nests or foraging offshore, varied in intensity by colony. Lasting effects of tags on the reproductive success in this study were minimal, suggesting that GPS tags may pose an acceptable level of risk to Herring Gulls for research.

**KEYWORDS:** animal welfare, human disturbance, Gulf of Maine, movement, observer influence, seabird, tracking

## Introduction

GPS tags are more accessible than ever before, allowing researchers to quantify fine-scale movements of individual animals that are relevant to questions of physiology, behavior and fitness (Burger and Shaffer 2008, Wilson and Vandenabeele 2012). With new technology comes the potential for new costs in research. Permitted bird banders agree to shoulder an ethical responsibility to minimize stress and the risk of injury to the animals they handle (Bird Banding Laboratory 2016). This responsibility must be taken seriously if we are to maintain the integrity of our research community. Additionally, using data collected from stressed or injured birds may lead to erroneous scientific conclusions, as the sampled population may no longer represent the wild population that the researcher is attempting to understand (Robinson and Jones 2014, Chivers et al. 2015). Hawkins (2004) notes potential avenues of impact that loggers may have on birds, including stress due to capture and handling, longer-term physiological effects from carrying a device, and researchers' limited ability to monitor animals following release so that intervention may be possible if issues are detected.

Though several studies use tracking data to assess Herring Gull (*Larus argentatus*) behavior, no studies to date directly test for an effect of the tracking devices on the Herring Gulls' physiology, behavior, or fitness (Rock *et al.* 2016). However, GPS tags have been used extensively on a closely related species, the Lesser Black-backed Gull (*L. fuscus*), in Europe, and measures of hatch success, chick growth rate, and adult survival were used to determine that the tags did not significantly alter the movement behavior of the tagged individuals (Camphuysen *et al.* 2015, Thaxter *et al.* 2014, Garthe

*et al.* 2016, Thaxter *et al.* 2016). Two of these studies (Camphuysen *et al.* 2015, Garthe *et al.* 2016) noted small percentages of nest failure by Lesser Black-backed Gulls following tag deployment, but found no change in the longer-term effect metrics. In this study, we aimed to test the effect of two styles of GPS loggers on Herring Gulls nesting at three colonies in the Gulf of Maine, USA and Bay of Fundy, Canada.

## **Methods**

Fieldwork took place between May-Aug. on Brier Island, Nova Scotia (44.275, -66.345; 2014-2015), Kent Island, New Brunswick (44.581, -66.756; 2015), and Great Duck Island, Maine (44.146, -68.250; 2016) in colonies each containing >1,000 pairs of breeding Herring Gulls. Incubating adults were captured on 3-egg nests using walk-in nest traps, and morphometric data were collected during tagging at all three sites. In addition, on Kent and Brier islands, an 80  $\mu$ L sample of blood was drawn from the tarsal or brachial vein of every individual and the top 3 cm was clipped from the oldest feather among the innermost primaries, P1-P3 ( $n_{\text{Brier}}=56$ ,  $n_{\text{Kent}}=33$ ). Logger models include battery-powered i-GotU (MobileAction Technology, 19g,  $n=15$ ) and solar-powered HARIER-L (Ecotone Telemetry, 17g,  $n=32$ ) tags, and were attached using Teflon ribbon to make a leg-loop harness (Mallory and Gilbert 2008). For birds equipped with i-GotU tags, recapture was attempted for data retrieval approximately two weeks after tag deployment. No recapture was attempted at nests where the bird carried an Ecotone logger, as this model remotely transmitted data to a base station when the bird flew within 300 m of an antenna (UNB animal care permit 14027; Table 2.1).

It was not logistically possible to standardize the point in the incubation stage when tags were deployed. Consequently, Brier Island tags were deployed early-mid incubation, Kent Island in mid-incubation, and Great Duck Island tags within days of the mean date of first hatch within Control nests in that colony.

During the incubation stage in 2015-2016, 30-57 nests were chosen for monitoring on each island (Table 2.2). Monitored nests included all nests with a tagged individual (hereafter, Tagged; n=32), a sample of nests where adult birds were trapped and handled but not tagged (hereafter, Procedural Control; n=55), and a sample of nests where no trapping was attempted (hereafter, Control; n=52; Table 2.2). Sex was determined for tagged individuals on Brier Island and Kent Island using a discriminant function (Robertson et al. 2016):

$$D = 2.893 * BD + 0.892 * HL + 0.136 * WL - 232$$

where *BD* is bill depth perpendicular to the bill at the gonys, *HL* is head length from the back of the skull to the tip of the bill, and *WL* is wing length, otherwise called relaxed wing chord. When  $D > 0$ , the bird is determined to be male with 95% confidence.

On Great Duck Island, morphometric measurements were incomplete so we determined sex by observing tagged mating pairs from the top of a lighthouse. The larger of the two birds was classified as the male of the pair (Pierotti and Good 1994).

Eggs and chicks in monitored nests were checked daily through the hatching period, and then every other day (weather permitting) after chicks were banded. Chicks were weighed and measured until they were at least 21 days old, a proxy for fledge success (Hunt and Hunt 1976). Chick survival data on Great Duck were supplemented with a binary “Dead” or “Alive” categorization during daily watches from the lighthouse.

### *Nest productivity*

We compared the proportion of eggs hatched per nest by experimental nest type. Colony location did not contribute to differences in hatch success (ANOVA;  $df=2$ ;  $F=0.136$ ;  $p=0.873$ ), so data were pooled from all three colonies for this analysis. Second, we compared chick growth rates by nest type (reported as mean  $\pm$  standard deviation) by using nest monitoring data from Brier Island only. Third, we tested the proportion of hatched chicks surviving to Day 21 according to nest type, pooling Brier Island nest monitoring data with observations from Great Duck Island since Colony had no significant effect on chick survival (ANOVA;  $df=1$ ;  $F=2.571$ ;  $p=0.115$ ). Two-way Analyses of Variance (ANOVA) were performed in R version 3.2.3 using base package `aov` (R Core Development Team 2013). When  $p<0.05$ , Tukey's honest significant difference (HSD) test was used to identify contrasting groups. The sample size for each experimental nest type is listed by colony in Table 2.2.

### *Length of incubation period*

To assess whether trapping or tagging affected the length of incubation, the mean date of first hatch from every clutch was compared at Tagged ( $n=6$ ) and Control ( $n=30$ ) nests on Great Duck Island, and at Tagged ( $n=8$ ), Procedural Control ( $n=22$ ), and Control ( $n=19$ ) nests on Brier Island using a two-way ANOVA with post-hoc Tukey HSD. We assumed that lay date did not vary according to nest type since all monitored nests were selected at the time of trapping and were scattered haphazardly throughout the colony.

### *Assessment of post-deployment behavior*

To determine how gull behavior was affected immediately after tag deployment, we ran three ANOVAs comparing (1) the mean percentage of records falling within 40m of the tagged individuals' nest sites (i.e. attending their territory), (2) the mean percentage of records falling within 1km of the tagged individuals' nest sites (i.e. off-colony movement), and (3) the mean distance travelled per hour of tagged individuals in eight 24-hour periods following tag deployment. These post-deployment periods included Days 0-1, 1-2, 2-3, 6-7, 10-11, 14-15, 25-26, and 29-30, with Day 0 starting with the first GPS record following an individual's release from capture. When  $p < 0.05$ , a Tukey HSD post-hoc test was used to identify significant differences between post-deployment periods. We predicted that the factor Sex would influence gulls' responses to tag attachment since females are smaller than males (and so are burdened proportionately more by tag mass) and because reproductive duties vary measurably between the sexes during the incubation stage when birds are being tagged (Pierotti and Good 1994).

### **Results**

The mean weight of Herring Gulls at all three colonies was 1,022 g (range: 820-1260 g). Therefore, the tags (including casing and harness) comprised means of 1.9% (range: 1.5-2.3%) and 1.7% (1.3-2.1%) of gull body mass for i-GotU and Ecotone tags, respectively. Of the individuals we tagged on Brier Island, 10 were female, 5 were male, and one could not be classified. On Kent Island we tagged 7 females and 7 males. On Great Duck Island, we tagged 3 females and 3 could not be classified.

### *Nest productivity*

At nests where GPS tags were deployed, one or more eggs disappeared from the nest following a capture or recapture attempt at 50% of i-GotU nests (n=10) and 50% of Ecotone nests (n=22); some of these (40% of i-GotU nests and 14% of Ecotone nests) lost all 3 of the eggs. Conversely, only 0.03% of Control nests (n=61) lost a full clutch of eggs. Overall, nest type had a significant effect on hatch success (ANOVA;  $p=0.001$ ;  $n_{\text{Control}}=61$ ,  $n_{\text{Procedural Control}}=51$ ,  $n_{\text{Tagged}}=32$ ) with eggs in Tagged nests being less likely to hatch ( $\text{hatch}_{\text{Control}}=83.7 \pm 0.3\%$ ,  $\text{hatch}_{\text{Procedural Control}}=86.9 \pm 0.9\%$ ,  $\text{hatch}_{\text{Tagged}}=62.3 \pm 0.4\%$ ). Trapping and handling alone (Procedural Control) did not affect hatch success (Tukey post-hoc HSD;  $p=0.834$ ), suggesting that it was tag attachment and not just capture that caused egg losses in Tagged nests (Fig. 2.1).

Chick growth rate was significantly lower at Procedural Control nests ( $34.3 \pm 6.6\text{g/day}$ ;  $n=21$ ) than at either Control ( $37.5 \pm 6.7\text{g/day}$ ;  $n=13$ ) or Tagged nests ( $38.7 \pm 5.0\text{g/day}$ ;  $n=8$ ;  $p<0.001$ ; Fig. 2.2). There was no significant difference in proportion of hatched chicks which survived through Day 21 according to nest type ( $p=0.192$ ;  $n_{\text{Control}}=11$ ,  $n_{\text{Procedural Control}}=16$ ,  $n_{\text{Tagged}}=11$ ; Fig. 2.3).

### *Length of incubation period*

There was no difference in mean date of first hatch between the three treatment levels on Brier Island. On Great Duck Island, the mean date of first hatch for Tagged nests was later than Control nests by 8 days (see colored bars in Fig. 2.4c). The between-colony differences in tag effect were detected again in our assessment of post-deployment behavior (Fig. 2.4a, c). Our experimental design makes it impossible to determine

whether colony-level differences were due to inherent differences in colony location or due to differences in the timing of our fieldwork in relation to the gulls' incubation stage.

#### *Assessment of post-deployment behavior*

Comparing patterns in movements of Tagged gulls 0-1 days and 1-2 days after tagging with 24-hr periods later in the breeding season suggests that tag attachment causes an immediate and short-term change in gull behavior at one of the three study sites (i.e. Great Duck Island). While there were no significant differences in nest attendance on Brier Island (Fig. 2.4a) and Kent Island (Fig. 2.4b), Tagged gulls on Great Duck Island attended their nests approximately half as often 1-2 days after tagging compared to other 24-hr periods during the incubation stage of the breeding cycle (Fig. 2.4c). Lower nest attendance also appears to be likely in the 0-1-day interval on Great Duck Island, and may not be statistically significant due to a low sample size ( $n=6$ ; Tukey HSD post-hoc; post-deployment days 0-1 vs. 10-11  $p=0.052$  and post-deployment days 0-1 vs. 14-15  $p=0.051$ ). Sex did not affect nest attendance patterns overall (ANOVA;  $n_{\text{female}}=20$ ,  $n_{\text{male}}=12$ ,  $F=1.44$ ;  $p=0.231$ ).

Second, we tested whether gulls were less likely to travel more than 1 km from their nest in the days following tag deployment. In this analysis, data from all three colonies were pooled because we found no effect of colony on the likelihood of travel away from the nest (ANOVA;  $df=2$ ,  $F=2.152$ ,  $p=0.118$ ). Sex also had no significant effect (ANOVA;  $n_{\text{female}}=20$ ,  $n_{\text{male}}=12$ ,  $F=3.25$ ,  $p=0.072$ ). Overall, we found a statistically significant difference in the 0-1 days following tag attachment, where Tagged gulls in this period spent more time within 1 km of their nest site than gulls in any other 24-hr

period during the incubation stage (ANOVA;  $n=36$ ;  $p<0.035$ ; Fig. 2.5).

Third, we tested for a difference in mean distance travelled per hour between each of the eight post-deployment time periods. Colony and Sex had no effect on distance travelled per hour (ANOVA; Colony:  $df=2$ ,  $F=1.118$ ,  $p=0.328$ ; Sex:  $n_{female}=20$ ,  $n_{male}=12$ ,  $F=0.168$ ,  $p=0.682$ ), so data from all individuals at all sites were pooled for analysis. The model overall was statistically significant (ANOVA;  $n=36$ ;  $p<0.001$ ; Fig. 2.6). The mean distance travelled per hour 0-1 days after tag attachment were significantly lower than all 24-hr periods beginning with the 6-7-day period (Tukey HSD post-hoc;  $n=36$ ;  $p<0.026$ ; Fig. 2.6). However, 1-2 days after tag attachment were not significantly different from other 24-hr periods during the incubation stage (Tukey HSD post-hoc;  $n=36$ ;  $p>0.164$ ; Fig. 2.6).

## **Discussion**

Negative effects of GPS tag attachment on gulls in this study were immediate and short-term. Barring instances where all 3 eggs at a nest disappeared, tagged gulls resumed regular incubation and off-island movement patterns within 48 hours of logger deployment. Unexpectedly, we detected a lower chick growth rate at Procedural Control nests as compared to Control or Tagged nest types. This could be a Type II effect, or it could indicate that our chick growth and survival measurements are biased high at Tagged nests with healthier adults since adults in poor condition may have been the ones to abandon their nests immediately following trapping attempts. In this case, we note that the difference in chick growth rate between the Procedural Control group and the other

two groups was minimal (5 g/day) and may not be biologically important. Further, that there was no difference between Control and Tagged nests in chick survival suggests that tagged gulls are not hindered in their ability to forage and defend their nests for the remainder of the breeding season.

Sex was not a significant factor in any of our post-deployment behavioral analyses. However, our sample size was small ( $n_{\text{female}}=20$ ,  $n_{\text{male}}=12$ ) and we were unable to determine the sex of 3 of the 6 individuals tagged on Great Duck Island where tag effects were most dramatic. More work should be done to determine whether male and female Herring Gulls respond to tagging events differently.

Taken together, the post-deployment behavioral analyses lead us to believe that high egg loss following tag attachment is likely to result from a tendency for tagged individuals to stay too far from their nests to incubate or properly defend their eggs, but too close to their nest sites to forage in the 48 hours after tag attachment. Mean distance travelled per hour was expected to gradually increase over the course of the breeding season as gulls were forced to spend more energy gathering food for their growing chicks, but there was no *a priori* reason to expect a difference in mean distance travelled per hour over the incubation period except as an effect of tag attachment. That mean distance travelled per hour was depressed in 0-1 days after tag attachment substantiates the claim that gulls were less likely to travel from the colony immediately after tag attachment. We suggest that this 48-hr “sulking” period is common among tagged Herring Gulls as they preen and adjust to flying with the harness. We reiterate that i-GotU tags, which require bird recapture for data retrieval, suffered higher egg loss than remotely communicating Ecotone tags, and suggest that the difference could be due to

differences in tag model shape (where homemade waterproofing on i-GotU tags made them bulkier than their Ecotone counterparts), tag model weight (i-GotU tags added 0.2% of mean gull weight), or (most probably) the disturbance of repeat capture events.

Garthe *et al.* (2016) reported nest failures by two of the nine gulls tagged in their study, stating that nest failures during incubation are not uncommon and should not be causally linked to the tagging event. We believe that the differences we identified in individuals' movement patterns in the 48 hours after tag deployment demonstrate that tagging activities did contribute to egg loss. Future research should aim to identify the point in the incubation state in which abandonment is least likely for the most cost-effective, least disruptive research.

Reporting of tag effects in the seabird literature has lagged behind the increase in the number of publications using movement data (Vandenabeele *et al.* 2011). Here, we conclude that the negative effect of tagging on Herring Gulls in our study was incurred in the first 48 hours after tag deployment, and that impacts thereafter were negligible. We stress that tag effect may vary according to the point in the incubation period in which tagging occurred, and that food, weather, and other ecological conditions that influence the background stress levels of the birds are likely to also affect the severity of a tag effect. A multi-year study is necessary to assess the lifetime impact of permanently attached solar-powered tags, but we suggest that these may have less impact overall on Herring Gulls than tag types that demand recapture for data retrieval.

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**Table 2.1.** Sample size of GPS tags deployed at three Herring Gull colonies 2014-2016. Bird recapture is required to retrieve data from i-GotU tags.

Location	Lat., Long.	Year	GPS Tag Model		Total by Location
			Ecotone	i-GotU	
Brier Island, NS	44.275, -66.345	2014	10	5	<b>27</b>
		2015	2	10	
Kent Island, NB	44.581, -66.756	2015	14	0	<b>14</b>
Great Duck Island, ME	44.146, -68.250	2016	6	0	<b>6</b>
<b>Total by Model</b>			<b>32</b>	<b>15</b>	

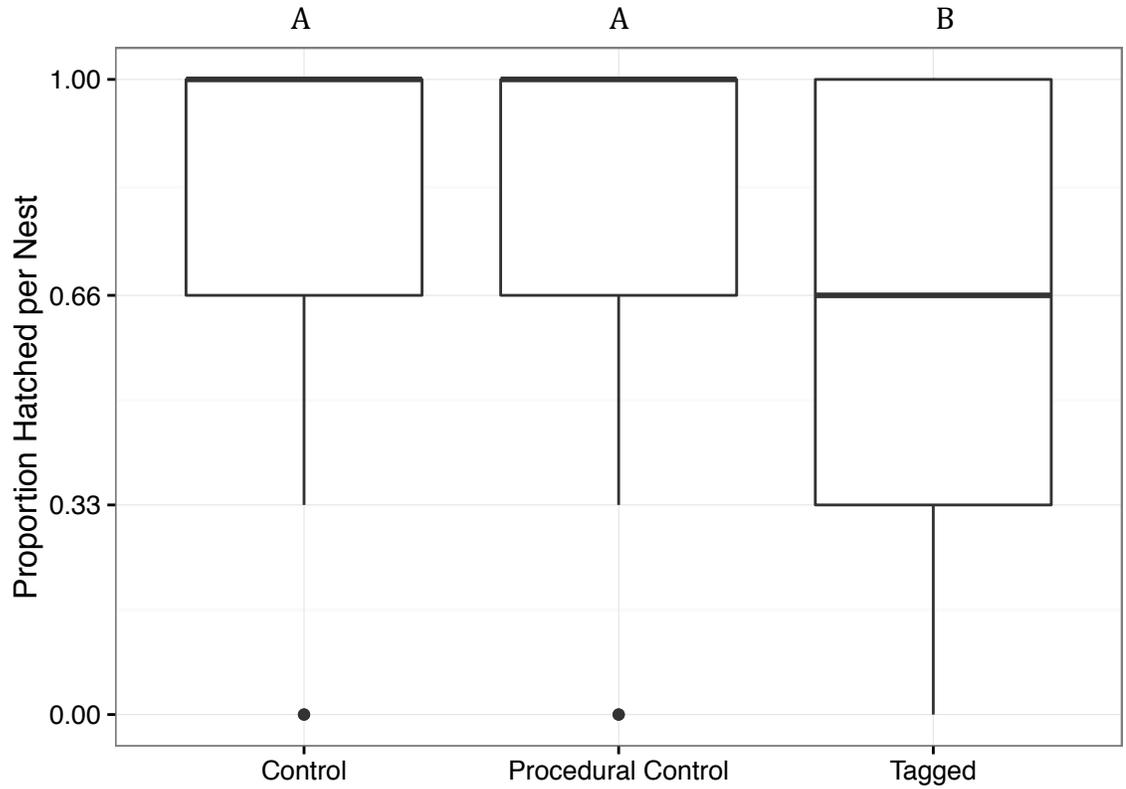
**Table 2.2.** Sample size of nests monitored by location and nest type. Nest types included: Tagged, where incubating Herring Gulls were trapped, handled and tagged; Procedural Control, where gulls were trapped and handled only; and Control, where trapping was never attempted.

<b>Location</b>	<b>Nest Type</b>		
	<u>Control</u>	<u>Procedural Control</u>	<u>Tagged</u>
Brier Island, NS	11	19	**12
Kent Island, NB	22	21	14
Great Duck Island, ME	19	5	6
<b>Total nests monitored*:</b>	<b>52</b>	<b>55</b>	<b>32</b>

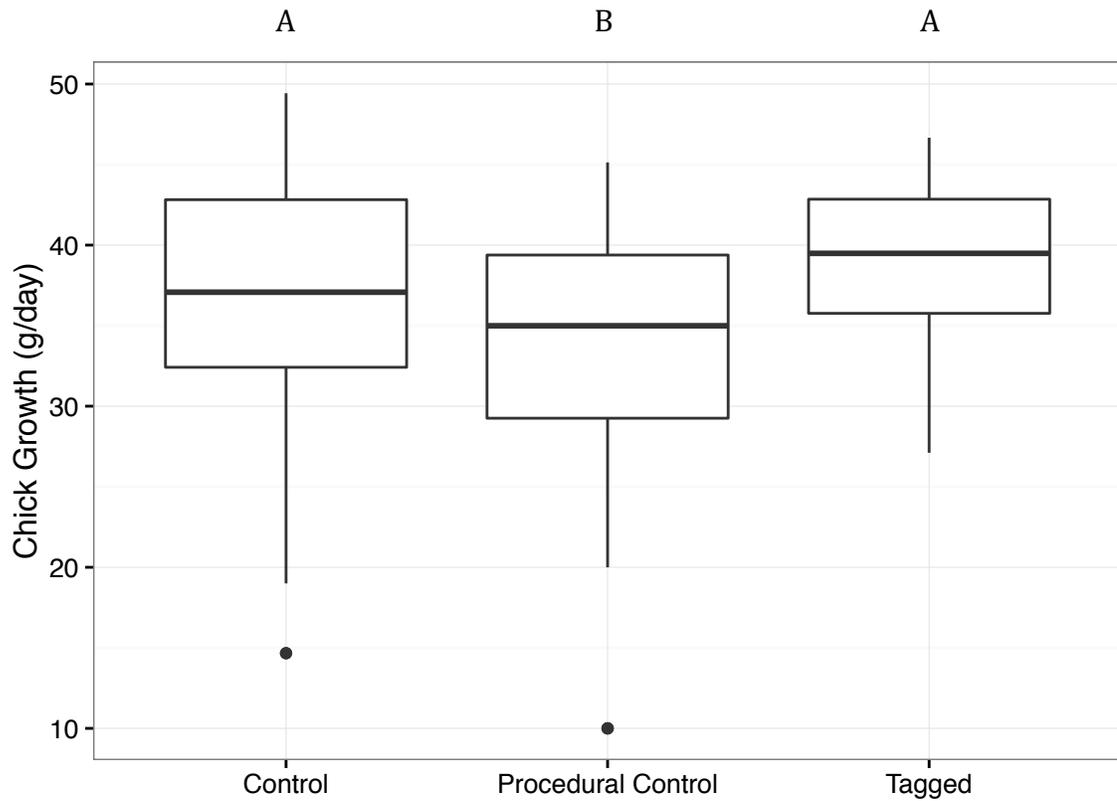
\*Nests in all locations were monitored through hatch success; chick growth and fledge data were complete for Brier Island only.

\*\*Includes i-GotU (n=10) and Ecotone (n=2) model tags. Recapture is required for retrieval of data from i-GotU tags only.

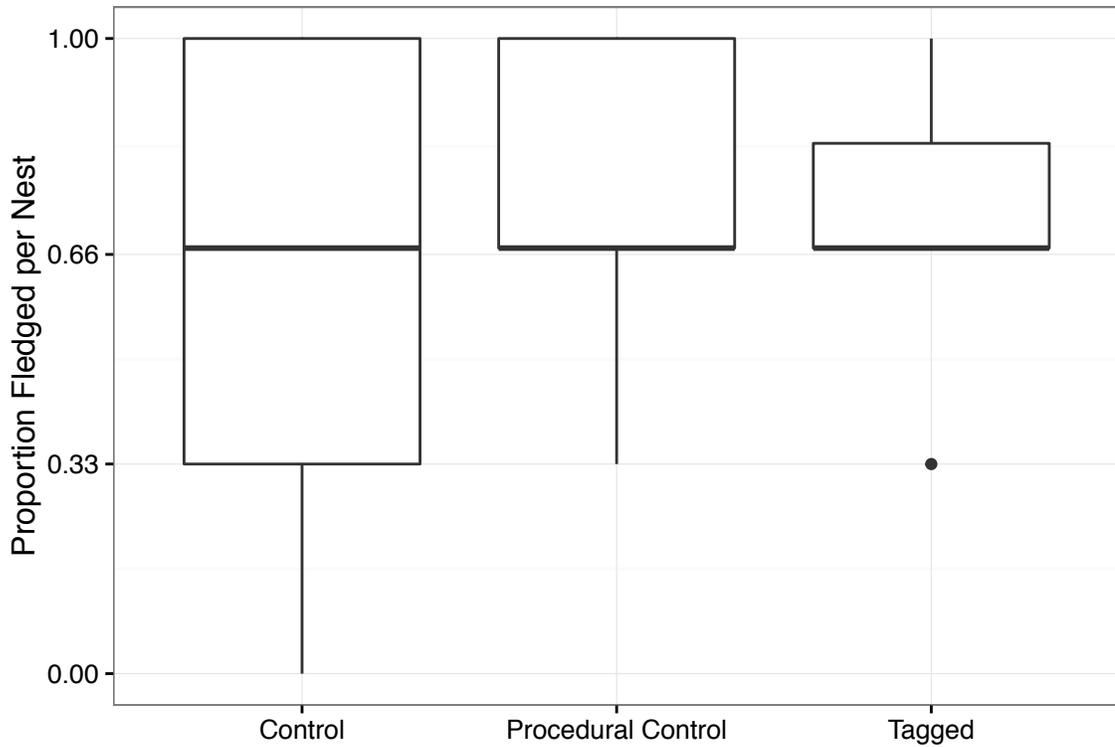
**Figure 2.1.** Mean proportion of Herring Gull eggs hatched by experimental nest type. Location did not contribute to variation in hatch success ( $p=0.873$ ) and data from all three colonies (Brier Island, NS in 2015, Kent Island, NB in 2015, and Great Duck Island, ME in 2016) were pooled for analysis. ANOVA with post-hoc Tukey HSD;  $p=0.001$ ;  $n_{\text{Control}}=61$ ,  $n_{\text{Procedural Control}}=51$ ,  $n_{\text{Tagged}}=32$ . Different letters indicate significant differences among groups.



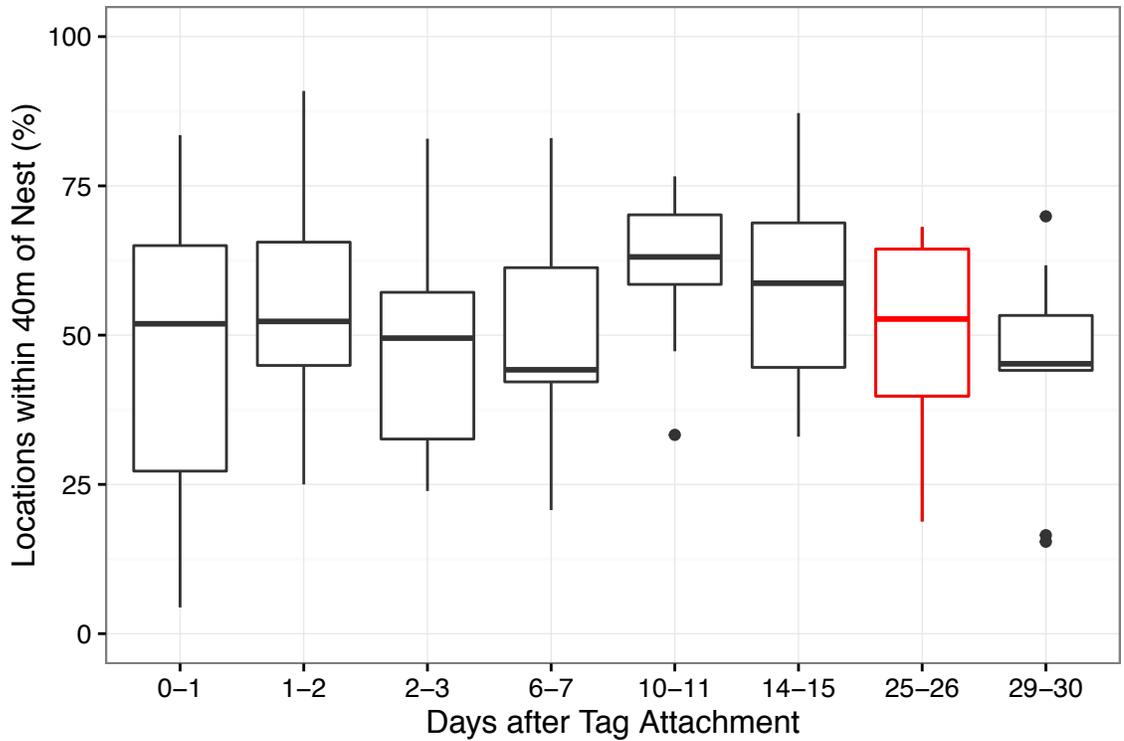
**Figure 2.2.** Mean Herring Gull chick growth rate (g/day) during the period of linear growth by experimental nest type. Data are from Brier Island colony only in 2015. ANOVA with post-hoc Tukey HSD;  $p < 0.001$ ;  $n_{\text{Control}} = 13$ ,  $n_{\text{Procedural Control}} = 21$ ,  $n_{\text{Tagged}} = 8$ . Different letters indicate significant differences among groups.



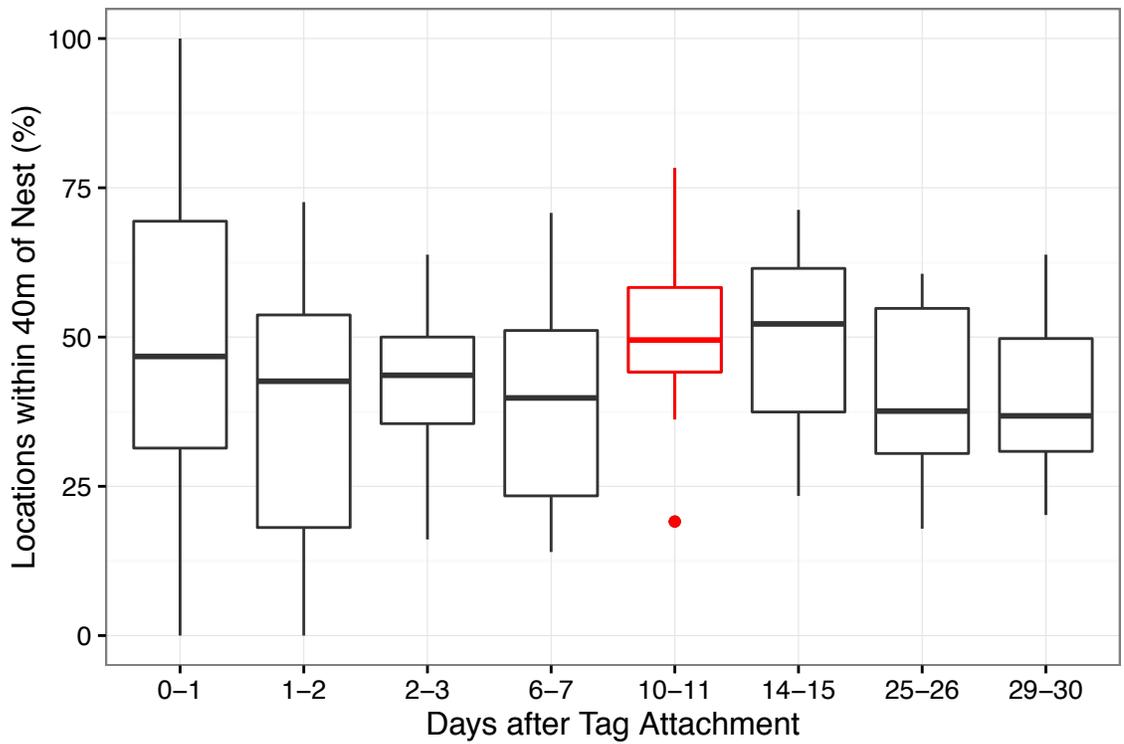
**Figure 2.3.** Mean proportion of Herring Gull chicks surviving past Day 21 by experimental nest type. Analysis excludes nests where zero eggs hatched. Location did not contribute to variation in chick survival ( $p=0.115$ ) so data from the Brier Island, NS (2015) and Great Duck Island, ME (2016) colonies were pooled for analysis. There was no statistically significant difference in the mean proportion of chicks surviving by nest type (ANOVA;  $p=0.192$ ;  $n_{\text{Control}}=11$ ,  $n_{\text{Procedural Control}}=16$ ,  $n_{\text{Tagged}}=11$ ).



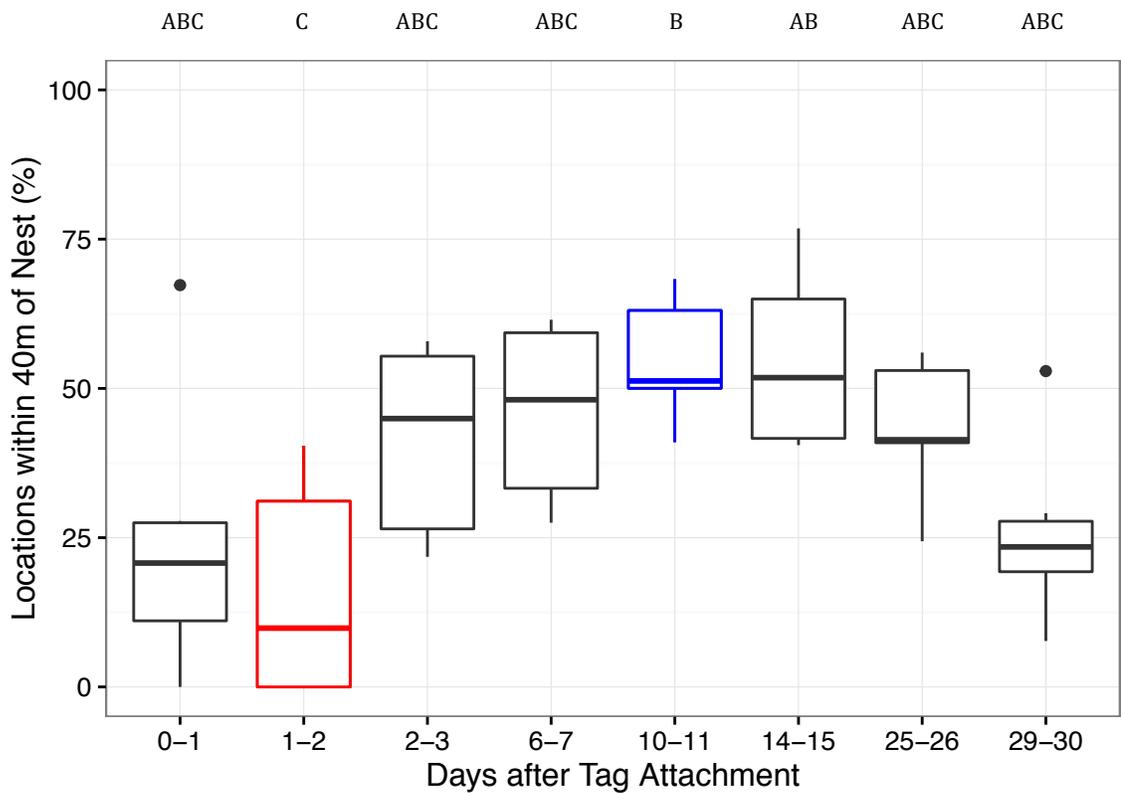
**Figure 2.4a.** Mean percent GPS locations recorded within 40m of tagged birds' nest sites in the days following tag attachment at Brier Island, NS in 2014-2015. The red bar indicates mean hatch date for the colony and signifies a predicted shift in nest attendance patterns due to the transition from incubation to the chick-rearing period of the breeding cycle. Differences in mean percentages were not statistically significant (ANOVA;  $p=0.14$ ;  $n=16$ ).



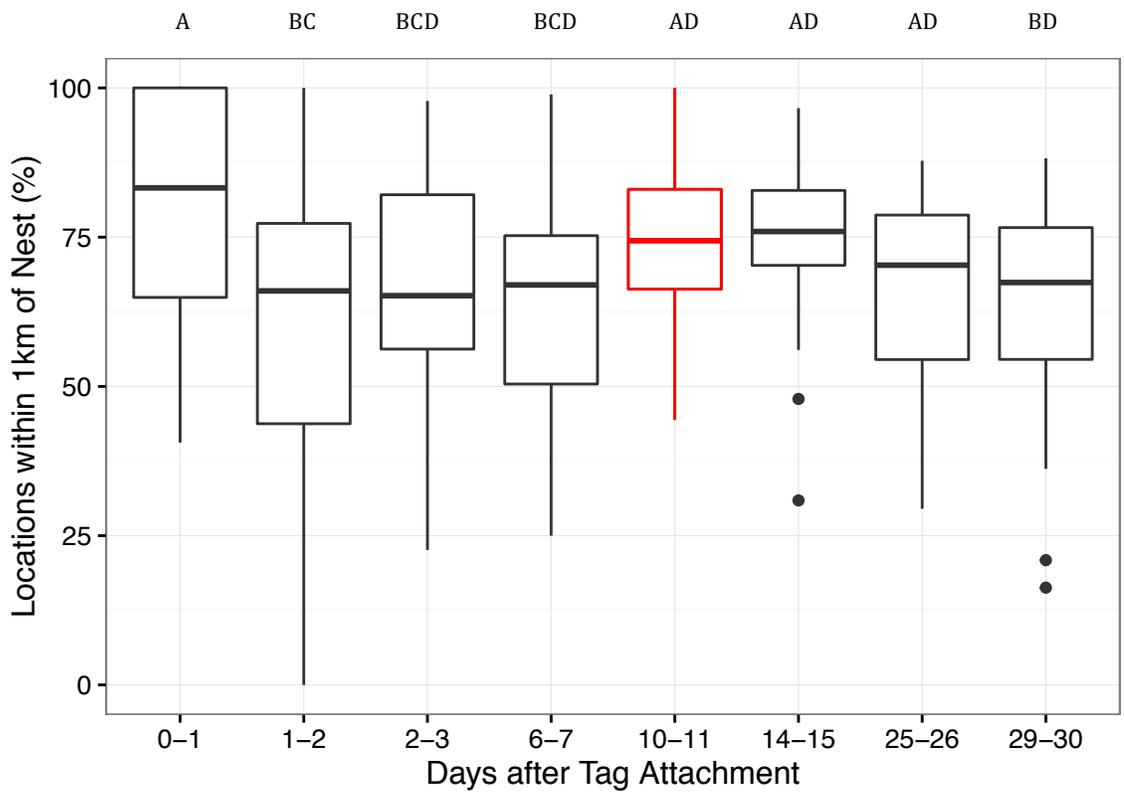
**Figure 2.4b.** Mean percent GPS locations recorded within 40m of tagged birds' nest sites in the days following tag attachment at Kent Island, NB in 2015. The red bar indicates mean hatch date for the colony and signifies a predicted shift in nest attendance patterns due to the transition from incubation to the chick-rearing period of the breeding cycle. Differences in mean percentages were not statistically significant (ANOVA;  $p=0.67$ ;  $n=14$ ).



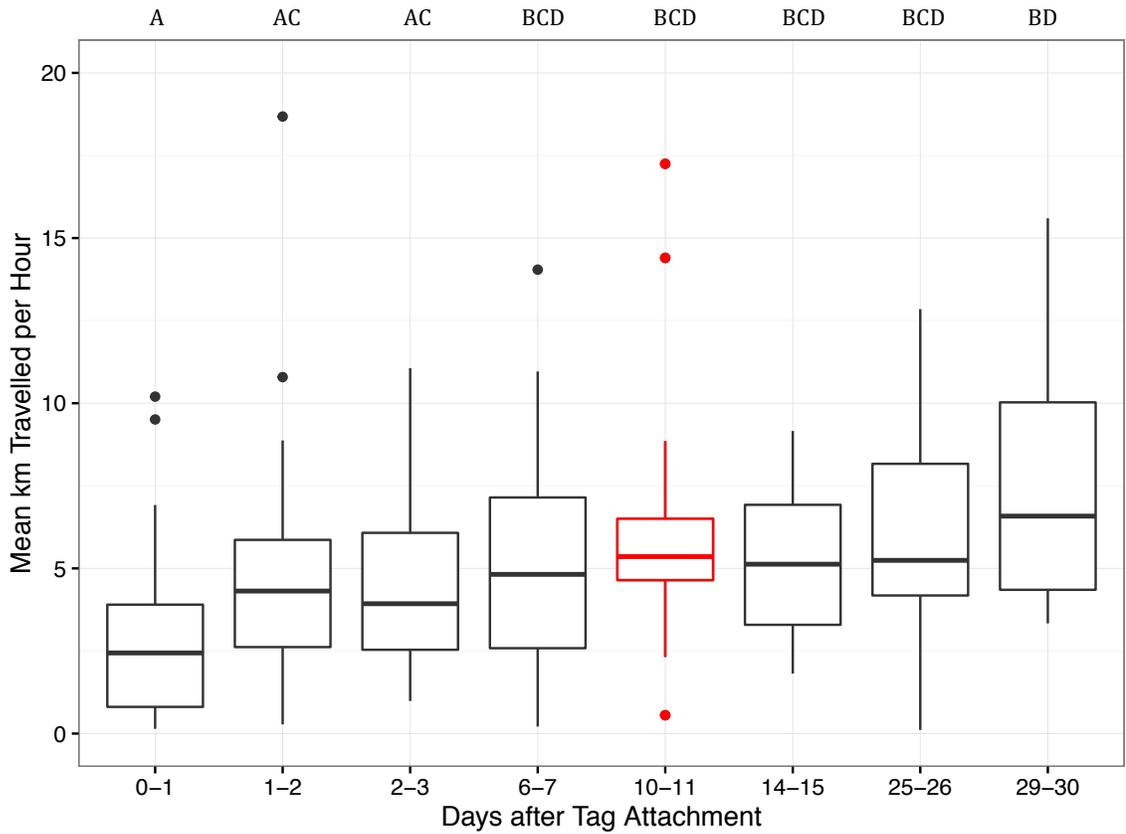
**Figure 2.4c.** Mean percent GPS locations recorded within 40m of tagged birds' nest sites in the days following tag attachment at Great Duck Island, ME in 2016. The red bar indicates the mean hatch date for Control and Procedural Control nests and the blue bar indicates the mean hatch date for Tagged nests only. Mean hatch signifies a predicted shift in nest attendance patterns due to the transition from incubation to the chick-rearing period of the breeding cycle. Differences were statistically significant (ANOVA;  $p < 0.001$ ;  $n = 6$ ), so post-hoc Tukey HSD was used to identify significant differences amongst post-deployment periods. Different letters indicate significant differences among groups.



**Figure 2.5.** Mean percent GPS locations recorded within 1km of tagged birds' nest sites in the days following tag attachment. Colony location did not contribute variation in the likelihood that birds stayed within 1km ( $p=0.118$ ), so data from all three colonies (Brier Island, NS, Kent Island, NB, and Great Duck Island, ME in 2014-2016) were pooled for analysis. ANOVA with post-hoc Tukey HSD was used to identify differences between post-deployment periods ( $p<0.001$ ;  $n=36$ ). The red bar indicates the mean hatch date of all colonies and signifies a predicted shift in nest attendance patterns due to the transition from incubation to the chick-rearing period of the breeding cycle. Different letters indicate significant differences among groups.



**Figure 2.6.** Mean distance (km) travelled per hour in the days following tag attachment. Colony location did not contribute to variation in distance travelled ( $p=0.328$ ), so data from all three colonies (Brier Island, NS, Kent Island, NB, and Great Duck Island, ME in 2014-2016) were pooled for analysis. ANOVA with post-hoc Tukey HSD was used to identify differences between post-deployment periods ( $p<0.001$ ;  $n=36$ ). The red bar indicates the mean hatch date of all colonies and signifies a predicted shift in behavioral patterns due to the transition from incubation to the chick-rearing period of the breeding cycle. Different letters indicate significant differences among groups.



**Chapter 3: Quantifying use of anthropogenic food types by Herring Gulls (*Larus argentatus*) nesting on neighboring colonies in the Bay of Fundy, Canada**

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## **Abstract**

Recent literature on Herring Gulls (*Larus argentatus*) in North America and Europe emphasize a shift in diet toward terrestrial, anthropogenic-sourced food, and a concurrent decline in nesting gull abundance. We deployed GPS loggers and collected whole blood and feather samples for  $\delta^{13}\text{C}$  and  $\delta^{15}\text{N}$  stable isotope analysis of diet during the incubation and chick-rearing stages of the breeding season of Herring Gulls in two large colonies in the Bay of Fundy, Canada. GPS locations and isotope analysis together provide evidence for spatial segregation in the foraging areas used by gulls at these two neighboring colonies. However, all gulls took advantage of a variety of anthropogenic food sources with some specializing more than others on fisheries (i.e., town wharfs, fish packaging plants, salmon aquaculture rings) or mink farms. No gulls fed regularly at landfills. This study provides valuable baseline information about the reliance of gulls on human activity for population maintenance, providing clues as to what impact changes in industry practice or regulation may have on patterns in nesting and foraging in this generalist species.

**KEYWORDS:** stable isotope analysis, diet, GPS tracking, foraging behavior, nuisance species, population decline, wildlife management

## Introduction

In Atlantic Canada, gulls (*Larus* spp.) are a source of concern for wildlife managers for conflicting reasons: first for their threat as a ‘nuisance’ species in relation to human health and industry (Blokpoel and Tessier 1986, Cleary et al. 2006, Clark et al. 2013, NBWBSS 2013), as well as their threat to other species of conservation (e.g., terns) and economic (e.g., eiders) interest (Donehower and Bird 2008, LaRue 2016, Scopel and Diamond 2017); and second, for the sharp, multi-decade decline in the abundance of breeding Ring-billed Gulls (*Larus delawarensis*), Great Black-backed Gulls (*L. marinus*), Lesser Black-backed Gulls (*L. fuscus*), and Herring Gulls (*L. argentatus*) in both North America and Europe (Anderson et al. 2016a). One long-standing hypothesis states that the declines are driven primarily by the widespread closure of landfills and loss of fisheries. These industries were once major sources of food to gulls across their range, and were thought to have sustained an elevated gull carrying capacity by subsidizing diet, especially during the winter months (Schreiber 1968, Drury 1973, Pierotti and Good 1994). This interpretation further implies that the gull population declines were predictable, and that populations will stabilize at a lower carrying capacity. This view has been implicitly adopted by wildlife management agencies in Canada and the United States (USFWS 2005, Cotter et al. 2012).

Though the relationship between diet and gull population dynamics largely remains empirically untested (Anderson et al. 2016b; though with some notable exceptions on a small temporal and geographic scale, e.g., Annett and Pierotti 1999), major shifts in diet over the past three decades are well recorded in *Larus* spp., including

switchovers to previously unexploited anthropogenic food sources (Hobson et al. 2015, Osterback et al. 2015, Ramírez et al. 2015, Bond 2016). Possibly related to this anthropogenic source shift is a shift toward terrestrial-sourced foods, even by gulls nesting on off-shore colonies (Blight et al. 2015, Garthe et al. 2016, Gyimesi et al. 2016, Bond 2016). The relationship between anthropogenic food and terrestrial food is unintuitive, as local fishing industries frequently provide an abundant source of marine-based anthropogenic food (e.g., by-catch returns, discarded bait, aquaculture feed, wharf offal; Furness and Monaghan 1987), and many food types found in terrestrial settings are not supplied by humans (e.g., worms, insects, seabirds). However, the number of rooftop nesting gulls has grown in eastern North America and Europe (Raven and Coulson 1997, Perlut et al. 2016, Rock et al. 2016), supporting this notion of increased proximity of gull and human populations.

Stable isotope analysis and GPS tracking have been successfully used to describe the foraging behavior of other *Larus* spp. (Caron-Beaudoin et al. 2013, Ceia et al 2014, Corman et al. 2016). To quantify anthropogenic food use in particular, the researcher must be able to verify the prey eaten and the source from which those prey were taken. For example, a researcher assessing diet using pellet or regurgitate sampling may be able to identify the bones of an Atlantic mackerel (*Scomber scombrus*), but is not able to confirm whether the bird caught that fish wild, from a fisherman at the wharf, or from a boat out at sea; likewise, stable isotope analysis may also be able to identify “large fish”, but the source of those fish remains unconfirmed. Similarly, GPS tracking allows the scientist to specify where the bird has travelled outside the colony, but does not confirm which travel destinations allowed for food gathering. Combining multiple methods of

dietary analysis is necessary to accurately judge the importance of anthropogenic food sources to local gull colonies.

The aim of this study was to describe the use of anthropogenic food types by Herring Gulls during the breeding season in the Bay of Fundy, Canada. We hope this analysis will provide a practical baseline for ornithologists to continue to define the relationship between diet and current gull population declines, and will be detailed enough to allow wildlife managers to more fully predict the effects of broad changes to industry policy or activity on gulls.

## **Methods**

Fieldwork was conducted during the breeding season (May-Aug.) in 2015 at the colony on Kent Island, New Brunswick (44.581, -66.756) and in 2014-2015 at the colony on Brier Island, Nova Scotia (44.275, -66.345; UNB animal care permit 14027). These two colonies each contained >3,000 pairs of breeding Herring Gulls and are located <40 km apart, making it theoretically possible that gulls from each colony overlap entirely in their foraging ranges (Drury and Nisbet 1972). Incubating adults were captured on 3-egg nests using walk-in nest traps. An 80  $\mu$ L sample of blood was drawn from the tarsal or brachial vein of every individual, and the top 3 cm was clipped from the oldest feather among the innermost primaries, P1-P3 ( $n_{\text{Brier}}=56$ ,  $n_{\text{Kent}}=33$ ). GPS loggers were deployed on gulls using a leg-loop harness made of Teflon ribbon (Mallory and Gilbert 2008). Two logger types were used including battery-powered i-GotU (MobileAction Technology, 19g,  $n=7$ , Brier Island only) and solar-powered HARIER-L (Ecotone Telemetry, 17g,

n=20, both islands). I-GotU loggers were programmed to record speed and GPS coordinates once every 5 minutes, and Ecotone loggers were programmed to record speed and latitude-longitude coordinates once every 15 minutes during the breeding season. For birds equipped with i-GotU tags, recapture was attempted for data retrieval approximately two weeks after tag deployment. No recapture was attempted at nests where the bird carried a solar-powered logger. Instead, a long-range antenna was placed at the edge of both colonies to download GPS data from tagged gulls every time they flew to their nests. The effect of loggers on adult gull behavior and survival was determined to be negligible for the purposes of this study (Chapter 2). We returned to each colony briefly in 2016 to set up a long-range antenna to collect GPS data from any previously tagged gulls returning to the colonies. These data were also included in the GPS analysis.

### *GPS analysis*

GPS data were collated and then filtered for speeds  $<2.0$  km/hr to limit analysis to the birds' foraging destinations by excluding in-transit locations (Fig. 3.1). Average hatch dates were calculated for both colonies based on nest monitoring data (2015) and conditions during trapping (all years). Average hatch dates were then used to establish incubation periods (beginning 6 weeks prior to average colony hatch) and chick rearing periods (ending 6 weeks after average colony hatch) in each year for each colony. In years of logger deployment (Brier 2014-2015, Kent 2015), the incubation period was set to begin 3 days after logger deployment to avoid analysis of abnormal behavior immediately following gull capture (Chapter 2).

The latitude and longitude coordinates of known anthropogenic food sources were delineated using Google Earth and then entered manually into R. These sources include: Fisheries (i.e. town wharfs, fish packaging plants, and salmon aquaculture pens), Mink (i.e., mink (*Neovison vison*) farms where gulls could access mink feed that has fallen through animal cages and animal composting facilities), and Landfill (i.e. waste transfer stations, solid waste parks, municipal compost sites). These categories were chosen based on observations made during site visits (2015) and preliminary GPS results (2014), and were further informed by informal conversation with town residents on where gulls are known to congregate and feed. All off-colony GPS records not classified in a Known Anthropogenic category were placed in an Unassigned category. Therefore, Unassigned points may be non-anthropogenic sources of food, unknown anthropogenic sources of food, or non-foraging resting locations. To improve explanatory potential for records in the Unassigned category, Unassigned locations were split into three generic habitat classifications: terrestrial (>3 km inland), coastal ( $\pm 3$  km of shoreline), and marine (>3 km offshore).

#### *Stable isotope analysis*

Stable isotope sample collection followed the procedures outlined in Steenweg et al. (2011). Since the turnover rate for whole blood is approximately 4 weeks in gulls (Hobson and Clark 1992), blood samples drawn at the time of trapping reflect the nest building and incubation stages of the birds' breeding cycle. Regarding feathers, gulls in the Bay of Fundy begin molting their innermost primaries during the incubation period

(Diamond unpub. data, Shlepr unpub. data), so old primary feathers collected at the time of trapping reflect the individuals' diets during the incubation period one year prior.

Whole blood samples were dried in an oven at 60 °C for 48 hours, and then were ground by hand using a mortar and pestle. Feathers were washed with a 2:1 chloroform methanol solution to remove surface impurities, and then were placed in a 60°C oven for 1-2 hours to dry. Prey source samples were dried in a 60°C oven, ground, and, if necessary, were treated with sulfuric acid (to dissolve carbonate shells) or a 2:1 chloroform methanol solution (to extract lipids). Samples were weighed, and then were submitted to the Stable Isotopes in Nature Laboratory (Fredericton, NB) for chemical analysis. Continuous Flow-Isotope Ratio Mass Spectrometry used for stable isotope analysis of  $\delta^{13}\text{C}$  and  $\delta^{15}\text{N}$ . Experimental error was determined to be 0.1‰ for both isotopes based on round robin testing of in-house secondary standards that were calibrated against and traceable to International Atomic Energy Agency primary standards.

Discrimination factors for whole blood (Carbon:  $-0.06 \pm 0.71$ ; Nitrogen:  $2.75 \pm 0.4$ ) and primary feathers (Carbon:  $1.16 \pm 0.71$ ; Nitrogen:  $4.14 \pm 0.4$ ) were taken from Herring Gull studies by Steenweg et al. (2011) and Ronconi et al. (2014) who averaged the discrimination factors from experiments with Ring-billed Gulls (*L. delawarensis*; Hobson and Clark 1992) and other seabirds (Bearhop et al. 2002, Cherel et al. 2005, Becker et al. 2007). Prey sources were grouped with attention to isotopic similarity into “Anthropogenic”, “Marine Fish”, and “Natural” categories (Figure 3.3). “Marine fish” were classified as their own group, as gulls may obtain these naturally at sea or from anthropogenic sources (i.e., fisheries discard at boats or wharfs). Potential prey sources

were eliminated before running final mixing models when results from preliminary isotope models, GPS analysis (Table 3.1), or field observations (including pellet sampling and behavioral observations at foraging sites) suggested that these prey types were not an important part of local gull diet (Fig. 3.3). All statistical analyses were run in program R (R Core Development Team 2013) using the Bayesian package MixSIAR (Stock and Semmens 2015). We also used Analysis of Variance ( $p_{\alpha}=0.05$ ) to test whether year (Brier Island only, 2014 vs. 2015) and colony (Brier Island vs. Kent Island) contributed to differences in mean stable isotope values.

#### *Analysis of individuals with paired results*

To quantitatively combine GPS and stable isotope results, we ran a simple linear regression model using the `lm` base package in R (R Core Development Team 2013) comparing the mean estimated contribution of Known Anthropogenic food types using  $\delta^{13}\text{C}$  and  $\delta^{15}\text{N}$  values from the P1 feather (all years) to the percentage of GPS records classified in the Known Anthropogenic category for all possible GPS tagged individuals ( $n=19$ ). The closer the slope of the regression line is to 1.0 (i.e., a perfect match between the time gulls spend at known anthropogenic locations and the proportion that known anthropogenic prey types contribute to diet), the more confirmation we have that gulls successfully obtain food at the anthropogenic sites they visit. A slope greater or less than 1.0 may indicate a mismatch between the amount of time the gulls spend at anthropogenic sites and the proportion of the diet coming from those sites.

## Results

### *GPS analysis*

GPS records indicated that gulls from the Brier Island colony spent 52-76% (mean $\pm$ SD: 62.7 $\pm$ 19.6%) of their off-colony time at rest in a Known Anthropogenic site, while gulls from the Kent Island colony ranged from 27-40% (mean $\pm$ SD: 32.7 $\pm$ 23.2%) in the same analysis (Table 3.1). For gulls from both colonies, most GPS points that were located outside a Known Anthropogenic site were instead in coastal ( $\pm$ 3 km from shoreline) habitat (Brier: 24.7 $\pm$ 15.9%, Kent: 59.3 $\pm$ 21.8%), which may reflect intertidal foraging or time spent loafing without foraging. Gulls overall spent little time at rest in the marine (offshore) environment (Brier: 7.5 $\pm$ 11.3%, Kent: 6.0 $\pm$ 10.4%; Fig. 3.1).

As is reflected by the high standard deviations in the Known Anthropogenic site category (Table 3.1), individual use of Known Anthropogenic food sources varied widely, especially amongst gulls from Kent Island (Fig. 3.2a). Fisheries (including town wharfs, fish packaging plants, and salmon aquaculture rings) contributed most to this variation, with a continuous range of use by individuals from both colonies (Fig. 3.2b). Contrarily, individuals appear to use mink farms heavily or not at all. Colony of origin appears to be the biggest determinant for this food source, as 6 of 9 gulls from Brier Island spent at least 25% of their off-colony time at mink farm sites compared to 1 of 11 Kent Island gulls (Fig. 3.2c). Only 1 gull (Kent Island) ever visited a landfill, and that site type constituted <1% of all records for that individual. Overall, landfill visits constituted <0.1% of all records in the Bay of Fundy.

### *Stable isotope analysis*

Colony was an important factor contributing to differences in mean stable isotope values, with Brier Island gulls showing lower mean  $\delta^{13}\text{C}$  ( $-19.0 \pm 0.4$ ) and  $\delta^{15}\text{N}$  ( $11.9 \pm 1.1$ ) values than Kent Island gulls ( $\delta^{13}\text{C}$ :  $-17.9 \pm 0.8$ ,  $\delta^{15}\text{N}$ :  $12.5 \pm 1.0$ ) for samples collected within the same year ( $p_{\delta^{13}\text{C}} < 0.001$ ,  $p_{\delta^{15}\text{N}} = 0.024$ ; Fig. 3.4, 3.5). The factor Year also had a large effect on  $\delta^{13}\text{C}$  values for the Brier Island colony where we analyzed two breeding seasons' data ( $p_{\delta^{13}\text{C}} < 0.001$ ;  $p_{\delta^{15}\text{N}} = 0.365$ ). Thus, we considered Colony and Year effects when interpreting model outputs.

Blood (Fig. 3.4) and feather (Fig. 3.5) mixing models produce similar patterns in food source contribution, most clearly showing the colony-level separation in  $\delta^{13}\text{C}$ . Gulls from the Brier Island colony obtain a higher proportion of their diet from the Known Anthropogenic source category than Kent Island gulls (range of contribution of known anthropogenic food sources over both years, both tissue types: 15.6-30.3% Brier, 5.0-7.8% Kent), though the Known Anthropogenic category was not the main component of gull diet in either colony in either year (Table 3.2). The source of Brier Island gull diet is not clear, as the mean contribution of all prey categories was relatively even (Known Anthropogenic:  $28.5 \pm 11.1\%$ , Marine Fish:  $38.5 \pm 12.2\%$ , Natural:  $33.0 \pm 12.1\%$ ; Fig. 3.4b, 3.5b). Kent Island gulls appear to primarily consume intertidal prey (Natural:  $66.2 \pm 14.8\%$ ) and scarcely obtain Known Anthropogenic food types (Known Anthropogenic:  $7.0 \pm 5.9\%$ ; Fig. 3.4c, 3.5c). We are not able to determine from isotopes alone whether the Marine Fish category is an anthropogenic or a natural source of food. Therefore, Known Anthropogenic isotope percentages may be underestimated if Marine Fish prey are obtained by gulls primarily as bait from fishing boats.

### *Analysis of individuals with paired results*

Individuals that spent more time at Known Anthropogenic GPS locations had higher estimated contributions of Known Anthropogenic prey types by stable isotopes ( $p=0.022$ ), though the  $R^2$  value (0.229) is moderately low and colony-level segregation on both axes is high (Figure 3.6). The slope of the linear model is 0.93, close to the 1:1 ratio that suggests a perfect match in the amount of time gulls spend at anthropogenic sites and the proportion of the diet that comes from those same locations. That the slope is slightly less than 1.0 suggests that gulls visit known anthropogenic food sources but do not always obtain food there.

### **Discussion**

Superficially, it appears that the stable isotope analysis results in a more conservative estimate of the use of anthropogenic food sources by gulls as compared to the GPS analysis. This difference may be real, indicating that at a large portion of gulls' off-colony stopovers are non-foraging destinations. Alternatively, mixing models are known to be sensitive to change in the researchers' choices in prey source groupings (Phillips et al. 2005). Our models are no exception, particularly since the list of possible prey sources in a species as generalist as the Herring Gull spans the entire range of  $\delta^{13}\text{C}$  and  $\delta^{15}\text{N}$  values one would expect to find in the Bay of Fundy. For the results we report here, the isotopic overlap in prey categories is worth noting (Fig. 3.3). Ground herring is the primary ingredient in both mink feed and salmon aquaculture pellets, so these two

sources, in combination with wild-caught or bait herring, are difficult if not impossible to distinguish using isotope mixing models. Another problem inherent to Bayesian isotope analysis is that gulls with diets high in the prey types that have moderate isotope values (e.g., fish pipe waste, blue mussels (*Mytilus edulis*)) may fall into the same position on an isotope bi-plot as gulls who split their diet between prey items with opposing extreme isotope values (e.g., mink feed and lobster). Therefore, GPS analysis or other traditional diet sampling methods must be employed to further investigate the importance of these prey types in the birds' diets. For instance, our GPS analysis shows that gulls spend much of their time at coastal sites and little time offshore (Table 3.1), which may suggest that gulls in our study are more likely to obtain Atlantic herring (*Clupea harengus*) and Atlantic mackerel by anthropogenic means (i.e., fishing bait) rather than catching these fish wild at sea, even if Marine Fish appear as a separate contribution from the Known Anthropogenic category in the mixing model outputs. The lack of Herring Gull-specific discrimination factors may also have influenced our stable isotope results (Bond and Diamond 2011).

It is possible that our GPS analysis is biased against gulls foraging at sea. We filtered GPS records for near-stationary speeds (<2 km/hr) based on field observations at foraging sites where gulls primarily employed an arrive-and-wait foraging strategy. However, marine foragers, more so than coastal (i.e., intertidal) or terrestrial foragers, are more likely to fly steadily in search of food because the marine environment is patchy (Weimerskirch 2007) and gulls are visual hunters (Tinbergen 1953). Given the overall scarcity of gull records located offshore in our raw dataset, we chose to move forward with our analysis under the assumption that gull attendance in the marine environment

truly was low relative to coastal and inland areas. However, marine foraging specialists deserve more attention in future studies.

Though the Brier Island and Kent Island colonies are located <40 km apart (Chapter 1)—well within the typical foraging range of the species (Drury and Nisbet 1972)—we found colony-level differences not only in where gulls forage, but in the types of prey they obtain in each habitat type. Gulls from Brier Island consistently spent more than half of their off-colony time at sites known to supply anthropogenic sources of food. Gulls nesting on Kent Island appeared to rely less on anthropogenic-sourced food types, particularly mink farms, though approximately one-third of their off-colony movements fell into one of the anthropogenic classifications (Table 3.1).

Variation in prey type at the individual and colony levels may ultimately explain differences in annual productivity and colony return rates if the energetic gains from these prey types also vary. This relationship is not always straightforward. Hunt (1972) found no difference in growth rate amongst chicks at four neighboring gull colonies, yet noted that chick survival was higher on the two in-shore colonies. He hypothesized that, while food quantity or quality were not limiting factors at any of the colonies, depredation rates were lower at the inshore colonies because adults were better able to guard their nests due to proximity to their food sources. Therefore, it was not an energetic difference that explained patterns in colony productivity, but an indirect behavioral consequence of diet. The precise relationship between diet and productivity at our colonies in the Bay of Fundy should be tested empirically in the future.

GPS tracking and stable isotope analysis are two approaches to understanding Herring Gull diet during the breeding season, each with their own strengths and biases.

Along with reliable, site-specific field observations on the natural history of the species, these methods allow us to better explain variation in gull diet in the Bay of Fundy, especially in relation to these birds' use of anthropogenic sources of food. Understanding the way that human activities influence gull behavior and health allows us a means to predict the impacts of various management possibilities on the gull population overall. Such knowledge is critical for informed decision-making when there are conflicting calls to protect gulls against current population declines and control their impacts on human health and economy.

### **Acknowledgements**

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**Table 3.1.** Mean percentage ( $\pm$  SD) of GPS records by landscape type for Herring Gulls nesting at two colonies in the Bay of Fundy. GPS records were restricted to speeds  $< 2\text{km/hr}$  during the breeding season. “Incubation” includes the 6 weeks before each colony’s mean hatch date, and “Chick rearing” includes the 6 weeks after each colony’s mean hatch date, except for in years of logger deployment (Brier 2014, Kent 2015) where “Incubation” begins 3 days after the final logger was deployed.

	n	Known Anthropogenic (%)				Unassigned (%)					
		Fisheries	Mink	Landfill	Total	Terrestrial	Coastal	Marine	Total		
<b>Brier</b>	2014	Incubation	14	15.4 (23.0)	41.5 (26.5)	0.0 (0.0)	56.8 (20.3)	5.4 (6.3)	28.6 (12.8)	9.2 (13.1)	43.2 (20.3)
		Chick rearing	*9	25.6 (25.2)	37.7 (23.5)	0.0 (0.0)	63.3 (17.1)	3.1 (3.8)	18.6 (15.3)	15.0 (15.8)	36.7 (17.1)
2015	Incubation	**8	20.3 (26.7)	31.8 (26.7)	0.0 (0.0)	52.1 (20.9)	6.3 (5.8)	33.9 (17.0)	7.7 (10.0)	47.9 (20.9)	
	Chick rearing	*6	19.5 (31.3)	56.6 (31.9)	0.0 (0.0)	76.1 (16.6)	4.1 (3.8)	15.8 (15.3)	4.0 (5.4)	23.9 (16.6)	
2016	Incubation	*6	27.1 (27.4)	38.8 (29.9)	0.0 (0.0)	66.0 (17.3)	7.2 (9.5)	25.2 (18.5)	1.7 (3.2)	34.0 (17.3)	
	Chick rearing	*6	22.9 (32.8)	52.2 (30.9)	0.0 (0.0)	75.1 (16.0)	4.0 (2.7)	19.8 (15.5)	1.1 (2.3)	24.9 (16.0)	
	<b>Colony average</b>	16	<b>20.9 (25.8)</b>	<b>41.8 (27.3)</b>	<b>0.0 (0.0)</b>	<b>62.7 (19.6)</b>	<b>5.1 (5.6)</b>	<b>24.7 (15.9)</b>	<b>7.5 (11.3)</b>	<b>37.3 (19.6)</b>	
<b>Kent</b>	2015	Incubation	11	23.9 (25.7)	3.9 (13.1)	0.0 (0.0)	27.8 (25.3)	0.8 (1.4)	65.6 (22.2)	5.7 (7.2)	72.2 (25.3)
		Chick rearing	*11	22.9 (20.6)	5.1 (11.8)	0.0 (0.1)	28.0 (19.8)	2.4 (6.4)	58.1 (21.2)	11.5 (16.0)	72.0 (19.8)
2016	Incubation	*10	31.2 (25.2)	4.1 (12.9)	0.1 (0.4)	35.4 (23.8)	2.5 (3.9)	59.4 (24.6)	2.6 (4.2)	64.6 (23.8)	
	Chick rearing	*10	33.8 (26.2)	6.0 (18.5)	0.5 (1.4)	40.3 (24.8)	2.3 (3.5)	53.6 (21.3)	3.8 (8.8)	59.7 (24.8)	
	<b>Colony average</b>	11	<b>27.7 (24.0)</b>	<b>4.8 (13.7)</b>	<b>0.2 (0.7)</b>	<b>32.7 (23.2)</b>	<b>2.0 (4.1)</b>	<b>59.3 (21.9)</b>	<b>6.0 (10.4)</b>	<b>67.3 (23.2)</b>	

\*Repeat sampling of individuals from initial deployment (Brier: Incubation 2014; Kent: Incubation 2015)

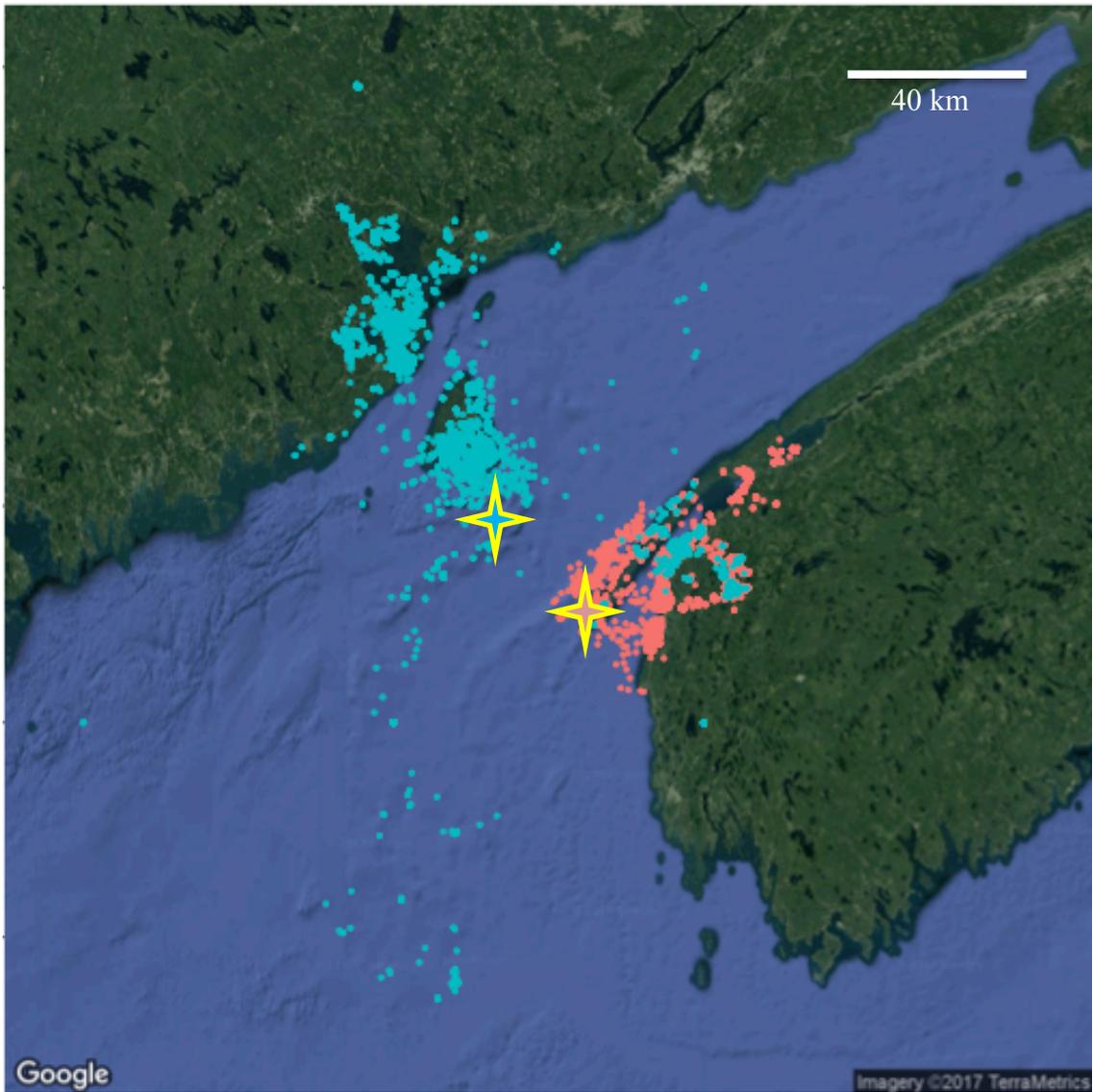
\*\*Sample includes repeat of 6 individuals from initial deployment (Incubation 2014) plus logger deployment on 2 new individuals

**Table 3.2.** Mean percentage ( $\pm$  SD) contribution of each prey source category to colony diet as estimated by isotope mixing models. Data are  $\delta^{13}\text{C}$  and  $\delta^{15}\text{N}$  values of whole blood and primary feather samples from Herring Gulls nesting at two colonies in the Bay of Fundy. See Figure 2 for specific prey items included in each prey source category.

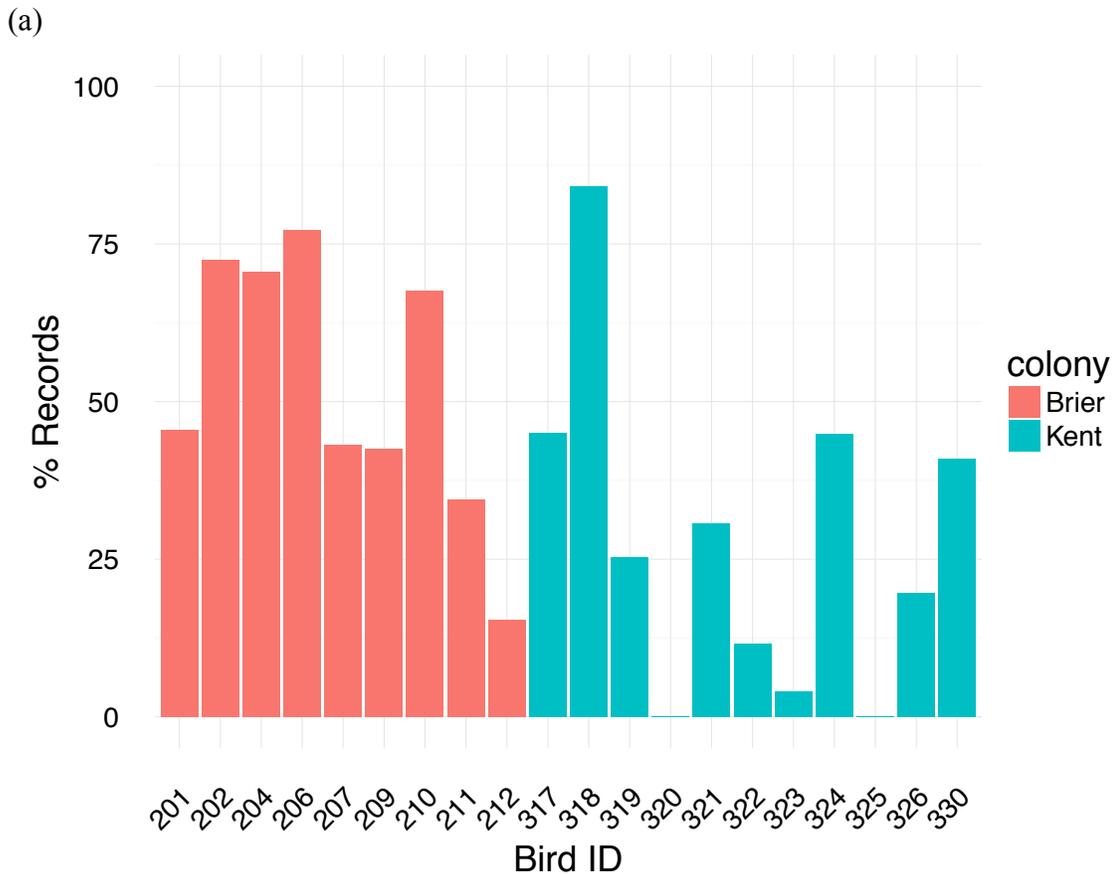
		Prey Source Category			
		Known Anthropogenic	Marine Fish	Natural	
<b>Brier</b>	2014	Blood	30.3 (3.2)	45.0 (4.6)	24.7 (4.7)
		Feather	25.1 (3.7)	29.5 (5.1)	45.4 (5.9)
	2015	Blood	24.5 (3.3)	33.4 (4.8)	42.1 (5.2)
		Feather	15.6 (6.0)	36.7 (7.5)	47.7 (7.1)
	<b>*Colony average</b>	<b>28.5 (11.1)</b>	<b>38.5 (12.2)</b>	<b>33.0 (12.1)</b>	
<b>Kent</b>	2015	Blood	5.0 (2.9)	23.0 (7.1)	72.0 (7.1)
		Feather	5.3 (3.5)	28.9 (8.4)	65.8 (8.2)
		<b>*Colony average</b>	<b>7.0 (5.9)</b>	<b>30.8 (14.0)</b>	<b>62.2 (14.8)</b>

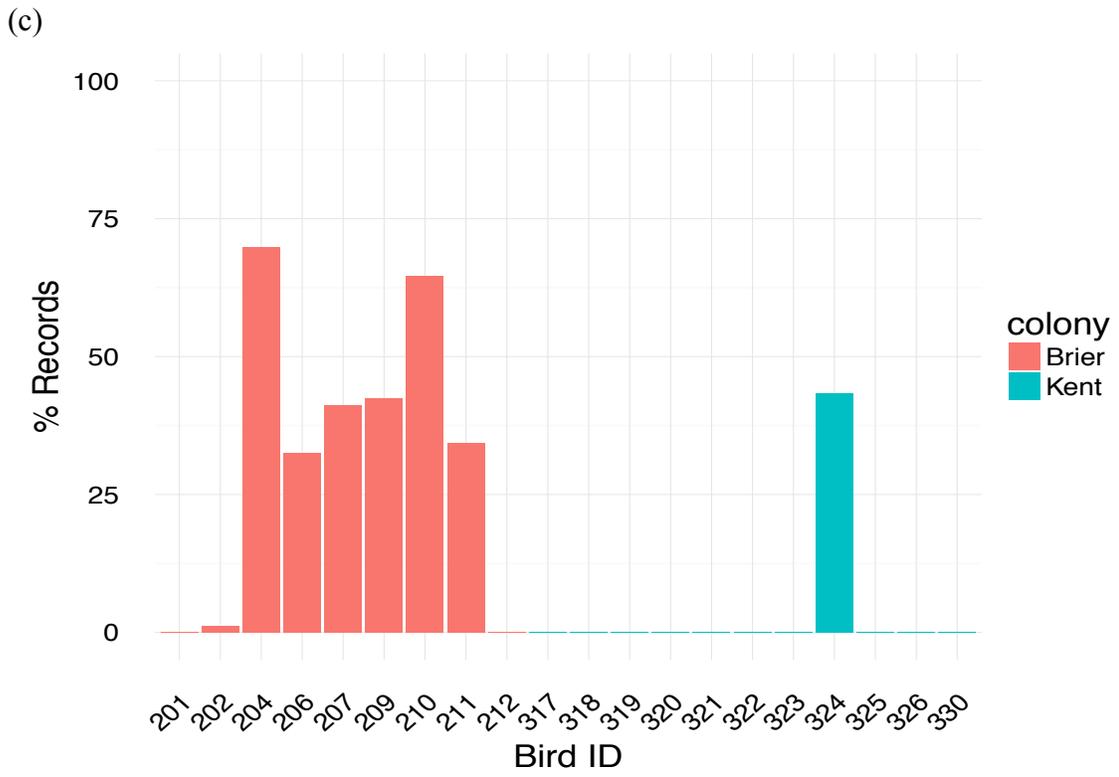
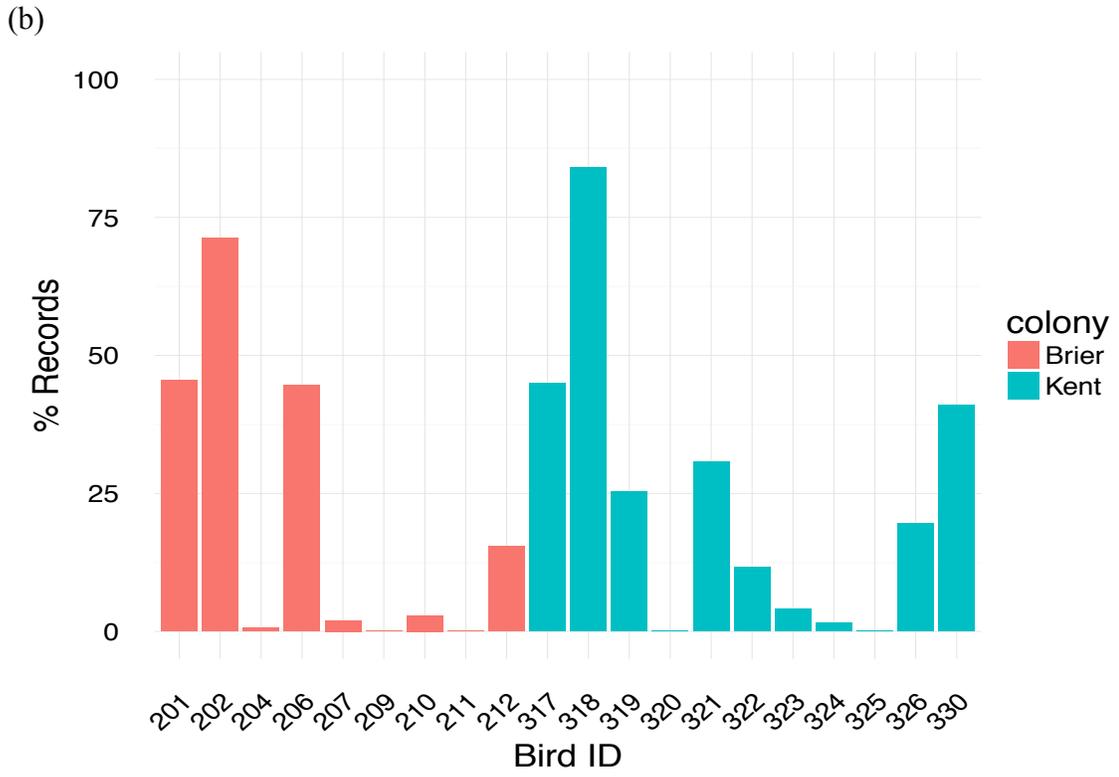
\*Colony average values are given by the model of blood samples only. They were included here for ease of comparison with Table 3.1 results.

**Figure 3.1.** GPS locations recorded during the breeding season for Herring Gulls on Kent Island (blue star; n=11) and Brier Island (pink star; n=16), 2014-2016. Records are filtered to exclude speeds < 2 km/hr.

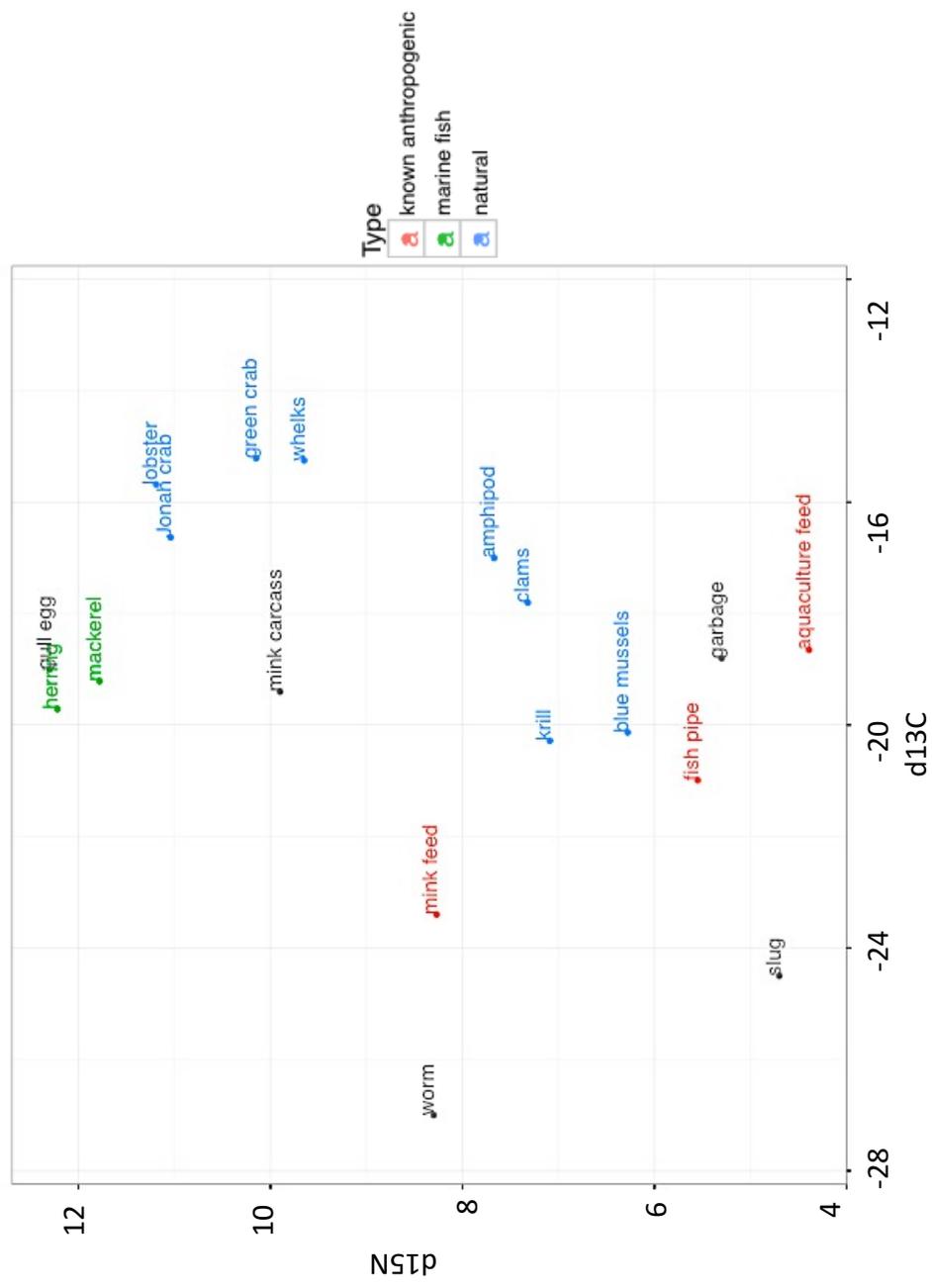


**Figure 3.2.** Percentage of off-colony GPS records for individual Herring Gulls (“Bird ID”) at known sources of anthropogenic food during the incubation period in 2015 for (a) all Known Anthropogenic types combined (Fisheries, Mink farms, and Landfills), (b) Fisheries, and (c) Mink farms. Records were filtered for speeds <2 km/hr to minimize locations caught in-transit. Landfills are not graphed separately because visits to these sites constituted no more than 0.1% of locations for either colony (Table 3.1).



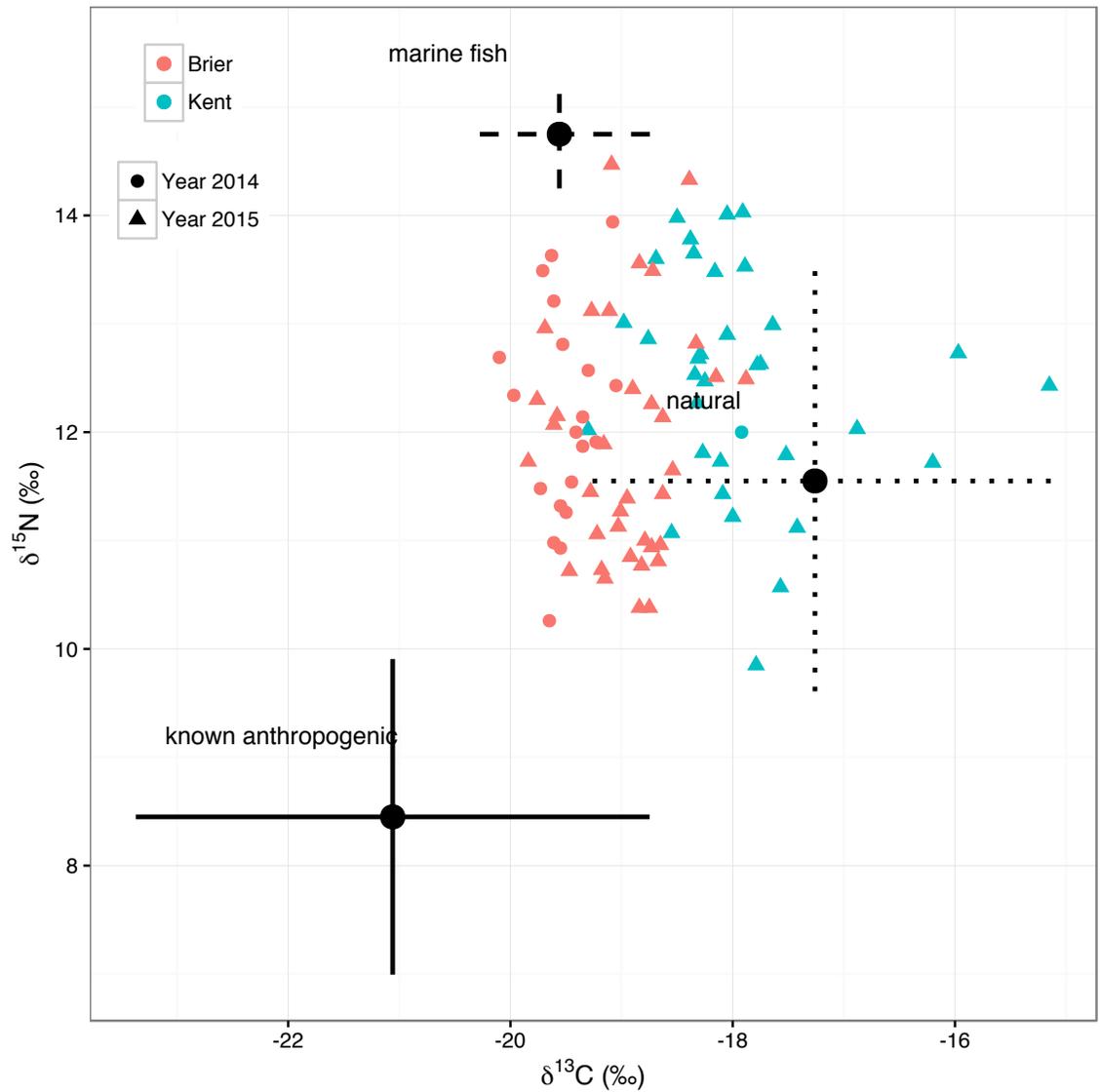


**Figure 3.3.** Mean  $\delta^{13}\text{C}$  and  $\delta^{15}\text{N}$  values of potential prey items collected in the southern Bay of Fundy in summer 2015. Label colors represent prey source categories used in the final mixing model analyses. Items in grey were left out of the final analyses (see Methods section for rationale).

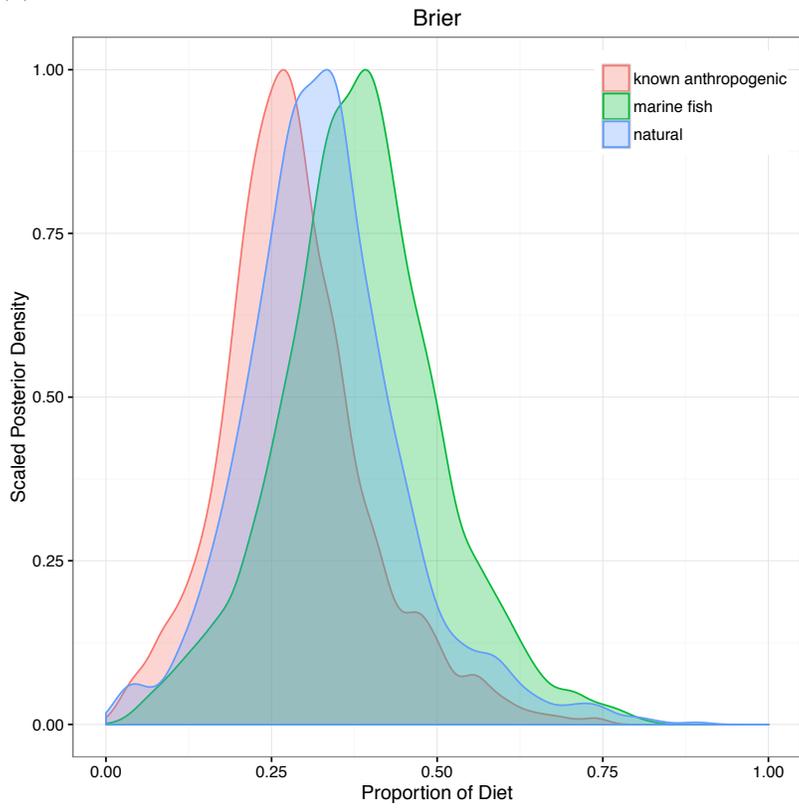


**Figure 3.4.** (a) Bayesian mixing model and posterior density plots for (b) Brier Island and (c) Kent Island colonies based on  $\delta^{13}\text{C}$  and  $\delta^{15}\text{N}$  values of whole blood samples collected from nesting Herring Gulls in 2014 and 2015. These samples reflect individual gull diet during the nest building and incubation periods of the breeding season.

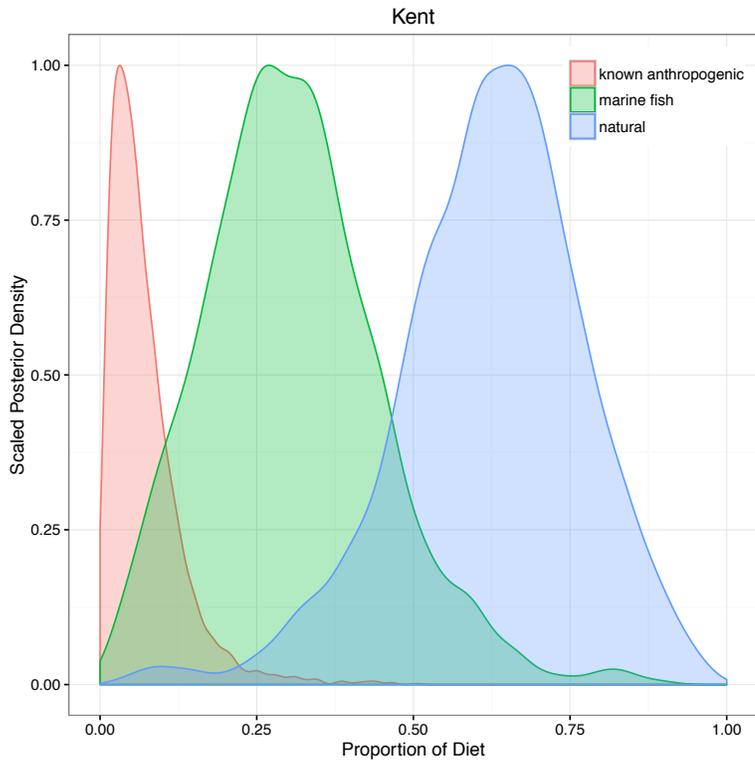
(a)



(b)

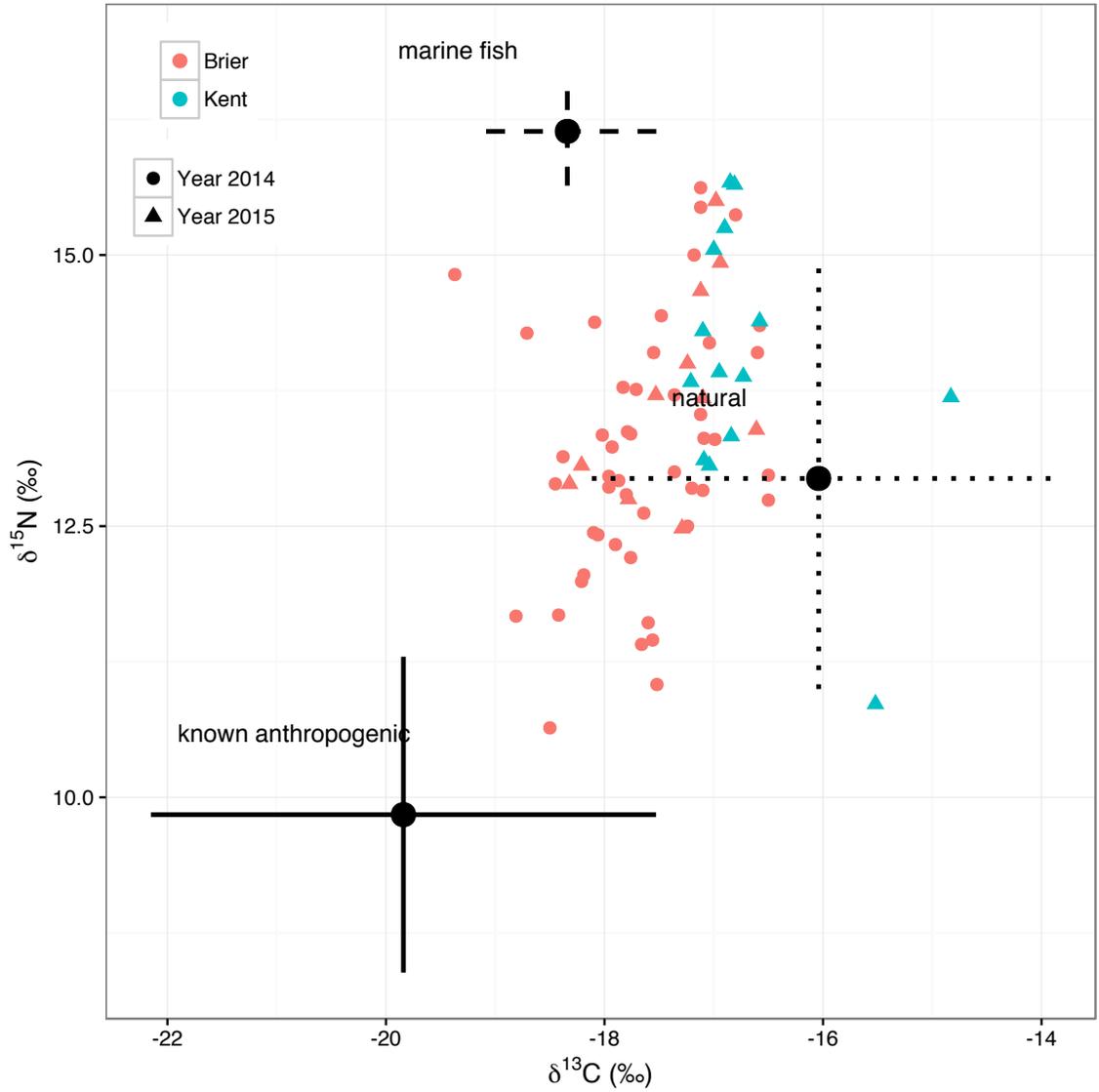


(c)

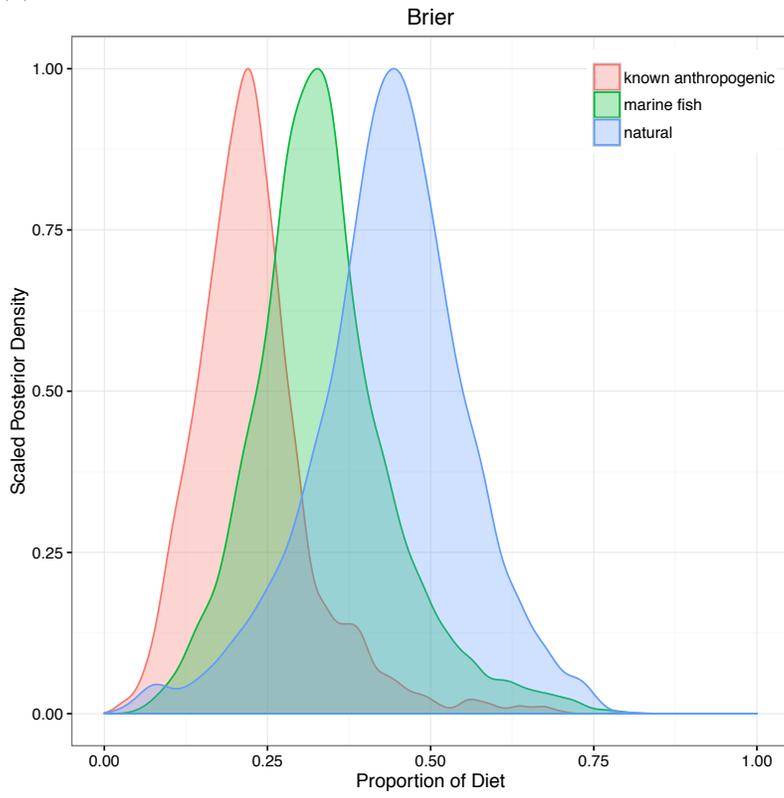


**Figure 3.5.** (a) Bayesian mixing model and posterior density plots for (b) Brier Island and (c) Kent Island colonies based on  $\delta^{13}\text{C}$  and  $\delta^{15}\text{N}$  values of feather samples collected from nesting Herring Gulls in 2014 and 2015. These samples reflect individual gull diet during the incubation period of the year prior.

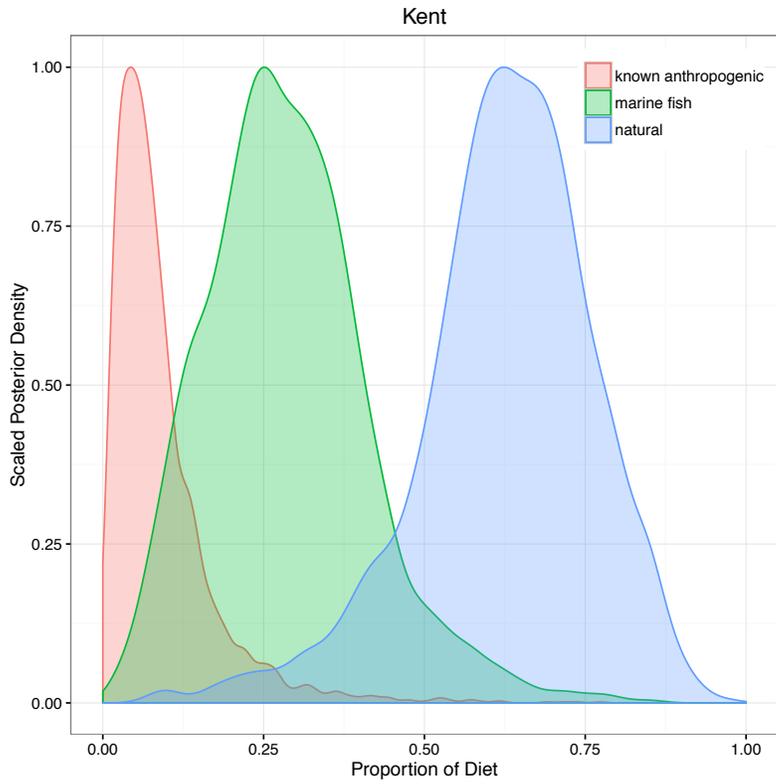
(a)



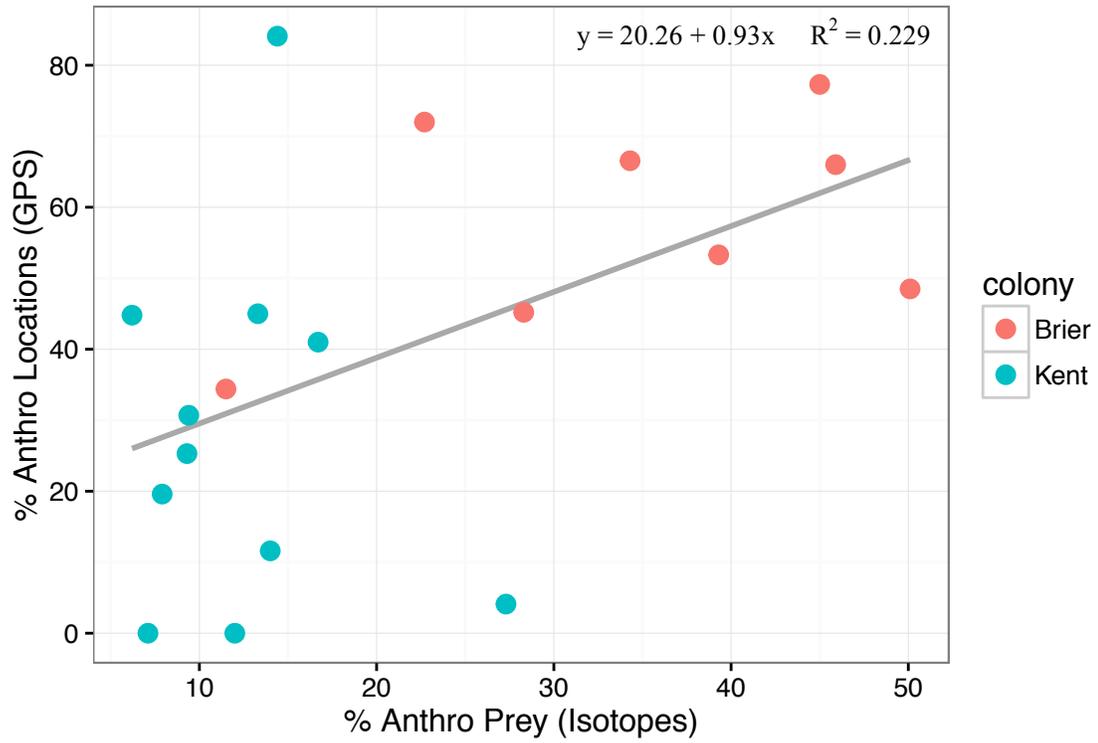
(b)



(c)



**Figure 3.6.** Percentage of anthropogenic foraging locations (GPS analysis) versus the mean estimated contribution of anthropogenic prey (stable isotope analysis) for Herring Gulls at two colonies in the Bay of Fundy. A least-squares line of regression is shown (n=19; p = 0.022).



## Chapter 4: Conclusion

### Rationale

Many aspects of Herring Gull life history have been thoroughly observed. Studying variations between individual gulls rather than generalizing the species *en masse* will be key to improving our understanding of the link between long-term population trends and shifts in diet, and to understanding how gulls adapt to a rapidly changing environment like the current Gulf of Maine.

### Findings

Modern GPS tags allow researchers to pursue questions at the level of the individual in greater detail than ever before. To my knowledge, this thesis provides the first test of the effect of GPS tagging on Herring Gull behavior, and combines GPS tracking analysis with more established methods of diet analysis to better understand how Herring Gulls nesting in the Bay of Fundy are influenced by anthropogenic food sources.

Chapter 2 of this thesis is aimed at determining whether GPS tags may provide reliable, representative data on patterns in Herring Gull movement by comparing nest success attributes at a sample of nests with a tagged adult, nests where an adult was captured and measured without tag attachment, and nests where adult capture was never attempted. I found that nest failure occurred at nests with a tagged individual, especially when the tag type required re-capture for data retrieval, and conclude that this was likely due to nest abandonment within the first 48 hours of tag attachment. To test this

conclusion, I examined the behavior of tagged individuals in eight 24-hour periods following tag attachment. Tagged individuals were less likely to attend their nests and forage off-colony in the 48 hours following tag attachment, which supports the notion that nests are at least temporarily abandoned by tagged individuals after tag deployment. This effect was not consistent at all three study colonies, however, and more follow-up work is needed to determine whether the difference in gull response is site-specific or is due to differences in the timing of tagging relative to mean colony hatch date. Such a study would be particularly relevant, as two previous tag effects studies on Lesser Black-backed Gulls noted small percentages of nest abandonment without investigating the cause of abandonment (Camphuysen *et al.* 2015, Garthe *et al.* 2016). As in these studies, effects of GPS tags in my study on the ability of a Herring Gull pair to raise young were not lasting. I found no differences in chick growth rate or chick survival to Day 21 between nests of tagged birds and nests of control birds. This result aligns with conclusions from previous studies on the Lesser Black-backed Gull (Camphuysen *et al.* 2015, Thaxter *et al.* 2014, Garthe *et al.* 2016, Thaxter *et al.* 2016).

After concluding in Chapter 2 that the movements of gulls after the first 48 hours of tag attachment are not significantly biased due to a tag effect, I used GPS locations collected from gulls at two colonies in the Bay of Fundy to study individual- and colony-level foraging strategies and reported the results in Chapter 3. The notion of “anthropogenic food subsidies” has been part of our scientific narrative of gull population change in the last century (USFWS 2005, Cotter *et al.* 2012), but rarely have researchers been able to demonstrate both what gulls eat and the source location of those prey items to quantify the reliance by gulls on anthropogenic sources of food. In addition to

analyzing the proportion of GPS records that were located at known anthropogenic food sources, I analyzed  $\delta^{13}\text{C}$  and  $\delta^{15}\text{N}$  stable isotope values of blood and feather samples from gulls to estimate the contribution of known anthropogenic prey types to the gulls' diet. Combined, these methods show colony-level differences in both foraging location and prey choice, and high within-colony variation in the use of particular types of anthropogenic food sources, especially at the colony (Kent Island) further from the mainland. Even considering this high variation between individuals, anthropogenic food sources appear to be a key component to modern gull diet in the Bay of Fundy as has been observed in other parts of the world (Yoda et al. 2012, Washburn et al. 2013, Hobson et al. 2015, Gyimesi et al. 2016). Regional changes to fisheries or mink farm practices may have a significant impact on gull movements, diet, and nest success, and these may ultimately lead to widespread population increases or declines like the ones we have observed in the past century (Wilhelm et al. 2016).

### **Recommendations for future research**

This thesis provides baseline information on Herring Gull diet and foraging behavior in the Bay of Fundy region. Parallel to the Bay of Fundy fieldwork in 2015, GPS tags were deployed on gulls in Witless Bay, Newfoundland, the second largest Herring Gull colony in Atlantic Canada. More work should be done to compare Herring Gull behavior in the Bay of Fundy to this colony in Newfoundland and the colony on Great Duck Island, Maine. In Chapter 3 I focused on the off-colony destinations during the breeding season, but many questions remain regarding foraging strategy (e.g.

comparing individual flight routes rather than endpoints) and Herring Gull behavior outside the incubation stage of the breeding cycle. Many of these questions can be preliminarily investigated with the three years of data we have already collected. Finally, to solidify the link between foraging strategy and the reproductive success of individuals, gulls with similar diets or movement patterns from different colonies should be grouped, and measures of reproductive success should be compared. To do so, nest monitoring efforts should be expanded to all colonies where tags are currently deployed (i.e. Newfoundland, Bay of Fundy, and Maine).

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## Curriculum Vitae

### Education

B.A. Human Ecology, College of the Atlantic, Bar Harbor, ME. 2009-2013

- Thesis: *Ecology and conservation in northern British Columbia*

### Publications

- Special Issue on Gull Biology. Eds. J.G.T. Anderson, A.L. Bond, R.A. Ronconi, and **K.R. Shlepr**. 2016. *Waterbirds* 39 (sp 1). 288 pp.
- Anderson, J.G.T., **K.R. Shlepr**, A.L. Bond and R.A. Ronconi. 2016. Introduction: A historical perspective on trends in Herring Gull and Great Black-backed Gull populations around the North Atlantic. *Waterbirds* 39 (sp 1): 1-9.

### Select Conference Presentations

- **Shlepr, K.R.** 2017. Quantifying the use of anthropogenic food sources by gulls. Gulf of Maine Seabird Working Group, Bangor, ME. Talk.
- **Shlepr, K.R.**, J.G.T. Anderson and A.W. Diamond. 2016. GPS tag attachment is likely to affect hatching but not chick rearing in Herring Gulls (*Larus argentatus*). Waterbird Society annual meeting, New Bern, NC. Talk.
- **Shlepr, K.R.** and A.W. Diamond. 2016. A dilemma in environmental ethics: What is the ecological role of the 'nuisance' herring gull in our Bay of Fundy? Bay of Fundy Partnership workshop, Fredericton, NB. Poster.
- Anderson, J.G.T and **K.R. Shlepr**. 2016. The use of GPS tags in evaluating the impact of oyster farms on gull foraging patterns. Waterbird Society annual meeting, New Bern, NC. Poster.
- **Shlepr, K. R.** 2016. 'Sea'birds no longer: Herring Gulls and their interactions with industry in Nova Scotia and beyond. Mersey Tobeatic Research Institute, Kempt, NS. Invited talk.
- **Shlepr, K.R.** 2015. Is food currently a limiting factor for Herring Gulls nesting in the Bay of Fundy? Waterbird Society annual meeting, Bar Harbor, ME. Talk.