

**Winter Distribution of the Black Guillemot (*Cepphus grylle*) in Atlantic Canada**

ENVS 4901 Environmental Science Undergraduate Honours Thesis

Submitted by  
Julia Baak  
Dalhousie University, Halifax NS

April 2019

Supervisors:

Dr. Marty Leonard  
Dean of Graduate Studies  
Dalhousie University, Halifax, NS

Dr. Robert Ronconi  
Wildlife Biologist  
Canadian Wildlife Service, Dartmouth, NS

Course Coordinator:

Dr. Tarah Wright  
Professor of Environmental Science  
Dalhousie University, Halifax, NS

## Table of Contents

<b>Acknowledgements .....</b>	<b>3</b>
<b>Abstract.....</b>	<b>4</b>
<b>1.0 Introduction.....</b>	<b>5</b>
<b>2.0 Literature Review .....</b>	<b>8</b>
<b>2.1 Conservation applications of understanding seabird distribution and movement.....</b>	<b>8</b>
<b>2.2 Methods of seabird distribution and movement monitoring .....</b>	<b>9</b>
<i>2.2.1 Observational studies in conjunction with tracking studies .....</i>	<i>9</i>
<i>2.2.2 Tracking devices.....</i>	<i>9</i>
<b>2.3 Black Guillemot.....</b>	<b>11</b>
<b>2.4 Conclusion .....</b>	<b>12</b>
<b>3.0 Methods.....</b>	<b>12</b>
<b>3.1 Study area .....</b>	<b>12</b>
<b>3.2 Tag deployment and recapture.....</b>	<b>14</b>
<b>3.3 Geolocation data analysis .....</b>	<b>15</b>
<b>3.4 Effect of tagging .....</b>	<b>18</b>
<b>4.0 Results .....</b>	<b>19</b>
<b>4.1 Movements and distribution .....</b>	<b>20</b>
<b>4.2 Habitat use.....</b>	<b>25</b>
<b>4.2 Effect of Tagging.....</b>	<b>27</b>
<i>4.2.1 Adult mass .....</i>	<i>27</i>
<i>4.2.2 Hatch success .....</i>	<i>28</i>
<b>5.0 Discussion.....</b>	<b>28</b>
<b>5.1 Winter distribution and habitat use .....</b>	<b>28</b>
<b>5.2 Effect of tagging .....</b>	<b>32</b>
<b>5.3 Future implications.....</b>	<b>33</b>
<b>6.0 Conclusion .....</b>	<b>35</b>
<b>8.0 References.....</b>	<b>36</b>

## **Acknowledgements**

Thank you to my honours supervisors, Dr. Marty Leonard (Dalhousie University) and Dr. Robert Ronconi (Canadian Wildlife Service) for their continued guidance and support throughout the project and for reviewing previous drafts. Thank you to my honours professor, Dr. Tarah Wright (Dalhousie University) for her instruction and encouragement throughout the semester. Thank you to Mark Dodds (University of New Brunswick) for processing the global location sensor data and Sarah Wong for the extractions of sea surface temperature and depth data. Finally, thank you to Carina Gjerdrum and the Country Island field crew for assisting with deployments and recovery of tagged birds. Financial support was provided by the Natural Sciences and Engineering Research Council of Canada and Acadia University.

## Abstract

An understanding of animal movements contributes important knowledge on the spatial and temporal distribution of these animals. In particular, research on the distribution of seabirds, which are important ecological indicators, can provide new insights and understanding of the physical and biological aspects of the marine environment. Information on distribution can also be used to delineate marine protected areas and oil spill response strategies. Black Guillemots (*Cephus grylle*) are particularly susceptible to various threats in the marine environment such as vessel disturbance, tidal energy development and oil spills due to their drifting and diving foraging behaviour. As tidal energy development and oil exploration increase, the effects on Black Guillemots may go unobserved due to our limited understanding of their at-sea distribution. Little is known about Black Guillemot distribution in Atlantic Canada, particularly in the winter (nonbreeding) season. To examine the winter distribution Black Guillemots, Global Location Sensing (GLS) tags were deployed and recovered on seven individuals at two breeding colonies in Nova Scotia, Canada, and New Brunswick, Canada, during 2017-2018. Guillemots dispersed from breeding colonies throughout the region (Scotian shelf, Gulf of St. Lawrence, Bay of Fundy, Gulf of Maine) with both populations overlapping in the Bay of Fundy. Most bird locations (82%) were associated with the continental shelf, with 8% associated with pelagic waters and 10% associated with the shelf break (25 km buffer around the 200 m shelf break). Birds moved an average of 167 km from colony and 70 km from shore, with maximum offshore distances of 470 km and maximum depths of 4830 m. The application of GLS tagging methods on Black Guillemots enhances our ability to examine seabird distribution and to use seabirds as ecological indicators of the marine environment.

**Key words:** Black Guillemot, *Cephus grylle*, distribution, geolocator, migration, seabird tracking

## 1.0 Introduction

The migratory movements of seabirds have been increasingly studied in the last 30 years (Vandenabeele et al. 2011). An understanding of seabird movements contributes important knowledge on species spatial and temporal distribution, migration routes, and social behaviour (Vandenabeele et al. 2011, Robinson & Jones 2014). Information on the distribution and migration routes of seabirds, which are important ecological indicators, can provide new insights and understanding of the physical and biological aspects of the marine environment (Burger & Shaffer 2008, Vandenabeele et al. 2011, Hobson & Bond 2012).

The information from tracking studies can be used to measure seabird foraging distances, map migration routes, and identify important offshore habitats (Montevecchi et al. 2012, Tranquilla et al. 2014, Takahashi et al. 2015). This information, combined with data on prey availability or seasonal oceanic productivity, can identify factors influencing seabird distribution (Takahashi et al. 2015). In addition to understanding ecological drivers of seabird movements, information on movement patterns can also be used for conservation planning, such as identifying threats, delineating marine protected areas and planning oil spill response strategies (Hyrenbach et al. 2006, Fraser & Racine 2016). For example, tracking data have been used to identify various risks to Alcids, a group of coastal drifting and diving seabirds (Butler & Buckley 2002). Knowledge from tracking data suggest this group is susceptible to numerous threats in the marine environment, such as bycatch (Benjamins et al. 2008), vessel disturbance (Ronconi & St. Clair 2002), tidal energy development (Furness et al. 2012) and oil spills (Ronconi et al. 2015, Lieske et al. 2019). As such, tracking data have played an important role in understanding risks to Alcids in Atlantic Canada (Clarke et al. 2011, Montevecchi et al. 2012).

The Black Guillemot (*Cepphus grylle*) is a common species along the Atlantic coast in the Alcidae family that is likely exposed to some of the risks described above, yet we have limited understanding of its distribution (Nol & Gaskin 1987, Ronconi & St. Clair 2002, Ronconi & Wong 2003). Black Guillemots are coastal, pursuit-diving seabirds that forage by passively drifting in shallow coastal areas where prey is available (Cairns 1987, Nol & Gaskin 1987, Mehlum et al. 1993). These birds spend a high proportion of their time on the water surface or in the water column where they may come in contact with vessels (Ronconi & St. Clair 2002), tidal energy infrastructure (Furness et al. 2012) surface oil or oil and gas platforms (Furness et al. 2012, Lieske et al. 2019) and may also be at risk of bycatch (Lieske et al. 2019). As oil exploration and tidal energy development expands, the effects on Black Guillemots may go unobserved because we have limited understanding of their at-sea distribution. Therefore, it is essential to understand the movement and overwintering locations of this species (Nol & Gaskin 1987). Tracking studies on Black Guillemots will help determine important congregation areas, habitats and migration routes, which can help us understand their relative exposure to these threats.

Despite the need for this knowledge, there is limited information on distribution and habitat use by Black Guillemots throughout most of their range. Knowledge on their distribution is largely limited to the Arctic region, where guillemots prefer coastal areas and ice edges to offshore waters (Renaud & Bradstreet 1980, Cairns 1987, Prach & Smith 1992, Divoky et al. 2016). Information on distribution beyond the Arctic region is based on two studies conducted in the Atlantic region that also found Black Guillemots prefer coastal areas (Nol & Gaskin 1987, Huettman et al. 2005). However, these studies were conducted during the breeding season when the birds come to land to nest. There remains no research on the winter distribution, which

comprises the vast majority of their annual cycle where Black Guillemots spend the most time at sea (Butler & Buckley 2002), or the habitat use, of Black Guillemots in Atlantic Canada (Nol & Gaskin 1987, Prach & Smith 1992). Therefore, tracking studies on Black Guillemots in the winter season are necessary to fill significant knowledge gaps regarding their distribution and habitat use away from breeding colonies.

The purpose of my study is to examine the winter distribution and movement patterns of Black Guillemots in Atlantic Canada by deploying leg-mounted global location sensors to track birds from two Maritime breeding colonies to overwintering locations. Additionally, I aim to determine the primary winter habitat types of the Black Guillemot to better understand guillemot movements with respect to seasons and colonies.

Previous research has shown that leg-mounted tracking devices may have negative impacts on seabirds such as decreased reproductive rates, return rates, and adult and/or chick mass (Adams et al. 2009, Schacter & Jones 2017). Alcids are twice as likely as other seabirds to show negative effects due to their diving foraging behaviours (Schacter & Jones 2017). Therefore, tagging effects must be considered in the design of tracking studies, to determine if animals are adversely affected by tag attachment and to ensure devices are not affecting the parameters being measured (Barron et al. 2010, Vandenabeele et al. 2011, Robinson & Jones 2014, Schacter & Jones 2017). Therefore, I will also examine the effect of tagging on adult mass and hatch success to determine whether the deployment of tags can be continued without significant adverse effects.

## **2.0 Literature Review**

This literature review outlines research on the spatial distribution and migratory movement of seabirds in the family Alcidae, in particular the Black Guillemot. I also examine the potential effects of tracking devices on seabirds, especially in the Alcidae family. The main databases used for this literature review were Biological Abstracts, Web of Science Citation and Google Scholar. The key search terms used were: seabird\*, alcid\*, Black Guillemot?, distribut\*, migrat\*, movement?, tracking, effect\*, and affect\*. Conflicts, limitations and knowledge gaps in the literature will be identified. To conclude, directions for future research will be addressed.

### **2.1 Conservation applications of understanding seabird distribution and movement**

Knowledge on the distribution and movement of seabirds can help answer important conservation questions in marine biology. For example, information on migratory movements can be used to identify important feeding or stopover sites that can help designate marine protected areas (Burger & Shaffer 2008, Le Corre et al. 2012). This knowledge can also be applied to current marine protected areas, to determine if and how seabirds are using the space (Hyrenbach et al. 2006). Additionally, information on the distribution and movement of seabirds can be used in oil spill response planning (Takahashi et al. 2015, Fraser & Racine 2016). Seabirds impacted by oil spills, especially as oil exploration expands further offshore, may not be readily observed because we have limited understanding of their at-sea distribution (Ronconi et al. 2015). Therefore, knowledge on the distribution and movement of seabird species from tracking studies will allow us to adequately plan responses to potential threats and ensure the protection of these important ecological indicators.



## **2.2 Methods of seabird distribution and movement monitoring**

### ***2.2.1 Observational studies in conjunction with tracking studies***

In the 1970's, research on seabird distribution and movement was based on observational studies conducted from offshore vessels (Hunt et al. 1999). At-sea surveys are important because they can sample all species and age classes, whereas many tracking studies are limited to few species, few individuals, and often breeding age seabirds (Huettmann & Diamond 2000, Takahashi et al. 2015). However, offshore vessels survey large areas unevenly, which results in incomplete coverage of potential range or habitat (Huettmann & Diamond 2000, Tranquilla et al. 2013). Additionally, observational studies from vessels or aircraft may vary due to weather (i.e. precipitation, fog), observer differences, or disturbance from the vessel itself (Bradstreet 1979). The use of individual tracking devices can fill these information gaps by providing long-term locational data on a subset of the population observed from offshore vessels (Tranquilla et al. 2013). Therefore, data from at-sea observational studies can be used in conjunction with data from individual tracking studies to obtain more detailed information on the spatial distribution and migratory movements of seabirds (Louzao et al. 2009, Hedd et al. 2011).

### ***2.2.2 Tracking devices***

Advancements in tracking technology, including the miniaturization of tracking devices, has allowed for the deployment of tracking devices on pursuit-diving seabirds (Robinson & Jones 2014, Pollet et al. 2019). More specifically, global positioning system (GPS) and global location sensor (GLS) tracking devices have been decreasing in size and weight, allowing them to be used on smaller seabirds (Casper 2009, Wakefield et al. 2009). In addition, the increase in battery life and durability has allowed for the deployment for longer periods of time (Barron et al. 2010). For example, GLS tags can now be mounted to the leg or tarsus of a seabird instead of

feathers that are moulted bi-annually, which increases the lifespan of the tag attached to the bird and allows for data collection over multiple years (Casper 2009). These technological advancements in tracking devices have allowed for the deployment of tags for longer periods of time, allowing us to answer more complex questions about these animals. This information, in combination with data on prey availability and seasonal productivity, can be used to determine the factors influencing seabird distribution (Takahashi et al. 2015).

Tracking devices may, however, negatively affect seabird species by causing changes in energy expenditure, chick and/or adult mass, reproductive success, and site fidelity (Barron et al. 2010, Robinson et al. 2010, Schacter & Jones 2017). Information from tracking devices is essential in answering questions about seabird distribution and movement, but this information is only useful if it accurately represents the untagged population (Robinson & Jones 2014). Therefore, the effect on the individual and the validity of the data from these tracking devices must be assessed.

#### *2.2.2.1 Effects of tracking devices*

Species in the family Alcidae may be more susceptible to negative effects than other seabird taxa due to their diving foraging behaviours, but effects vary by species and the parameter being measured (Burger & Shaffer 2008, Schacter & Jones 2017). For instance, tracking devices add mass and drag (Whidden et al. 2007), which may reduce alcid diving depth and duration, ultimately leading to a reduced feeding (Elliott et al. 2007). Tags have been associated with reduced adult or chick mass, feeding rates, reproductive success and site fidelity of alcid species (Paredes et al. 2005, Schacter & Jones 2017). However, other studies show little to no negative effects on alcid behaviour and reproductive success (Hamel et al. 2004, Robinson & Jones 2014). Some of this variation appears to be the result of regional effects such as

temporal or geographic differences among study areas, and thus potential tag effects should be individually assessed for a species in a given region (Burger & Shaffer 2008, Schacter & Jones 2017). These studies are important in determining if tracking studies can be continued on certain species in the future.

### **2.3 Black Guillemot**

Black Guillemots are coastal, passive-drifting seabirds of the family Alcidae that move in relation to tides and prey availability (Bradstreet 1979, Nol & Gaskin 1987). These pursuit-diving seabirds feed on fish and crustaceans in shallow, inshore or open waters (Cairns 1987, Mehlum et al. 1993). Additionally, these birds spend the vast majority of the nonbreeding season foraging at sea (Butler & Buckley 2002). These behavioural characteristics make Black Guillemots particularly susceptible to threats such as vessel disturbance (Ronconi & St. Clair 2002), bycatch (Lieske et al. 2019), oil spills (Ronconi et al. 2015, Lieske et al. 2019) and tidal energy development (Furness et al. 2012). As oil exploration and tidal energy development continue to increase, the effects on Black Guillemots may go unobserved because of the limited knowledge on their at-sea distribution and habitat use, thus highlighting the importance of tracking studies on this species.

The at-sea distribution of Black Guillemots has been relatively well-studied in the breeding season (Bradstreet 1979, Nol & Gaskin 1987, Prach & Smith 1992). Breeding Black Guillemots are distributed near coastal areas and ice edges (Bradstreet 1979, Nol & Gaskin 1987, Prach & Smith 1992). In the winter season, high-Arctic populations follow the advancement of sea ice and prey availability (Divoky et al. 2016), whereas boreal and low-Arctic guillemots remain inshore close to breeding colonies (Brown 1985, Nettleship & Evans 1985, Butler & Buckley 2002). However, research on boreal Black Guillemot populations in the winter season is

limited (Nol & Gaskin 1987, Prach & Smith 1992). In particular, there is no research on the winter distribution of Black Guillemots in Atlantic Canada, where Black Guillemots appear to prefer inshore areas during the breeding season (Nol & Gaskin 1987, Huettman et al. 2005). However, Black Guillemot distribution and habitat use can vary by individual or by colony due to prey movements, productivity levels or climatic conditions, making it difficult to determine the location of a bird at a given time (Johnston et al. 2018). Therefore, research on the winter distribution of Black Guillemots in Atlantic Canada is needed to fill this knowledge gap.

## **2.4 Conclusion**

This literature review has underlined the importance of monitoring seabird distribution and movement in marine conservation. Knowledge gaps in the literature were identified, and the potential effects of this research on seabird species were examined. Though distribution and movement have been well-studied in various seabird species, there are few tracking studies on Black Guillemots. In particular, there is a need for further research on the distribution and movement of Black Guillemots in the Atlantic Canada region during the nonbreeding period. This knowledge gap will be addressed by the current study, where tracking devices will be used to examine the winter distribution of the Black Guillemot. The potential effects of these devices will also be considered.

## **3.0 Methods**

### **3.1 Study area**

This study was conducted on populations of Black Guillemots nesting on Country Island (CI), Nova Scotia and Kent Island (KI), New Brunswick from June 2017 to July 2018 (Figure 1). Country Island (44°58'N, 66°75'W) is a 19-hectare island located off the eastern shore of Nova Scotia, with a population of approximately 600 Black Guillemots (Trottier-Paquet & MacDonald

2017). Country Island is located on the Scotian Shelf, which is an area of high productivity due to upwelling near the outer shelf and shelf break (Atkinson et al. 2003). Kent Island (45°10'N, 61°54'W) is a 75-hectare island located in the Grand Manan Archipelago of the Bay of Fundy, New Brunswick, and supports approximately 61 breeding pairs of Black Guillemots (Cannell & Maddox 1983, Ronconi & Wong 2003). Due to the high tides of the Bay of Fundy, the Grand Manan Archipelago region experiences substantial tidal mixing throughout the year, resulting in high productivity in the area (Gran & Braarud 1935). This region is recognized as an area of important habitats for a variety of seabirds (Huettmann & Diamond 2000, Huettmann et al. 2005, Wong et al. 2018).

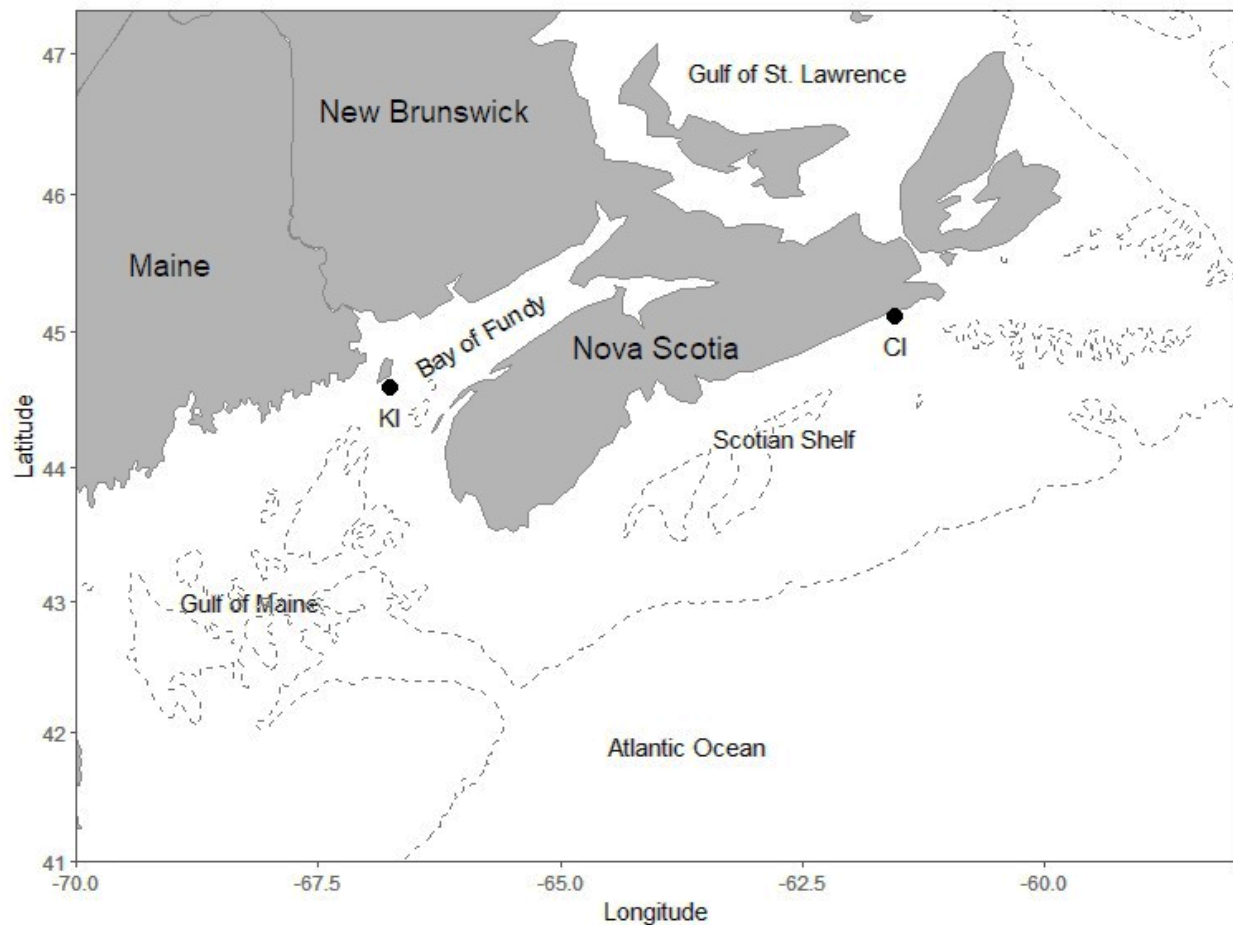


Figure 1. Southeastern Atlantic Canada showing the location of Country Island (CI), Nova Scotia and Kent Island (KI), New Brunswick where global location sensors were deployed on Black Guillemots. The dashed line represents the 200m bathymetric contour illustrating the continental shelf break line and basins on the shelf.

### 3.2 Tag deployment and recapture

Black Guillemots on both islands return to their breeding colony in April, begin courtship and breeding displays in May, and lay eggs in June (Winn 1950, Ronconi pers. comm.). Black Guillemots were captured in mid- to late-June, which is approximately halfway through the 29 day incubation period (Butler & Buckley 2002). In June 2017, breeding adults from Country Island ( $n=10$ ) and Kent Island ( $n=7$ ) were captured on-nest by convenience (non-random) and egg number, adult mass (g) and natural wing chord (mm) were recorded.

At the time of capture, a size 4 stainless steel band was attached to the tarsus of the right leg and a geolocator, or Global Location Sensor (GLS) (MK4093: 15 mm x 10 mm x 6 mm, Biotrak UK) was attached to the tarsus of the left leg using a plastic leg ring (as per Tranquilla et al. 2013 and Takahashi et al. 2015). Measurements, banding and GLS attachment took < 10min per bird and birds were returned to their burrow immediately after attachment. Geolocators should weigh less than 3% of the body weight of the bird (Phillips et al. 2003). The average mass of adult Black Guillemots on Country Island and Kent Island upon deployment was  $389.7 \text{ g} \pm 20.5$  (range: 360 - 435) and the total mass of the geolocator (1.52 g) and plastic leg ring (1 g) was 2.52 g, which is approximately 0.65% of body mass. Birds were recaptured one year following GLS attachment during the incubation period. Upon recapture, the mass (g) and natural wing chord (mm) of the bird were recorded as described above. An additional 10 untagged birds from Country Island and 5 untagged birds from Kent Island were captured as described above, and mass (g) and natural wing chord (mm) were recorded to later assess tag effects.

All animal care procedures (protocol #17RR01 and 18RR01) were approved by the Environment and Climate Change Canada's Wildlife Eastern Animal Care Committee.

### **3.3 Geolocation data analysis**

The geolocators recorded ambient light levels and wet/dry state in 5- and 10-minute intervals, respectively. For this analysis, light was used to estimate the day length and local noon time, which provides an estimate of latitude and longitude, respectively (Teo et al. 2004). Data from geolocators were decompressed using BAS-Trak software (Biotrak, Wareham, UK). Light-level data were analyzed in R v 0.1.0 (R Core Team 2018) using the "TwilightFree" (Bindoff et al. 2017) package that uses a Hidden Markov Model (Rabiner 1989) to produce daily position estimates from a hidden sequence of geographic locations and the pattern of light intensity

measured by the tag (Bindoff et al. 2017). Two tags (D323, D355) had weak electrical connections and were returned to Biotrak for downloading, where partial sets of light data were recovered and analyzed as above. Analyses were restricted to the non-breeding season. This was determined by colony attendance, where wet/dry data were filtered by presence/absence at colony and uninterrupted dry periods  $\geq 6$  hours were interpreted as colony attendance (Tranquilla et al. 2014). Light-level data from 10 Sep 2017 to 18 Oct 2017 and 20 Feb 2018 to 5 Apr 2018 were omitted *a priori* to exclude latitudes that cannot be accurately assessed due to the equinox (Hill 1994), where the greatest variability precedes the vernal equinox and follows the autumnal equinox (Hill & Braun 2001). Using pre-deployment calibration periods, Zenith angles and twilight threshold values for each tag in the calibrate function were determined (Bindoff et al. 2017).

To consider probable degrees of movement, cell transition parameters with a short-tailed distribution were used because previous studies on boreal and low-arctic populations of Black Guillemots show that birds remain inshore close to breeding colonies during the nonbreeding season (Brown 1985, Nettleship & Evans 1985, Butler & Buckley 2002). To restrict movements to a marine environment, a sea mask was incorporated and shading likelihood parameters were estimated to account for variable amounts of shading (Bindoff et al. 2017). Wet/dry data were used to filter periods of sustained flight for each bird, as tags were submerged when the bird was on the water, and a speed filter of 58 km/h (Ewins 1986) was applied to estimate the proportion of days a bird could have flown beyond the bounds of one cell, assuming it was flying in a straight line. This resulted in location estimates with a precision of  $0.5^\circ$  (~55.5 km). Finally, unreliable locations, determined by visual inspection, were deleted *post hoc* on an individual basis.



GLS locations typically have a mean error of 186-202 km after the application of TwilightFree models (Phillips et al. 2004, Shaffer et al. 2005). This is important for a species that remains relatively close to shore (Butler & Buckley 2002), because greater accuracy will allow a more confident analysis of their local distribution. In one case, data were omitted due to unusual movements at the end of the track, likely related to GLS light level errors when the bird was onshore. Bird D311 returned to colony on 28 May 2018 until 1 Jun 2018, then moved far offshore (>300 km) for two days before returning to colony again on 4 Jun 2018. The two days offshore (2 Jun 2018 and 3 Jun 2018) were excluded from analyses.

After processing, GLS data were mapped using RStudio 1.1.463 (R Core Team 2018). Maps were separated into four seasons; post-breeding (7 Jul 2017 to 10 Sep 2017), winter 1 (18 Oct 2017 to 17 Dec 2017), winter 2 (18 Dec 2017 to 19 Feb 2018) and pre-breeding (5 Apr 2018 to 9 Jun 2018). This separation was determined by natural breaks in the data due to the autumnal and vernal equinoxes, and an additional break added at the halfway point between the two equinoxes in December.

Distance from colony, distance from shore, sea surface temperature, depth and depth gradient (slope) were calculated for each location. Distance from colony (km) and distance from shore (km) were calculated by measuring the distance between the bird location and the colony or shoreline (including islands; CanCoast Geodatabase, Environment and Climate Change Canada, unpubl. data), respectively. Sea surface temperature (SST; °C) was extracted using the MGET tool in ArcGIS, with the SST product MUR-JPL-L4-GLOB-v4.1 to determine the temperature of individual bird locations. Depth (m) was calculated using ETOPO bathymetry, with a resolution of 3337 m by 3337 m (3 1/3 km) grid cells. Maximum and minimum depth were calculated from the depth raster file using a 3x3 grid (9 cells total), where maximum and

minimum depth within those 9 cells were averaged to the middle grid cell. Additionally, there were instances where depth (m) was 0, corresponding to a location on land. To correct for this, the nearest value from the day before or day after (depending on the closer value) was used.

Depth gradient (slope) was calculated from a raster produced by the following equation:

$$\frac{(\text{depth max} - \text{depth min})}{\text{depth max}} \times 100$$

In addition to measuring the above habitat variables, I also classified locations into three broad habitat types: continental shelf, shelf break, and pelagic. I measured distance to continental shelf break (200 m contour, Figure 1) after omitting small basins of 200 m depth on the shelf. Then, locations within 25 km of the shelf break were classified as “shelf-break” associated. The remainder of points were classified as continental shelf or pelagic (off-shelf). The precision of locations was 0.5°, equating to about 55.5 km. However, using a 55.5 km buffer around the shelf break to determine shelf-break association is quite large. Therefore, a 25 km buffer was used, despite my tags not matching this resolution, as it is better to under-report than over-report shelf-break influence. Statistical analyses (General Linear Mixed Models) could not be conducted on these data because data were non-normally distributed, often bi-modal, and showed strong differences among individuals. Therefore, I present summary statistics without the use of statistical tests. All averages for all variables are reported as mean ± SD unless otherwise indicated.

### **3.4 Effect of tagging**

To determine the effect of tagging on the Black Guillemot, I examined changes in adult mass and hatch success. I used two methods to determine the potential effect of tagging on adult mass. First, mass of tagged adults ( $n = 6$ ) was compared between 2017 and 2018 to determine if

mass significantly changed over the period of tag deployment. Second, adult mass was compared between tagged (Country Island:  $n = 4$ ; Kent Island  $n = 3$ ) and untagged (Country Island:  $n = 10$ ; Kent Island  $n = 5$ ) individuals in 2018. These comparisons were made using paired and unpaired t-tests, respectively.

Hatch success at nest sites on Country Island was compared between nests where adults were tagged and handled (2017,  $n = 10$ ; 2018,  $n = 4$ ), handled but not tagged (2017,  $n = 11$ ; 2018,  $n = 9$ ), and unhandled (2017,  $n = 30$ , 2018,  $n = 45$ ). Nests of all three groups were distributed haphazardly throughout the study colony (i.e. treatment types were not spatially clustered), and uneven sample sizes were due to logistical constraints of finding nests that could be readily monitored. Time restrictions and logistical limitations prevented the monitoring of burrows on Kent Island. Nests on Country Island were monitored every two weeks and clutch size and number of eggs hatched were recorded. Hatch success, defined as the proportion of nests that hatched at least 1 chick, was calculated for nests where adults were tagged and handled, handled but not tagged, and unhandled (control) and compared between treatments using Chi-square tests.

## 4.0 Results

Four tags were retrieved from Country Island birds and three tags were retrieved from Kent Island birds (total  $n = 7$ ; 41% recovery rate). Two additional tagged birds from Country Island were observed in 2018 but were not captured due to time and logistical constraints. With these birds included, return rate rises to nine tagged birds (53% recovery rate) across both sites. This total is conservative because some tagged likely went undetected. After location processing, the total number of location points was 1479, with an average of  $211 \pm 53.17$  points per bird (where D323 and D355 had 100 and 185, respectively, due to partial data recovery). On all

tagged birds that were recaptured, the skin at the site of tag attachment appeared uninjured and without infection.

#### **4.1 Movements and distribution**

On Country Island, birds left the colony between 7 and 28 Jul 2017 (mean 12 Jul  $\pm$  4.9 days). During the post-breeding phase (Figure 2), birds spread out on the Scotian shelf ( $n = 4$ ), next moving through the Strait of Canso to the Gulf of St. Lawrence ( $n = 4$ ) and finally off the continental shelf ( $n = 3$ ) or to the Scotian shelf ( $n = 1$ ). In the first winter phase, birds went in varying directions. One moved around Northern Nova Scotia and into the Gulf of Saint Lawrence, one moved into the Bay of Fundy, and the other birds ( $n = 2$ ) remained on the Scotian shelf or moved off the continental shelf into deeper waters before moving to the Gulf of Maine (Figure 2). In the second winter phase, the bird that moved to the Gulf of Saint Lawrence returned to the Scotian shelf near its colony, where the bird on the Scotian shelf remained. The other birds ( $n = 2$ ) remained in the Bay of Fundy or Gulf of Maine (Figure 2). In the pre-breeding phase, birds moved from the Bay of Fundy back to Northern Nova Scotia along the Scotian shelf ( $n = 1$ ), from beyond the continental shelf back to the Scotian shelf ( $n = 2$ ), or made another trip through the Strait of Canso to the Gulf of St. Lawrence before returning to the Scotian shelf ( $n = 1$ ). Birds returned to the colony between 29 May and 4 Jun 2018 (mean 1 Jun  $\pm$  2.6 days).

On Kent Island, birds left the colony on 13, 16 and 25 Jul 2017. During the post-breeding phase, birds moved out of the Bay of Fundy to the Gulf of Maine ( $n = 3$ ), with one bird moving south through the Gulf of Maine and off the continental shelf (Figure 2). In the first winter phase, the bird that moved off the continental shelf returned to the Bay of Fundy and Gulf of Maine, where the others ( $n = 2$ ) remained (Figure 2). In the second winter phase, birds ( $n = 2$ ) remained in the Bay of Fundy and Gulf of Maine (Figure 2). There are no data for the third bird in this

phase due to partial data recovery. In the pre-breeding phase, one bird moved throughout the Bay of Fundy and Gulf of Maine before returning to colony on 9 Jun 2018. Return dates for the other two birds are unknown due to partial data recovery.

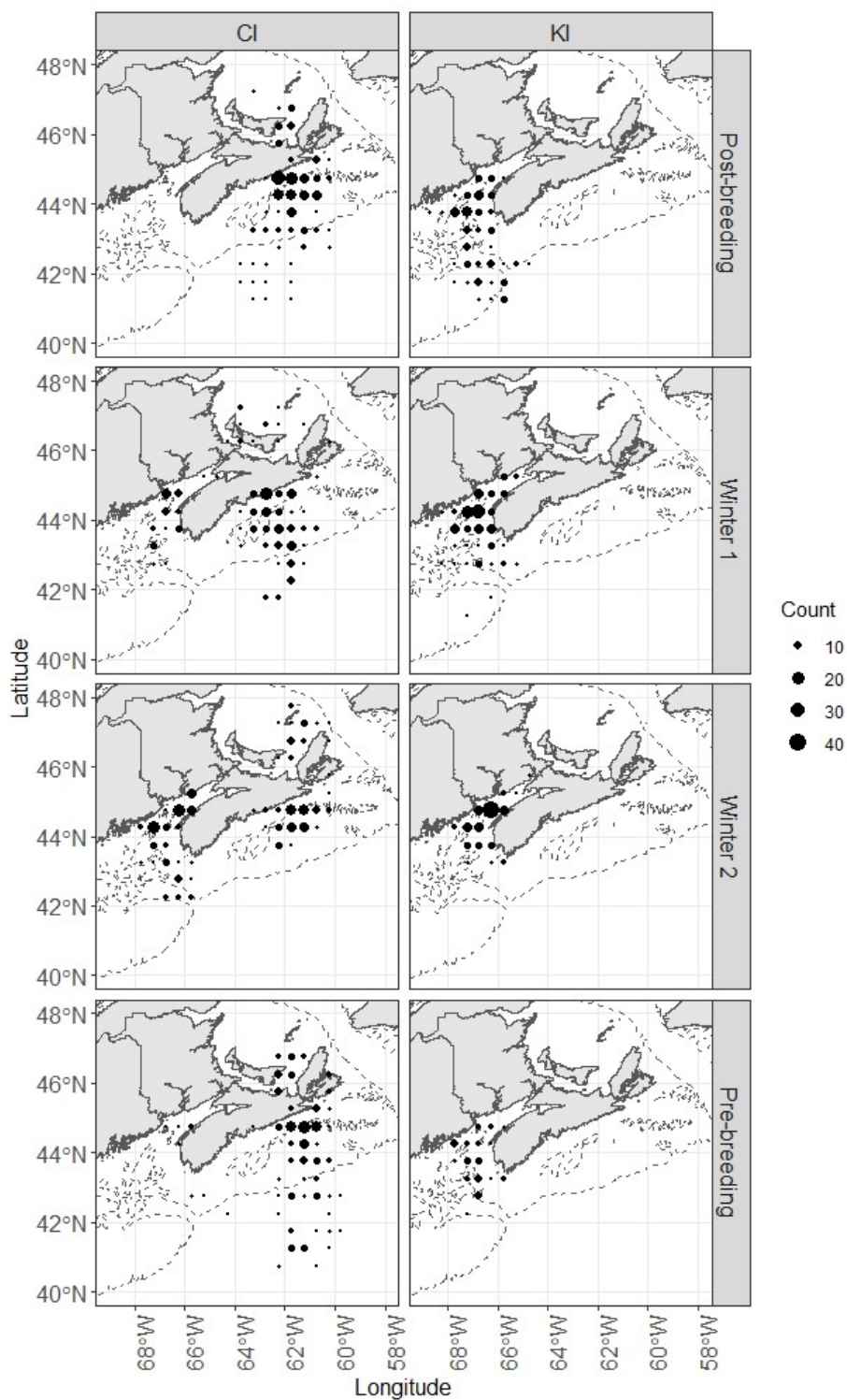


Figure 2. Graduated circles representing the count of Black Guillemots combined by 0.5° latitude/longitude grid cells from Country Island (CI), Nova Scotia, and Kent Island (KI), New Brunswick, during post-breeding (7 Jul 2017 to 10 Sep 2017), winter 1 (18 Oct 2017 to 17 Dec 2017), winter 2 (18 Dec 2017 to 19 Feb 2018) and pre-breeding (5 Apr 2018 to 9 Jun 2018). The 200m shelf break is indicated by the dashed lines.

Ninety percent of locations were within 428 km and 260 km of colony for Country Island and Kent Island, respectively (Figure 3). The mean distances from colony were  $196 \pm 140$  km (max 536 km) and  $112 \pm 86$  km (max 379 km) for Country Island and Kent Island, respectively. During the post-breeding phase, birds from both colonies showed a wide dispersion relative to their respective colonies (Country Island:  $143.0 \pm 97.6$  km, max 450 km; Kent Island:  $167.4 \pm 108.5$  km, max 379 km). During the first and second winter phases, mean distances from colony for Country Island birds were greater compared to the post-breeding phase (Winter 1:  $226.0 \pm 124.3$  km; Winter 2:  $263.7 \pm 166.6$  km), whereas mean distances from colony for Kent Island birds was less compared to the post-breeding phase (Winter 1:  $90.7 \pm 62.1$  km; Winter 2:  $64.8 \pm 39.7$  km). Additionally, two Country Island birds travelled past the continental shelf in the first and second winter phases (max 526 km), while the other two remained within 295 km of the colony (Figure 3). In the pre-breeding phase, Country Island birds moved closer to colony than the previous phase ( $162.6 \pm 123.9$  km) and Kent Island birds moved further than the previous phase ( $118.4 \pm 59.0$  km) before returning to colony for the breeding season.

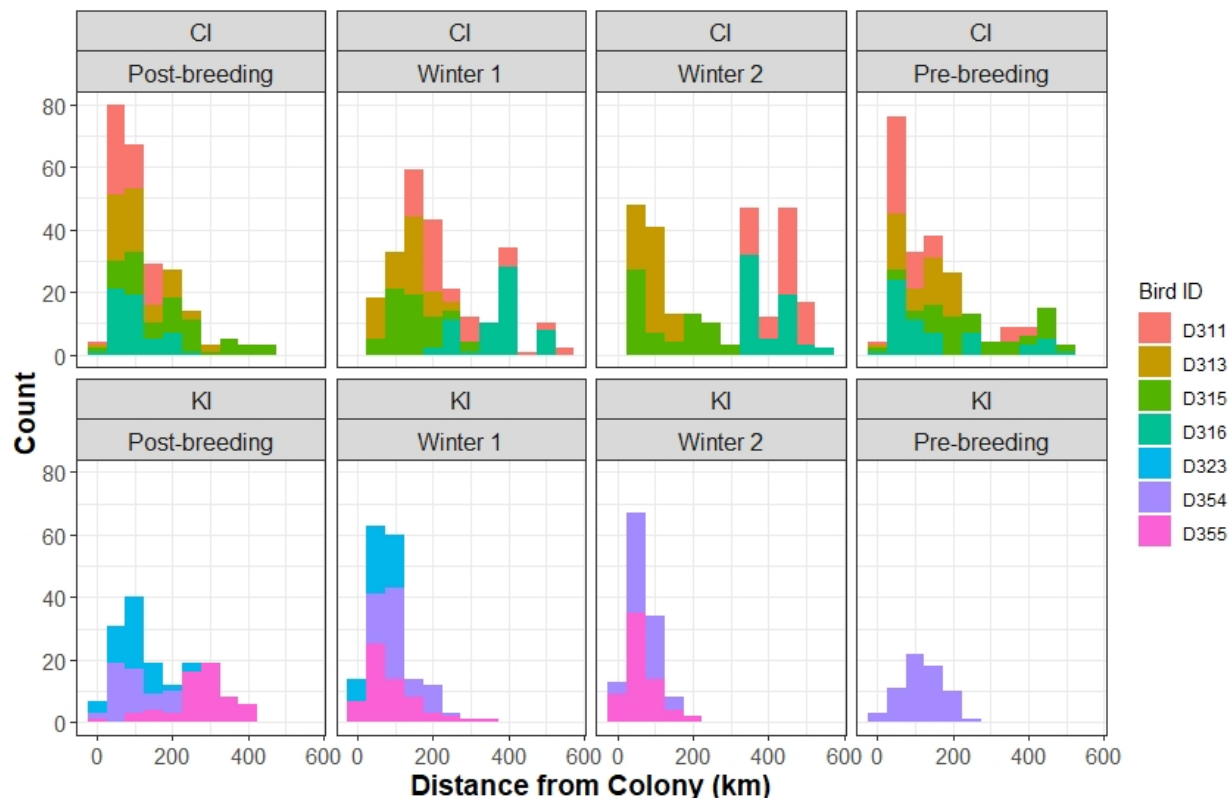


Figure 3. Histogram of the distance from colony (km) of Black Guillemots from Country Island (CI), Nova Scotia, and Kent Island (KI), New Brunswick, during post-breeding (7 Jul 2017 to 10 Sep 2017), winter 1 (18 Oct 2017 to 17 Dec 2017), winter 2 (18 Dec 2017 to 19 Feb 2018) and pre-breeding (5 Apr 2018 to 9 Jun 2018).

Ninety percent of locations were within 200 km and 129 km from shore for Country Island and Kent Island, respectively (Figure 4). The mean distances from shore were  $80 \pm 86$  km and  $53 \pm 54$  km for Country Island and Kent Island, respectively. During the post-breeding phase, the mean distance from shore for Country Island birds was  $83 \pm 76$  km and was  $92 \pm 70$  km for Kent Island birds. In the first winter phase, distance from shore was similar to the post-breeding phase for Country Island birds ( $84 \pm 84$  km), whereas birds moved closer to shore ( $36 \pm 36$  km) for Kent Island. However, three birds from Country Island travelled further from shore (max distance 259 km) while the other one remained within 82 km of the shore (Figure 4). In the second winter phase, Country Island and Kent Island birds returned closer to shore than the



previous phase (Country Island:  $47 \pm 35$  km; Kent Island:  $25 \pm 20$  km). In the pre-breeding phase, two Country Island birds travelled further from shore than the previous phase (max distance 471 km) before returning closer to shore ( $108 \pm 120$  km), and Kent Island birds remained relatively closer to shore ( $51 \pm 35$  km) before returning to the colony for the breeding season.

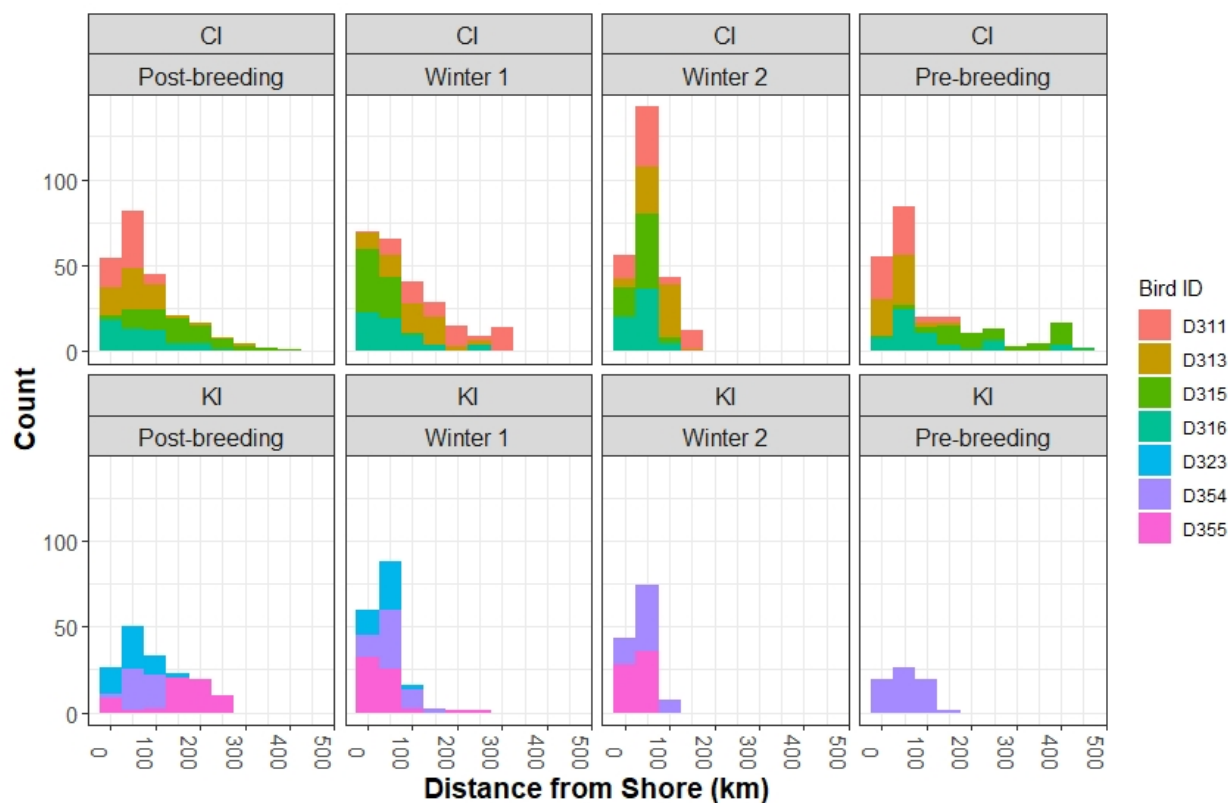


Figure 4. Histogram of the distance from shore (km) of Black Guillemots from Country Island (CI), Nova Scotia, and Kent Island (KI), New Brunswick, during post-breeding (7 Jul 2017 to 10 Sep 2017), winter 1 (18 Oct 2017 to 17 Dec 2017), winter 2 (18 Dec 2017 to 19 Feb 2018) and pre-breeding (5 Apr 2018 to 9 Jun 2018).

#### 4.2 Habitat use

I assessed the seasonal habitat use of Black Guillemots by investigating variability in sea surface temperature (SST), depth and depth gradient (slope) for bird locations (summarized in Table 1). Across all phases, the sea surface temperature associated with bird locations ranged

from -1.8 °C to 25.3 °C, mainly following seasonal cooling and warming. The highest mean slope values were in June and July. Median depth was similar across all months but there were clear patterns of birds using pelagic waters from July to September and again from April to May (max depth 4831 m and 3561 m, respectively; Table 1), associated with birds using waters beyond the continental shelf (Figure 2).

Table 1. Mean  $\pm$  SD [min, max] values for sea surface temperature (SST, °C) and depth gradient (slope) by month, and median [min, max] values for depth (m) by month of bird locations from Country Island (CI), Nova Scotia, and Kent Island (KI), New Brunswick. Due to the vernal equinox, there are no data for March 2018.

Month	Sample Size		SST		Depth Gradient		Depth	
	CI	KI	CI	KI	CI	KI	CI	KI
Jul	75	41	17.5 $\pm$ 1.3 [14.3, 20.4]	15.2 $\pm$ 2.7 [12.1, 21.3]	33.1 $\pm$ 28.3 [5.5, 79.2]	32.9 $\pm$ 23.9 [6.9, 82.4]	117 [19, 3077]	119 [0, 1619]
Aug	124	92	19.5 $\pm$ 1.1 [18.0, 25.3]	16.1 $\pm$ 2.3 [12.5, 24.1]	26.3 $\pm$ 25.0 [0, 87.8]	22.2 $\pm$ 18.2 [2.7, 82.4]	101 [29, 4483]	179 [0, 2463]
Sep	36	28	18.7 $\pm$ 1.7 [16.4, 22.0]	15.8 $\pm$ 2.2 [12.7, 22.5]	24.21 $\pm$ 29.9 9 [0, 87.83]	17.7 $\pm$ 18.9 [3.8, 78.4]	144 [1, 4021]	205 [67, 2463]
Oct	56	39	15.4 $\pm$ 1.9 [9.4, 17.9]	14.0 $\pm$ 0.9 [12.6, 16.3]	15.9 $\pm$ 15.8 [0, 79.2]	22.9 $\pm$ 15.4 [3.8, 82.4]	157 [1, 3755]	109 [0, 237]
Nov	119	90	12.2 $\pm$ 1.9 [4.5, 18.0]	10.9 $\pm$ 2.7 [-0.3, 13.7]	20.6 $\pm$ 22.0 [0, 87.8]	32.5 $\pm$ 18.9 [10.1, 90.2]	101 [0, 3143]	133 [0, 231]
Dec	124	67	7.6 $\pm$ 2.4 [1.1, 12.6]	9.1 $\pm$ 1.5 [4.1, 11.2]	23.3 $\pm$ 21.73 [0, 94.1]	32.5 $\pm$ 22.8 [10.1, 82.4]	117 [0, 1251]	119 [0, 231]
Jan	121	59	4.7 $\pm$ 3.3 [-1.8, 10.9]	6.5 $\pm$ 1.6 [2.7, 9.1]	24.3 $\pm$ 22.0 [0, 98.2]	26.8 $\pm$ 16.3 [14.6, 72.5]	119 [0, 237]	119 [33, 185]
Feb	76	37	2.5 $\pm$ 2.6 [-1.8, 6.8]	5.8 $\pm$ 0.9 [2.4, 7.3]	28.9 $\pm$ 22.3 [0, 72.5]	26.4 $\pm$ 16.5 [12.6, 72.5]	78 [1, 283]	119 [45, 215]
Mar	NA	NA	NA	NA	NA	NA	NA	NA
Apr	104	25	6.5 $\pm$ 6.6 [-1.4, 19.2]	4.9 $\pm$ 0.9 [2.9, 7.1]	18.6 $\pm$ 21.1 [0, 82.4]	24.4 $\pm$ 12.4 [10.1, 50.7]	117 [0, 4831]	185 [3, 275]
May	122	31	6.3 $\pm$ 2.7 [2.6, 17.0]	8.0 $\pm$ 1.0 [6.7, 10.3]	31.5 $\pm$ 24.7 [3.9, 87.8]	28.5 $\pm$ 18.3 [12.6, 82.4]	108 [19, 3561]	133 [0, 215]
Jun	4	9	9.3 $\pm$ 4.2 [6.5, 15.6]	9.5 $\pm$ 0.4 [8.9, 10.1]	57.7 $\pm$ 32.1 [11.4, 79.2]	34.8 $\pm$ 12.7 [18.5, 45.4]	134 [63, 205]	95 [63, 179]

Overall, bird locations were primarily (82%) associated with the continental shelf, with 8% associated with pelagic and 10% associated with the shelf break (Table 2). Though the continental shelf was the dominant habitat type across all months, Country Island shelf

association peaked in July and again in December and January, and was lowest in June, whereas Kent Island shelf association peaked in June. Country Island birds spent the most time in pelagic waters in April and October, whereas Kent Island birds had a relatively low pelagic presence throughout the nonbreeding period. Country Island shelf break association was lower than Kent Island, with a peak in February. On Kent Island, shelf break association was highest in September but mostly limited to July to October.

Table 2. Habitat type by month of Black Guillemots from Country Island (CI), Nova Scotia, and Kent Island (KI), New Brunswick, where shelf = location < 200m depth, pelagic = location > 200m depth, and break = locations in a 25km buffer of the continental shelf break (200m). Due to the spring equinox, there are no data for March 2018.

Month	% Shelf		% Pelagic		% Break	
	CI	KI	CI	KI	CI	KI
Jul	61.3	21.6	2.6	2.6	0.9	11.3
Aug	49.1	26.9	3.8	3.8	4.7	12.1
Sep	32.9	17.2	15.7	3.2	7.9	23.5
Oct	31.6	28.5	21.1	2.2	6.4	10.6
Nov	48.9	41.2	1.5	2	6.7	0
Dec	62.4	31.5	1.1	3.7	1.6	0
Jan	61.7	32.8	2.3	0	3.4	0
Feb	54	31	0	0	13.3	1.8
Mar	NA	NA	NA	NA	NA	NA
Apr	52	8.6	28	1.6	0.8	9.4
May	70	18.4	3.3	0	6.6	2
Jun	15.4	69.3	15.4	0	0	0

## 4.2 Effect of Tagging

### 4.2.1 Adult mass

Across both islands, adult mass of tagged individuals was not significantly different between 2017 (tag deployment) and 2018 (tag retrieval; two-tailed t-test:  $n = 6$ ,  $p = 0.723$ ). Additionally, the average adult mass did not differ significantly between tagged ( $387.6 \pm 13.9$  g;  $n = 7$ ) and untagged individuals ( $375.4 \pm 30.3$  g;  $n = 15$ ) across both islands in 2018 (two-tailed t-test:  $p = 0.211$ ).

### 4.2.2 Hatch success

On Country Island in 2017, hatch success did not differ significantly across tagged and handled (83.3%,  $n = 10$ ), handled but not tagged (54.6%,  $n = 11$ ), and unhandled nests (80%,  $n = 30$ ; Chi-square test:  $\chi^2 = 0.640$ ). On Country Island in 2018, hatch success did not differ significantly across tagged and handled (50%,  $n = 4$ ), handled but not tagged (11.1%,  $n = 9$ ), and unhandled nests (51.1%,  $n = 45$ ; Chi-square test:  $\chi^2 = 0.448$ ).

## 5.0 Discussion

### 5.1 Winter distribution and habitat use

In this study, I obtained full or partial tracks for seven Black Guillemots from two breeding colonies in Nova Scotia and New Brunswick, Canada, providing new insights on winter distribution and movement patterns of this species. My results suggest that Black Guillemots from these colonies may have several different overwintering strategies. Birds from Country Island either remained on the Scotian shelf, or travelled to the Gulf of St. Lawrence, Bay of Fundy or Gulf of Maine (Figure 2), whereas birds from Kent Island remained in the Bay of Fundy or Gulf of Maine (Figure 2). However, two birds from Kent Island had partial data. Due to the limited sample size for both colonies, the inference of overwintering strategies remains limited.

Black Guillemots from Country Island and Kent Island were distributed throughout different areas during the nonbreeding season and no single wintering location was identified (Figure 2). Variation in Black Guillemot distribution and habitat in the nonbreeding season has been previously recorded (Waggitt et al. 2016). This pattern is also consistent with observations on Common Murres (*Uria aalge*) and Thick-billed Murres (*Uria lomvia*, Tranquilla et al. 2013),

where birds from the same colony are distributed in different areas during the nonbreeding period. There are various factors that may influence these differences in winter distribution, including ice cover, prey availability, or productivity levels (Nol & Gaskin 1987, Prach & Smith 1992, Montevecchi et al. 2012, Divoky et al. 2016, Waggitt et al. 2016).

In terms of habitat, birds from Country Island were found on average 80 km offshore but up to 470 km offshore in deep pelagic waters, which contrasts the coastal inshore distribution of breeding Black Guillemots in Atlantic Canada (Nol & Gaskin 1987, Huetteman et al. 2005). Cairns (1987) suggests that guillemots primarily feed in coastal benthic waters due to risk avoidance. However, in this study, birds travelled to the continental shelf break and into pelagic waters with depths up to 4830 m (Table 1). This wide distribution may increase the potential of guillemots encountering various risks, such as bycatch (Benjamins et al. 2008), vessel disturbance (Ronconi & St. Clair 2002), tidal energy development (Furness et al. 2012) and oil spills (Ronconi et al. 2015, Lieske et al. 2019), thus suggesting that guillemots may have multiple foraging strategies (Haney 1991). Slope association ranged throughout the nonbreeding period, with the highest average slope values in July and June (Table 1), corresponding to the beginning of the post-breeding phase and end of the pre-breeding phase, respectively, when birds are nearest to colony (Figure 3). This slope association is also seen in Parakeet Auklets (*Aethia psittacula*) and Crested Auklets (*Aethia cristatella*), where birds are strongly associated with depth and depth gradients, distributed in all strata layers of the shelf (Haney 1991).

Bird locations from Country Island and Kent Island also overlapped during three phases of the nonbreeding period. In particular, Country Island birds moved into the same areas as some Kent Island birds, although the reverse was not the case with the Kent Island birds (Figure 2). While neighbouring seabird colonies frequently show spatial segregation during breeding

seasons (Grémillet et al. 2004, Hedd et al. 2018), overlapping winter distributions have been observed for alcids from different colonies (Tranquilla et al. 2013, 2014, Ratcliffe et al. 2014). This overlap may be explained by prey availability (Cairns 1987, Nol & Gaskin 1987, Divoky et al. 2016, Waggitt et al. 2016) or birds following pre-determined migration routes learned from parents that previously moved between colonies (Dearborn et al. 2003, Tranquilla et al. 2013).

Overall, Black Guillemot distribution over the winter season may be explained by a variety of factors. One factor that may influence Black Guillemot distribution is ice cover. Black Guillemot distribution in the Arctic is, primarily, influenced by ice cover (Bradstreet 1979, Prach & Smith 1992, Divoky et al. 2016). In ice-free areas, guillemots are thought to remain moderately near the colony throughout the nonbreeding season (Brown 1985), but tend to depart areas of solid ice cover for more open waters (Nettleship & Evans 1985). There is relatively little ice activity in the winter in the Bay of Fundy, Gulf of Maine and Scotian shelf, however, ice appears in the Gulf of St. Lawrence in mid-December along the coastal waters of New Brunswick, followed by in the Northumberland strait surrounding Prince Edward Island (Environment and Climate Change Canada 2018). In the post-breeding phase, all four Country Island birds spent time in the Gulf of St. Lawrence when there was no ice cover (Figure 2). However, at the end of the first winter phase and beginning of the second winter phase, only one guillemot remained in the gulf and as ice began to appear, the bird moved towards northeastern Nova Scotia and remained there until mid-February (Figure 2). Thus, it is possible that the bird was moving in relation to ice edges (Bradstreet 1979, Prach & Smith 1992, Divoky et al. 2016) or retreating from the area due to ice cover (Nettleship & Evans 1985). As exact dates of ice cover are unknown, it is also possible that the bird left the gulf before ice appeared, which may indicate that its migration routes are pre-determined (Tranquilla et al. 2013).

Black Guillemot movement has also been associated with prey availability (Cairns 1987, Nol & Gaskin 1987, Divoky et al. 2016, Waggitt et al. 2016). In the Bay of Fundy, Black Guillemots primarily feed on rock gunnels (*Pholis gunnellus*) in the autumn (Nol & Gaskin 1987), and are known to feed on sculpin (*Cottidae sp.*), cod (*Gadidae*), sandlance (*Ammodytidae*) and herring (*Clupeidae*) in their other ranges (Butler & Buckley 2002). Atlantic herring (*Clupea harengus*) are distributed throughout the Bay of Fundy and Gulf of Maine, with a large spawning area in the Gulf of Maine (Tibbo et al. 2011). Kent Island birds remained in the Bay of Fundy and Gulf of Maine year-round, but Country Island birds moved into this area during the second winter phase, when the density of herring larvae peaks in the Gulf of Maine (Tibbo et al. 2011). Additionally, cod and sandlance are distributed throughout the Bay of Fundy and Scotian shelf, concentrated in the Bay of Fundy (Scott 2010, Shackell et al. 2011). Thus, it is possible that Black Guillemots are moving in relation to prey availability.

Alcids may also associate with areas of higher productivity, such as areas of high surface chlorophyll concentrations and water temperatures, as these areas correspond to higher densities of prey species (Gaston et al. 2011, Montevecchi et al. 2012). Black Guillemots were primarily associated with the continental shelf throughout all phases in the winter season (Table 2). In terms of the shelf break, the highest density of Black Guillemots on the shelf break occurred in the post-breeding phase, from July to September, and the lowest density occurred in December (Table 2). The highest levels of productivity on the continental shelf occur near the outer continental shelf break, due to high upwelling (Atkinson et al. 2003), and the peak productivity on the Atlantic continental shelf occurs in August and the lowest productivity levels occur in December and January (Campbell & O'Reilly 1988). Therefore, it is possible that Black Guillemots travelled to this area during peaks in productivity and retreated during times of low

productivity. This behaviour has been previously recorded in Thick-billed Murres in Nunavut (Gaston et al. 2011) and the western North Atlantic (Montevecchi et al. 2012), where murres moved to areas of higher productivity on the continental shelf during the nonbreeding season.

The Bay of Fundy and Gulf of Maine have high productivity year-round due to high tidal ranges and vertical mixing (Gran & Braarud 1935), which may explain why Kent Island birds remained in these regions year-round (Figure 2). Additionally, since the productivity on the continental shelf is lowest in winter (Campbell & O'Reilly 1988) but productivity in the Bay of Fundy and Gulf of Maine remains high during this time (Gran & Braarud 1935), this may explain why two Country Island birds moved into the Bay of Fundy and Gulf of Maine during the winter phases. Likewise, the Bay of Fundy provides important winter habitat for other Alcids, such as Razorbills (*Alca torda*) that occur in high abundance (Huetteman et al. 2005) and come to this area from a number of colonies (Clarke et al. 2011), suggesting that the area supports a variety of species during the winter. Changes in prey species and productivity levels may drive populations or species into other foraging locations, causing additional competition between overlapping seabird populations (Waggitt et al. 2016). It is also known that age, sex and experience can influence distribution and movement of seabirds (Phillips et al. 2017). In this study, we were unable to determine the age, sex or experience of tracked adults, thus some variation in tracking data could be the result of differences in these variables. Thus, additional tracking will be required to more fully describe Black Guillemot distribution and habitat use.

## **5.2 Effect of tagging**

I found no difference in adult mass between tagged and untagged adults or between years. Previous research found that tagged alcids had lower mass than untagged alcids (Paredes et al. 2005), while others reported no significant effects (Robinson & Jones 2014) on adult mass.



These differences may be due to differences in tag attachment location (back-mounted vs. leg-mounted) or the weight of the tag. I also found no effect of tags on hatch success. Although the effect of tags on alcid hatching success has not been previously examined, tags have been associated with decreased chick growth rate in Whiskered Auklets (*Atheia pygmaea*, Schacter & Jones 2017) and Cassin's auklets (*Ptychoramphus aleuticus*; Ackerman et al. 2004) and decreased fledgling success in Tufted Puffins (*Fratercula cirrhata*; Whidden et al. 2007). In contrast, tags appeared not to affect fledgling success in Parakeet Auklets (Paredes et al. 2005). These differences may be due to physiological and behavioural differences in the species, such as mass, wing-loading or migration distances (Schacter & Jones 2017). Thus, tag effects can vary between species, reinforcing the need to assess species individually in a given region (Burger & Shaffer 2008, Schacter & Jones 2017). My results suggest that there are no significant effects of tagging on adult Black Guillemot mass or hatch success. However, these results should be viewed with some caution. The sample size and parameters measured were limited and because birds were caught by convenience (non-random), catchability related to bird experience may play a role in my results. Additional research on potential tag effects on Black Guillemot populations in Atlantic Canada is recommended.

### **5.3 Future implications**

If my results are representative of Black Guillemots from these two colonies, this research can inform management decisions on the development of marine protected areas, oil spill response strategies, or tidal energy. Knowledge on seabird distribution can provide important information on marine hotspots, which can be used to designate marine protected areas (Hyrenbach et al. 2006, Le Corre et al. 2012) and identify areas of high risk (Davoren 2007). The north Atlantic continental shelf has previously been identified as an important biological hotspot

that should be protected (Montevecchi et al. 2012), as alcids, such as the Razorbill, occur here in high abundance (Huettman et al. 2005, Clarke et al. 2011). The results of my study, in conjunction with other seabird or marine mammal tracking studies, can be used to identify specific marine hotspots along the north Atlantic continental shelf that could be developed into marine protected areas.

Information on Black Guillemot distribution can also be used to improve oil spill response strategies for this species. Black Guillemots are particularly vulnerable to oil spills because of their pursuit-diving and passive-drifting foraging behaviour that increases their risk of exposure to surface oil spills (Nettleship & Evans 1985, Cairns 1987). My results suggest that birds are widely distributed across the region during the winter, and that this distribution varies by colony and throughout the nonbreeding period. Thus, an oil spill in this region may have varying impacts individuals and populations depending on the time and location of the spill (Montevecchi et al. 2012, Tranquilla et al. 2013). However, as oil exploration continues to increase on the Scotian Shelf and Grand Banks due to the availability of exploitable oil reserves (Grant et al. 1986), knowledge on the distribution of Black Guillemots in these areas will be increasingly important to identify areas in which Black Guillemots may be most vulnerable to oil spills.

Knowledge on Black Guillemot distribution is also important in tidal energy development. Black Guillemots from Kent Island were widely distributed in the Bay of Fundy and Gulf of Maine during the entire nonbreeding period, with Country Island birds overlapping in these areas during the winter phases (Figure 2). However, the Bay of Fundy is also an important location for tidal energy development (Karsten et al. 2008). As tidal energy in the Bay of Fundy continues to be explored (Karsten et al. 2008, Furness et al. 2012), Black Guillemots

are at an increasing risk of disturbance or direct harm due to their diving and benthic foraging behaviour (Furness et al. 2012, Johnston et al. 2018). Information on Black Guillemot distribution in the Bay of Fundy will allow for sustainable decisions on the placement of tidal turbines and how to mitigate potential turbine impacts (Johnston et al. 2018).

## **6.0 Conclusion**

This research provides the first insights on the winter distribution of the Black Guillemot in Atlantic Canada. Black Guillemots from Country Island, Nova Scotia and Kent Island, New Brunswick, were distributed in the Gulf of St. Lawrence, Scotian Shelf, Bay of Fundy and Gulf of Maine during the nonbreeding period, in both continental and pelagic waters. This research, combined with other seabird, fish and marine mammal tracking studies, can be used in management decisions on the development of marine protected areas, oil spill response strategies, tidal energy and more. Although my sample of tracked birds was limited and may not be fully representative of the species behaviour in this part of their range, these results raise unique observations of offshore movements and provide new insights on the life-history of this poorly studied species. Further tracking would allow for modeling of species-habitat associations, allowing for predictions about how this species may respond to variability and changes in habitat over time. Additional tracking studies of more populations over several nonbreeding periods should be conducted to develop a better understanding of Black Guillemot overwintering locations and habitat use in this region.

## 8.0 References

- Ackerman JT, Adams J, Takekawa JY, Carter HR, Whitworth DL, Newman SH, Golightly RT, Orthmeyer DL (2004) Effects of radiotransmitters on the reproductive performance of Cassin's auklets. *Wildl Soc Bull* 32:1229–1241
- Adams J, Scott D, McKechnie S, Blackwell G, Shaffer SA, Moller H (2009) Effects of geolocation archival tags on reproduction and adult body mass of sooty shearwaters (*Puffinus griseus*). *New Zeal J Zool* 36:355–366
- Atkinson LP, Stephen Bishop S, Hofmann EE, Yoder JA, Lee TN (2003) Effect of upwelling on phytoplankton productivity of the outer southeastern United States continental shelf. *Cont Shelf Res* 1:385–404
- Barron DG, Brawn JD, Weatherhead PJ (2010) Meta-analysis of transmitter effects on avian behaviour and ecology. *Methods Ecol Evol* 1:180–187
- Benjamins S, Kulka DW, Lawson J (2008) Incidental catch of seabirds in Newfoundland Labrador gillnet fisheries, 2001-2003. *Endanger Species Res* 5:149–160
- Bindoff AD, Wotherspoon SJ, Guinet C, Hindell MA (2017) Twilight-free geolocation from noisy light data. *Methods Ecol Evol* 9:1190–1198
- Bradstreet MSW (1979) Thick-billed murre and black guillemots in the Barrow Strait area, N.W.T., during spring: distribution and habitat use. *Can J Zool* 57:1789–1802
- Brown RGB (1985) The Atlantic Alcidae at Sea. In: Nettleship DN, Birkhead TR (eds) *The Atlantic Alcidae: The evolution, distribution and biology of the auks inhabiting the Atlantic Ocean and adjacent water areas*. Academic Press, London, U.K., p 383–426
- Burger AE, Shaffer SA (2008) Application of tracking and data-logging technology in research and conservation of seabirds. *Auk* 125:253–264
- Butler RG, Buckley DE (2002) Black Guillemot (*Cepphus grylle*). In: Poole AF, Gill FB (eds) *The Birds of North America* Cornell Lab of Ornithology, version 2.0. Ithaca, NY, USA
- Cairns DK (1987) Diet and foraging ecology of Black Guillemots in northeastern Hudson Bay. *Can J Zool* 65:1257–1263
- Campbell JW, O'Reilly JE (1988) Role of satellites in estimating primary productivity on the northwest Atlantic continental shelf. *Cont Shelf Res* 8:179–204
- Cannell PF, Maddox GD (1983) Population change in three species of seabirds at Kent Island, New Brunswick. *J F Ornithol* 54:29–35
- Casper RM (2009) Guidelines for the instrumentation of wild birds and mammals. *Anim Behav* 78:1477–1483
- Clarke TCR, Diamond AW, Chardine JW (2011) Origin of Canadian Razorbills (*Alca torda*) Wintering in the Outer Bay of Fundy Confirmed by Radio-Tracking. *Waterbirds* 33:541–545

- Corre M Le, Jaeger A, Pinet P, Kappes MA, Weimerskirch H, Catry T, Ramos JA, Russell JC, Shah N, Jaquemet S (2012) Tracking seabirds to identify potential Marine Protected Areas in the tropical western Indian Ocean. *Biol Conserv* 156:83–93
- Davoren GK (2007) Effects of gill-net fishing on marine birds in a biological hotspot in the northwest Atlantic. *Conserv Biol* 21:1032–1045
- Dearborn DC, Anders AD, Schreiber EA, Adams RMM, Mueller UG (2003) Inter-island movements and population differentiation in a pelagic seabird. *Mol Ecol* 12:2835–2843
- Divoky GJ, Douglas DC, Stenhouse IJ (2016) Arctic sea ice a major determinant in Mandt's black guillemot movement and distribution during non-breeding season. *Biol Lett* 12:20160275
- Elliott KH, Davoren GK, Gaston AJ (2007) The influence of buoyancy and drag on the dive behaviour of an Arctic seabird, the Thick-billed Murre. *Can J Zool* 85:352–361
- Environment and Climate Change Canada (2018) East Coast Seasonal Summary: Winter 2017-2018.
- Ewins PJ (1986) The ecology of black guillemots *Cephus grylle* in Shetland. University of Oxford
- Fraser GS, Racine V (2016) An evaluation of oil spill responses for offshore oil production projects in Newfoundland and Labrador, Canada: Implications for seabird conservation. *Mar Pollut Bull* 107:36–45
- Furness RW, Wade HM, Robbins AMC, Masden EA (2012) Assessing the sensitivity of seabird populations to adverse effects from tidal stream turbines and wave energy devices. *ICES J Mar Sci* 69:1466–1479
- Gaston AJ, Smith PA, Tranquilla LMF, Montevecchi WA, Fifield DA, Gilchrist HG, Hedd A, Mallory ML, Robertson GJ, Phillips RA (2011) Movements and wintering areas of breeding age Thick-billed Murre *Uria lomvia* from two colonies in Nunavut, Canada. *Mar Biol* 158:1929–1941
- Gran HH, Braarud T (1935) A Quantitative Study of the Phytoplankton in the Bay of Fundy and the Gulf of Maine (including Observations on Hydrography, Chemistry and Turbidity). *J Biol Board Canada* 1:279–467
- Grant AC, McAlpine KD, Wade JA (1986) The continental margin of eastern Canada: geological framework and petroleum potential. In: Halbouty MT (ed) *Future Petroleum Provinces of the World*. American Association of Petroleum Geologists, p 177–205
- Grémillet D, Dell'Omo G, Ryan PG, Peters G, Ropert-Coudert Y, Weeks SJ (2004) Offshore diplomacy, or how seabirds mitigate intra-specific competition: A case study based on GPS tracking of Cape gannets from neighbouring colonies. *Mar Ecol Prog Ser* 268:265–279
- Hamel N, Parrish J, Conquest L, Burger A (2004) Effects of Tagging on Behavior, Provisioning, and Reproduction in the Common Murre (*Uria aalge*), A Diving Seabird. *Auk* 121:1161–1171

- Haney JC (1991) Influence of pycnocline topography and water-column structure on marine distributions of alcids (Aves: Alcidae) in Anadyr Strait, Northern Bering Sea, Alaska. *Mar Biol* 110:419–435
- Hedd A, Montevecchi WA, McFarlane Tranquilla L, Burke CM, Fifield DA, Robertson GJ, Phillips RA, Gjerdrum C, Regular PM (2011) Reducing uncertainty on the Grand Bank: Tracking and vessel surveys indicate mortality risks for common murrelets in the North-West Atlantic. *Anim Conserv* 14:630–641
- Hedd A, Pollet IL, Mauck RA, Burke CM, Mallory ML, McFarlane Tranquilla LA, Montevecchi WA, Robertson GJ, Ronconi RA, Shutler D, Wilhelm SI, Burgess NM (2018) Foraging areas, offshore habitat use, and colony overlap by incubating leach's storm-petrels *Oceanodroma leucorhoa* in the northwest Atlantic. *PLoS One* 13:e0194389
- Hill RD (1994) Theory of Geolocation by Light Levels. In: *Elephant Seals: Population Ecology, Behavior, and Physiology*. p 227–236
- Hill RD, Braun MJ (2001) Geolocation by light level—The next step: Latitude. In: *Electronic Tagging and Tracking in Marine Fisheries*.
- Hobson KA, Bond AL (2012) Extending an indicator: Year-round information on seabird trophic ecology from multiple-tissue stable-isotope analyses. *Mar Ecol Prog Ser* 461:233–243
- Huettman F, Diamond AW, Dalzell B, MacIntosh K (2005) Winter distribution, ecology and movements of Razorbills *Alca torda* and other auks in the outer bay of Fundy, Atlantic Canada. *Mar Ornithol* 33:161–171
- Huettmann F, Diamond AW (2000) Seabird migration in the Canadian northwest Atlantic Ocean: moulting locations and movement patterns of immature birds. *Can J Zool* 78:624–647
- Hunt G, Mehlum F, Russell R, Irons D, Beth M (1999) Physical processes, prey abundance, and the foraging ecology of seabirds. In: *Proceedings of the 22nd International Ornithological Congress, Durban*. p 16–22
- Hyrenbach KD, Keiper C, Allen SG, Ainley DG, Anderson DJ (2006) Use of marine sanctuaries by far-ranging predators: Commuting flights to the California Current System by breeding Hawaiian albatrosses. *Fish Oceanogr* 15:95–103
- Johnston DT, Furness RW, Robbins AMC, Tyler G, Taggart MA, Masden EA (2018) Black guillemot ecology in relation to tidal stream energy generation: An evaluation of current knowledge and information gaps. *Mar Environ Res* 134:121–129
- Karsten RH, McMillan JM, Lickley MJ, Haynes RD (2008) Assessment of tidal current energy in the Minas Passage, Bay of Fundy. *Proc Inst Mech Eng Part A J Power Energy* 222:493–507
- Lieske D, Tranquilla L, Ronconi R, Abbot S (2019) Synthesizing expert opinion to assess the at-sea risks to seabirds in the western North Atlantic. *Biol Conserv* 233:41–50
- Louzao M, Bécarea J, Rodríguez B, Hyrenbach KD, Ruiz A, Arcos JM (2009) Combining vessel-based surveys and tracking data to identify key marine areas for seabirds. *Mar Ecol*

Prog Ser 391:183–197

Mehlum F, Gabrielsen GW, Nagy KA (1993) Energy Expenditure by Black Guillemots (*Cepphus grylle*) during Chick-Rearing. *Colon Waterbirds* 16:45

Montevecchi WA, Hedd A, McFarlane Tranquilla L, Fifield DA, Burke CM, Regular PM, Davoren GK, Garthe S, Robertson GJ, Phillips RA (2012) Tracking seabirds to identify ecologically important and high risk marine areas in the western North Atlantic. *Biol Conserv* 156:62–71

Nettleship DN, Evans PGH (1985) Distribution and status of the Atlantic Alcidae. In: Nettleship DN, Birkhead TR (eds) *The Atlantic Alcidae: The evolution, distribution and biology of the auks inhabiting the Atlantic Ocean and adjacent water areas*. Academic Press, London, U.K., p 54–154

Nol E, Gaskin DE (1987) Distribution and movement of Black Guillemots (*Cepphus grylle*) in coastal waters of the southwestern Bay of Fundy, Canada. *Can J Zool* 65:2682–2689

Paredes R, Jones IL, Boness DJ (2005) Reduced parental care, compensatory behaviour and reproductive costs of thick-billed murrelets equipped with data loggers. *Anim Behav* 69:197–208

Phillips RA, Silk JRD, Croxall JP, Afanasyev V, Briggs DR (2004) Accuracy of geolocation estimates for flying seabirds. *Mar Ecol Prog Ser* 266:265–272

Phillips RA, Xavier JC, Croxall J (2003) Effects of Satellite Transmitters on Albatrosses and Petrels. *Auk* 120:1082–1090

Pollet IL, Ronconi R, Leonard M, Shutler D (2019) Migration routes and stopover areas of Leach's Storm Petrels. *Mar Ornithol* 47:53–63

Prach RW, Smith AR (1992) Breeding distribution and numbers of black guillemots in Jones Sound, NWT. *Arctic* 45:111–114

R Core Team (2018) *R: A language and environment for statistical computing*. R Found Stat Comput ISBN 3-900051-07-0

Rabiner LR (1989) A Tutorial on Hidden Markov Models and Selected Applications in Speech Recognition. *Proc IEEE* 77

Ratcliffe N, Crofts S, Brown R, Baylis AMM, Adlard S, Horswill C, Venables H, Taylor P, Trathan PN, Staniland IJ (2014) Love thy neighbour or opposites attract? Patterns of spatial segregation and association among crested penguin populations during winter. *J Biogeogr* 41:1183–1192

Renaud WE, Bradstreet MSW (1980) Late winter distribution of Black Guillemots in Northern Baffin Bay and the Canadian High Arctic. *Can F Nat* 94:421–425

Robinson WD, Bowlin MS, Bisson I, Shamoun-Baranes J, Thorup K, Diehl RH, Kunz TH, Mabey S, Winkler DW (2010) Integrating concepts and technologies to advance the study of bird migration. *Front Ecol Environ* 8:354–361

Robinson JL, Jones IL (2014) An experimental study measuring the effects of a tarsus-mounted

- tracking device on the behavior of a small pursuit-diving seabird. *Behaviour* 151:1799–1826
- Ronconi RA, Allard KA, Taylor PD (2015) Bird interactions with offshore oil and gas platforms: Review of impacts and monitoring techniques. *J Environ Manage* 147:34–45
- Ronconi RA, Clair C St. (2002) Management options to reduce boat disturbance on foraging black guillemots (*Cepphus grylle*) in the Bay of Fundy. *Biol Conserv* 108:265–271
- Ronconi RA, Wong SNP (2003) Estimates of changes in seabird numbers in the Grand Manan Archipelago, New Brunswick, Canada. *Waterbirds* 26:462
- Schacter CR, Jones IL (2017) Effects Of Geolocation Tracking Devices On Behavior, Reproductive Success, and Return Rate of *Aethia* Auklets: An Evaluation of Tag Mass Guidelines. *Wilson J Ornithol* 129:459–468
- Scott JS (2010) Occurrence of Pollock, *Pollachius virens*, and Sand Lance, *Ammodytes* sp., Larvae in the Bay of Fundy. *J Northwest Atl Fish Sci* 1:45–48
- Shackell NL, Frank KT, Petrie B, Brickman D, Shore J (2011) Dispersal of early life stage haddock (*Melanogrammus aeglefinus*) as inferred from the spatial distribution and variability in length-at-age of juveniles. *Can J Fish Aquat Sci* 56:2350–2361
- Shaffer SA, Tremblay Y, Awkerman JA, Henry RW, Teo SLH, Anderson DJ, Croll DA, Block BA, Costa DP (2005) Comparison of light- and SST-based geolocation with satellite telemetry in free-ranging albatrosses. *Mar Biol* 147:833–843
- Takahashi A, Ito M, Suzuki Y, Watanuki Y, Thiebot JB, Yamamoto T, Iida T, Trathan P, Niizuma Y, Kuwae T (2015) Migratory movements of rhinoceros auklets in the northwestern Pacific: Connecting seasonal productivities. *Mar Ecol Prog Ser* 525:229–243
- Teo SLH, Boustany A, Blackwell S, Walli A, Weng KC, Block BA (2004) Validation of geolocation estimates based on light level and sea surface temperature from electronic tags. *Mar Ecol Prog Ser* 283:81–98
- Tibbo SN, Legaré JEH, Scattergood LW, Temple RF (2011) On the Occurrence and Distribution of Larval Herring (*Clupea harengus* L.) in the Bay of Fundy and the Gulf of Maine. *J Fish Res Board Canada* 15:1451–1469
- Tranquilla LA, Montevecchi WA, Fifield DA, Hedd A, Gaston AJ, Robertson GJ, Phillips RA (2014) Individual winter movement strategies in two species of murre (*Uria* spp.) in the Northwest Atlantic. *PLoS One* 9:e90583
- Tranquilla LAMF, Montevecchi WA, Hedd A, Fifield DA, Burke CM, Smith PA, Regular PM, Robertson GJ, Gaston AJ, Phillips RA (2013) Multiple-colony winter habitat use by murre *Uria* spp. in the northwest atlantic ocean: Implications for marine risk assessment. *Mar Ecol Prog Ser* 472:287–303
- Trottier-Paquet M, MacDonald B (2017) Country Island Seabird Monitoring and Tern Restoration Project. Sackville
- Vandenabeele SP, Wilson RP, Grogan A (2011) Tags on seabirds: How seriously are instrument-



induced behaviours considered? *Anim Welf* 20:559–571

Waggitt JJ, Cazenave PW, Torres R, Williamson BJ, Scott BE (2016) Quantifying pursuit-diving seabirds' associations with fine-scale physical features in tidal stream environments. *J Appl Ecol* 53:1653–1666

Wakefield ED, Phillips RA, Matthiopoulos J (2009) Quantifying habitat use and preferences of pelagic seabirds using individual movement data: A review. *Mar Ecol Prog Ser* 391:165–182

Whidden SE, Williams CT, Breton AR, Buck CL (2007) Effects of transmitters on the reproductive success of Tufted Puffins. *J F Ornithol* 78:206–212

Winn HE (1950) The Black Guillemots of Kent Island, Bay of Fundy. *Auk* 67:477–485

Wong SNP, Ronconi RA, Gjerdrum C (2018) Autumn at-sea distribution and abundance of phalaropes phalaropus and other seabirds in the lower bay of fundy, Canada. *Mar Ornithol* 46:1–10