# Modelling the impact of hunting and oiling on Brünnich’s guillemot *Uria lomvia* populations in the Northwest Atlantic

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## Abstract

The Brünnich’s guillemot (or thick-billed murre) is a numerous pan-Arctic seabird, but several Atlantic breeding populations are declining. The species is is subject to traditional harvests at the important wintering areas off West Greenland and Newfoundland, and have been subject to chronic oil pollution where major shipping converge on the east coast of Canada. Until recently, knowledge on migration routes and winter distribution has been insufficient to assess the impact of these mortality sources on specific breeding populations. We collate existing information on mortality from bag statistics in Greenland and Canada and studies of oiling off Newfoundland, as well as new data on age distribution in the hunting bag. Based on the results of recent tracking studies, we construct a spatially explicit population model that allocates hunting and oiling mortality to breeding populations and estimates the impact on their growth rate. Results indicate that population growth rate is depressed by 0.010 – 0.039 by anthropogenic mortality sources. In addition to local breeders, hunting in Greenland mainly affects declining breeding populations in Svalbard and Iceland, while hunting and oiling in Newfoundland mainly affects guillemots breeding in Arctic Canada and north-west Greenland, where populations are relatively stable. The strongest impact is predicted on the small breeding population in Atlantic Canada, which winters mainly on the Newfoundland Shelf and thus is exposed to both hunting and oiling. Our results clarify the relationships between hunting in Greenland and Canada and growth of specific breeding populations, and thus have major implications for harvest management of guillemots in the Northwest Atlantic.

## Introduction

Many migratory birds are exposed to anthropogenic mortality sources in their wintering areas, and the impact of this mortality on specific breeding populations is determined by how much they mix in winter and thus the composition of the exposed wintering populations (Esler 2000). Assessing and managing this impact thus requires detailed knowledge of the species’ migration patterns and non-breeding distribution. For seabirds, such knowledge has until recently been limited, and e.g. determining which breeding populations have been affected by specific major oil spills in winter has been problematic (Cadiou et al. 2004). However, recent tracking studies have massively increased the available data on non-breeding distribution for many seabird species, and for some species the information is now so comprehensive that the composition of specific wintering populations can be estimated (Frederiksen et al. 2012).

One seabird species which is exposed to widespread, chronic anthropogenic mortality in its wintering range is the Brünnich’s guillemot (or thick-billed murre, *Uria lomvia*) (hereafter guillemot). This numerous pan-Arctic species has long been a popular hunting object in its important Atlantic wintering areas off Newfoundland and West Greenland (Elliot et al. 1991; Falk & Durinck 1992; Gaston & Robertson 2010), although the number of birds shot has decreased substantially in both areas (Frederiksen et al. 2016). In addition, large numbers of guillemots have fallen victim to chronic oil pollution in the important shipping corridor off Newfoundland (Wiese & Ryan 2003); the extent of this problem has also been reduced recently due to stricter regulation of discharges of oil and bilge water (Robertson et al. 2014). Nevertheless, the annual number of guillemots killed by hunting and oiling are still substantial (approx. 150,000; Robertson et al. 2014; Frederiksen et al. 2016). Guillemot populations are declining rapidly in many parts of the Atlantic breeding range, including Greenland (Merkel et al. 2014), Iceland (Garðarsson et al. in press) and Svalbard (Descamps et al. 2013), and it is highly relevant for managers to assess the potential role of direct anthropogenic mortality in driving this decline.

The recent compilation of tracking data from all major Atlantic breeding guillemot populations formed the basis of estimation of the composition of wintering population in terms of breeding origin (Frederiksen et al. 2016). Here, we use the results of this study in combination with recent information on hunting and oiling mortality in Greenland and Canada to construct a spatially explicit population model that estimates the impact on growth rates of specific breeding populations. Our aim is to provide an improved basis for pan-Atlantic management of this declining migrant seabird. This study is an update and extension of the model presented by Wiese et al. (2004) for Canadian guillemots.

## Methods

### Study areas and winter population composition

Frederiksen et al. (2016) estimated the size and composition of wintering guillemot populations in the Atlantic based on tracking data. We focused on three wintering areas with substantial anthropogenic winter mortality: SW Greenland Shelf, CW Greenland Shelf, and Newfoundland Shelf (Fig. 1). Seven breeding populations of widely differing size were represented in these wintering areas in more than trivial numbers, and thus included in the population model: Atlantic Canada, Hudson Bay, Arctic Canada, Northwest Greenland, Southwest Greenland, Iceland and Spitsbergen (Fig. 1). Between 14 and 51 % of breeders from these populations used the focal wintering areas, and each area was estimated to hold several hundred thousand wintering breeders alone (Fig. 2). Populations breeding at Bjørnøya and in mainland Norway hardly used these wintering areas, whereas tracking data were missing for the populations breeding in East Greenland, on Jan Mayen and in Arctic Russia. Tracking data were only available for adult breeders. Recoveries of ringed birds show small differences in distribution between age classes (Donaldson et al. 1997; Bakken et al. 2003; Lyngs 2003), and we here assume that pre-breeders are distributed in the same way as adults.

### Hunting mortality – Greenland

Data on reported hunting mortality of guillemots in Greenland were provided by the Ministry of Fisheries and Hunting, Government of Greenland, from the database Piniarneq/LULI (extracted 9 June 2017). We used data for the period 2008/09-2015/16 when hunting regulations were unchanged (15 October – 28/29 February south of 67.5°N and 1 September - 28/29 February north of 67.5°N) and numbers reported shot were remarkably constant. Data in Piniarneq are broken down by administrative districts, and we summarised them for the wintering areas used in Frederiksen et al. (2016). Assuming equal sex ratio, we divided the reported number shot by 2 because the model represents females only. The mean number of females reported shot during the winter season (September – March) was 10,614 (SD 977) in SW Greenland, and 17,658 (SD 2925) in CW Greenland. The mean proportion of the harvest reported before 1 January was 66% in CW Greenland and 79% in SW Greenland.

Samples of shot birds (Table 2) were collected within approximately 50 km of Nuuk and first-winter birds were distinguished from older birds by the interorbital width of skull, measured externally <12.5 mm. Where possible this rule of thumb was used in combination with the presence or absence of Bursa fabricii, the size of testicles in males and the size of the oviduct in females.

Because the proportion of first-winter birds in the hunting bag was higher before 1 January than after (see Results), we calculated a mean proportion for CW Greenland as an average weighted by the numbers of birds reported shot during the two periods. We had no access to recent samples from SW Greenland. Falk and Durinck (1992) reported > 90% first-winter birds among shot birds in this area in 1988/89, but also suggested that this season was atypical and that a somewhat higher proportion of older birds would occur in most years. We assumed a higher proportion of first-winter birds in SW Greenland than in CW Greenland (85% before 1 January, 80% after, weighted mean 84 %). In both areas, we used a standard error of 0.05 in the stochastic model.

### Hunting mortality – Canada

Beginning in 2010, annual estimates of guillemot harvest (both species) in Canada are collected as part of the National Harvest Survey (Gendron and Smith 2017). All guillemot hunters are now required to purchase of Migratory Game Bird Hunting Permit, and a sample of these hunters are sent a survey to complete that asks for information on numbers of guillemots harvested throughout the hunting season. These results are used to estimate total number of guillemot harvested in Newfoundland and Labrador. Since both guillemot species are harvested in Canada, the proportion of Brunnich’s guillemot in the harvest is estimated by a separate Species Composition Survey. In this survey, a different sample of hunters are asked to participate by mailing in wings of harvested game birds (including guillemots). Hunters that agree to participate are sent a set of plastic lined envelopes, with instructions on how to complete the information requested and mail in wings of guillemots that they harvested. The species and age of all wings are determined by the methods developed by Wilhelm et al. (2008), which examines plumage colour, numbers of faded greater secondary coverts and relative length of inner primaries and outer secondaries to assign species and age (juvenile or older) to each wing. These data provide annual estimates of the proportion of guillemots harvested which were Brunnich’s guillemot, and annual estimates of the proportion of those harvested guillemots that were first winter birds.

### Oiling mortality – Canada

Mortality from chronic oil pollution was obtained from estimates from Robertson et al. (2014), using the Oiled Seabird Mortality Model (OSMM) developed by Wiese and Robertson (2004). In summary, numbers of beached bird carcasses found on regularly surveyed beaches in southeastern Newfoundland are used to extrapolate total mortality from chronic oiling in the region. Carcass persistence and detection on beaches are accounted for, and annual weather (specifically wind patterns) are used to derive estimates of total mortality. Due to the relatively low numbers of carcasses found, extrapolations of total mortality are based on all carcasses found, which are then assigned to species based on their relative frequency among all carcasses found that year.

### Population model

We constructed a stochastic female-only matrix population model with six age classes and a pre-breeding census (Caswell 2001). Demographic parameter values for the basic model were selected to represent optimal conditions, i.e. a population not exposed to anthropogenic mortality and with near-optimal reproduction (Table 1). For pre-breeding survival, these values were taken from a long-term study of an unexploited population of the closely related common guillemot (*Uria aalge*) (Harris et al. 2007). Each of the seven breeding populations was initiated with a population size (breeding pairs) as in Frederiksen et al. (2016) and a stable age distribution defined by the demographic parameter values (Stubben & Milligan 2007) (Table 2). Total female population size was calculated using the stable age distribution and age-specific proportions of breeders (Table 2). For simplicity, we assumed that anthropogenic mortality occurred at mid-winter, and the model populations were projected from year to year in two stages (autumn and spring) (see also Wiese et al. 2004; Gilliland et al. 2009). Age-specific natural mortality was allocated to the two stages by taking the square root of annual survival, except for first-winter birds where autumn survival was set to and spring survival to , reflecting the assumption that enhanced natural mortality of juveniles occurred prior to mid-winter. During the first stage, reproduction and autumn natural mortality occurred. Anthropogenic mortality (in absolute numbers) was subtracted between stages, and spring natural mortality occurred during the second stage. The total number of females shot or killed by oiling was allocated to breeding populations based on the estimated composition of the wintering populations in the three focus areas. For oiling, we assumed that all age classes were equally vulnerable and allocated mortality proportional to their relative abundance (age distribution after reproduction and autumn natural mortality; Robertson et al. 2006). For hunting, we used empirical data to estimate the proportion of first-winter birds shot, and allocated the remaining mortality to older age classes proportional to their relative abundance (see also Wiese et al. 2004). We assumed that anthropogenic mortality was completely additive to natural mortality, which is typically the case for long-lived animals (Péron 2013).

Stochastic values of demographic parameters were generated by drawing random values from beta distributions with means and standard errors from the literature (Table 1). Generally fecundity values are drawn from normal or other distributions but since guillemots can only produce a maximum of one chick each year, fecundity values are bounded between 0 and 1 and are effectively modelled as a beta distribution. However, for first-year survival the observed distribution was very flat, and we instead drew random values from the empirical distribution (Harris et al. 2007). For initial breeding population sizes, we assumed a coefficient of variation of 20% and drew values from normal distributions independently for each breeding population.

For Canadian mortality sources, random draws from the empirical distribution of harvest for the years 2010-2014 (5 estimates) and oiling for the years 2009-2012 (4 estimates) were taken for each simulation. Similarly, the proportion of first-winter guillemots in the harvest was taken as a draw from the empirical distribution from the same years (2010-2014).

We ran 10,000 stochastic realisations of the model. To assess the short-term impact of hunting and oiling, we calculated for each realisation the difference in growth rate over the second model year between populations exposed to one or more sources of mortality and ones not exposed (but with the same stochastic values of fecundity and natural mortality).

To assess the generality of our findings, we repeated the model run with a more pessimistic set of demographic parameter values, representing a population at sub-optimal conditions, which would be declining in the absence of anthropogenic mortality (values in brackets in Table 1).

## Results

### Age and sex distribution in the CW Greenland harvest

The proportion of first-winter birds in the sample of shot birds from the Nuuk area was consistently much higher before 1 January (74%) than after (24%). There was also a considerably lower proportion of juveniles in the first part of the study period (1995-2006) than later (2007-2017), see Table 3. The birds included originated from a relatively small number of samples, each of which might have a biased age composition. We therefore pooled data from the entire study period. To estimate the overall age composition of the harvest in CW Greenland, we calculated a weighted mean proportion of first-winter birds based on the proportion of the total harvest reported before 1 January (66%): 0.66\*0.74 + 0.34\*0.24 = 57%.

The sample of sexed shot birds was smaller, particularly before 1 January. The proportion of females was 39% (24/61) before 1 January, and 50% (170/343) after 1 January. In the model, we assumed that the harvest was equally distributed between sexes.

### Predicted impact of anthropogenic mortality

The basic optimistic model scenario showed an asymptotic annual growth rate λ of 1.053, while λ in the pessimistic scenario was 0.976, both in the absence of anthropogenic mortality. This corresponds to respectively 5.3 % increase and 2.4 % decrease per year.

The mean predicted impact of anthropogenic mortality on growth rate of the seven breeding populations was 0.010 – 0.039 (Fig. 3). Hunting (all areas) caused a decline in growth rate of 0.006 – 0.020, while the effect of oiling was 0 – 0.018. There was considerable uncertainty around these predicted impacts, mostly caused by the high year-to-year variability in oiling mortality. The largest impact was predicted for the small breeding population in Atlantic Canada, which to a large extent winters on the Newfoundland Shelf and thus is exposed to mortality from both hunting and oiling. In addition, oiling and hunting in Canada had a considerable impact on the breeding population in Northwest Greenland. The smallest impact was predicted for the Hudson Bay population, which largely winters further north on the Labrador Shelf. Hunting in CW Greenland mainly affected the Iceland breeding population, while hunting in SW Greenland had the largest impact on the local breeding population as well as on guillemots breeding in Spitsbergen. However, the high proportion of first-year birds in the hunting bag in SW Greenland led to a relatively small impact on population growth rate.

The predicted impacts of anthropogenic mortality (all sources) on growth rate in the seven breeding populations were slightly (15-18%) larger under the pessimistic scenario than under the basic optimistic scenario (results not shown).

## Discussion

### Summary

Our estimates of the age distribution among shot guillemots in Canada and CW Greenland, including the increase in the proportion of older birds over the season, are similar to previous studies (Elliot et al. 1991; Falk & Durinck 1992). The estimated proportion of first-winter birds was considerably higher in the hunting bag than in the population (57% vs 12.7% after autumn natural mortality), implying a higher relative hunting risk for first-winter birds (risk ratio = 4.5, odds ratio = 9.1).

Results from our population model show that the largest projected impact of anthropogenic mortality (0.039) was on the small breeding population in Atlantic Canada, specifically Labrador. Trend data is limited for this region, but generally the small Brunnich’s breeding population appears to be variable but stable (Colonial Waterbird Database, ECCC-CWS, Atlantic Region) in spite of this harvest pressure, while common guillemots in Labrador are declining (Colonial Waterbird Database, ECCC-CWS, Atlantic Region). The Northwest Greenland breeding population was also affected quite strongly (projected impact on growth rate: 0.026); this population has been considered stable (Merkel et al. 2014), but recent surveys indicate substantial declines in some colonies and smaller increases in others (F. Merkel, unpubl. data). Although the projected impact on the more easterly breeding populations in Spitsbergen, Iceland and Southwest Greenland was smaller (0.011 – 0.018), these populations are known to decline quite rapidly (Spitsbergen 6%/year (Fauchald et al. 2015), Iceland 3.5%/year (Garðarsson et al. in press), Southwest Greenland up to 4.4%/year (Merkel et al. 2014)). Project impacts on the large Canadian Arctic breeding populations were modest (X.XX – X.XX), and those populations are thought to be stable (Gaston et al. 2012).

Previous assessments of the impact of harvest and oiling calculated reductions in growth rate of Canadian Brunnich’s guillemots of 0.020 due to harvest and 0.025 due to oiling in the late 1990s (Wiese et al. 2004). Our results showed reduced effects, likely due to a number of factors. Firstly, the population size of Canadian breeders is now larger than estimates used in Wiese et al. (2004). Additionally, harvest levels and especially oiling mortality have declined considerably since the late 1990s (Frederiksen et al. 2016, Robertson et al. 2014).

### Model limitations

Not all sources of uncertainty were included in our stochastic model. In particular, we treated the composition of wintering populations as known without error. This is obviously not the case; positions derived through geolocation are quite imprecise (Phillips et al. 2004), the samples of tracked birds were relatively small for some populations, and some very large colonies were not represented (Frederiksen et al. 2016). In addition, we had no data on winter distribution of pre-breeding guillemots and therefore assumed that they behave like adult breeders. Nevertheless, the overall patterns accord well with all other information on guillemot winter distribution (e.g. ring recoveries), and we are confident that our main conclusions regarding impacts on specific breeding populations are robust. Further work using biological markers and next-generation DNA sequencing is underway to directly assign harvested birds to source colonies and corroborate harvest derivations based on the geologger data.

Although the overall conclusions and relatively magnitude of the effects of harvest were consistent across different demographic conditions (growing versus declining populations), the input vital rates were collated from limited sources, and for post-fledging rates, data from common guillemots were used. Without robust site-specific demographic data, our models cannot effectively predict whether any particular colony or region is growing or declining, nor assess accurately the potential effect of a mortality source at any one site. However, for understanding the potential relative effect of mortality sources,

Further, the effects of mortality sources are only as good as the estimates used. Estimates for harvest are likely to be reasonable, as both are based on large scale harvest surveys. However, these surveys are not perfect and are known to have certain biases. A major issue for Canada remains illegal harvest, often followed by the illegal sale of guillemots to the public. Wildlife enforcement officers in Canada suggest that the illegal harvest may be as high as the estimated legal and reported harvest. Addressing this illegal harvest is a priority for Canadian guillemot conservation efforts.

Oiling mortality from chronic sources in Canada, on the other hand, appears to be continuing to decline, to the point where so few oiled carcasses are now found on beached bird surveys that estimating mortality from oiling is challenging (Robertson et al. 2014). Changes to Canadian and international maritime law, coupled with improved environmental practices in the maritime shipping industry appear to have had the desired effects of reducing seabird mortality from ship-source oil pollution in eastern Canadian waters.

### Implications for management

This study clearly demonstrates that anthropogenic mortality (hunting and oiling) of guillemots in the wintering areas affects breeding populations in most of the Atlantic range. In most cases, the breeding populations concerned are affected by mortality in a different country. International coordination is thus a prerequisite for successful harvest management of guillemots. Specific attention should be directed at the declining and red-listed breeding populations in Spitsbergen, Iceland and Southwest Greenland. Although anthropogenic mortality in the wintering areas only can explain a part of the observed decline in these populations, principles of sustainable harvesting would suggest that …

In Canada, where most harvest is on populations that appear to be stable, the focus will be on ensuring harvest levels remain sustainable, and focusing efforts to reduce illegal harvests of guillemots for the purposes of commercial selling.

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## Tables

Table 1. Values (mean and standard error) of demographic parameters used in the population model. For *S0*, we sampled from the empirical distribution (which was very flat) rather than using a specified standard error. Mean values used in the more pessimistic scenario are shown in brackets.

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Label | Parameter | Mean | Standard error | Source |
| *S0* | First-year survival | 0.56 | [0.40, 0.31, 0.52, 0.91, 0.30, 0.55, 0.35, 0.33, 0.85, 0.86, 0.67, 0.77, 0.52, 0.73, 0.75, 0.67, 0.67, 0.45, 0.38] | (Harris et al. 2007) |
| *S1* | Second-year survival | 0.79 (0.75) | 0.033 | (Harris et al. 2007: , standard error assumed) |
| *S2* | Third-year survival | 0.92 (0.85) | 0.033 | (Harris et al. 2007: , standard error assumed) |
| *Sa* | Adult survival | 0.95 (0.90) | 0.033 | (Wiese et al. 2004; Smith & Gaston 2012) |
| *Pb3* | Proportion of 3-year-olds breeding | 0.025 | - | (Wiese et al. 2004) |
| *Pb4* | Proportion of 4-year-olds breeding | 0.367 | - | (Wiese et al. 2004) |
| *Pb5* | Proportion of 5-year-olds breeding | 0.700 | - | (Wiese et al. 2004) |
| *Pbad* | Proportion of adults breeding | 0.985 | - | (Wiese et al. 2004) |
| *B* | Breeding productivity | 0.69 (0.49) | 0.088 | (Smith & Gaston 2012) |
| *sr* | Sex ratio | 0.5 | - | this study, McFarlane Tranquilla et al. 2010 |

Table 2. The total female population size at the pre-breeding census (*NPB*), relative to the number of breeding pairs, was estimated based on the model stable age distribution (*SAi*) and the age-specific proportions of breeders (*Pbi*). Total female population size at the start of the breeding season is thus 1.55 times the number of breeding pairs.

|  |  |  |  |
| --- | --- | --- | --- |
| Age class *i* | *SAi* | *Pbi* |  |
| 1 | 0.118 | 0 | 0.183 |
| 2 | 0.089 | 0 | 0.137 |
| 3 | 0.077 | 0.025 | 0.120 |
| 4 | 0.070 | 0.367 | 0.108 |
| 5 | 0.063 | 0.700 | 0.098 |
| 6+ (adult) | 0.583 | 0.985 | 0.902 |
| Total | 1 |  | 1.548 |

Table 3. The number and proportion of first-winter (FW) and older (AFW) guillemots in the sample of shot aged birds in the Nuuk area, 1995-2017.

|  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
|  | 1995-2006 | | | 2007-2017 | | | 1995-2017 | | |
|  | FW | AFW | % FW | FW | AFW | % FW | FW | AFW | % FW |
| Oct-Dec | 29 | 19 | 60% | 43 | 6 | 88% | 72 | 25 | 74% |
| Jan-Mar | 27 | 209 | 11% | 63 | 74 | 46% | 90 | 283 | 24% |

## Figure legends

Figure 1. Maps showing the focal wintering areas (grey shading) and the breeding populations involved (ellipses). Wintering areas: 1: Newfoundland Shelf, 2: CW Greenland Shelf, 3: SW Greenland Shelf. Breeding populations: A: Arctic Canada (540,000 pairs), B: Atlantic Canada (8200 pairs), C: Hudson Bay (1,000,000 pairs), D: Northwest Greenland (310,000 pairs), E: Southwest Greenland (14,000 pairs), F: Iceland (330,000 pairs), G: Spitsbergen (735,000 pairs).

Figure 2. a) Composition of the wintering populations in the three focal areas, in terms of breeding origin. The total estimated number of breeding birds wintering in each area is shown in brackets. b) Percentage of each breeding population that winters in the three focal areas. Data from Frederiksen et al. (2016).

Figure 3. The predicted impact of anthropogenic mortality on seven breeding populations of Brünnich’s guillemots in the Northwest Atlantic (see Fig. 1). The impact is shown as the reduction in population growth rate over the second year of the model run, based on 10,000 stochastic realisations. The boxes show 1st and 3rd quantiles, split by the median. The whiskers extend to either the most extreme observations or 1.5 times the length of the box, whichever is closer to the median. For clarity, outliers are not shown.

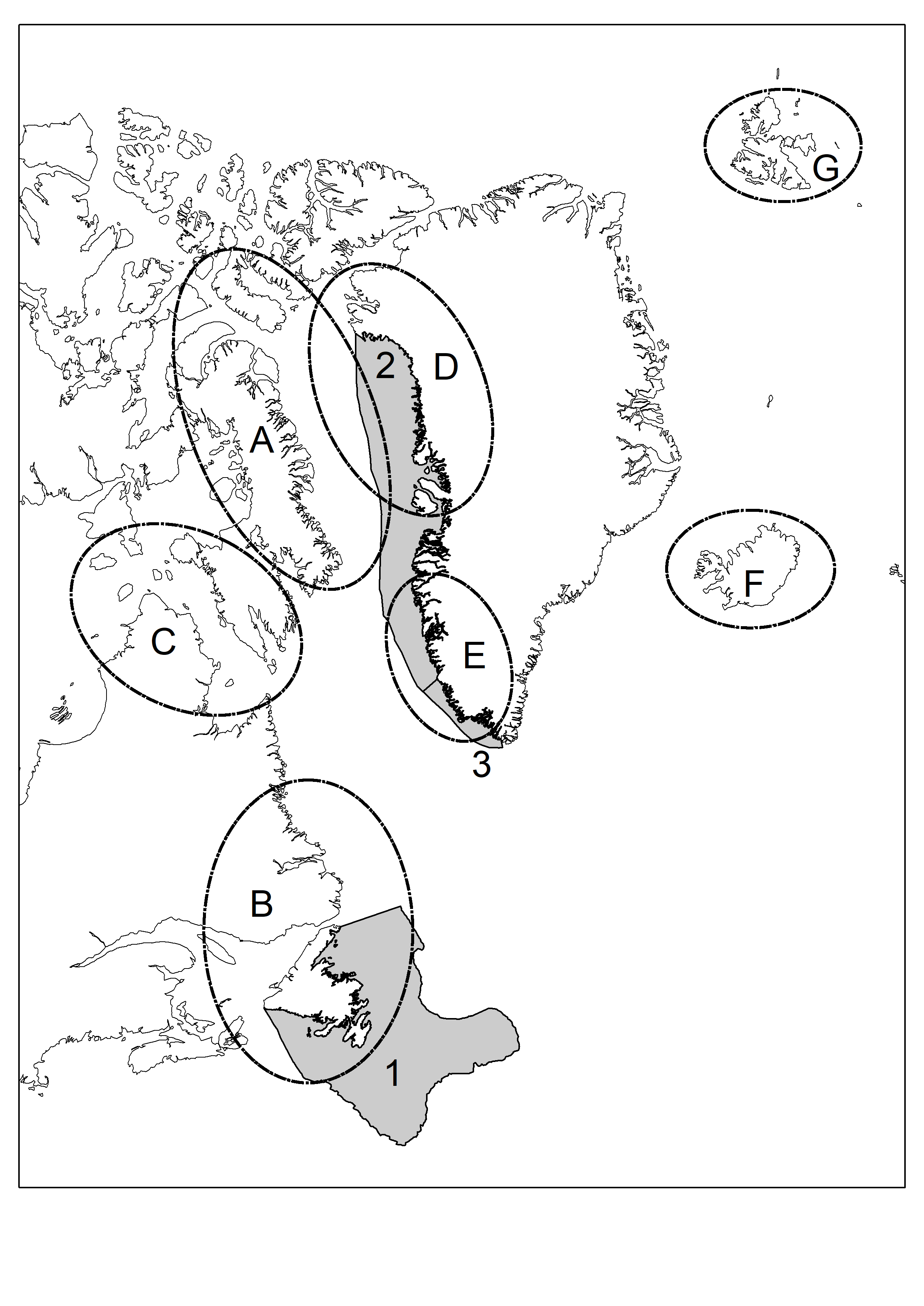


Figure 1.

a)



b)



Figure 2.

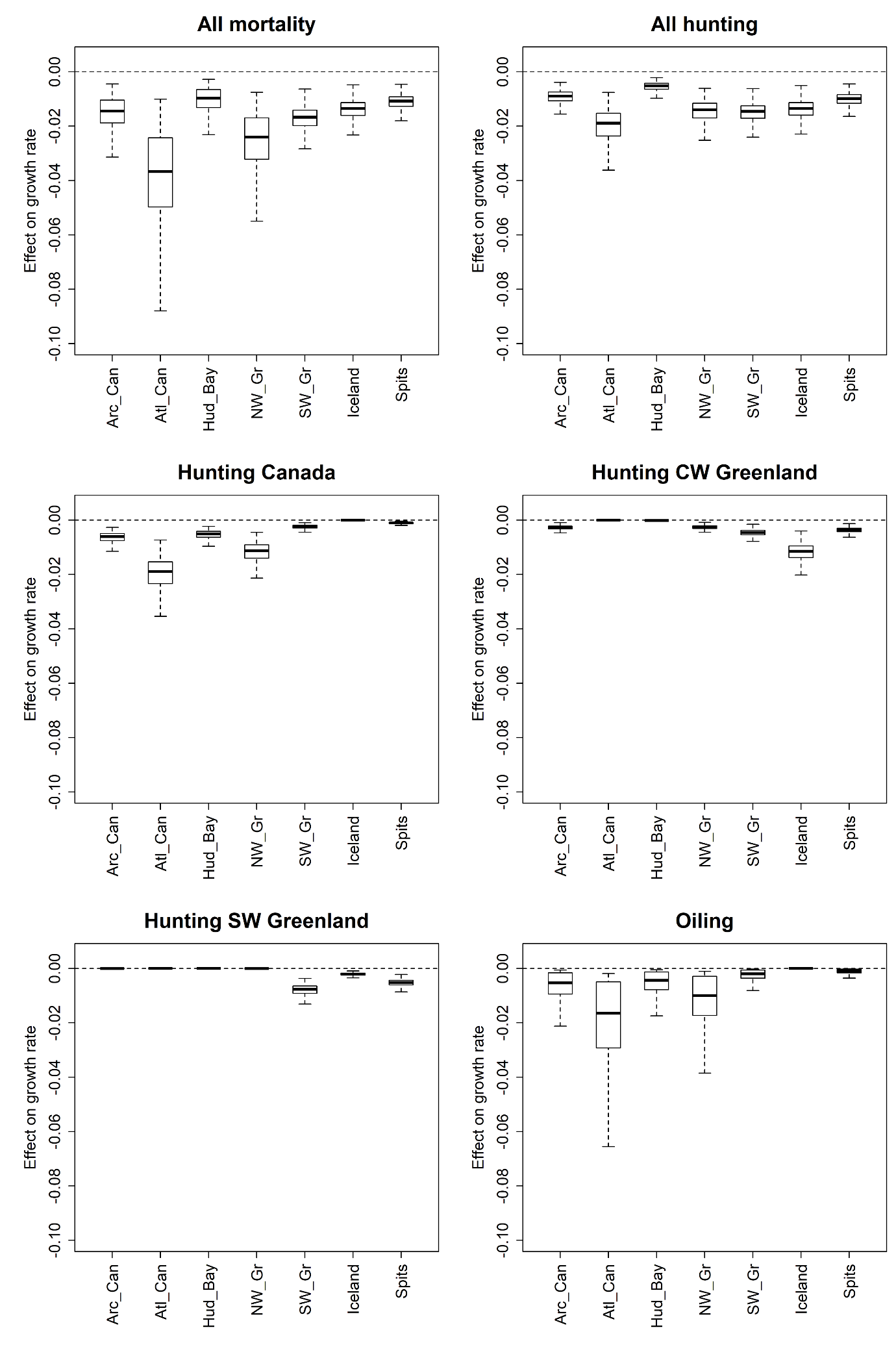


Figure 3.