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Exposure of the Common Eider (*Somateria mollissima*) to toxic elements in relation to migration strategy and wintering area

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Abstract

The Common Eider (*Somateria mollissima*) is a long-lived sea duck with a Holarctic distribution. Eiders within breeding populations have a predictable migration strategy, shown by capture-recapture research using geolocation devices. Within the Arctic, the Svalbard breeding population of eiders are migratory, flying south to Norway and Iceland during the winter. Other populations such as those breeding in Iceland and Norway are sedentary, remaining in the wintering area year-round. This difference in migration strategy likely affects exposure to toxic elements due to difference in diet, geography and anthropogenic emissions.

During the breeding period of 2010, 2011, 2012 and 2017, eggs were collected from breeding female eiders in Svalbard, Northern Norway and North East Iceland. Eggs were analysed for a suite of elements including toxic elements mercury (Hg), arsenic (As), lead (Pb) and selenium (Se). By analysing eggs from both the breeding and wintering area of Svalbard eiders, we aimed to elucidate the relative contributions of breeding and wintering area to exposure of eiders to toxic elements. Additionally, by analysing eggs from migratory and sedentary eiders, we aimed to determine whether migration strategy plays a role in exposure of eiders to toxic elements.

Breeding area rather than wintering area had a significant effect on toxic elements. Eiders breeding on Svalbard had similar levels of toxic elements regardless of wintering area, indicating extensive feeding in the breeding area prior to egg-laying. This has implications for what is known about resource allocation strategy in eiders and warrants further investigation. Migratory eiders had a large variability in levels of toxic elements, likely explained by the variability in arrival date to the breeding ground. Additionally, eiders breeding on Svalbard had elevated Pb compared to sedentary eiders, likely explained by geologic enrichment on Svalbard. Sedentary eiders breeding in Norway had elevated As and Se, possibly reflecting a more marine diet due to the proximity of this population to the open ocean. There was no difference in Hg between breeding groups. All toxic element concentrations were below levels associated with toxic effects in wild birds.

These findings have implications for management of migratory and sedentary populations, as difference in migration strategy appears to expose eiders, and potentially other seabirds to varying levels of toxic elements such as Hg, Pb and As.

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"Men can be fickle, but in birds, I always trust". – Varys of Lys, Game of Thrones

Contents

1 Introduction

Toxic elements such as mercury (Hg), cadmium (Cd), lead (Pb), nickel (Ni) and arsenic (As) are present in the environment and levels vary naturally according to local geology (AMAP, 2005). Although naturally occurring, anthropogenic activity such as industry, agriculture and transport has led to the redistribution of toxic elements, attributing to high concentrations in some environments (AMAP, 2005). In the high Arctic, local anthropogenic contributions of toxic elements are generally low compared to industrialised areas at lower latitudes, however concentrations are surprisingly high given the remoteness of the arctic regions. This is due to the process of long range transport, known to facilitate the movement of Hg to high latitudes, and the same process may also be true for other toxic metals such as Pb and Cd (AMAP, 2011). The process of long range transport results in enrichment of these toxic elements, relative to background levels at high latitudes.

Arctic organisms are exposed to toxic elements through their diet. Whilst adverse effects from exposure to toxic elements are not pronounced in most arctic wildlife, effects have been associated with organisms occupying high trophic levels such as marine mammals and some seabirds, some of which bioaccumulate high levels of toxic elements such as Hg (AMAP, 2011).

In addition to exposure to toxic elements, organisms are also exposed to a range of non-toxic elements, some of which are essential for life e.g. macroelements such as phosphorus (P), potassium (K), calcium (Ca), magnesium (Mg) and microelements such as zinc (Zn), iron (Fe), copper (Cu) and selenium (Se)(da Silva and Williams, 2001). Whilst baseline levels of essential elements are necessary for normal bodily functions, and deficiency can be detrimental to wildlife, high concentrations can lead to toxic effects (Goldhaber, 2003). There are many extrinsic factors affecting concentrations of toxic and non-toxic elements, such as geology and local sources that differ due to differences in geographic location species, geographic location. There are also many intrinsic factors influencing exposure, such as species, physiology, feeding habits, age and sex of the organism (Giulio and Newman, 2013).

Within the Arctic, the Norwegian archipelago of Svalbard is an important breeding area for many seabird species (Isaksen and Bakken, 1995), and many of these species are migratory. Avian migration is a large-scale seasonal ecological adjustment carried out by 19% of the worlds bird population (Kirby et al., 2008), thought to be a response to seasonality in food and climate (Somveille et al., 2015). In the Arctic, food availability in winter is scarce due to cold temperatures and ice extent, therefore many breeding arctic seabirds migrate southwards to find more favourable conditions in autumn. In contrast to migratory birds, individuals within the same species may be sedentary: remaining present at the same latitude year-round (Newton and Dale, 1996).

Seabirds are integral to aquatic ecosystems and are frequently used as biomonitors of marine pollution. Seabird populations are known to fluctuate in response to environmental disturbances such as oil pollution, extreme weather events and fluctuations in food supply (Furness and Camphuysen, 1997). This is due to the ability of seabirds to adapt their reproductive effort, breeding success or survival in response to changes in their environment (Mallory et al., 2010).

Sea ducks are found in arctic and subarctic coastal areas. As entirely marine birds, sea ducks form a vital component of the marine arctic food web. There have been documented declines in populations of some sea ducks e.g. the Beaufort Sea population of king eiders (*Somateria spectabilis* Suydam et al., 2000), whilst other populations generally remain stable, like the Svalbard common eider (*Somateria mollissima*) population (Norwegian Polar Institute, 2018). Migratory duck species such as eiders provide a range of ecosystem services in the Arctic due to the provision of down, eggs and meat, particularly for indigenous populations (Green and Elmberg, 2014). Additionally, sea ducks are of vital importance as bioindicators of disease and pollution (Mallory et al., 2010).

1.1 Study species

The common eider is a long-lived sea duck with a Holarctic distribution, present in both Eurasian and North American continents (Waltho and Coulson, 2015). Within Europe, the breeding extent of eiders spans from the Netherlands in the South to the high Arctic fjords of Svalbard in the North (Hanssen et al., 2016). Eiders are coastal benthic divers, typically feeding on small invertebrates and molluscs, specifically the blue mussel, *Mytilus edulis* in sandy or hard-bottomed environments (Waltho and Coulson, 2015). In the high Arctic, where blue mussels are not so abundant, eiders may feed on other bivalves and gastropods such as *Mya sp., Serripes sp.* (Varpe, 2010), and may also feed on a range of amphipods and crustacea including *Gammarellus homari, Anonyx sarsi* and *Mysis oculate* (Lydersen et al., 1989).

The common eider is considered a capital breeder, utilizing endogenous reserves for egg-production. By contrast, income breeders rely on recently acquired, exogenous reserves (Drent and Daan, 2002). It has recently been shown that several assumed capital breeders nesting at high latitudes rely extensively on exogenous resources (Gauthier et al., 2003). In true capital breeders, this reserve gathering is typically done in the wintering area prior to migration. In line with this definition, Svalbard breeding eiders cannot be considered true capital breeders, as they arrive in the breeding area 40-50 days before the commencement of egg-laying (Hanssen et al., 2016), and are therefore expected to feed extensively in the pre-breeding area, prior to breeding. On commencement of egg-laying, the female eider will undergo a fasting period during egg incubation until hatching, investing significant energy into reproduction. During this incubation fast (approximately 26 days), females lose up to 35-40% of their body mass through the process of lipid metabolism (Gabrielsen et al., 1991; Parker and Holm, 1990).

Within breeding populations, individual eiders have a varied migration strategy: with some remaining sedentary such as the Northern Norway and North East Iceland breeding populations. Other breeding eiders, such as the Svalbard population, are migratory, choosing to migrate south to avoid the harsh Arctic winters. This information has been obtained from the deployment of geolocation devices (geologgers) on female eiders in Svalbard during the summer months (Bjørnlid, 2016; Hanssen et al., 2016). From capture-recapture research, it has been shown that Svalbard eiders have a predictable migration strategy, returning to the same wintering locations each year, North East Iceland and Northern Norway (Figure 1.1.). Svalbard breeding eiders have a large variability in the timing of arrival and departure to and from the breeding area, arriving between early April to late May and departing between late August and late December (Hanssen et al., 2016). Within Svalbard, the Kongsfjord population of eiders has been studied annually since 1981 by the Norwegian Polar Institute, and the population has generally remained stable over the course of the monitoring, estimated to be around 3000-3500 breeding pairs. However since 2012, there has been a 27% decline in the number of breeding pairs found in Kongsfjorden, and consequently there is ongoing research into the causes of this decline (Norwegian Polar Institute, 2018).

As mentioned, the Northern Norway and North East Iceland breeding eiders are sedentary, remaining in the wintering locations year-round (Bakken et al., 2003; Kilpi et al., 2015). Within Norway, eiders have a wintering range from Central Norway to Troms in North Norway (Hanssen et al., 2016). Within Iceland, eiders have a wintering range between northwest to southeast Iceland. The Norwegian eider population has declined significantly in recent years (Fauchald et al., 2015), and there is indication that the Icelandic population may also be declining in response to climatic variation (Jónsson et al., 2013).

This variation in migration strategy between breeding populations is likely to expose individuals of the same species to varying levels of contaminants. Wintering area has been shown to have a significant influence on concentrations and patterns of persistent pollutants and toxic metals in other migratory seabird species (Fort et al., 2014; Lavoie et al., 2015, 2014; Leat et al., 2013). Eiders and other sea ducks have a tendency to accumulate elements such as Hg, Cd and Se, although the mechanisms as to why are not understood (Lovvorn et al., 2011). It is thought that the eiders' benthic feeding habits and proximity to coastal areas increases exposure to these trace elements due to the naturally elevated levels of toxic elements in sediments and benthic biota (Wilson et al., 2004). Marine sediments can act as a sink for toxic metals and high concentrations have been found in certain areas close to local sources, for example, in the Russian Arctic, extensive combustion of fossil fuels has led to enrichment of Pb and Hg (AMAP, 2002). Additionally, filter feeding molluscs such as the blue mussel, which form a large component of an eiders' diet, are known to accumulate high levels of toxic elements such as Hg and As (Andersen et al., 1996; Sloth and Julshamn, 2008). It is well established that eiders are exposed to toxic elements through their diet and some groups, such as breeding populations in the Baltic, are at risk from toxic effects, particularly from exposure to Pb (Franson et al., 2000).

There have been a number of studies documenting concentrations and potential effects of toxic elements in eiders breeding in the Canadian and Norwegian arctic (Fenstad et al., 2017; Provencher et al., 2016), however the majority of toxicity studies in eiders have focussed on toxic metals in blood, feathers and organs. Only a handful of studies have addressed levels of toxic elements found in eggs, and many of these have been done in the Canadian arctic (e.g. Akearok et al. 2010; Pratte et al. 2015; Peck et al. 2016). Collection of eggs offers a non-invasive method of sampling bird populations. Additionally, high levels of toxic elements found in eggs may have implications for reproductive success and recruitment to the population.

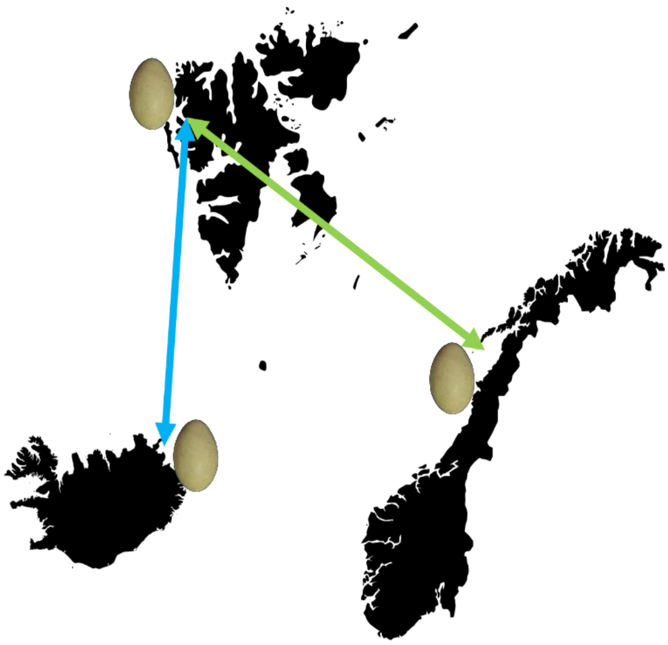

Figure 1.1. Migration pathways of common eiders (*Somateria mollissima*) breeding on Svalbard. Graphic based on geolocator recovery data from Hanssen et al., 2016. Egg symbol represents locations where eider eggs were sampled, and subsequent migration information from nesting females was obtained.

2 Objectives and aims

The present study was designed to test the effect of migration strategy and wintering area on toxic element concentrations in eggs of common eiders breeding in Svalbard. Eggs were collected from migratory females breeding on islets in Kongsfjorden, Svalbard that had previously been fitted with geologgers. Two migration strategies were determined for the breeding colony on Svalbard: wintering in Iceland and Northern Norway (See Figure 1.1). Additionally, sedentary females were sampled from North East Iceland and Northern Norway where these birds remain in their breeding areas all year-round. The eggs collected from sedentary eiders were used as proxies for toxic element exposure in the wintering areas. By accounting for exposure in the wintering area, we can distinguish the relative contributions of toxic elements in both the wintering and breeding areas. Analysing elemental concentrations in eggs provides a non-invasive method for assessing toxic element levels and it has been shown that levels correlate well with that of blood.

The main objectives of this study were to:

1. establish differences in exposure of toxic elements between sedentary eiders breeding in Iceland and Norway, respectively.

2. establish whether there are differences in exposure of toxic elements between migratory eiders breeding in Svalbard and wintering in Iceland and Norway, respectively.
3. establish whether there are differences in toxic element exposure within sedentary and migratory populations overwintering in Norway and Iceland, respectively

3 Materials and Methods

3.1 Sampling of eiders

Eggs were collected from incubating female eiders during June-July 2010-2012 and 2017 at Storholmen, Kongsfjorden (78°56'N, 12°13'E). Birds were caught on the nest with a nylon noose attached to a fishing rod. These birds had previously been fitted with geologgers and thus were retrieved from the bird. New loggers were mounted before release. Additionally, in 2017, eggs were collected from sedentary birds breeding in North East Iceland (65°47'51N, 14°50'33E - Yri-Nýpur) and Northern Norway (66°58'46N, 12°22'90E - Selvær).

One egg was sampled randomly from the nest soon after laying to avoid well-developed embryos. Eggs were frozen (- 20 °C) and thus addled within 6 hours of collection and then transported to the Norwegian Institute for Nature Research (NINA) for storage and analysed for concentrations of elements at the Norwegian University of Science and Technology (NTNU).

In addition to the egg samples collected in 2017, the present study also uses data from eider eggs collected and analysed in 2010, 2011 and 2012, as part of the doctoral work by Anette A. Fenstad. Eggs collected in 2012 were analysed at NTNU in 2013 (Fenstad et al. unpublished data). In this thesis I refer to this as the 2012-analysis. Eggs collected in 2010, 2011 and 2017 were analysed at NTNU in 2017, and I refer to this as the 2017-analysis.

3.2 Data from geolocators

Geolocators were provided by British Antarctic Survey, Biotrack, Migrate Technology and Lotek (see Hanssen et al., 2016, Bjørnlid 2016 and Kilen 2016 for detailed information on data downloading and analysis and logger specifications). These devices measure light level with reference to time, with which latitude and longitude can be determined from the timing of dusk/dawn and the timing of midday/midnight. Although the average error is about 180km (Fox, 2009; Phillips et al., 2004), this level of accuracy is sufficient for the large-scale movements assessed in this study. Information about the wintering areas was obtained from previous studies (Hanssen et al. 2016; Bjørnlid 2016 and Moe et al., unpublished data). If the logger was faulty, and therefore data was irretrievable, data from previous years were used. This is regarded as a valid method as it has previously been established that individual female eiders winter in the same area each winter (Bjørnlid, 2016). Information regarding timing of migration for the Svalbard breeding eiders was obtained on the population level from Hanssen et al (2016).

3.3 Sample preparation and analysis

3.3.1 Homogenisation and contamination test

Prior to homogenisation of the eider eggs and to account for and minimize any contamination, three methods of homogenisation were compared using store bought chicken (*Gallus gallus domesticus*) eggs. Nine eggs (approx. 60mL each) were combined using a pair of acid cleaned Teflon pincers. The mixture was then split into three aliquots and homogenised further using one of three methods: mixing with Teflon pincers (clean), UltraTurrax® T-25 (UT) and a BOSCH® MCM2050 food processor (BOSCH). The test samples were then analysed as described in Section 3.3.4.

Results from this test revealed that compared to the clean method, the UT grinder constituted a significant amount of Ni, Bi and Zr to the samples (Appendix A). Considering the extremely high Ni contamination from this method (18,000% compared to clean method), the UT grinder was not used for homogenisation of the eider eggs.

Furthermore, the contamination test revealed that the BOSCH processor contributed to some elemental contamination, with a 600% increase in Hg concentration relative to the clean method (Appendix A). This was assumed to be due to insufficient cleaning of the blender prior to use. The blender was therefore acid washed in a bath of 1M HNO_3 (HNO_3 ultra-pure grade, 14.4 M) and then rinsed thoroughly with detergent and MilliQ water.

The homogenisation and subsequent analysis of chicken eggs was repeated using the BOSCH and clean method during the homogenisation of the eider duck eggs as a further methodological check and to account for any potential contamination. After the second test, the Hg concentration was significantly reduced in samples homogenised with the BOSCH processor, however there appeared to be Ag contamination from the second test, which was not apparent from the first test. Nevertheless, the potential Ag contamination from the BOSCH blender

(0.000052 µg/g difference compared to clean method) was assumed to be insignificant compared to the average concentration found in eider eggs (0.01 µg/g; present study).

3.3.2 Eider egg homogenisation

The BOSCH method of homogenisation was used in 2012 by A. Fenstad for the 2012-analysis. Therefore the 2017 eider eggs were also homogenised using the BOSCH processor to be consistent with previous studies, to allow comparison of results (this will be discussed in Section 3.3.6).

Eider eggs were carefully opened using a sterile scalpel. Care was taken not to include any eggshell into the sample. Each egg was homogenised for 3 minutes using the previously described BOSCH method, to achieve a standard homogenate. Some eggs were more developed than others and it was therefore difficult to obtain a well-homogenised sample due to the presence of feathers and cartilage. After homogenisation, the sample was poured into 100mL LDPE bottles and refrigerated until acid digestion.

3.3.3 Acid digestion

Prior to elemental analysis, the samples underwent acid digestion in order to remove the organic fraction of the sample. Samples were shaken vigorously prior to sub-sampling to ensure a representative sample was taken. 8 mL of concentrated nitric acid (HNO_3 ultra-pure grade, 14.4 M) was added to 0.8-1.2g of sample in acid washed 18mL PFA vessels designed for UltraClave. Samples were digested under high pressure in an UltraClave Microwave Digestion Chamber (Milestone, Shelton, CT, USA) for 2 h at a temperature of up to 240 ^{o}C and pressure of 160 bar. Digested samples were diluted to between 78-82mL using ion exchanged Milli-Q-water before elemental analysis. Samples were then poured into sterile 15mL VWR vials in preparation for elemental analysis.

3.3.4 Metal determination by ICP-MS

Samples were analysed for a total of 59 elements (Appendix C) by inductively coupled plasma mass spectrometry (ICP-MS) at the Department of Chemistry, NTNU. Vials were uncapped and placed into the sample introduction system before analysis. The use of ICP-MS is favoured as it typically has a low detection limit for a wide range of elements and it is highly accurate and precise. Samples are introduced into an argon plasma and are transformed into aerosol by a nebuliser and spray chamber. In the plasma, molecules are subjected to high temperature (6000°C) and dissociate as they gain energy, eventually changing from a liquid to a gas. The gaseous atoms are converted to ions by the removal of an electron which are subsequently detected by the MS. Within the MS is a quadrupole consisting of 4 parallel rods conducting an electrical current. As ions pass through the quadrupole, the MS detects individual elements according to their mass-to-charge ratio. The quadrupole is capable of scanning at a rate of >5000 atomic mass units per second, making ICP-MS a very efficient detection method (PerkinElmer, 2004). Elemental concentrations in all eggs are reported on a wet weight (ww) basis in μg/g.

3.3.5 Quality control and method reliability

Three method blanks containing only HNO_3 were analysed with every 36 samples. Elemental concentrations in eider eggs were blank corrected. The blank correction accounts for any contamination that may have occurred during the sample preparation for acid digestion. Additionally, three replicates of each sample were run during the analysis and RSD% between replicates were determined (Appendix C).

Three replicates of certified reference material (CRM) Polish Virginia tobacco leaves (INCT-PVTL-6) were analysed. CRMs are homogenous samples that are analysed during analysis in order to validate the accuracy of the analytical method. The CRM has well established concentrations of an array of elements. Accuracy of the present study to published values of this CRM are shown in Appendix B. Most elements had recoveries within the accepted range of 85-115%. Regarding the elements of interest to this study, Hg had an accuracy of 113, within the accepted range. Accuracies of As and Pb were slightly lower than is deemed acceptable, at 77 and 71% respectively. Low recoveries are typically caused by the digestion procedure. Concentrations of elements with low recoveries should be interpreted with caution and may be present in higher concentrations than the reported value in analysed samples.

The limit of detection was calculated from the maximum value of: $3x$SD of the blank and the instrument detection limit.

3.3.6 Methodological consistency between analyses

To check for consistency between the 2012- analysis and 2017- analysis, six eider egg samples from the 2012- analysis were reanalysed with the 2017-analysis. A Student’s T-test was carried out to compare means in elemental concentration between analyses. Results from both analyses are shown in Appendix G. The macro-elements such as Ca, K, Se, sodium (Na) and sulfur (S) showed significant differences between analyses. As these are essential elements, they are present in high concentration in eggs. The difference in mean concentration between 2012- and 2017-analyses is likely due to insufficient homogenisation and/or settling of the sample over time resulting in a biased subsample. For many other elements including As, Pb and Hg, there were no significant differences in element concentration, indicating consistency between 2012- and 2017-analyses. Other elements that were significantly different between analyses such as gold (Au) and zirconium (Zr) also had large RSD % for both 2012 and 2017 analyses, indicating some instrumental contamination.

3.4 Data treatment and statistical analysis

All statistical analysis was done in R (R Development Core Team, 2008), with the exception of the principal components analysis which was performed in SIMCA (Umetrics n.d.)

For both 2012- and 2017- analyses, elements with <50% of samples below the limit of detection (LOD) were removed. After removal of these elements, 26 remained in the dataset for statistical analysis. After checking for normality using Shapiro-Wilk, all data was log transformed (ln) to obtain normal distributions, thus fulfilling the criteria for further parametric statistics.

For elements that contained values below the LOD (censored values), the semi- parametric regression on order statistics (ROS) method was used to impute the censored values. Under the assumption of a normal distribution, this method creates a linear regression for the log of the censored data. The slope and intercept are computed using the uncensored observations and summary statistics are estimated for the entire population. This method is preferred over substituting censored values with a fraction of the detection limit as it maintains the general pattern of the data whilst retaining a normal distribution (Helsel, 2011).

Three eider egg samples were removed from the dataset due to more than 50% of the elements below the LOD. These samples included one egg collected from a bird breeding in Svalbard (CA23697), and two collected from birds breeding in Northern Norway (Selvaer4 and Selvaer8), and all were analysed in 2017. A number of eggs were collected from the same female eiders over multiple years, in this case only one sample was retained in the dataset after randomly removing the other samples.

Paired Student's t-tests were carried out to compare the mean element concentrations between analyses. This was done as a check for methodological consistency between 2012- and 2017-analyses. Results of the paired t-test are shown in Appendix G. For multivariate analysis, only the results from the first analysis in 2012 were retained in the dataset.

Four toxic and non-toxic elements (Hg, Pb, As and Se) were selected for analysis in relation to wintering area and migration strategy. Linear models were performed using the 'lm' function in R with element concentration as the dependent variable and migration strategy as the independent variable. As eggs from migratory birds were collected during a range of years, it was first determined whether sample year had a significant effect on element concentration in eider eggs. For Pb and As, year was a significant factor and therefore 'sample year' was included as a fixed effect in the models. To determine if significant differences were present between wintering area (i.e. Norway or Iceland) and migration strategy (i.e. sedentary or migratory), ANOVA was carried out with a significance level set to 0.05.

To establish patterns of all elements between sampling locations, a principal component analysis (PCA) was done. PCAs are typically used for multivariate analyses where there are many explanatory variables. In the present analyses it was used to visualise the difference in patterns of elements in relation to breeding area and migration strategy.

4 Results

4.1 Migration data and collected egg samples

Eggs and subsequent element concentration data were collected from 54 female eiders breeding in Svalbard during the summers of 2010, 2011, 2012 and 2017 (Table 4.1). These females migrate to Northern Norway (n = 12) and Iceland (n = 52). Additionally, eggs were collected from 38 breeding female eiders that remain in their breeding grounds year-round, in Northern Norway (n = 24) and Northeast Iceland (n = 14). Information regarding the number of eggs sampled in the respective sampling years is given in Table 4.1. Information regarding timing of migration for the eider populations are given in **Error! Reference source not found.**Table 4.2.

4.2 Patterns of elements in breeding populations

In the whole sample set of eider eggs, the average abundance of quantifiable elements was as follows: Fe>Zn>Sr>Cu>Rb>Se>Mn>B>As>Ba>Hg>Li>Mo>Ni>Ag>Co>Pb>Tl>Bi>Nd>Sn>Ce>Zr>Y. Mean concentrations of all elements from the 2012 and 2017 datasets are given in Appendix C.

The PCA (Figure 4.1) shows distinct patterns of elements related to breeding area (Figure 4.1b) and migration strategy (Figure 4.1c). Eggs from eiders breeding on Svalbard have a similar concentration pattern for most elements, regardless of wintering area, clearly shown by Figure 4.1c. When samples are grouped according to migration strategy, eider eggs from Svalbard breeding birds remain in the same cluster. Within the Svalbard breeding eiders, a number of eggs from eiders wintering in Iceland had similar elemental patterns to eggs from Icelandic breeding eiders. However, there appears to be no similarity between eggs from sedentary and migratory eiders wintering in Norway. Generally, eggs from eiders breeding in Iceland and Norway have different patterns of elements compared to eggs from Svalbard breeding eiders, shown by the three distinct clusters in Figure 4.1b and 4.1c.

Table 4.1. Number of female common eiders for which eggs and migration data were obtained in the present study. Wintering information is provided from Hanssen et al., 2016, Bjørnlid., 2016 and Moe et al (unpublished data). Note that sedentary birds were only sampled in 2017.

Breeding area	Wintering area	Sampling location	2010	2011	2012	2017
Svalbard	NE Iceland	78°56'04 N 12°13'04 E Kongsfjorden	5	7	15	25
Svalbard	N. Norway		3	2	3	4
N.Norway	N.Norway	66°58'46N, 12°22'90E Selvær	*no sample collection*			24
NE Iceland	NE Iceland	65°47'51N, 14°50'33E Yri-Nýpur				14
Total			8	9	18	67

Table 4.2. Wintering and breeding area information data obtained from common eiders in the present study. Range of dates shown in parentheses. Data from migratory birds is obtained from light-level loggers as described in section 2.2. Information regarding sedentary birds is obtained from the SEATRACK program. Information regarding migratory birds is obtained from Hanssen et al., 2016 and Bjørnlid 2016.

Breeding area	Wintering area	Number of individuals	Departure date from wintering area	Time from spring arrival until egg-laying	Start of autumn migration	Time spent in wintering area
Svalbard	N. Norway	12	22 Apr ± 2 days *(29th Mar - 25th May)*	47 ± 2 days *(20 - 75 days)*	24 Oct ± 4.5 days *(28th Aug - 24th Dec)*	± 176 days *(96 - 252 days)*
Svalbard	NE Iceland	52				
N. Norway	N. Norway	14	*Sedentary year round*			
NE Iceland	NE Iceland	24				

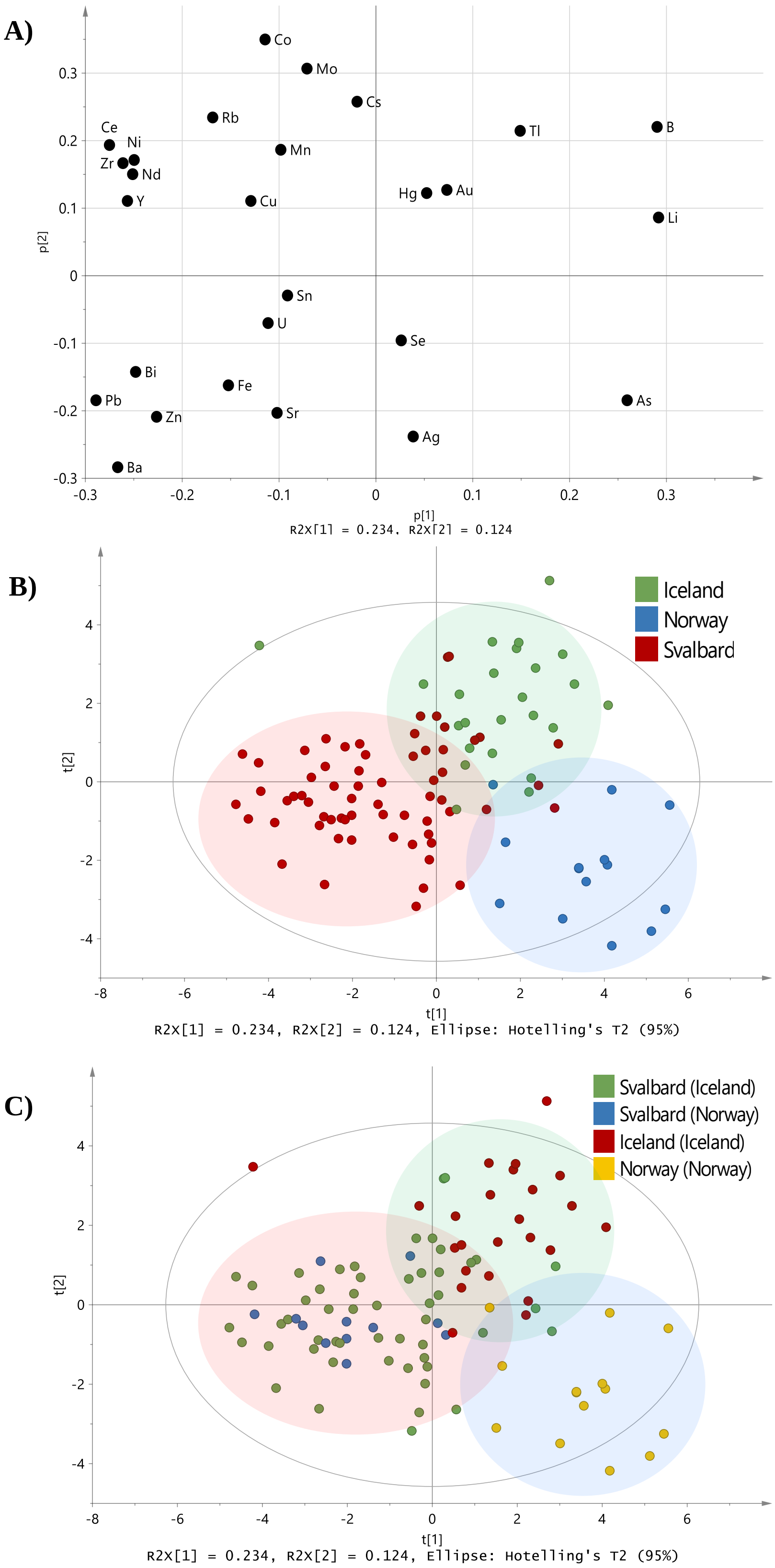

Figure 4.1. **A)** Score plot of 27 elements from principal components analysis (PCA) where PC1 and 2 explain 23.4 and 12.4% of the variation of the dataset, respectively. **B)** Loading plot of eider egg samples grouped according to breeding area, where Iceland is Northeast Iceland and Norway is Northern Norway. Coloured circles show where most samples from breeding populations are clustered. **C)** Loading plot of samples grouped according to migration strategy, labelled by breeding area and wintering area is denoted in parentheses. The same coloured circles are used to show the similarity between the element burden in eggs from the same breeding area.

4.3 Toxic elements in eider eggs

Mean concentrations of toxic elements in eider eggs are shown in Appendix E. Information regarding ANOVA p-values for comparison of toxic element concentrations between wintering area and migration strategy is shown in Appendix F.

4.3.1 Differences between sedentary breeding groups

Eider eggs from sedentary breeding eiders from Northern Norway and Northeast Iceland showed no significant difference in Hg, with a mean concentration of 0.08 µg/g. Selenium was higher in eggs from Norwegian breeding eiders (0.61 µg/g) compared to Icelandic breeding eiders (0.54 µg/g). As was higher in eggs of breeding eiders from Norway (0.41 µg/g) compared to eggs from eiders breeding in Iceland (0.14 µg/g). Pb was also higher in eggs from Norwegian breeding eiders (0.001 µg/g) compared to those breeding in Iceland (0.0004 µg/g).

4.3.2 Differences between migratory breeding groups

There were no differences in concentrations of Hg, Se, As or Pb in eggs of eiders breeding in Svalbard, regardless of wintering area. Mean egg concentrations were 0.09, 0.56, 0.12 and 0.04 µg/g ww for Hg, Se, As and Pb respectively. Sampling year had a significant effect on As and Pb.

4.3.3 Differences between migratory and sedentary birds wintering in Iceland

There was no difference in Hg or Se in eggs from sedentary and migratory eiders wintering in Iceland. Mean Hg and Se concentrations in eggs were 0.09 and 0.56 µg/g ww respectively (Figure 4.4). Arsenic did not differ between eggs from sedentary and migratory eiders and the mean concentration was 0.13 µg/g. Lead concentration was significantly different in eggs from sedentary (0.0004 µg/g) and migratory birds (0.004 µg/g) overwintering in Iceland. Sampling year had an effect on As and Pb concentration.

4.3.4 Differences between migratory and sedentary birds wintering in Norway

There was no difference in Hg or Se in eggs from sedentary and migratory birds wintering in Norway. Mean concentrations were 0.08 and 0.59 µg/g ww for Hg and Se respectively. Eggs from eiders sedentary eiders wintering in Norway had a much higher As concentration (0.41 µg/g) compared to that of migratory birds (0.11 µg/g). Eggs from eiders wintering in Norway but breeding on Svalbard had a significantly higher Pb concentration (0.005 µg/g) compared to eggs from sedentary birds that remain in Norway year-round (0.001 µg/g). Sample year had an effect on Pb concentration only.

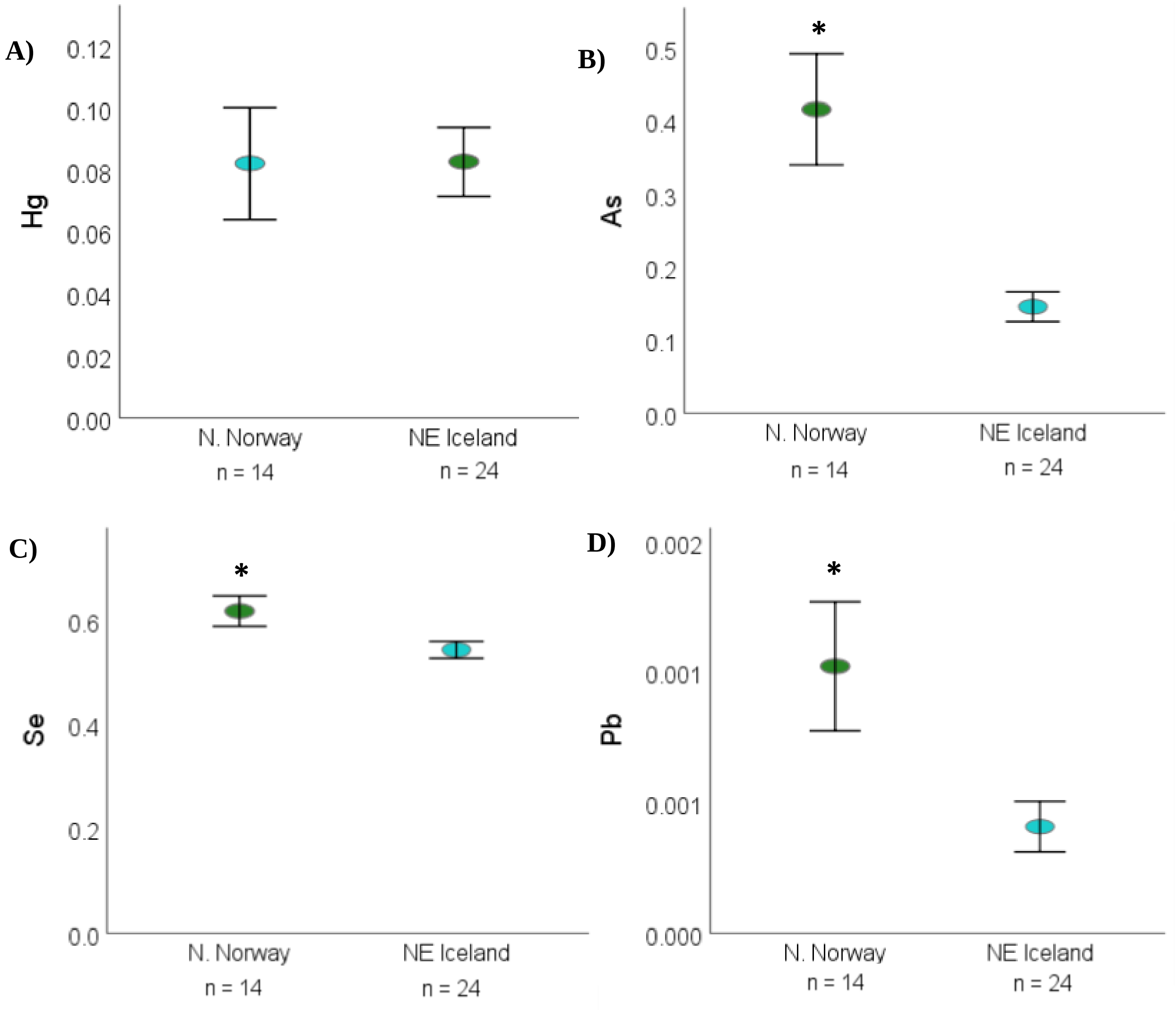

Figure 4.2. Concentration of A) mercury, B) arsenic, C) selenium and D) lead (µg/g ww) in eggs of sedentary breeding eiders in Northern Norway (N. Norway) and Northeast Iceland (NE Iceland). Statistical significance of $p < 0.05$ is shown by asterix (*). Error bars represent ± 1SE.

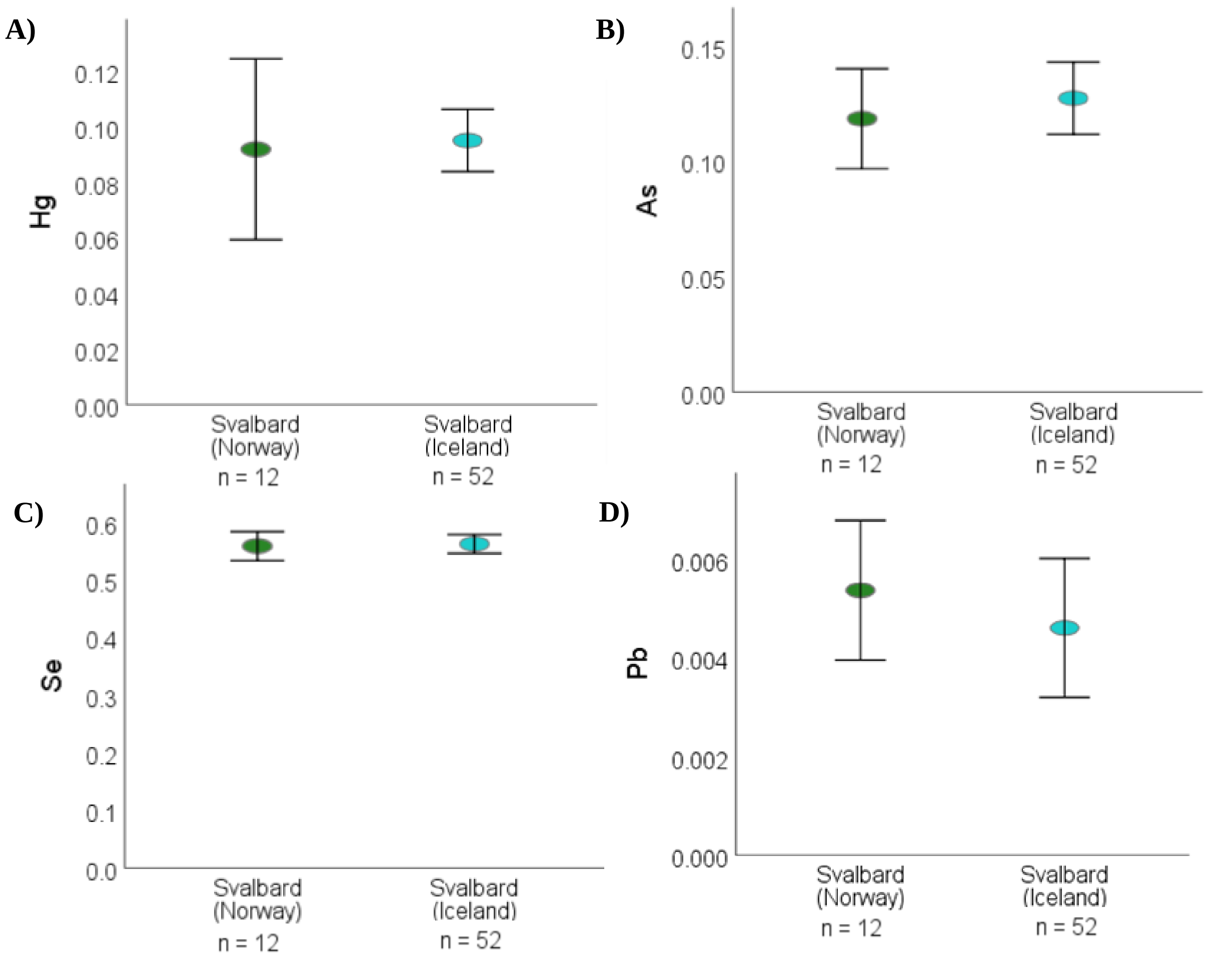

Figure 4.3. Concentration of A) mercury, B) arsenic, C) selenium and D) lead (µg/g ww) in eggs of migratory breeding eiders in Svalbard with different wintering areas (shown in parentheses), Norway and Iceland. Statistical significance of $p < 0.05$ is shown by asterix (*). Error bars represent ± 1SE.

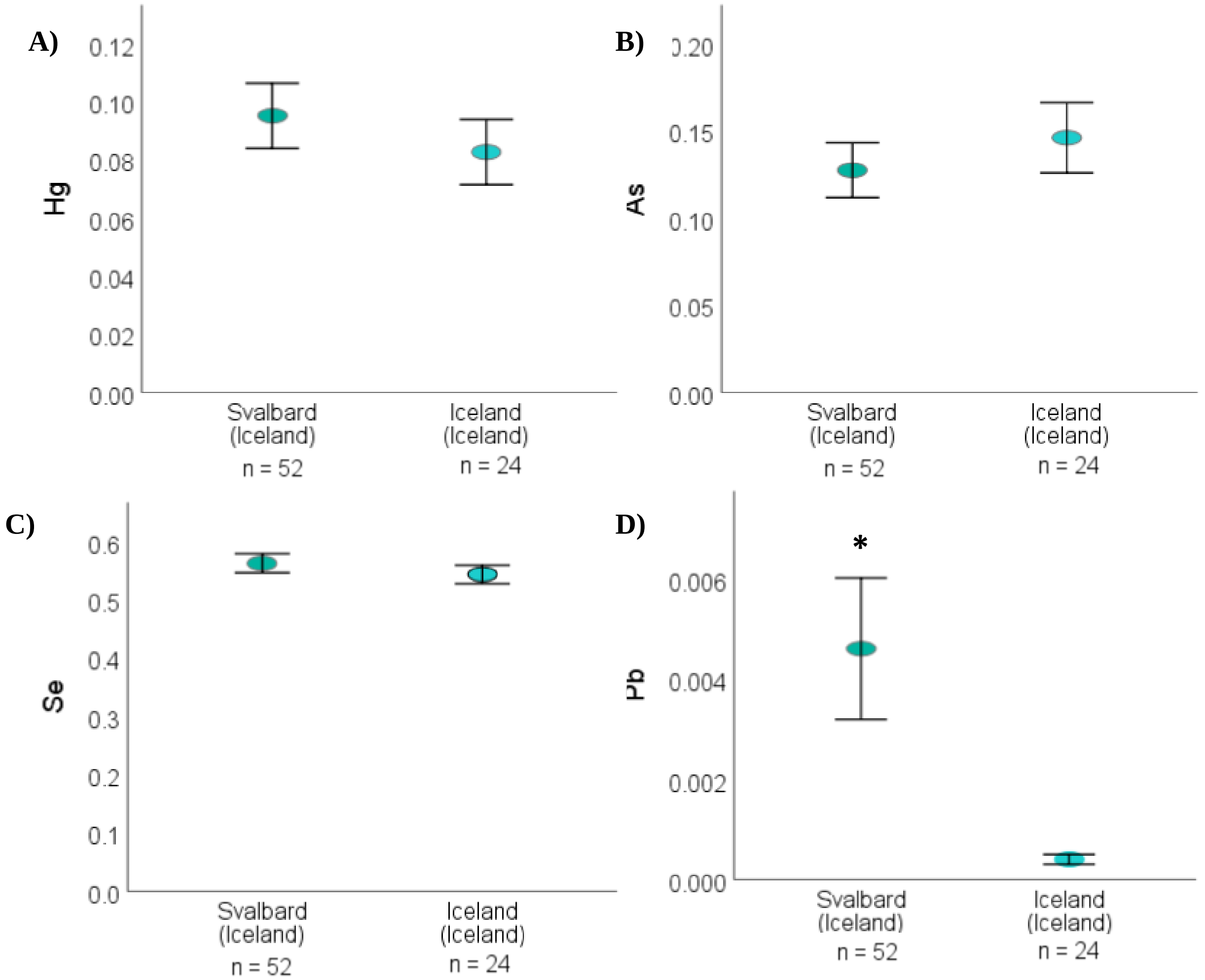

Figure 4.4. Concentration of A) mercury, B) arsenic, C) selenium and D) lead (µg/g ww) in eggs of migratory (breeding in Svalbard) and sedentary eiders (breeding in Iceland) wintering in Iceland. Wintering area is shown in parentheses. Statistical significance of $p < 0.05$ is shown by asterix (*). Error bars represent ± 1SE.

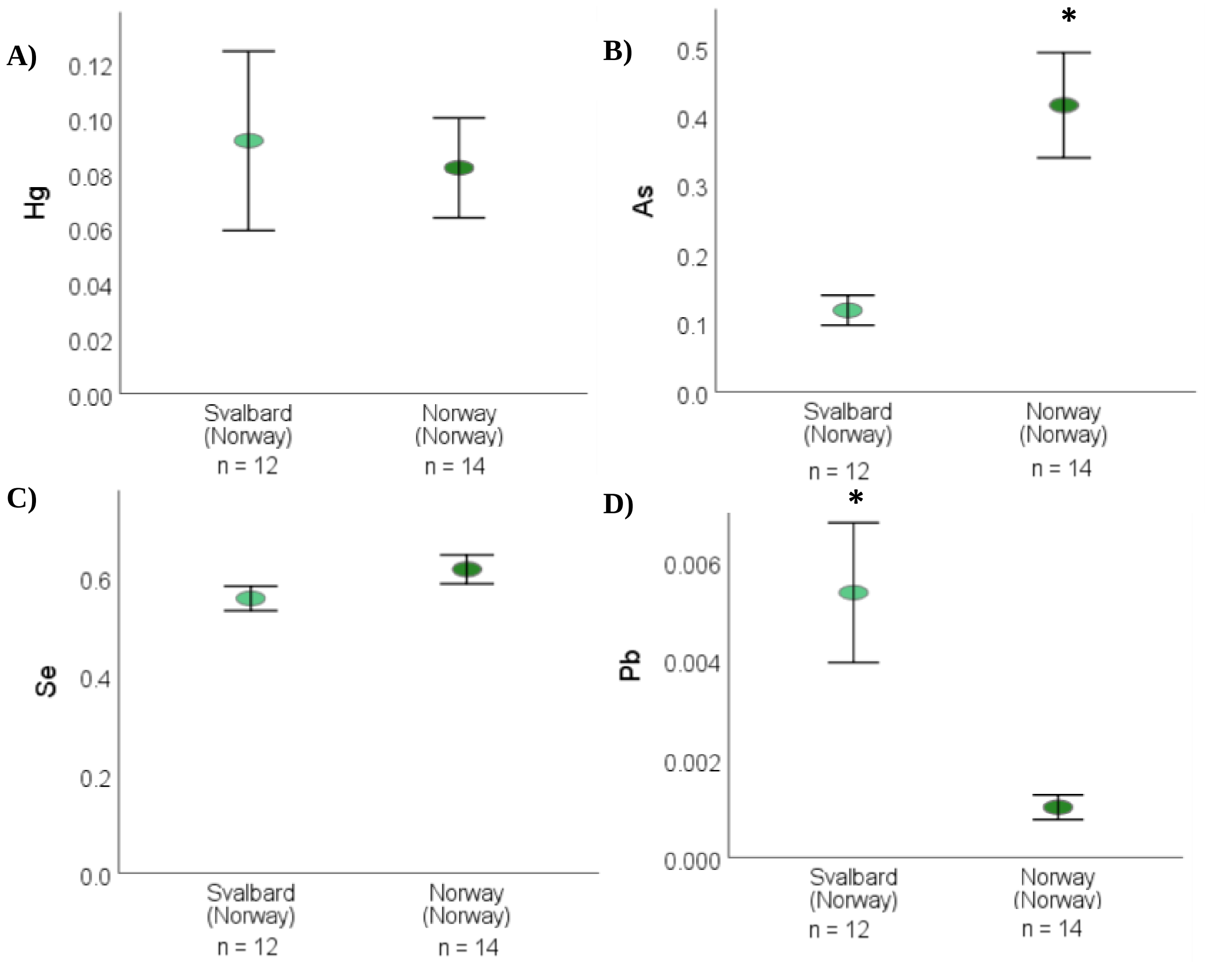

Figure 4.5. Concentration of A) mercury, B) arsenic, C) selenium and D) lead (µg/g ww) in eggs of migratory (breeding in Svalbard) and sedentary eiders (breeding in Norway) wintering in Norway. Wintering area is shown in parentheses. Statistical significance of $p < 0.05$ is shown by asterix (*). Error bars represent ± 1SE.

5 Discussion

5.1 Patterns of elements in eider eggs

The main hypothesis of this thesis was that eiders would have different patterns of toxic elements depending on the wintering location, and this would be reflected in the eggs. During data analysis, it became clear that breeding area, rather than wintering area had more influence on toxic element concentrations in eider eggs. In order to visualise the differences in elemental patterns, a PCA was carried out, grouping samples by breeding area (Figure 4.1b) and migration strategy (Figure 4.1c). The first two components of the PCA only account for 35% of the variance, indicating there are many other factors influencing the concentration of elements in eider eggs. Eiders have a large variation in the timing of arrival to the breeding ground. Time spent in the breeding area in relation to element concentration has not been investigated in the present study, but likely accounts for some of the variability in exposure of eiders to toxic and non-toxic elements. Nevertheless, it is clear that the three breeding groups of eiders (Svalbard, Northern Norway and North East Iceland) are exposed to different levels of many elements. Furthermore, breeding eiders in Svalbard appear to have similar patterns of elements, regardless of wintering area (Iceland or Norway), indicating similar exposure. Interestingly, the PCA also shows that a number of eggs collected from birds breeding in Iceland contained similar element patterns to eggs from birds breeding in Svalbard overwintering in Iceland i.e. the same wintering area. This indicates that some Svalbard breeding eiders have similar exposure levels to the breeding Icelandic eiders, possibly due to a similar wintering location.

As mentioned, common eiders predominantly feed upon blue mussels, however in Svalbard these are scarcely available, and thus eiders are likely to feed on similar bivalve mollusc species available in Kongsfjorden, and have also been reported to eat a range of amphipods (Lydersen et al., 1989; Varpe, 2010). Therefore, difference in diet likely explains why eiders breeding on Svalbard have a different pattern of elements in their eggs, compared to eggs from eiders breeding Northern Norway and North East Iceland. In addition, migratory birds are inherently exposed to different elements due to exposure of different geologies along their migratory pathways at potential stop-over locations. This difference in diet coupled with the large geographic range likely explains the higher levels of many elements seen in Svalbard eiders, such as the rare earth elements (Nd, Y, Ce) and Pb.

5.2 Levels of toxic elements in relation to migration strategy

Generally, migratory birds breeding on Svalbard had much higher variability in most toxic element concentrations, compared to sedentary birds breeding in both Iceland and Norway. Migratory eiders have a large range in the timing of arrival to the breeding ground, and Icelandic wintering eiders may depart the breeding ground earlier than Norwegian wintering eiders (Hanssen et al., 2016). As it has been shown, it appears eiders wintering in both Iceland and Norway feed during the pre-breeding period in Svalbard. Time spent in the breeding ground, and therefore time spent feeding in Svalbard likely affects levels of elements in the eider eggs, explaining the high variation seen in migratory eider eggs. The wintering range of migratory birds is large within Iceland and Norway (Bjørnlid, 2016; Hanssen et al., 2016), therefore a further explanation for the high variation in migratory birds could be due to differences in specific wintering location. Stop-over points during the migration to Svalbard have not been defined in this study and could also account for the variation seen in migratory birds.

Many previous studies reporting toxic element concentrations in eggs have reported on a dry weight (dw) basis, and therefore where necessary, a wet weight to dry weight conversion factor of 3.3 has been used, based on an average egg moisture content of 70% (Ohlendorf and Heinz, 2011; Stanley et al., 1996).

5.2.1 Mercury

Mercury concentration in eider eggs from the present study was in the range of 0.02 to 0.25 µg/g. No differences in Hg concentration were seen between wintering area or migration strategy. It was anticipated there would be a difference in Hg between wintering locations due to differences in geology and anthropogenic emissions, however we found no such difference. Furthermore, no difference in Hg was found between migratory and sedentary birds, regardless of wintering area. The observed levels were low compared to reported values in eider eggs from the Aleutians (0.43 µg/g dw; Burger et al., 2008) and comparable with those reported in eggs from Nova Scotia (0.01-0.16 µg/g; Pratte et al., 2015).

The similarity in Hg between wintering area and migration strategy could be explained by the persistence of MeHg. In other migratory seabird species such as the Double-crested Cormorant (*Phalacrocorax auritus*) and the Caspian Tern (*Hydroprogne caspia*), it has been shown that previous exposure to Hg in the wintering grounds influences Hg concentration during the breeding period (Lavoie et al., 2015, 2014). Furthermore, a study on Arctic Skua (*Stereocarius parasiticus*) documented differences in Hg concentration between wintering area, however the Arctic Skua winters over a larger geographic range, and feeds at a significantly higher trophic level than eiders due to their kleptoparasitic feeding habits (Skottene, 2015). The present study used two wintering locations, both of which are remote and assumed to be distant from point sources of Hg, but geographically close in terms of atmospheric Hg distribution.

In aquatic organisms, Hg is mainly present in the form of MeHg. MeHg is more toxic and persistent than inorganic Hg compounds, and it bioconcentrates within individuals. Total Hg was measured in the present study, but it is assumed that a substantial proportion of this was in the form of MeHg, as reported by previous studies (Ackerman et al., 2016). Mercury is listed as a 'priority hazardous substance' by the European Union, with a recommended environmental quality standard (EQS) of 0.02 mg/kg (0.02 µg/g; The European Parliament and the Council of the European Union, 2008). The EQS is the maximum recommended concentration of a compound for an appropriate prey tissue, accounting for potential accumulation by top predators. All eider eggs analysed in the present study contained Hg concentrations above the EQS suggested by the EU, with an average concentration of 0.09 µg/g, and the maximum concentration found was 0.25 µg/g. Species which feed upon eider eggs in Svalbard include the arctic fox (*Vulpes lagopus*), glaucous gull (*Larus hypoboreus*), great skua (*Stercorarius skua*) and arctic skua (*Stercorarius parasiticus*) (Hanssen et al., 2013). In recent years, observations of nest predation by polar bears has been increasing, thought to be due to a decrease in availability of ice-associated prey (Prop et al., 2015). Due to the bioaccumulative properties of MeHg, there is concern that predators may be exposed to high levels of Hg through their diet. Nevertheless, the observed Hg in in eider eggs are below the levels associated with no adverse effect in eggs of other bird species (0.4 µg/g ww; Shore et al., 2011).

The highest Hg concentration in the present study (0.25 µg/g) was from a single Svalbard breeding eider that overwinters in Iceland (CA40035 – see Appendix D for reference). This indicates that some Icelandic wintering individuals may be exposed to higher Hg concentrations. Nevertheless, the highest concentration from the present dataset is well below levels known to induce reproductive toxicity, obtained from experimental studies (0.5 to 2.0 µg/g ww; Thompson, 1996).

Although Hg levels in all eider eggs exceed the EQS set by the EU, eiders from which eggs were analysed in the present study are not at risk from toxic effects. There appears to be no difference in Hg concentration with regards to migration strategy and wintering area, contrary to what was expected. However, some individuals had high Hg levels in eggs compared to the mean concentration of the population.

5.2.2 Selenium

Selenium levels were in eggs were in the range of 0.35 to 0.85 µg/g ww. Se was slightly higher in eggs from sedentary Norwegian birds (0.61 µg/g ww) than eiders breeding in Iceland and Svalbard (See Appendix E). The Se levels in the present study were higher than reported values in eggs from Baltic and Canadian arctic eiders (0.09 and 0.1 µg/g ww respectively; Franson et al., 2000; Pratte et al., 2015). The average Se concentration measured in Svalbard birds (0.5 µg/g ww) is comparable with previously reported Se concentration in feathers (2.3 µg/g ww) for this population, and much lower than reported concentrations in blood (Fenstad et al., 2017).

Selenium is an essential trace element, required in small amounts for normal cell functioning, however, high levels of dietary Se in its organic form can also lead to toxicity (Ohlendorf and Heinz, 2011). Selenium concentrations in the present study were within assumed adequate nutritional levels, and below toxic levels reported in poultry eggs (>2.5 µg/g ww; Puls, 1988). Selenium concentration in eggs reflects dietary levels and this has been shown by a number of experimental studies (e.g. Heinz 1993; DeVink et al. 2008). Given the extensive feeding period Svalbard eiders undergo in the breeding area prior to nesting, the measured Se in eggs from the present study likely reflects exposure in the breeding area. Overall, sedentary Norwegian eiders have higher levels of Se in eggs compared to eiders breeding in Svalbard and Iceland, likely due to a higher dietary exposure of Se, reflected in the eggs.

5.2.3 Arsenic

Arsenic levels in the present study were in the range of 0.07 to 0.69 µg/g. As in eggs from Icelandic and Svalbard birds were low (0.14 and 0.12 µg/g respectively), comparable to levels found in spectacled and common eider eggs from the Canadian Arctic (0.1 µg/g; Grand et al., 2002; 0.12 µg/g; Pratte et al., 2015). Arsenic concentrations found in eggs from eiders breeding in Norway were significantly higher than eggs from eiders breeding in Iceland and Svalbard, and higher than reported levels in eider eggs from the Canadian Arctic (0.12 µg/g) and the Aleutians (0.7 µg/g dw; Burger et al., 2008). Selenium was also higher in eggs from Norwegian breeding eiders. It has been shown that Se has an interactive effect with As, and As may even reduce Se accumulation in mallard eggs, thereby alleviating toxic effects of Se in eggs (Hoffman et al., 1992; Stanley et al., 1994).

The high As levels found in eggs of sedentary Norwegian eiders indicates that Norwegian birds are exposed to As year-round. As is excreted rapidly from the body and eggs have higher concentrations than other compartments (Burger et al., 2008), indicating a significant proportion of the total body burden of As is excreted via the egg. Interestingly, eider eggs sampled from a nearby and similar location (Røst, 67°30N, 12°00E) had comparable As levels to those found sedentary Norwegian eiders (0.39, 0.41 µg/g ww respectively; Huber et al., 2015). Arsenic is typically found in higher concentrations in marine environments relative to freshwater environments (Kunito et al., 2008), and oceanography plays a significant role in exposure of seabirds to toxic contaminants (Lovvorn et al., 2011). An explanation for the high As concentration seen in sedentary Norwegian eider eggs could be proximity to the open ocean. The breeding location in Northern Norway is located on the island of Selvær, approximately 50km from the Norwegian mainland, and heavily influenced by the ocean. By contrast, the breeding locations in Iceland and Svalbard are within fjordic areas with a large amount of freshwater input. In a study on a more polluted population of eiders in the Baltic, As in eggs was not quantifiable above the detection limit of 0.1 µg/g ww (Franson et al., 2000). As this Baltic group of eiders feed in a brackish environment, they are likely feeding on a less-marine influenced diet than eiders that feed in a more saline environment (Fenstad et al., 2017). This supports the inference that sedentary Norwegian birds in the present study are feeding on a more marine influenced diet than Svalbard and Icelandic birds, and therefore much higher As levels are seen in eggs.

Waterfowl, including eiders can be exposed to high levels of As through their diet. In adult mallards experimentally administered a 25µg/g dietary supplement of sodium arsenate, total egg concentrations were found to be 0.46 µg/g dw, much lower than levels found in Norwegian eider eggs (approx. 1.32 µg/g dw). Exposure to this experimental dose caused reduced weight gain, reduced liver weight, delayed onset of egg-laying and eggshell thinning (Stanley et al., 1996). However, mallards are freshwater species and are generally exposed to much lower As levels than marine species. Eiders can be exposed to higher As levels due to their marine ecology, and thus likely have a higher tolerance to As. Nonetheless, sedentary Norwegian eiders may be at risk from toxic effects from As and it may be necessary in future studies to determine if toxic effects of As are visible in Norwegian eiders.

5.2.4 Lead

Lead concentration in eggs of the present study were in the range of 0.0001 to 0.033 µg/g ww. Svalbard eiders had significantly higher Pb compared to sedentary birds, and levels were similar to Pb levels reported in Canadian arctic eider eggs from Nova Scotia (Pratte et al., 2015). The higher Pb level in Svalbard eiders indicates that individuals are exposed to Pb in the breeding grounds, regardless of wintering location. As previously mentioned, this is likely due to the difference in diet compared to Icelandic and Norwegian breeding eiders. Previously reported Pb levels in blood for the Svalbard population are low but close to the threshold level for adverse effects in wild birds (Fenstad et al., 2017).

Generally, Pb levels were low in all eggs and much lower than reported average values in eggs of Baltic eiders (0.08 µg/g; Franson et al., 2000). As Pb has been documented to accumulate in bone (Franson and Pain, 2011), Pb may preferentially accumulate in the egg-shell and this may explain the low concentrations found in the present study compared to previously documented levels in blood (0.048 µg/g ww; Fenstad et al., 2017). It has been suggested that eggs may not be a useful compartment for evaluating Pb exposure in birds (Franson et al., 2004; Ohlendorf, 1993).

Lu et al. 2013 have shown that surface sediments in Kongsfjorden are enriched with Pb compared to other arctic seas, predominantly due to differences in geology and to a lesser extent anthropogenic inputs (Berg et al., 2004). Waterfowl are exposed to significant levels of Pb due to its widespread use in ammunition. Ingestion of Pb containing sediments by benthic feeders such as eiders can attribute to high concentrations in tissues.

Svalbard eiders appear to be exposed to Pb in the breeding ground, however whole eggs are not a representative matrix for assessing Pb exposure, however egg shell may accumulate significant Pb levels. Future studies should focus on other biological matrices for assessing Pb exposure in relation to migration strategy and wintering area.

5.3 Eiders as both capital and income breeders

There is discussion as to whether eiders are principally capital breeders: relying on body reserves obtained prior to arrival in the breeding grounds, or whether they are income breeders: using reserves obtained from feeding close to the breeding area prior to egg laying (Hobson et al., 2015). Analysis of eggs from migratory eiders in this study indicate that during the breeding period in Svalbard, eiders are exposed to Pb, in addition to many other non-toxic elements. This indicates that eiders breeding in Svalbard are mainly utilising reserves acquired in the breeding ground (or pre-breeding ground) to produce eggs, contrary to what is currently understood about resource allocation strategy in eiders.

As previously suggested, it may be that eiders use both exogenous and endogenous reserves for building different egg compartments. For example, it has been shown that egg yolk contains stable isotopes indicating utilisation of exogenous reserves, whereas the albumen contained isotope patterns reflecting endogenous reserves (Hobson et al., 2015). In addition, it has been shown that within a breeding population, body condition on arrival to the breeding ground may also determine whether birds form their eggs using exogenous or endogenous reserves (Jaatinen et al., 2016). If food is plentiful in the wintering areas, then it may be sufficient to rely on endogenous reserves. However, if food is scarce in the wintering areas, birds may rely on exogenous reserves, and this has been shown through stable isotope analysis (Jaatinen et al., 2016).

In ‘true’ capital breeders, body reserves required for reproduction are obtained prior to egg laying, before arrival in the breeding grounds. Svalbard eiders cannot be defined as ‘true’ capital breeders (sensu Drent & Daan 2002), as they appear to gain their breeding condition in the breeding ground, and this has been observed in . This is a phenomenon also observed in geese: the degree to which individuals are capital or income breeders can vary within populations (Arzel et al., 2006).

Migration is energetically costly, and the Svalbard population migrate larger distances than many other European wintering eiders (Bakken et al., 2003; Waltho and Coulson, 2015). On arrival to the breeding grounds, eiders may be in poor body condition and therefore must obtain reserves needed for the equally, if not more costly breeding period. It has been shown that some Anitidae species may change this strategy in response to food availability in the wintering and breeding grounds. Svalbard birds appear to feed extensively in the breeding area prior to egg laying, and this may be an evolutionary response to variability in food resources, as seen in other Anitidae species (Arzel et al., 2006; Madsen, 2001).

5.4 Implications and future direction

In contrast to what was expected, wintering area did not affect toxic element concentration in eggs, however Hg concentration was similar in both migratory and sedentary eiders within the same wintering area. This suggests that migratory eiders share the same body burden of Hg as sedentary eiders, possibly from exposure in the wintering area. Previous studies in other species have shown that wintering area is a large contributor to Hg exposure in breeding seabirds, however this has not been determined for other toxic elements, particularly using eggs as a proxy. For other, less persistent elements such as As, further studies are required to establish the use of this method for determining relative exposure in breeding and wintering areas. This is especially important given that Norwegian eiders appear to be exposed to high levels of As.

This study has revealed that Svalbard breeding eiders are exposed to an array of elements during the pre-breeding period, during which female eiders feed extensively. As suggested in the previous section, the knowledge that eiders are capital breeders needs to be revisited as recent literature on stable isotopes reveals that resource allocation strategy can vary depending on body condition of individuals. Understanding this is vital in predicting breeding success in relation to food availability and subsequent exposure to toxic elements during the annual cycle. To accurately determine the resource allocation strategy of eiders, egg albumen and egg yolk should be analysed separately as it has been shown that nutrient allocation varies within egg compartments. By coupling toxic element analysis with stable isotope analysis, this method can also be used to further elucidate the relative exposure of common eiders to contaminants in the respective breeding and wintering areas.

6 Conclusion

By analysing common eider (*Somateria mollissima*) eggs from migratory and sedentary populations from two distinct wintering areas, we aimed to elucidate the relative contribution of toxic elements during the wintering and breeding period, respectively. It was expected that toxic element concentration in eider eggs would reflect the exposure during the wintering period, as previously shown for Hg in other migratory seabirds.

We have shown that migratory eiders breeding on Svalbard have similar patterns of elements, regardless of wintering location, indicating Svalbard eiders use reserves acquired in the breeding area to produce eggs. This resource allocation strategy in Svalbard breeding eiders has profound implications for exposure to toxic elements and warrants further investigation. We have shown that migratory eiders have distinct patterns of toxic and non-toxic elements in their eggs compared to eiders from the same wintering areas, contrary to what was expected. It is suggested that the difference in elemental patterns is due to the varied diet that eiders feed upon in Svalbard, coupled with the variability in arrival date to the breeding area.

Contrary to what was expected, Hg concentration did not differ between wintering area or migration strategy. This indicates that within the geographic range of this study, eiders are exposed to similar levels of mercury. Additionally, Hg levels in all eggs from the present study were below previously reported values for toxic effects. Eiders appear to be exposed to Pb in Svalbard; however, eggs are not a useful proxy for Pb estimation and therefore future studies should quantify Pb in relation to migration strategy using other biological matrices such as blood or liver. Eiders breeding and wintering in Northern Norway are exposed to high As that may pose risks for sedentary populations exposed year-round. It is suggested this is due to the proximity to open ocean relative to the fjordic environments of Iceland and Svalbard and may warrant further investigation in terms of effects. Selenium did not differ between wintering area or migration strategy; however, levels were slightly higher in eiders breeding and wintering in Northern Norway, which may indicate an interactive effect with As. Toxic element concentration varied greatly between individuals in migratory eiders, whereas sedentary eiders showed minor variation, comparatively. This indicates that exposure may vary according to timing of arrival to the breeding ground and exact wintering location, which was not defined in the present study.

To conclude, wintering area does not appear to be a factor in exposure of eiders to toxic elements, as shown by analysis of eider eggs. Whether eiders are migratory or sedentary appears to be a significant factor in exposure to toxic elements. Furthermore, migratory eiders may be able to rid themselves of some toxic elements during time spent away from the area of exposure, whereas sedentary birds are exposed year-round. The findings of this study have implications for the management of sedentary and migratory populations, as each may be exposed to varying levels of toxic elements, depending on breeding and wintering location and the time spent in the respective areas.

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8 Appendix

Appendix A

Element concentrations in chicken eggs (Gallus gallus domesticus) homogenised using three different methods: clean method with Teflon pincers (Clean), UltraTurrax (UT) and BOSCH food processor (BOSCH). Test done prior to main analysis (1st test) and with main analysis (2nd test) after equipment was soaked in 1M HNO3 for two days and rinsed thoroughly. Percentage difference between clean and two mechanical homogenisations are shown. Those values in red denote a percentage difference of over 100% and potential contamination from the homogenisation process.

Element	1st test					2nd test		
	Clean µg/g	UT µg/g	Difference %	BOSCH µg/g	Difference %	Clean µg/g	BOSCH µg/g	Difference %
Ag	0.00007	0.00009	*26.2*	0.00007	*-4.4*	0.00008	0.00060	*667.7*
As	0.00091	0.00074	*-18.7*	0.00074	*-18.4*	0.00068	0.00069	*1.1*
Au	0.00003	0.00001	*-47.3*	0.00001	*-44.7*	0.00018	0.00012	*-36.3*
B	0.12693	0.10476	*-17.5*	0.10319	*-18.7*	0.11185	0.10326	*-7.7*
Ba	0.40465	0.31577	*-22.0*	0.31852	*-21.3*	0.23659	0.24158	*2.1*
Bi	0.00000	0.00003	*673.2*	0.00001	*265.7*	0.00000	0.00000	*-183.0*
Ce	0.00001	0.00001	*-6.3*	0.00001	*-21.0*	0.00003	0.00002	*-39.6*
Co	0.00115	0.00123	*7.3*	0.00098	*-14.1*	0.00082	0.00098	*19.9*
Cs	0.00068	0.00056	*-17.5*	0.00054	*-21.1*	0.00068	0.00071	*4.4*
Cu	0.63459	0.52456	*-17.3*	0.52737	*-16.9*	0.63505	0.75851	*19.4*
Fe	22.77573	17.92182	*-21.3*	18.09737	*-20.5*	17.99528	18.12669	*0.7*
Hg	0.00070	0.00031	*-56.0*	0.00490	*596.2*	0.00050	0.00035	*-30.0*
Li	0.00118	0.00214	*81.4*	0.00186	*57.8*	0.00250	0.00271	*8.6*
Mn	0.54401	0.42847	*-21.2*	0.43172	*-20.6*	0.44632	0.45143	*1.1*
Mo	0.05083	0.04692	*-7.7*	0.04008	*-21.1*	0.04250	0.04371	*2.8*
Nd	0.00001	0.00000	*-59.2*	0.00001	*-47.2*	0.00004	0.00004	*13.9*
Ni	0.00012	0.02285	*18417.0*	-0.00015	*-222.2*	0.00101	0.00197	*94.5*
Pb	0.00082	0.00066	*-19.5*	0.00019	*-77.4*	0.00056	0.00126	*124.1*
Rb	0.95509	0.78756	*-17.5*	0.78208	*-18.1*	0.75616	0.76070	*0.6*
Se	0.27133	0.21962	*-19.1*	0.22145	*-18.4*	0.18702	0.18250	*-2.4*
Sn	0.00017	0.00020	*20.3*	0.00013	*-24.3*	0.00055	0.00028	*-49.0*
Sr	0.47915	0.37905	*-20.9*	0.38470	*-19.7*	0.34434	0.34961	*1.5*
Tl	0.00052	0.00042	*-18.7*	0.00042	*-18.9*	0.00032	0.00028	*-12.9*
U	0.00000	0.00000	*0.2*	0.00001	*37.5*	0.00000	0.00000	*27.1*
Y	0.00002	0.00002	*-21.6*	0.00003	*23.3*	0.00001	0.00003	*168.2*
Zn	14.48981	11.31387	*-21.9*	11.60613	*-19.9*	11.88539	12.07341	*1.6*
Zr	0.00006	0.00014	*113.5*	0.00007	*3.6*	0.00009	0.00008	*-3.5*

Appendix B

Certified reference material from Institute of Nuclear Chemistry and Technology Warzawa - Poland, Polish Virginia Tobacco Leaves (INCT-PVTL-6). Certified concentrations (µg/g) compared to values obtained from the present study. Certified values are italicized where only info values are provided. Accuracy is determined by % recovery. Green indicates a recovery between 85-115%, red indicated <85% and blue indicates >115%.

Element	Certified value	Present study	Accuracy
	Mean	Mean ± SD	%
Ag	0.0191	0.02 ± 0.01	101
Al	252	350.12 ± 1.47	139
As	0.138	0.11 ± 0.01	77
B	33.4	36.03 ± 1.44	108
Ba	41.60	38.44 ± 0.03	92
Bi	*0.140*	0.16 ± 0.01	114
Ca	22,970	22802 ± 572.48	99
Cd	2.23	2.38 ± 0.08	106
Ce	0.743	0.79 ± 0.03	106
Co	0.154	0.13 ± 0.01	84
Cr	*0.911*	0.59 ± 0.01	64
Cs	0.0266	0.03 ± 0.01	95
Cu	5.12	4.21 ± 0.03	82
Er	0.0185	0.03 ± 0.01	124
Fe	*258*	253.64 ± 1.63	98
Hf	0.161	0.01 ± 0.01	4
Hg	0.0232	0.03 ± 0.01	113
K	26,400	23804.16 ± 478.55	90
La	0.54	0.45 ± 0.01	83
Li	3.35	3.85 ± 0.12	115
Mg	2,410	2462.92 ± 90.6	102
Mn	136	129.67 ± 2.51	95
Mo	0.396	0.35 ± 0.01	87
Na	*62.4*	68.99 ± 1.6	111
Nd	0.322	0.32 ± 0.01	99
Ni	1.49	1.1 ± 0.05	74
P	2,420	2403.31 ± 33.24	99
Pb	0.972	0.7 ± 0.02	71
Pr	*0.0829*	0.09 ± 0.01	107
Rb	5.97	5.46 ± 0.14	91
S	3,780	3039.24 ± 59.5	80
Sb	0.0372	0.03 ± 0.01	64
Sc	*0.0595*	0.04 ± 0.01	52
Sm	0.0580	0.06 ± 0.01	97
Sn	*0.031*	0.05 ± 0.01	136
Sr	133	129.08 ± 1.96	97
Tb	0.0081	0.01 ± 0.01	96
Th	0.0888	0.06 ± 0.01	64
Ti	*12.3*	15.83 ± 0.06	129
Tl	*0.0228*	0.03 ± 0.01	107
U	*0.022*	0.02 ± 0.01	74
V	0.405	0.34 ± 0.02	83
Y	*0.218*	0.27 ± 0.01	123
Yb	*0.0283*	0.02 ± 0.01	64
Zn	43.6	37.46 ± 0.81	86

Appendix C

Sample size, mean, average RSD % and number of samples below limit of detection (LOD) for 2012 (a) and 2017 (b) analysis.

a)

2012

	Ag	Al	As	Au	B	Ba	Be	Bi	Ca43/44	Cd111/114	Ce	Co
Sample size	26	26	26	26	26	26	26	26	26	26	26	26
Mean	0.01	0.03	0.11	0.00	0.14	0.15	0.00	0.00	1089.27/994.22	0.0003/0.0003	0.00	0.01
Average RSD%	9.84	5.29	2.66	28.57	4.10	4.36	56.40	7.67	4.16/4.61	33.24/21.19	14.08	7.41
no. of <LOD	0.00	24.00	0.00	8.00	0.00	0.00	24.00	0.00	0/0	25/25	0.00	0.00

	Cr	Cs	Cu	Dy	Er	Fe	Ga	Hf	Hg	Ho	K	La
Sample size	26	26	26	26	26	26	26	26	26	26	26	26
Mean	0.29	0.00	1.29	0.00	0.00	39.70	0.00	0.00	0.09	0.00	1507.39	0.00
Average RSD%	5.08	6.85	3.02	52.90	83.78	5.19	48.46	57.48	2.21	29.16	5.16	30.21
no. of <LOD	7.00	0.00	0.00	25.00	22.00	0.00	25.00	21.00	0.00	15.00	0.00	12.00

	Li	Lu	Mg	Mn	Mo	Na	Nb	Nd	Ni	P	Pb	Pr
Sample size	26	26	26	26	26	26	26	26	26	26	26	26
Mean	0.04	0.00	139.31	0.53	0.08	1230.90	0.00	0.00	0.19	2972.59	0.00	0.00
Average RSD%	3.83	93.36	4.86	3.78	4.11	4.78	63.69	40.16	11.27	4.21	3.71	32.15
no. of <LOD	0.00	25.00	0.00	0.00	0.00	0.00	12.00	0.00	1.00	0.00	0.00	10.00

	Rb	S	Sb	Se78/82	Sc	Si	Sm	Sn	Sr	Ta	Tb	Th
Sample size	26	26	26	26	26	26	26	26	26	26	26	26
Mean	0.83	2437.95	0.00	.617/0.63	0.00	0.40	0.00	0.00	4.80	0.00	0.00	0.00
Average RSD%	3.22	4.42	44.01	.316/3.44	41.27	2.98	46.15	14.10	4.00	48.39	76.48	26.64
no. of <LOD	0.00	3.00	25.00	0/0	25.00	23.00	15.00	2.00	0.00	25.00	25.00	25.00

	Ti	Tl	Tm	U	V	W	Y	Yb	Zn	Zr
Sample size	26	26	26	26	26	26	26	26	26	26
Mean	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	19.24	0.00
Average RSD%	28.50	6.52	86.90	10.82	11.68	20.24	13.08	80.61	3.86	13.30
no. of <LOD	6.00	0.00	25.00	0.00	0.00	13.00	0.00	25.00	0.00	0.00

2017

b)

	Ag	Al	As	Au	B	Ba	Be	Bi	Ca44	Cd	Ce	Co
Sample size	123	123	123	123	123	123	123	123	123	123	123	123
Mean	0.01	0.06	0.16	0.00	0.28	0.10	0.00	0.00	779.32	0.00	0.00	0.00
Average RSD%	0.01	5.44	15.76	38.32	2.55	9.75	70.80	15.96	2.02	25.46	30.39	17.15
no. of <LOD	7.00	128.00	3.00	13.00	3.00	3.00	51.00	40.00	3.00	14.00	3.00	3.00

	Cr	Cs	Cu	Dy	Er	Fe	Ga	Hf	Hg	Ho	Ir	K
Sample size	123	123	123	123	123	123	123	123	123	123	123	123
Mean	0.02	0.00	1.03	0.00	0.00	39.40	0.00	0.00	0.09	0.00	0.00	1306.67
Average RSD%	11.93	8.41	2.83	66.72	97.47	2.43	102.26	45.14	2.51	31.44	77.50	2.86
no. of <LOD	113.00	3.00	3.00	123.00	122.00	3.00	122.00	123.00	2.00	123.00	123.00	3.00

	La	Li	Lu	Mg	Mn	Mo	Na	Nb	Nd	Ni	P	Pb
Sample size	123	123	123	123	123	123	123	123	123	123	123	123
Mean	0.00	0.06	0.00	122.75	0.52	0.05	1068.41	0.00	0.00	0.01	2614.37	0.00
Average RSD%	70.68	3.10	80.01	1.92	2.60	7.78	2.25	36.34	71.49	43.80	2.31	6.83
no. of <LOD	121.00	3.00	123.00	3.00	3.00	3.00	0.00	123.00	10.00	58.00	0.00	4.00

	Pr	Pt	Rb	S	Sb	Sc	Se	Si	Sm	Sn	Sr	Tb
Sample size	123	123	123	123	123	123	123	123	123	123	123	123
Mean	0.00	0.00	0.72	1947.41	0.00	0.00	0.53	11.29	0.00	0.00	3.71	0.00
Average RSD%	51.66	44.54	4.07	1.53	61.51	33.45	12.00	1.39	46.73	21.54	2.04	72.76
no. of <LOD	122.00	122.00	3.00	3.00	123.00	123.00	3.00	122.00	123.00	15.00	3.00	76.00

	Th	Ti	Tl	Tm	U	V	W	Y	Yb	Zn	Zr
Sample size	123	123	123	123	123	123	123	123	123	123	123
Mean	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	16.41	0.00
Average RSD%	58.65	31.89	14.32	105.49	35.68	27.28	30.63	31.73	69.64	2.29	35.98
no. of <LOD	120.00	122.00	2.00	123.00	41.00	108.00	7.00	3.00	123.00	3.00	28.00

Appendix D

Raw elemental concentration data for migratory and sedentary eiders eggs. Sampled from nesting common eiders in Svalbard during 2010, 2011, 2012 and 2017 and from Northern Norway and Northeast Iceland in 2017 only. Bird ID is the unique identification code for eiders from which eggs were taken in the present study. M/S column indicates whether birds are migratory (M) or sedentary (S).

Bird ID	Wintering area	M/S	Breeding area	Ag	As	Au	B	Ba	Bi	Ce	Co	Cs	Cu	Fe	Hg
2010															
CA15877	Iceland	M	Svalbard	0.0023	0.0829	0.0001	0.1251	0.0641	0.0005	0.0001	0.0037	0.0009	1.1663	42.5000	0.0654
CA16417	Iceland	M	Svalbard	0.0102	0.1071	0.0000	0.1172	0.0754	0.0002	0.0003	0.0057	0.0007	1.1553	31.1293	0.1026
CA23728	Iceland	M	Svalbard	0.0089	0.1112	0.0002	0.5905	0.0927	0.0008	0.0001	0.0044	0.0013	1.0404	44.9984	0.0599
CA23734	Iceland	M	Svalbard	0.0202	0.1449	0.0001	0.2585	0.0229	0.0013	0.0001	0.0038	0.0015	1.2828	43.4223	0.1269
CA33803	Iceland	M	Svalbard	0.0045	0.1067	0.0001	0.0807	0.1431	0.0008	0.0003	0.0056	0.0012	1.6614	43.7738	0.0757
CA23058	Norway	M	Svalbard	0.0083	0.0785	0.0001	0.1073	0.1454	0.0002	0.0002	0.0037	0.0013	1.0778	37.2409	0.0737
CA23732	Norway	M	Svalbard	0.0116	0.1625	0.0001	0.1528	0.1080	0.0036	0.0002	0.0042	0.0013	1.1596	45.5485	0.0442
CA23737	Norway	M	Svalbard	0.0089	0.1210	0.0001	0.1238	0.1308	0.0007	0.0005	0.0046	0.0008	1.2006	47.5175	0.0603
2011															
394995	Iceland	M	Svalbard	0.0106	0.0984	0.0001	0.1123	0.1937	0.0004	0.0002	0.0035	0.0015	1.1571	33.1993	0.1190
CA23056	Iceland	M	Svalbard	0.0048	0.1657	0.0000	0.1011	0.1693	0.0003	0.0002	0.0048	0.0009	1.0626	42.5117	0.1076
CA23537	Iceland	M	Svalbard	0.0036	0.2078	0.0001	0.1394	0.0908	0.0016	0.0003	0.0042	0.0011	1.1522	52.2261	0.1241
CA23726	Iceland	M	Svalbard	0.0164	0.0746	0.0000	0.0616	0.2423	0.0005	0.0001	0.0052	0.0008	0.7762	46.8605	0.0524
CA23730	Iceland	M	Svalbard	0.0020	0.2083	0.0001	0.1018	0.0890	0.0013	0.0002	0.0039	0.0011	1.1741	42.0601	0.0790
CA23731	Iceland	M	Svalbard	0.0113	0.0922	0.0000	0.0805	0.4195	0.0003	0.0004	0.0046	0.0017	0.8099	41.6916	0.0224
CA23740	Iceland	M	Svalbard	0.0064	0.0595	0.0001	0.0810	0.1949	0.0008	0.0005	0.0040	0.0014	1.1183	42.0540	0.1557
CA33766	Norway	M	Svalbard	0.0327	0.1301	0.0002	0.0772	0.1596	0.0009	0.0003	0.0049	0.0010	0.7603	48.0102	0.1749
CA35959	Norway	M	Svalbard	0.0056	0.1412	0.0000	0.0968	0.0547	0.0006	0.0001	0.0050	0.0009	1.0512	54.1561	0.1239

Appendix D cont.

Raw elemental concentration data for migratory and sedentary eiders eggs. Sampled from nesting common eiders in Svalbard during 2010, 2011, 2012 and 2017 and from Northern Norway and Northeast Iceland in 2017 only. Bird ID is the unique identification code for eiders from which eggs were taken in the present study. M/S column indicates whether birds are migratory (M) or sedentary (S).

Bird ID	Wintering area	M/S	Breeding area	Li	Mn	Mo	Nd	Ni	Pb	Rb	Sn	Sr	Tl	U	Y	Zn	Zr	Se
2010																		
CA15877	Iceland	M	Svalbard	0.0192	0.5324	0.0498	0.0001	0.0035	0.0033	0.7823	0.0012	3.2371	0.0012	0.0001	0.0001	14.8592	0.0004	0.3871
CA16417	Iceland	M	Svalbard	0.0194	0.4788	0.0373	0.0001	0.0055	0.0098	0.6094	0.0052	2.8959	0.0008	0.0001	0.0001	17.5325	0.0005	0.4181
CA23728	Iceland	M	Svalbard	0.1331	0.4544	0.0493	0.0001	0.0016	0.0021	0.6339	0.0004	5.3852	0.0007	0.0001	0.0001	17.8573	0.0001	0.4651
CA23734	Iceland	M	Svalbard	0.0431	0.6779	0.1106	0.0001	0.0019	0.0044	0.7082	0.0003	2.0890	0.0004	0.0000	0.0001	15.1779	0.0001	0.5135
CA33803	Iceland	M	Svalbard	0.0162	0.5810	0.0500	0.0002	0.0078	0.0092	0.8228	0.0018	3.6110	0.0008	0.0001	0.0001	20.0639	0.0004	0.6894
CA23058	Norway	M	Svalbard	0.0209	0.3579	0.0531	0.0001	0.0039	0.0066	0.6608	0.0032	4.7882	0.0006	0.0001	0.0001	19.1436	0.0002	0.4836
CA23732	Norway	M	Svalbard	0.0150	0.5678	0.0996	0.0001	0.0035	0.0069	0.8301	0.0013	4.0264	0.0008	0.0001	0.0001	20.3380	0.0002	0.7078
CA23737	Norway	M	Svalbard	0.0122	0.4662	0.0303	0.0002	0.0052	0.0080	0.8718	0.0030	2.9666	0.0009	0.0002	0.0002	18.5961	0.0005	0.4749
2011																		
394995	Iceland	M	Svalbard	0.0242	0.3502	0.0463	0.0001	0.0118	0.0024	0.7916	0.0003	4.6776	0.0025	0.0001	0.0002	16.5918	0.0001	0.8162
CA23056	Iceland	M	Svalbard	0.0315	0.5959	0.0331	0.0001	0.0003	0.0044	0.8561	0.0002	3.7774	0.0012	0.0001	0.0001	17.9504	0.0000	0.5031
CA23537	Iceland	M	Svalbard	0.0554	0.4790	0.0805	0.0001	0.0073	0.0039	0.8752	0.0002	3.1360	0.0011	0.0001	0.0001	16.3463	0.0001	0.6206
CA23726	Iceland	M	Svalbard	0.0146	0.4999	0.0321	0.0001	0.0023	0.0074	0.7438	0.0003	4.4447	0.0005	0.0001	0.0001	22.0548	0.0001	0.4838
CA23730	Iceland	M	Svalbard	0.0200	0.6258	0.0777	0.0000	0.0052	0.0025	0.7430	0.0004	3.2650	0.0009	0.0002	0.0001	18.7190	0.0003	0.5063
CA23731	Iceland	M	Svalbard	0.0152	0.5344	0.0243	0.0003	0.0073	0.0036	0.8087	0.0003	5.0390	0.0006	0.0001	0.0003	22.1175	0.0003	0.4265
CA23740	Iceland	M	Svalbard	0.0140	0.5930	0.0458	0.0003	0.0151	0.0132	0.8246	0.0003	3.0181	0.0002	0.0001	0.0004	17.4291	0.0001	0.5805
CA33766	Norway	M	Svalbard	0.0225	0.5567	0.0248	0.0001	0.0028	0.0075	0.8466	0.0004	2.6428	0.0011	0.0001	0.0002	20.2485	0.0002	0.5825
CA35959	Norway	M	Svalbard	0.0112	0.5099	0.0629	0.0001	0.0096	0.0086	0.5742	0.0003	2.2360	0.0011	0.0001	0.0001	17.7374	0.0002	0.5126

Appendix D cont.

Raw elemental concentration data for migratory and sedentary eiders eggs. Sampled from nesting common eiders in Svalbard during 2010, 2011, 2012 and 2017 and from Northern Norway and Northeast Iceland in 2017 only. Bird ID is the unique identification code for eiders from which eggs were taken in the present study. M/S column indicates whether birds are migratory (M) or sedentary (S).

Bird ID	Wintering area	M/S	Breeding area	Ag	As	Au	B	Ba	Bi	Ce	Co	Cs	Cu	Fe	Hg
2012															
394987	Iceland	M	Svalbard	0.0026	0.0741	0.0000	0.0900	0.1422	0.0004	0.0002	0.0047	0.0010	1.1711	36.7282	0.0794
CA16374	Iceland	M	Svalbard	0.0145	0.0810	0.0001	0.1546	0.3580	0.0002	0.0001	0.0037	0.0014	0.8878	46.7260	0.0513
CA23095	Iceland	M	Svalbard	0.0047	0.0800	0.0000	0.0829	0.2266	0.0002	0.0002	0.0060	0.0011	1.5405	36.1248	0.0551
CA23704	Iceland	M	Svalbard	0.0066	0.1503	0.0000	0.0984	0.1231	0.0005	0.0001	0.0090	0.0008	1.0529	46.3948	0.0664
CA23705	Iceland	M	Svalbard	0.0066	0.0871	0.0000	0.0866	0.1062	0.0016	0.0002	0.0036	0.0009	1.4707	46.7271	0.1218
CA23707	Iceland	M	Svalbard	0.0099	0.0961	0.0000	0.0680	0.1738	0.0004	0.0001	0.0065	0.0010	0.9568	45.7102	0.0789
CA23712	Iceland	M	Svalbard	0.0037	0.1013	0.0000	0.0763	0.2868	0.0008	0.0002	0.0054	0.0011	1.3184	43.8062	0.0583
CA23714	Iceland	M	Svalbard	0.0080	0.0795	0.0000	0.1418	0.2516	0.0002	0.0003	0.0037	0.0009	1.0647	46.9371	0.0587
CA23715	Iceland	M	Svalbard	0.0013	0.1061	0.0000	0.3218	0.0676	0.0002	0.0002	0.0060	0.0011	1.6165	37.5874	0.1256
CA23716	Iceland	M	Svalbard	0.0039	0.0735	0.0000	0.2203	0.1595	0.0012	0.0002	0.0068	0.0009	1.7331	47.0621	0.1386
CA23727	Iceland	M	Svalbard	0.0102	0.1459	0.0000	0.1192	0.0561	0.0008	0.0002	0.0054	0.0012	1.4279	35.7196	0.1248
CA23733	Iceland	M	Svalbard	0.0041	0.0684	0.0000	0.1341	0.0481	0.0001	0.0002	0.0077	0.0007	1.0520	27.3565	0.1110
CA23738	Iceland	M	Svalbard	0.0060	0.0780	0.0001	0.0969	0.0448	0.0003	0.0001	0.0073	0.0013	1.2395	28.1467	0.0808
CA23841	Iceland	M	Svalbard	0.0017	0.0645	0.0000	0.1058	0.3086	0.0004	0.0002	0.0053	0.0010	1.1249	27.4271	0.0776
CA30210	Iceland	M	Svalbard	0.0015	0.0662	0.0001	0.2354	0.0355	0.0003	0.0002	0.0115	0.0012	1.0454	32.7507	0.0522
CA22932	Norway	M	Svalbard	0.0190	0.1113	0.0000	0.1609	0.1922	0.0001	0.0001	0.0062	0.0009	1.2486	47.3343	0.1934
CA23697	Norway	M	Svalbard	0.0064	0.0783	0.0000	0.1408	0.1152	0.0011	0.0001	0.0078	0.0010	1.3640	41.1731	0.0515
CA23849	Norway	M	Svalbard	0.0118	0.0723	0.0001	0.0669	0.1372	0.0002	0.0001	0.0051	0.0009	1.3424	46.8806	0.0378
CA33757	Norway	M	Svalbard	0.0073	0.1420	0.0000	0.0770	0.1110	0.0014	0.0002	0.0051	0.0009	1.1196	44.7336	0.0979

Appendix D cont.

Raw elemental concentration data for migratory and sedentary eiders eggs. Sampled from nesting common eiders in Svalbard during 2010, 2011, 2012 and 2017 and from Northern Norway and Northeast Iceland in 2017 only. Bird ID is the unique identification code for eiders from which eggs were taken in the present study. M/S column indicates whether birds are migratory (M) or sedentary (S).

Bird ID	Wintering area	M/S	Breeding area	Li	Mn	Mo	Nd	Ni	Pb	Rb	Sn	Sr	Tl	U	Y	Zn	Zr	Se
2012																		
394987	Iceland	M	Svalbard	0.0151	0.4344	0.0379	0.0001	0.0165	0.0131	0.7561	0.0002	4.5692	0.0005	0.0001	0.0002	24.4889	0.0002	0.8097
CA16374	Iceland	M	Svalbard	0.0203	0.4606	0.0243	0.0000	0.0000	0.0024	0.7548	0.0001	7.2262	0.0007	0.0000	0.0001	20.6313	0.0001	0.3654
CA23095	Iceland	M	Svalbard	0.0199	0.4890	0.0953	0.0001	0.0009	0.0022	0.7678	0.0001	4.7711	0.0006	0.0002	0.0001	22.4840	0.0002	0.4922
CA23704	Iceland	M	Svalbard	0.0133	0.6449	0.1272	0.0001	0.3366	0.0033	0.6160	0.0005	4.4201	0.0004	0.0002	0.0001	25.8801	0.0003	0.6069
CA23705	Iceland	M	Svalbard	0.0481	0.5171	0.0569	0.0002	0.0006	0.0073	0.9560	0.0001	6.8436	0.0003	0.0001	0.0001	17.4625	0.0000	0.6002
CA23707	Iceland	M	Svalbard	0.0117	0.7047	0.0867	0.0001	0.0918	0.0030	0.7985	0.0002	4.6419	0.0007	0.0002	0.0001	22.1814	0.0002	0.5779
CA23712	Iceland	M	Svalbard	0.0237	0.4748	0.0619	0.0001	0.0719	0.0060	0.9422	0.0002	7.7927	0.0005	0.0001	0.0002	24.2181	0.0004	0.7795
CA23714	Iceland	M	Svalbard	0.0340	0.3912	0.0263	0.0002	0.0232	0.0017	0.7288	0.0000	5.5137	0.0007	0.0001	0.0002	19.8857	0.0003	0.4419
CA23715	Iceland	M	Svalbard	0.1666	0.4296	0.0336	0.0001	0.0004	0.0049	0.8024	0.0001	3.7956	0.0014	0.0001	0.0001	14.5385	0.0001	0.6710
CA23716	Iceland	M	Svalbard	0.0530	0.6335	0.0364	0.0001	0.0012	0.0107	0.7264	0.0001	5.3495	0.0007	0.0001	0.0001	17.6758	0.0003	0.5600
CA23727	Iceland	M	Svalbard	0.0368	0.7591	0.0984	0.0001	0.0019	0.0038	0.9170	0.0001	8.9629	0.0013	0.0001	0.0001	19.9852	0.0003	0.7858
CA23733	Iceland	M	Svalbard	0.0240	0.4612	0.0815	0.0001	0.2545	0.0016	0.7215	0.0002	2.9639	0.0006	0.0000	0.0000	14.6076	0.0001	0.4818
CA23738	Iceland	M	Svalbard	0.0346	0.3955	0.0872	0.0000	0.2986	0.0020	0.9639	0.0002	2.1844	0.0012	0.0000	0.0001	11.0984	0.0003	0.4661
CA23841	Iceland	M	Svalbard	0.0206	0.2929	0.0595	0.0001	0.2355	0.0032	0.8445	0.0004	4.7812	0.0005	0.0001	0.0001	16.5385	0.0003	0.4617
CA30210	Iceland	M	Svalbard	0.0584	0.3406	0.0872	0.0000	0.2662	0.0018	0.6514	0.0002	2.5473	0.0004	0.0000	0.0001	12.3954	0.0001	0.4021
CA22932	Norway	M	Svalbard	0.0335	0.8850	0.0504	0.0001	0.0668	0.0034	0.8371	0.0002	4.7771	0.0010	0.0001	0.0001	23.9533	0.0003	0.6184
CA23697	Norway	M	Svalbard	0.0367	0.3805	0.1120	0.0001	0.4482	0.0064	0.8763	0.0006	3.0129	0.0005	0.0000	0.0001	17.6170	0.0002	0.5517
CA23849	Norway	M	Svalbard	0.0201	0.2944	0.0440	0.0001	0.0004	0.0025	0.7831	0.0001	6.5504	0.0007	0.0001	0.0001	18.5031	0.0001	0.4566
CA33757	Norway	M	Svalbard	0.0184	0.4522	0.0469	0.0001	0.1034	0.0048	0.8816	0.0005	3.9507	0.0012	0.0001	0.0001	20.5144	0.0003	0.7163

Appendix D cont.

Raw elemental concentration data for migratory and sedentary eiders eggs. Sampled from nesting common eiders in Svalbard during 2010, 2011, 2012 and 2017 and from Northern Norway and Northeast Iceland in 2017 only. Bird ID is the unique identification code for eiders from which eggs were taken in the present study. M/S column indicates whether birds are migratory (M) or sedentary (S).

Bird ID	Wintering area	M/S	Breeding area	Ag	As	Au	B	Ba	Bi	Ce	Co	Cs	Cu	Fe	Hg
2017															
394992	Iceland	M	Svalbard	0.0026	0.1741	0.0001	0.1175	0.0866	0.0013	0.0001	0.0042	0.0009	1.1103	41.3211	0.1143
CA23709	Iceland	M	Svalbard	0.0040	0.1618	0.0000	0.1683	0.0737	0.0004	0.0002	0.0042	0.0010	1.1178	36.9185	0.1056
CA23710	Iceland	M	Svalbard	0.0080	0.3078	0.0001	0.0822	0.1357	0.0026	0.0004	0.0043	0.0012	1.0947	51.0217	0.0567
CA23735	Iceland	M	Svalbard	0.0022	0.1025	0.0001	0.0970	0.0741	0.0006	0.0001	0.0035	0.0014	1.0052	34.7960	0.0862
CA23829	Iceland	M	Svalbard	0.0057	0.0638	0.0001	0.0539	0.1490	0.0001	0.0002	0.0059	0.0014	1.1452	41.8798	0.0722
CA23834	Iceland	M	Svalbard	0.0020	0.1917	0.0000	0.0781	0.0954	0.0024	0.0001	0.0033	0.0009	0.9670	46.1014	0.1068
CA23844	Iceland	M	Svalbard	0.0098	0.1394	0.0000	0.0896	0.0549	0.0012	0.0001	0.0041	0.0010	0.9719	48.5282	0.0772
CA23847	Iceland	M	Svalbard	0.0018	0.1088	0.0001	0.0782	0.0784	0.0004	0.0001	0.0035	0.0007	1.1080	34.7904	0.0560
CA40012	Iceland	M	Svalbard	0.0068	0.1014	0.0000	0.1068	0.0800	0.0007	0.0001	0.0030	0.0007	0.8936	44.6092	0.0810
CA40020	Iceland	M	Svalbard	0.0054	0.1541	0.0000	0.1352	0.1060	0.0004	0.0001	0.0043	0.0008	1.1691	39.4438	0.0703
CA40035	Iceland	M	Svalbard	0.0059	0.2632	0.0000	0.2915	0.0229	0.0004	0.0001	0.0054	0.0012	0.8943	31.4068	0.2506
CA40038	Iceland	M	Svalbard	0.0115	0.2192	0.0000	0.1590	0.0441	0.0006	0.0001	0.0048	0.0013	1.0387	39.4198	0.1113
CA40039	Iceland	M	Svalbard	0.0088	0.0840	0.0001	0.1055	0.1337	0.0004	0.0002	0.0027	0.0011	1.6047	38.3114	0.0980
CA40042	Iceland	M	Svalbard	0.0069	0.1860	0.0000	0.1682	0.0524	0.0004	0.0001	0.0036	0.0011	1.0822	29.1054	0.1648
CA40045	Iceland	M	Svalbard	0.0052	0.1856	0.0000	0.3083	0.0393	0.0018	0.0002	0.0046	0.0014	1.1522	41.4509	0.1831
CA42614	Iceland	M	Svalbard	0.0086	0.1241	0.0001	0.1098	0.0893	0.0021	0.0001	0.0032	0.0009	0.8990	40.4331	0.0853
CA42615	Iceland	M	Svalbard	0.0032	0.1112	0.0000	0.1679	0.1005	0.0006	0.0002	0.0036	0.0011	0.8906	39.7814	0.0821
CA42619	Iceland	M	Svalbard	0.0064	0.1611	0.0000	0.1837	0.0371	0.0003	0.0001	0.0052	0.0013	0.9448	31.4815	0.1193
CA42620	Iceland	M	Svalbard	0.0017	0.1980	0.0001	0.4025	0.0696	0.0005	0.0001	0.0058	0.0013	1.0803	40.4375	0.1766

Appendix D cont.

Raw elemental concentration data for migratory and sedentary eiders eggs. Sampled from nesting common eiders in Svalbard during 2010, 2011, 2012 and 2017 and from Northern Norway and Northeast Iceland in 2017 only. Bird ID is the unique identification code for eiders from which eggs were taken in the present study. M/S column indicates whether birds are migratory (M) or sedentary (S).

Bird ID	Wintering area	M/S	Breeding area	Li	Mn	Mo	Nd	Ni	Pb	Rb	Sn	Sr	Tl	U	Y	Zn	Zr	Se
2017																		
394992	Iceland	M	Svalbard	0.0151	0.4342	0.0275	0.0001	0.0002	0.0017	0.6015	0.0002	3.8198	0.0003	0.0000	0.0001	16.9407	0.0001	0.5422
CA23709	Iceland	M	Svalbard	0.0480	0.5682	0.0321	0.0001	0.0002	0.0040	0.7110	0.0001	2.9582	0.0006	0.0001	0.0001	14.8338	0.0001	0.7176
CA23710	Iceland	M	Svalbard	0.0137	0.4978	0.0423	0.0001	0.0003	0.0331	0.8473	0.0003	4.2490	0.0004	0.0004	0.0002	22.2948	0.0001	0.6515
CA23735	Iceland	M	Svalbard	0.0195	0.3988	0.0312	0.0001	0.0004	0.0049	0.8043	0.0001	1.8611	0.0005	0.0000	0.0001	13.7760	0.0002	0.8559
CA23829	Iceland	M	Svalbard	0.0389	0.6647	0.0211	0.0002	0.0006	0.0048	0.6277	0.0004	3.7568	0.0006	0.0001	0.0001	16.0109	0.0001	0.6457
CA23834	Iceland	M	Svalbard	0.0138	0.7377	0.0255	0.0000	0.0000	0.0014	0.6712	0.0003	4.5718	0.0004	0.0000	0.0000	15.7760	0.0000	0.6108
CA23844	Iceland	M	Svalbard	0.0139	0.6841	0.0582	0.0001	0.0012	0.0022	0.7498	0.0002	3.6809	0.0008	0.0001	0.0001	17.4846	0.0001	0.4796
CA23847	Iceland	M	Svalbard	0.0137	0.3457	0.0550	0.0001	0.0018	0.0020	0.6470	0.0002	3.3830	0.0006	0.0001	0.0000	14.8359	0.0001	0.4833
CA40012	Iceland	M	Svalbard	0.0213	0.3529	0.0344	0.0001	0.0011	0.0017	0.6013	0.0003	3.1052	0.0007	0.0001	0.0001	15.5125	0.0001	0.5442
CA40020	Iceland	M	Svalbard	0.0584	0.2778	0.0438	0.0001	0.0005	0.0015	0.6151	0.0003	5.6380	0.0012	0.0002	0.0001	15.7128	0.0001	0.5740
CA40035	Iceland	M	Svalbard	0.1814	0.5654	0.0469	0.0001	0.0002	0.0008	0.5514	0.0002	3.1059	0.0007	0.0000	0.0001	13.4067	0.0000	0.5621
CA40038	Iceland	M	Svalbard	0.0335	0.6185	0.0638	0.0000	0.0017	0.0024	0.6830	0.0004	2.7978	0.0004	0.0000	0.0001	15.8882	0.0001	0.5926
CA40039	Iceland	M	Svalbard	0.0243	0.3366	0.0370	0.0002	0.0014	0.0035	0.6999	0.0004	3.5516	0.0003	0.0001	0.0002	19.9814	0.0001	0.5006
CA40042	Iceland	M	Svalbard	0.0656	0.4051	0.0270	0.0000	0.0015	0.0013	0.7207	0.0002	3.1443	0.0005	0.0000	0.0001	12.5063	0.0000	0.4680
CA40045	Iceland	M	Svalbard	0.0623	1.2112	0.0435	0.0001	0.0005	0.0020	0.6598	0.0003	4.3799	0.0005	0.0000	0.0001	15.8550	0.0000	0.4806
CA42614	Iceland	M	Svalbard	0.0200	0.4648	0.0384	0.0001	0.0002	0.0046	0.7759	0.0000	3.1106	0.0004	0.0001	0.0001	17.0774	0.0001	0.5307
CA42615	Iceland	M	Svalbard	0.0357	0.4510	0.0284	0.0001	0.0004	0.0064	0.5974	0.0001	3.5738	0.0006	0.0002	0.0001	18.0991	0.0001	0.7840
CA42619	Iceland	M	Svalbard	0.0360	0.4835	0.0397	0.0001	0.0004	0.0017	0.8361	0.0002	2.7227	0.0011	0.0001	0.0001	13.2638	0.0001	0.6487
CA42620	Iceland	M	Svalbard	0.1097	0.6383	0.0486	0.0001	0.0017	0.0020	0.7211	0.0002	5.5618	0.0010	0.0001	0.0001	16.5567	0.0000	0.5206

Appendix D cont.

Raw elemental concentration data for migratory and sedentary eiders eggs. Sampled from nesting common eiders in Svalbard during 2010, 2011, 2012 and 2017 and from Northern Norway and Northeast Iceland in 2017 only. Bird ID is the unique identification code for eiders from which eggs were taken in the present study. M/S column indicates whether birds are migratory (M) or sedentary (S).

Bird ID	Wintering area	M/S	Breeding area	Ag	As	Au	B	Ba	Bi	Ce	Co	Cs	Cu	Fe	Hg
CA42644	Iceland	M	Svalbard	0.0025	0.2126	0.0001	0.2393	0.0346	0.0005	0.0001	0.0043	0.0008	1.0270	34.6919	0.0954
CA47512	Iceland	M	Svalbard	0.0144	0.0816	0.0001	0.1013	0.1051	0.0049	0.0002	0.0042	0.0011	1.0077	39.3904	0.0557
CA47514	Iceland	M	Svalbard	0.0021	0.0675	0.0001	0.0514	0.1007	0.0005	0.0002	0.0032	0.0009	1.0293	40.2632	0.0866
CA47519	Iceland	M	Svalbard	0.0188	0.1330	0.0000	0.1160	0.1129	0.0011	0.0001	0.0033	0.0009	0.9734	48.0433	0.0734
CA47541	Iceland	M	Svalbard	0.0023	0.1681	0.0001	0.1704	0.0491	0.0003	0.0002	0.0046	0.0010	1.0811	40.2650	0.0716
CA47548	Iceland	M	Svalbard	0.0232	0.1144	0.0000	0.1319	0.0310	0.0005	0.0001	0.0036	0.0009	0.5807	35.5644	0.0997
CA23843	Norway	M	Svalbard	0.0201	0.1205	0.0001	0.2065	0.0478	0.0004	0.0003	0.0049	0.0011	1.0424	42.1624	0.1169
CA40010	Norway	M	Svalbard	0.0060	0.1766	0.0001	0.2093	0.0993	0.0002	0.0001	0.0055	0.0010	0.8047	38.2864	0.0501
CA40028	Norway	M	Svalbard	0.0076	0.0886	0.0001	0.3506	0.0762	0.0008	0.0001	0.0025	0.0019	0.8918	40.8277	0.0800
Iceland1	Iceland	S	Iceland	0.0061	0.2167	0.0001	0.7337	0.0243	0.0000	0.0006	0.0042	0.0012	0.8410	48.6807	0.0725
Iceland10	Iceland	S	Iceland	0.0026	0.1108	0.0002	0.7513	0.0313	0.0000	0.0002	0.0043	0.0013	1.5212	40.9640	0.1315
Iceland11	Iceland	S	Iceland	0.0044	0.1674	0.0002	0.2775	0.0717	0.0001	0.0002	0.0039	0.0008	1.3569	45.2444	0.0736
Iceland12	Iceland	S	Iceland	0.0073	0.1797	0.0001	0.6579	0.0380	0.0000	0.0001	0.0054	0.0012	1.1389	46.8764	0.1102
Iceland13	Iceland	S	Iceland	0.0015	0.1030	0.0001	0.6601	0.0478	0.0000	0.0002	0.0078	0.0012	1.1202	50.3895	0.0435
Iceland14	Iceland	S	Iceland	0.0104	0.0863	0.0001	0.5305	0.0829	0.0001	0.0018	0.0057	0.0013	0.8614	45.8489	0.0646
Iceland15	Iceland	S	Iceland	0.0013	0.1225	0.0002	0.3594	0.0199	0.0001	0.0001	0.0093	0.0011	1.2698	31.3050	0.0689
Iceland16	Iceland	S	Iceland	0.0084	0.1349	0.0001	0.6347	0.0813	0.0001	0.0001	0.0058	0.0008	1.0177	36.3859	0.0666
Iceland17	Iceland	S	Iceland	0.0044	0.1023	0.0001	0.1620	0.0677	0.0001	0.0001	0.0032	0.0007	0.9845	40.8955	0.0416
Iceland18	Iceland	S	Iceland	0.0101	0.1542	0.0002	0.1754	0.0589	0.0001	0.0001	0.0049	0.0007	0.7904	42.0167	0.0547
Iceland19	Iceland	S	Iceland	0.0067	0.1915	0.0001	1.1475	0.0196	0.0000	0.0001	0.0046	0.0015	1.1255	38.9944	0.0815
Iceland2	Iceland	S	Iceland	0.0118	0.1618	0.0001	0.5963	0.0396	0.0001	0.0002	0.0058	0.0012	0.7285	28.1645	0.1075
Iceland20	Iceland	S	Iceland	0.0050	0.2550	0.0001	0.5812	0.0338	0.0001	0.0003	0.0048	0.0010	1.1124	38.9886	0.1161

Appendix D cont.

Raw elemental concentration data for migratory and sedentary eiders eggs. Sampled from nesting common eiders in Svalbard during 2010, 2011, 2012 and 2017 and from Northern Norway and Northeast Iceland in 2017 only. Bird ID is the unique identification code for eiders from which eggs were taken in the present study. M/S column indicates whether birds are migratory (M) or sedentary (S).

Bird ID	Wintering area	M/S	Breeding area	Li	Mn	Mo	Nd	Ni	Pb	Rb	Sn	Sr	Tl	U	Y	Zn	Zr	Se
CA42644	Iceland	M	Svalbard	0.0630	0.4615	0.0440	0.0000	0.0001	0.0009	0.7206	0.0001	4.0425	0.0006	0.0000	0.0001	14.0940	0.0000	0.4399
CA47512	Iceland	M	Svalbard	0.0231	0.4860	0.0495	0.0001	0.0021	0.0120	0.7867	0.0001	5.3492	0.0004	0.0001	0.0001	18.1857	0.0001	0.5556
CA47514	Iceland	M	Svalbard	0.0142	0.4410	0.0265	0.0001	0.0003	0.0024	0.8095	0.0001	3.8792	0.0002	0.0001	0.0001	17.2892	0.0001	0.4326
CA47519	Iceland	M	Svalbard	0.0255	0.3741	0.0317	0.0001	0.0001	0.0034	0.6560	0.0002	4.7450	0.0006	0.0001	0.0001	17.5574	0.0001	0.5824
CA47541	Iceland	M	Svalbard	0.0349	0.6481	0.0831	0.0002	0.0005	0.0032	0.5157	0.0004	2.5880	0.0003	0.0000	0.0001	14.5590	0.0001	0.5860
CA47548	Iceland	M	Svalbard	0.0434	0.7994	0.0763	0.0001	0.0001	0.0031	0.6564	0.0002	2.3113	0.0003	0.0001	0.0000	13.7166	0.0001	0.5412
CA23843	Norway	M	Svalbard	0.0616	1.0371	0.0593	0.0002	0.0006	0.0048	0.6865	0.0001	2.5363	0.0006	0.0001	0.0001	14.2806	0.0001	0.5807
CA40010	Norway	M	Svalbard	0.0337	0.6156	0.0516	0.0001	0.0002	0.0026	0.8936	0.0002	5.1343	0.0008	0.0002	0.0001	15.9968	0.0000	0.5351
CA40028	Norway	M	Svalbard	0.0657	0.2614	0.0478	0.0001	0.0013	0.0026	0.8072	0.0002	4.8988	0.0004	0.0001	0.0001	16.8480	0.0000	0.4835
Iceland1	Iceland	S	Iceland	0.0873	0.6790	0.0670	0.0003	0.0012	0.0002	0.6811	0.0001	3.4036	0.0044	0.0001	0.0002	15.3894	0.0001	0.5372
Iceland10	Iceland	S	Iceland	0.0835	0.4136	0.0949	0.0001	0.0013	0.0005	0.8788	0.0002	2.3873	0.0068	0.0001	0.0001	16.2487	0.0001	0.6576
Iceland11	Iceland	S	Iceland	0.0377	0.5175	0.2051	0.0002	0.0013	0.0002	0.5998	0.0002	3.5053	0.0012	0.0002	0.0001	14.7734	0.0000	0.5345
Iceland12	Iceland	S	Iceland	0.0622	0.6199	0.0704	0.0001	0.0001	0.0004	0.7506	0.0003	5.1517	0.0034	0.0001	0.0001	16.4307	0.0001	0.5861
Iceland13	Iceland	S	Iceland	0.0755	0.7249	0.0910	0.0001	0.0016	0.0007	0.6651	0.0004	6.0044	0.0006	0.0000	0.0001	18.7296	0.0002	0.3596
Iceland14	Iceland	S	Iceland	0.0597	0.5022	0.0469	0.0015	0.0057	0.0010	0.7733	0.0003	6.8530	0.0017	0.0001	0.0019	15.4003	0.0026	0.4276
Iceland15	Iceland	S	Iceland	0.0508	0.7233	0.0724	0.0001	0.0001	0.0003	0.7083	0.0000	3.0220	0.0006	0.0001	0.0001	14.2675	0.0002	0.4755
Iceland16	Iceland	S	Iceland	0.0846	0.6361	0.0750	0.0000	0.0015	0.0006	0.6667	0.0001	5.1823	0.0040	0.0002	0.0001	19.7392	0.0001	0.5101
Iceland17	Iceland	S	Iceland	0.0249	0.5293	0.0343	0.0001	0.0001	0.0004	0.7354	0.0000	5.1174	0.0012	0.0001	0.0001	17.3733	0.0001	0.5552
Iceland18	Iceland	S	Iceland	0.0302	0.5426	0.0853	0.0001	0.0011	0.0003	0.8089	0.0000	3.7180	0.0042	0.0001	0.0001	18.5923	0.0008	0.5431
Iceland19	Iceland	S	Iceland	0.0779	0.3961	0.1097	0.0001	0.0002	0.0007	0.8373	0.0002	2.4890	0.0024	0.0001	0.0001	15.4576	0.0001	0.5826
Iceland2	Iceland	S	Iceland	0.0745	0.3759	0.1484	0.0001	0.0004	0.0003	0.6577	0.0001	4.2687	0.0002	0.0001	0.0001	12.8594	0.0000	0.4831
Iceland20	Iceland	S	Iceland	0.0660	0.4170	0.0502	0.0001	0.0028	0.0010	0.8437	0.0009	2.7849	0.0040	0.0001	0.0001	16.3032	0.0003	0.5434

Appendix D cont.

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Bird ID	Wintering area	M/S	Breeding area	Ag	As	Au	B	Ba	Bi	Ce	Co	Cs	Cu	Fe	Hg
Iceland21	Iceland	S	Iceland	0.0065	0.1625	0.0001	0.2429	0.0500	0.0001	0.0001	0.0042	0.0008	0.8040	46.2218	0.0816
Iceland22	Iceland	S	Iceland	0.0067	0.2282	0.0001	0.9863	0.0171	0.0000	0.0001	0.0058	0.0012	0.9085	40.5844	0.0640
Iceland23	Iceland	S	Iceland	0.0029	0.0966	0.0001	0.6243	0.0220	0.0001	0.0002	0.0064	0.0014	1.0029	29.7007	0.1125
Iceland24	Iceland	S	Iceland	0.0114	0.2111	0.0001	0.2264	0.0350	0.0001	0.0001	0.0055	0.0006	0.8991	41.3649	0.0341
Iceland3	Iceland	S	Iceland	0.0193	0.1116	0.0000	0.4124	0.0588	0.0001	0.0001	0.0048	0.0010	0.8615	41.2889	0.1006
Iceland4	Iceland	S	Iceland	0.0036	0.1478	0.0001	1.2417	0.0152	0.0001	0.0001	0.0067	0.0022	0.9780	30.0836	0.1159
Iceland5	Iceland	S	Iceland	0.0176	0.1184	0.0001	0.6223	0.0588	0.0001	0.0002	0.0052	0.0010	1.4095	38.5302	0.1162
Iceland6	Iceland	S	Iceland	0.0028	0.0914	0.0001	0.4948	0.0320	0.0001	0.0002	0.0061	0.0013	1.0234	31.4881	0.0793
Iceland7	Iceland	S	Iceland	0.0045	0.0993	0.0001	0.7841	0.0376	0.0000	0.0001	0.0030	0.0014	1.1777	31.2213	0.0810
Iceland8	Iceland	S	Iceland	0.0056	0.1440	0.0000	0.9098	0.0231	0.0000	0.0001	0.0053	0.0012	0.8873	31.8797	0.0840
Iceland9	Iceland	S	Iceland	0.0017	0.1082	0.0001	0.6994	0.0210	0.0000	0.0001	0.0043	0.0014	1.1364	32.0836	0.0837
Selvaer1	Norway	S	Norway	0.0100	0.4978	0.0000	0.3407	0.0338	0.0001	0.0000	0.0029	0.0007	1.0869	28.7328	0.0625
Selvaer10	Norway	S	Norway	0.0120	0.3685	0.0001	0.4714	0.0267	0.0001	0.0000	0.0033	0.0009	0.9239	34.7582	0.1302
Selvaer11	Norway	S	Norway	0.0251	0.5005	0.0001	0.4584	0.0900	0.0001	0.0001	0.0029	0.0010	0.9328	54.3968	0.0980
Selvaer13	Norway	S	Norway	0.0127	0.2304	0.0000	0.4210	0.0358	0.0001	0.0003	0.0037	0.0008	0.8942	47.6537	0.0736
Selvaer14	Norway	S	Norway	0.0093	0.3537	0.0001	0.5884	0.0633	0.0001	0.0000	0.0048	0.0011	0.9378	35.3351	0.1013
Selvaer15	Norway	S	Norway	0.0086	0.4417	0.0001	0.3444	0.0432	0.0000	0.0000	0.0025	0.0008	0.9580	28.1515	0.0475
Selvaer16	Norway	S	Norway	0.0258	0.2380	0.0000	0.3359	0.0337	0.0000	0.0001	0.0027	0.0009	0.9097	36.8720	0.1201
Selvaer17	Norway	S	Norway	0.0183	0.5151	0.0001	0.6252	0.0423	0.0001	0.0001	0.0035	0.0006	0.9534	45.3365	0.1384
Selvaer2	Norway	S	Norway	0.0121	0.3929	0.0000	0.2509	0.0576	0.0000	0.0000	0.0028	0.0010	0.9164	33.4142	0.0737
Selvaer3	Norway	S	Norway	0.0165	0.5446	0.0001	0.4760	0.0511	0.0000	0.0000	0.0018	0.0012	1.0816	46.6332	0.0830
Selvaer5	Norway	S	Norway	0.0045	0.3800	0.0001	0.3973	0.0751	0.0001	0.0001	0.0035	0.0010	0.9691	48.3491	0.0680
Selvaer6	Norway	S	Norway	0.0117	0.4487	0.0001	0.3425	0.0767	0.0001	0.0000	0.0027	0.0008	1.0692	34.7579	0.0351
Selvaer7	Norway	S	Norway	0.0141	0.2252	0.0001	0.5279	0.6783	0.0001	0.0001	0.0024	0.0009	0.8906	45.9587	0.0520
Selvaer9	Norway	S	Norway	0.0230	0.6904	0.0001	0.4128	0.1126	0.0001	0.0001	0.0039	0.0012	0.9620	44.7290	0.0672

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Bird ID	Wintering area	M/S	Breeding area	Li	Mn	Mo	Nd	Ni	Pb	Rb	Sn	Sr	Tl	U	Y	Zn	Zr	Se
Iceland21	Iceland	S	Iceland	0.0232	0.4421	0.0738	0.0001	0.0015	0.0003	0.7092	0.0002	4.1250	0.0022	0.0001	0.0001	16.6293	0.0002	0.6087
Iceland22	Iceland	S	Iceland	0.0777	0.6040	0.0311	0.0001	0.0001	0.0003	0.7300	0.0001	1.8876	0.0036	0.0001	0.0001	14.4890	0.0001	0.5821
Iceland23	Iceland	S	Iceland	0.0516	0.4057	0.0609	0.0001	0.0017	0.0002	0.8103	0.0001	3.5125	0.0026	0.0001	0.0001	14.8938	0.0001	0.5111
Iceland24	Iceland	S	Iceland	0.0377	0.5673	0.1325	0.0001	0.0001	0.0002	0.5922	0.0000	3.4648	0.0047	0.0001	0.0001	19.2918	0.0001	0.4951
Iceland3	Iceland	S	Iceland	0.0718	0.5778	0.0227	0.0001	0.0001	0.0002	0.8593	0.0002	3.8949	0.0043	0.0001	0.0001	18.2451	0.0000	0.7013
Iceland4	Iceland	S	Iceland	0.1400	0.5947	0.0713	0.0001	0.0012	0.0003	1.0507	0.0002	2.8177	0.0088	0.0001	0.0001	13.5766	0.0001	0.5822
Iceland5	Iceland	S	Iceland	0.1015	0.5996	0.0286	0.0001	0.0016	0.0005	0.8509	0.0002	3.4125	0.0042	0.0001	0.0001	17.4066	0.0001	0.6665
Iceland6	Iceland	S	Iceland	0.0660	0.3343	0.0488	0.0001	0.0001	0.0002	0.8171	0.0002	4.7163	0.0022	0.0001	0.0001	15.0591	0.0000	0.5054
Iceland7	Iceland	S	Iceland	0.0843	0.6432	0.0427	0.0000	0.0000	0.0004	0.8203	0.0004	4.0224	0.0021	0.0001	0.0001	16.8867	0.0001	0.4999
Iceland8	Iceland	S	Iceland	0.0754	0.4695	0.0391	0.0000	0.0000	0.0003	0.7712	0.0002	1.9271	0.0073	0.0001	0.0001	16.6207	0.0000	0.6274
Iceland9	Iceland	S	Iceland	0.0593	0.5259	0.0461	0.0000	0.0012	0.0005	0.8372	0.0001	3.2756	0.0035	0.0001	0.0001	13.0997	0.0001	0.4661
Selvaer1	Norway	S	Norway	0.0602	0.3468	0.0226	0.0000	0.0000	0.0008	0.4459	0.0002	4.0040	0.0001	0.0000	0.0000	14.5893	0.0000	0.6982
Selvaer10	Norway	S	Norway	0.1298	0.2800	0.0277	0.0001	0.0014	0.0007	0.6587	0.0003	2.3593	0.0047	0.0002	0.0000	14.0233	0.0001	0.5527
Selvaer11	Norway	S	Norway	0.2291	0.2929	0.0200	0.0001	0.0001	0.0020	0.5666	0.0004	5.1650	0.0028	0.0003	0.0001	18.9467	0.0001	0.8234
Selvaer13	Norway	S	Norway	0.0884	0.5281	0.0584	0.0001	0.0014	0.0009	0.6119	0.0003	3.4879	0.0027	0.0001	0.0001	16.9758	0.0001	0.5214
Selvaer14	Norway	S	Norway	0.5097	0.4851	0.0417	0.0000	0.0000	0.0011	0.6728	0.0005	2.2238	0.0035	0.0001	0.0000	15.2028	0.0000	0.6244
Selvaer15	Norway	S	Norway	0.0831	0.2472	0.0186	0.0000	0.0000	0.0006	0.4790	0.0003	4.1830	0.0002	0.0000	0.0000	14.0300	0.0000	0.5455
Selvaer16	Norway	S	Norway	0.0852	0.2896	0.0200	0.0001	0.0001	0.0008	0.6266	0.0003	3.7450	0.0032	0.0001	0.0001	13.9047	0.0000	0.7114
Selvaer17	Norway	S	Norway	0.2819	0.3890	0.0332	0.0001	0.0014	0.0010	0.4064	0.0003	4.1724	0.0050	0.0001	0.0001	16.8703	0.0000	0.8322
Selvaer2	Norway	S	Norway	0.0661	0.2339	0.0333	0.0000	0.0012	0.0008	0.6633	0.0001	4.6045	0.0005	0.0000	0.0001	15.4899	0.0001	0.5376
Selvaer3	Norway	S	Norway	0.0550	0.4635	0.0500	0.0000	0.0000	0.0007	0.6224	0.0001	5.5627	0.0009	0.0002	0.0000	18.0974	0.0001	0.5823
Selvaer5	Norway	S	Norway	0.3433	0.4449	0.0199	0.0000	0.0000	0.0012	0.7072	0.0005	4.1119	0.0021	0.0001	0.0000	18.2051	0.0000	0.5955
Selvaer6	Norway	S	Norway	0.0864	0.2315	0.0201	0.0000	0.0000	0.0007	0.4887	0.0001	5.5495	0.0002	0.0000	0.0001	16.4762	0.0000	0.5310
Selvaer7	Norway	S	Norway	0.0758	0.3710	0.0413	0.0000	0.0001	0.0015	0.6459	0.0005	4.8227	0.0017	0.0001	0.0001	17.7421	0.0000	0.4804
Selvaer9	Norway	S	Norway	0.2637	0.4221	0.0179	0.0001	0.0014	0.0016	0.8347	0.0005	4.0037	0.0042	0.0004	0.0001	20.7224	0.0002	0.6130

Appendix E

Concentrations of toxic elements arsenic (As), mercury (Hg), lead (Pb) and selenium (Se) in eggs of common eiders grouped by migration strategy (migratory or sedentary) and wintering area (Iceland or Norway). Sample size is indicated by n. Concentrations are in whole egg, given on a wet weight (ww) basis in µg/g. Mean is shown ± standard deviation.

Breeding area	**Wintering area**	**Strategy**	**Element**	*n*	*Mean*	*Median*	*Min*	*Max*
Svalbard	N. Norway	Migratory	*As*	12	0.11 ± 0.03	0.12	0.07	0.17
Svalbard	Iceland	Migratory		58	0.12 ± 0.05	0.1	0.05	0.3
N. Norway	N. Norway	Sedentary		14	0.41 ± 0.13	0.41	0.22	0.69
NE Iceland	NE Iceland	Sedentary		24	0.14 ± 0.04	0.13	0.08	0.25
Svalbard	N. Norway	Migratory	*Hg*	12	0.09 ± 0.05	0.07	0.03	0.19
Svalbard	Iceland	Migratory		58	0.09 ±0.04	0.08	0.02	0.25
N. Norway	N. Norway	Sedentary		14	0.08 ± 0.03	0.07	0.03	0.13
NE Iceland	NE Iceland	Sedentary		24	0.08 ± 0.02	0.08	0.03	0.13
Svalbard	N. Norway	Migratory	*Pb*	12	0.005 ± 0.002	0.005	0.002	0.008
Svalbard	Iceland	Migratory		58	0.004 ± 0.005	0.003	0.0008	0.033
N. Norway	N. Norway	Sedentary		14	0.001 ± 0.0004	0.0003	0.0005	0.002
NE Iceland	NE Iceland	Sedentary		24	0.0004 ± 0.0002	0.0008	0.0001	0.0009
Svalbard	N. Norway	Migratory	*Se*	12	0.55 ± 0.08	0.54	0.45	0.71
Svalbard	Iceland	Migratory		58	0.56 ± 0.11	0.54	0.36	0.85
N. Norway	N. Norway	Sedentary		14	0.61 ± 0.1	0.58	0.48	0.83
NE Iceland	NE Iceland	Sedentary		24	0.54 ± 0.07	0.54	0.35	0.7

Appendix F

Results from ANOVAs of linear models analyzing egg concentrations (ww) from breeding common eiders (*Somateria mollissima*) from Svalbard (n = 64), Northeast Iceland (n = 24) and Northern Norway (n = 14). Each factor represents a separate ANOVA model. ANOVAs for Hg, Se, As and Pb are shown using the following factors: 1) sedentary breeding eiders breeding in Iceland and Norway, 2) migratory Svalbard breeding eiders wintering in Iceland and Norway, 3) breeding eiders wintering in Iceland with different migration strategies, 4) breeding eiders wintering in Norway with different migration strategies and 5) sample year. Statistical significance of <0.05 is denoted with an asterix (*).

Eggs

Element	Factor	n	df	F- statistic	p
Hg	**Wintering area (sedentary eiders)**	38	1	0.031	0.86
	Wintering area (migratory eiders)	64	1	0.38	0.53
	Migration strategy (Iceland wintering eiders)	76	1	3.12	0.08
	Migration strategy (Norway wintering eiders)	26	1	0.0025	0.96
	Year	102	3	0.566	0.637
Se	**Wintering area (sedentary eiders)**	38	1	5.66	0.02 *
	Wintering area (migratory eiders)	64	1	0.003	0.95
	Migration strategy (Iceland wintering eiders)	76	1	0.84	0.36
	Migration strategy (Norway wintering eiders)	26	1	1.59	0.22
	Year	102	3	0.78	0.5
As	**Wintering area (sedentary eiders)**	38	1	91.61	< 0.001 *
	Wintering area (migratory eiders)	64	1	0.037	0.84
	Migration strategy (Iceland wintering eiders)	76	1	0.023	0.87
	Migration strategy (Norway wintering eiders)	26	1	30.4	< 0.001 *
	Year	102	3	10.49	< 0.001 *
Pb	**Wintering area (sedentary eiders)**	38	1	37.97	< 0.001 *
	Wintering area (migratory eiders)	64	1	1.32	0.25
	Migration strategy (Iceland wintering eiders)	76	1	114.93	< 0.001 *
	Migration strategy (Norway wintering eiders)	26	1	28.73	< 0.001 *
	Year	102	3	17.29	< 0.001 *

Appendix G

Results of paired t-test and descriptive statistics for method check between 2012- and 2017-analyses. Values in red indicate significant differences between analyses.

Element	Mean 2012 ug/g	RSD %	Mean 2017 ug/g	RSD %	Std. Deviation	Sig. (2-tailed)
Ag	0.01	9.84	0.01	0.01	0.00	0.31
As	0.09	2.66	0.08	15.76	0.01	0.21
Au	0.00	28.57	0.00	38.32	0.00	0.00
B	0.16	4.10	0.14	2.55	0.01	0.00
Ba	0.17	4.36	0.18	9.75	0.03	0.57
Bi	0.00	7.67	0.00	15.96	0.00	0.35
Ca	823.5	4.2	992.6	2.02	396.46	0.34
Ce	0.000	14.08	0.000	30.39	0.000	0.31
Co	0.006	7.41	0.005	17.15	0.001	0.18
Cs	0.001	6.85	0.001	8.41	0.000	0.71
Cu	1.31	3.02	1.15	2.83	0.04	0.00
Fe	40.31	5.19	39.77	2.43	4.58	0.79
Hg	0.12	2.21	0.12	2.51	0.02	0.46
K	1439.1	5.16	1292.1	2.86	59.79	0.00
Li	0.05	3.83	0.05	3.10	0.01	0.23
Mg	137.05	4.86	136.82	1.92	14.73	0.97
Mn	0.56	3.78	0.57	2.60	0.11	0.89
Mo	0.05	4.11	0.05	7.78	0.01	0.95
Na	1290.2	4.78	1149.4	2.25	54.02	0.00
Nd	0.00	40.16	0.00	43.80	0.00	0.48
Ni	0.07	11.27	0.08	2.31	0.02	0.28
P	2970.2	4.21	2700.6	6.83	340.27	0.11
Pb	0.006	19.2	0.006	1.40	0.001	0.61
Rb	0.79	3.71	0.75	4.07	0.03	0.03
S	2448.3	4.42	2133.2	1.53	128	0.00
Se	0.62	2.30	0.55	12.00	0.04	0.01
Sn	0.00	14.10	0.00	21.54	0.00	0.24
Sr	4.65	4.00	5.13	2.04	1.62	0.50
Tl	0.001	6.52	0.001	14.32	0.000	0.45
U	0.000	10.82	0.000	35.68	0.000	0.44
Y	0.000	13.08	0.000	31.73	0.000	0.30
Zn	19.90	3.86	17.92	2.29	2.02	0.06
Zr	0.00	13.30	0.00	35.98	0.00	0.00