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GRADE / DEGREE

Department of Biology

FACULTÉ, ÉCOLE, DÉPARTEMENT / FACULTY, SCHOOL, DEPARTMENT

Biotransport of Organic Contaminants and Mercury to a costal Food Web in the Canadian High Arctic

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BIOTRANSPORT OF ORGANIC CONTAMINANTS AND MERCURY TO A COASTAL FOOD WEB IN THE CANADIAN HIGH ARCTIC

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Thesis submitted to the

Faculty of Graduate and Postdoctoral Studies

University of Ottawa

in partial fulfillment of the requirements for the

M.Sc. degree in the

Ottawa-Carleton Institute of Biology

Thèse soumise à

Faculté des études supérieures et postdoctorales

Université d'Ottawa

en vue de l'obtention de la maîtrise ès sciences

L'Institut de biologie d'Ottawa-Carleton

Your file Votre référence
ISBN: 978-0-494-58197-1
Our file Notre référence
ISBN: 978-0-494-58197-1

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Abstract

Seabird-derived nutrients enhance plant abundance in coastal ecosystems, increasing rates of primary productivity, and indirectly increasing consumer populations. However, at Cape Vera, concentrations of contaminants in the sediment of ponds below nesting colonies of northern fulmars *(Fulmarus glacialis)* are 10 to 60 times higher than in reference ponds (Blais et al. 2005). This pattern suggests that the colony concentrates hexachlorobenzene (HCB), total mercury (THg), and dichlorodiphenyltrichloroethane (DDT) through guano to pond sediments (Blais et al. 2005). It remains unclear whether the effects of these contaminants are localized to the ponds or whether they enter the food chain. This study was designed to determine whether organochlorines and mercury were transferred from a seabird colony to coastal food webs. Contaminant concentrations were measured in primary producers and animals. Nitrogen stable isotopes were used to detect seabird influence. Concentrations of ΣPCB and ΣDDT in organisms were high relative to other Arctic areas; however, THg concentrations were similar. Snow buntings *(Plectrophenax nivalis)* had ΣPCB (mean: 168 ng/g ww) and ΣDDT (mean: 106 ng/g ww) concentrations that surpassed environmental guidelines for protecting wildlife. Biovector transport may be a source of contaminants to certain organisms at Cape Vera.

Résumé

Les nutriments à base d'oiseaux marins accroissent l'abondance de plantes dans les écosystèmes côtiers, augmentant ainsi les taux de productivité primaire, et augmentant indirectement les populations de consommateurs. Cependant, les concentrations de contaminants dans les sédiments d'étangs sous les sites de nidification des colonies de fulmars boréals *(Fulmarus glacialis)* sont de 10 à 60 fois plus élevées que celles des étangs de référence. Cette tendance suggère que la colonie de fulmars concentre l'hexaclorobenzène (HCB), le mercure total (HgT), et le dichlorophényltrichloroéthane (DDT) via le guano dans les sédiments d'étangs (Blais et al. 2005). Il est incertain si les effets de ces contaminants sont précis aux étangs seuls ou s'ils sont incorporés dans la chaîne alimentaire, menaçant ainsi la faune. Cette étude a été developpée pour déterminer si les contaminants étaient transférés d'une colonie d'oiseaux marins à la faune côtière. Les concentrations de contaminants ont été mesurées dans les producteurs primaires et dans les animaux. Les isotopes stables d'azote sont utilisés pour détecter l'influence d'oiseaux marins. Les concentrations de Σpolychlorobiphényles (BPC) et de ΣDDT dans les organismes étaient élevées comparativement à d'autres régions de l'Arctique; cependant, les concentrations de HgT étaient similaires. Les bruants des neiges *(Plectrophenax nivalis)* possédaient des concentrations de ΣBPC (moyenne: 168 ng/g ps) et de ΣDDT (moyenne: 106 ng/g ps) qui dépassaient les normes environnementales pour la protection de la faune. Le transport biovecteur est possiblement une source de contaminants pour certains organismes de Cape Vera.

Acknowledgements

I would like to thank my supervisor, Jules Blais, for sharing his expertise, knowledge, and advice throughout this project.

I greatly appreciate the expertise, feedback and guidance provided by my committee members, Dr. David Lean and Dr. Ross Norstrom.

Many Cape Vera samples were identified at the Museum of Nature in Aylmer, Quebec. I would particularly like to thank Dr. Irwin Brodo, Dr. Laurie Consaul, and Dr. Kamal Khidas (Museum of Nature) dedicated their time to help identify specimens, and teach me proper identification and dissection techniques.

Dr. Jennifer Keyte (Animal Care Committee at the University of Ottawa) took a lot of time to help approve the techniques and insure they were conducted in a humane manner.

Sample collection would not have been possible without the help of: Mark Mallory and Alain Fontaine (Canadian Wildlife Services), Dr. Robie MacDonald (Department of Fisheries and Oceans), John Smol (Queen's University).

Finally, thank-you to Blais lab-mates and assistants, particularly Linda Kimpe, Samantha Brimble, Angelina Buchar, Brad Mills, Victoria Renner, Martine Gauthier, Karen Foster, Laura Hill, Mayasa Al-Bayati, as well as Emmanuel Yumvihoze and members of the G.G. Hatch Stable Isotopes Lab.

Introduction

The High Arctic is characterized by adverse environmental conditions: long, cold winters; short growing seasons; low summer temperatures; and limited nutrient availability (AMAP 1998). Few species can fill the niches of a High Arctic ecosystem, due to the specific adaptations required. This makes Arctic ecosystems particularly sensitive to environmental change (Bliss 1973).

Sparsely scattered throughout the High Arctic there are areas of high productivity and species diversity known as polar oases. Although they cover only 2% of the High Arctic terrestrial environment and 6% of the Canadian Arctic, these oases are important ecological grazing grounds for small mammals and birds (Freedman et al. 1994, AMAP 1998).

Nutrient-poor High Arctic environments may be transformed into polar oases through the fertilizing actions of biological transport, for example, seabirds are known to transfer allochthonous nutrients to coastal and island ecosystems (Sanchez-Pinero and Polis 2000). At Cape Vera, on Devon Island, Nunavut, Canada (76°15'N, 89°15'W), there is evidence that a large colony of northern fulmars (*Fulmarus glacialis)* play an important role in creating nutrient rich habitat. Beside the cliffs of the nesting seabird colony, Cape Vera is rich with green moss, emergent insects, and small birds and mammals. Beyond the areas of seabird influence at Cape Vera, little plant and animal life exists (Blais et al. 2007).

Along with their role in fertilizing the ecosystem, northern fulmars may be transferring contaminants to the coastal food web. Elevated concentrations of total mercury (THg), dichlorodiphenyltrichloroethane (DDT) and heavy metals have been found in the sediment of the ponds adjacent to the cliffs at Cape Vera relative to reference sites (Blais et al. 2005, Brimble

2008). This study examined seabird-derived nutrients to determine whether they were major contributors of: 1) THg; 2) polychlorinatedbiphenyls (PCBs), and DDT to Cape Vera food webs.

Total mercury (THg) concentrations in the Arctic are high, largely due to atmospheric deposition. Despite reduced emissions in North America and Europe, THg concentrations remain high, and have even increased in some regions (AMAP 2004). Processes unique to the Arctic that are believed to contribute significant quantities of mercury are atmospheric mercury depletion events (AMDE) that occur during polar sunrise in the springtime (AMAP 2004). The importance of AMDE's have come under scrutiny since mercury from depletion events may be reconverted into gaseous elemental mercury and volatized back into the atmosphere (Lahoutifard et al. 2005). Snow melt is also a significant source of THg and methyl mercury (MeHg) to Arctic ecosystems (Loseto et al. 2004).

Biological transport of mercury has been found primarily in salmon, who release contaminants and nutrients to their nursery lakes when they die after spawning (Sarica et al. 2004). However, seabirds from the South China Sea were found to transfer significant quantities of mercury to plants, soil, and sediments through their droppings and potentially their feathers, eggshells, and bones (Liu et al. 2006). In this study, the THg concentrations in lichen, saxifrage, bird, and small mammals, as well as phyto/zooplankton and emergent insect from ponds at Cape Vera were measured and compared to values from reference sites in the High Arctic. Organochlorines are a diverse group of synthetic contaminants that share similar physicochemical characteristics, such as hydrophobicity, resistance to microbial or environmental degradation, and low vapour pressure (Borgå et al. 2004). This study specifically examines PCBs and DDT. PCBs (formula $C_{12}H_{10-n}Cl_n$) are mixtures of chlorinated hydrocarbons. DDT is a persistent insecticide that can be degraded into soils into two stable

metabolites: dichlorodiphenyldichloroethylene (DDE) and dichlorodiphenyldichloroethane (DDD) (Erikson 1997, AMAP 1998). Jewel lichen is an ornithocophilous lichen that grows on bird roosts (McCarthy 1997, Brodo et al. 2001). Pollutants from Eurasia carried by air masses are believed to contribute the largest contaminant burden (Wania and Mackay 1993).

Seabirds transport and concentrate significant quantities of PCBs and DDT to High Arctic and Antarctic ecosystems through guano (Evenset et al. 2004a, Evenset et al. 2004b, Evenset et al. 2007, Roosens et al. 2007). In this study, we measured the concentrations of PCBs and DDT in five organisms (*Xanthoria elegans, Thamnolia vermicularis, Dicrostonyx groenlandicus, Plectrophenax nivalis,* and *Mustela erminea arctica*) and compared their concentrations to those from reference sites. Furthermore, lichens were used as point source indicators to determine if the highest contaminant burdens were in areas most affected by birds. Several studies found that measuring contaminants in lichens was informative for determining spatial patterns (Thomas et al. 1992, Nash and Gries 1995, Chiarenzelli et al. 2001). This study examined two species of lichen that flourish on the coast of Cape Vera: worm lichen (*Thamnolia vermicularis*) and jewel lichen (*Xanthoria elegans*). Contaminant concentrations in jewel and worm lichen were measured along gradients of seabird influence as determined by nitrogen stable isotopes values and distance from the cliffs.

2.0 - Spatial patterns of mercury accumulation in relation to stable isotopes of carbon and nitrogen in the food web linked to seabird-derived nutrients at Cape Vera, Devon Island, Nunavut, Canada

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2.1-Abstract

At Cape Vera, Devon Island, Nunavut, Canada, a colony of northern fulmars (*Fulmarus glacialis)* concentrates and releases nutrients through the deposition of guano to the coastal environment, thus creating habitats important to insects, birds, and mammals by fertilizing the ecosystem. However, high concentrations of total mercury were also detected in the sediments of ponds located below colonies of nesting fulmars relative to reference ponds (Blais et al. 2005). It is unknown whether these contaminants are transferred to the food webs. The purpose of this study was to determine whether mercury was transferred from a large seabird colony to coastal food webs. Stable isotopes ($\delta^{15}N$, $\delta^{13}C$) were used to identify trophic linkages and possible routes of contaminant transfer in the food web. The relationship between nitrogen stable isotopes and THg concentrations in primary producers and phyto/zooplankton were examined with respect to distance from the seabird colony. Nitrogen stable isotope values increased significantly with decreasing distance from the colony in three of six localized species (jewel lichen, worm lichen, and tufted saxifrage), demonstrating a gradient of seabird influence. Nitrogen stable isotope values of species at Cape Vera were high relative to species from our reference site at Cape Herschel. Carbon stable isotopes showed little variation among terrestrial species, and increased significantly with increasing nitrogen isotopes values in only two of six species (jewel lichen and zooplankton), indicating that carbon isotopes were not influenced by seabirds. Concentrations of THg in primary producers and phyto/zooplankton were not significantly correlated with distance from the seabird colony or $\delta^{15}N$ values, and were similar to other species from the High Arctic. We conclude that $\delta^{15}N$ values in all organisms were affected by seabird guano, but statistical results do not support its influence on THg concentrations or $\delta^{13}C$ values in the food webs.

2.2-Introduction

Long range transport by atmospheric and ocean currents are the major transfer routes of contaminants to the Arctic (Gamberg et al. 2005). However, recent studies have demonstrated that biovector transport, the ability of migratory species to focus and release contaminants at specific receptor sites, may have important consequences to the Arctic (Blais et al. 2007). For example, contaminants can be efficiently transferred to coastal and inland freshwater ecosystems via migratory species (Ewald et al. 1998, Krümmel et al. 2003, Evenset et al. 2004a, Blais 2005). This form of contaminant transport may be particularly significant in the Arctic, where many bird, fish, and mammal species congregate as seasonal migrants.

At Cape Vera, Devon Island, Nunavut, a colony of 11,000 breeding pairs of northern fulmars (*Fulmarus glacialis*) serve as keystone species by supporting a rich and diverse ecosystem adjacent to their nesting sites through fertilization via guano, feathers, stomach oils, and mortality. During the breeding season, fulmars forage hundreds of kilometres away from Cape Vera in the North Water Polynya of Baffin Bay (Mallory 2006). After feeding from the marine ecosystem, fulmars return to their nesting sites on the cliffs at Cape Vera, where they fertilize the ecosystem below (Blais et al. 2005). Since the High Arctic terrestrial environment is very nutrient poor, seabird guano is an important subsidy for plant growth and primary productivity (Cocks et al. 1998).

Evidence for nutrient enrichment of ponds at Cape Vera by seabirds has been quantified by algal growth, water quality variables, and nitrogen stable isotopes (Blais et al. 2005, Keatley et al. 2009). The landscape immediately adjacent to the seabird cliffs of Cape Vera is blanketed by green moss, saxifrage, and lichens; however, areas outside of seabird influence at Cape Vera

have almost no plant and animal life (Blais et al. 2007). Species such as northern collared lemmings (*Dicrostonyx groenlandicus*), ermines (*Mustela erminea Arctica*), snow buntings (*Plectrophenax nivalis*), and Arctic foxes (*Alopex lagopus*) inhabit the most biologically productive areas of Cape Vera.

Although the fulmar colony supplies nutrients to Cape Vera, there is evidence that guano may also be a significant source of contamination to the local ecosystems. Concentrations of hexachlorobenzene (HCB), total mercury (THg) and dichlorodiphenyltrichloroethane (DDT) in sediment from ponds closer to seabird colonies were 10 to 60-fold higher than ponds outside of the area of seabird influence. Although sediment surveys on contaminants have been performed, the effect of these contaminants on local food webs is unknown. The purpose of this study was to determine if species near the fulmar colony have elevated THg concentrations (relative to reference sites) due to fulmar guano. Since the fulmar colony fertilizes the local ecosystem at Cape Vera, we predict that contaminants may enter the food web via the seabird biovector. Contaminant concentrations were measured in several species: lichens, saxifrage, periphyton, mixed zooplankton and phytoplankton, chironomids, lemmings, small birds, and ermines. By analyzing primary producers (lichens, saxifrage, periphyton) and phyto/zooplankton collected from ponds at distances that span a gradient of seabird influence and using stable isotopes of carbon and nitrogen as indicators of seabird derived nutrients, we will determine if guano is a significant source of contamination.

Our first objective was to use stable isotopes and stomach contents to identify trophic linkages in the Cape Vera food web. Carbon stable isotopes remain relatively constant across trophic positions but vary among different carbon sources (Peterson and Fry 1987). Therefore, organisms that derive their carbon from the same source should have similar $\delta^{13}C$ values. Our

null hypothesis was: there should be no significant differences in $\delta^{13}C$ values among species of the same food web. The trophic linkages will be confirmed by identifying stomach contents of the consumers.

Our second objective was to test if stable isotope values ($\delta^{15}N$, $\delta^{13}C$) were enriched in primary producers and animals near the seabird colony. Organisms take up both nitrogen isotopes (^{14}N, ^{15}N) through diet, but preferentially remove the lighter ^{14}N isotope through the excretion of ammonia and urea. As a result of the continuous elimination of the lighter isotope, $\delta^{15}N$ values increase 3 to 4‰ (2.4‰ for birds) with each trophic level in a food web. Nitrogen stable isotopes ($\delta^{15}N$) are frequently used as tracers of nutrient input from biovectors to local ecosystems at food webs (Evenset et al. 2004b, Blais et al. 2005, Gregory-Eaves et al. 2007). Guano from fulmars, which is already enriched in $\delta^{15}N$ (14.1‰) relative to the atmosphere (0 ‰), is deposited mostly as uric acid and transformed by microorganisms into ammonia and nitrate (Mizutani and Wada 1988, Blais et al. 2005). Volatization of ammonia results in further isotopic fractionation, enriching the $\delta^{15}N$ signature (Mizutani and Wada 1988). Evaporated ammonia is dissolved in rain, which may be precipitated back onto the landscape, continuing the cycle (Lindeboom 1984). We collected several primary producers and phyto/zooplankton from and near fifteen ponds across a 4 km distance gradient from the seabird colony. Our null hypothesis was: $\delta^{15}N$ values in localized species are independent of distance from the colony.

Unlike nitrogen, seabird-derived organic carbon undergoes little fractionation once deposited into the soil (Mizutani and Wada 1988). Seabird guano is not a direct contributor of high $\delta^{13}C$ values to sediment and biota; however, large inputs of nitrogen through guano can increase primary productivity rates of algae and periphyton (Mizutani and Wada 1988, Cocks et al. 1998, Wainwright et al. 1998, Evenset et al. 2004a, Gregory-Eaves et al. 2007). Increased

productivity and growth rates of pond primary producers can lead to a decrease in carbon fractionation as a result of increased carboxylation rates, and as a result, less discrimination against the heavier ^{13}C isotope leading to an increase in $\delta^{13}C$ values (Wainwright et al. 1998, Gu et al. 1999). Since $\delta^{13}C$ remains relatively constant within a food web, the enriched $\delta^{13}C$ values from primary producers will be passed on to their consumers. We predict that across a distance gradient of seabird influence, $\delta^{15}N$ values should increase significantly with $\delta^{13}C$ values within a localized species. The specific null hypothesis was: $\delta^{15}N$ values in primary producers and phyto/zooplankton are independent of $\delta^{13}C$ values. Since the Arctic tundra and terrestrial environment are depleted in ^{13}C and ^{15}N, stable isotope values in primary producers affected by seabird-derived nutrients should be significantly higher than background values from reference sites.

Our third objective was to test to determine if total mercury (THg) concentrations in food webs at Cape Vera may be influenced by seabird guano. Although data are scarce, THg concentrations in terrestrial High Arctic species are generally low (AMAP 1998, Poissant et al. 2008). In small mammals, THg concentrations ranged from 40 to 250 ng/g (ww) in the liver of red backed voles (*Clethrionomys rutilus*) and snowshoe hare (*Lepus americanus)* from the Northwest Territories (Poissant et al. 2008). THg concentrations in wolf (*Canis lupus)* tissues, the top terrestrial carnivore in the Northwest Territories, were reported well below levels that cause adverse effects (30μg/g), and ranged from 180 ± 60 to 1060 ± 610 ng/g (ww) and 30 ± 20 to 1450 ± 2240 ng/g(ww) (Poissant et al. 2008).

Although the main pathway of mercury to Arctic ecosystems is the atmosphere, THg and methyl mercury (MeHg) have the potential for biovector transport (Sarica et al. 2004, Sarica et al. 2005, Blais et al. 2007). On the Dongdao Island of the South China Sea, Hg concentrations in

plant, soil, and sediment samples were significantly higher at nesting sites of red-footed booby (*Sula sulai)* colonies than those from control sites without the influence of bird droppings (Liu et al. 2006) . If fulmar guano was a significant source of THg to food webs, we expect THg concentrations in organisms from Cape Vera to be significantly higher than organisms from reference sites that receive their THg from abiotic sources. We analyzed THg concentrations in primary producers and phyto/zooplankton across a distance gradient from the seabird colony.The specific null hypothesis was: THg concentrations in localized species are independent of distance from the seabird colony. If nitrogen stable isotopes were indicators of seabird influence, we also predict that THg concentrations in primary producers and consumers increased significantly with $\delta^{15}N$ values. The null hypothesis was: THg concentrations are independent of $\delta^{15}N$ values in localized species.

2.3-Methods

2.3.1- Study Area

Cape Vera is located on Devon Island, Nunavut (Figure 2.1; 76°15' N, 89°15'W). Cliffs run along the coastline of Cape Vera 245 to 313 metres above sea level. Approximately 11, 000 breeding pairs of northern fulmars have nests along 6.4 km of the cliffs (Gaston et al. 2006). A series of 12 sites adjacent to ponds (CV5, 6, 8, 9, 9a, 10, 13-15, 20, 30, 31) located below the seabird cliffs with distances spanning a 4 km gradient of ornithogenic influence were sampled at Cape Vera (Figure 2.1) (Blais et al. 2005).

Samples of lichen and saxifrage were collected at different elevations and from rocky ledges at the base of the seabird cliff. Jewel lichen samples were collected on the cliffs at

elevations of 119 and 140 metres above sea level. Worm lichen was collected on the cliffs at 65 metres. Saxifrage and lichen samples were also collected along a rocky ledge 6 metres high at the base of the cliff, next to CV43 approximately 34 metres from main cliff of the colony.

Reference sites

Reference (background) ponds (CV 1, 12, 40) were located approximately 2.5 to 4 km away from the immediate influence of the seabird colony and were chosen based on their distance from the colony. Lichen, saxifrage, periphyton, and zooplankton samples were also collected from or near ponds (Pond 12, Willow and Horseshoe pond) at Cape Herschel (n=3), an area without seabirds on Ellesmere Island (Figure 2.2; 78°37'N, 74°42'W).

2.3.2-Sample Collection and Preparation

All food web samples were collected between July 1 to July 20, 2006, and July 8 to July 21, 2007. Lichens, saxifrage, and fungi were collected near ponds along a gradient of seabird influence spanning approximately 4 km (Brimble 2008). Lichens (*Xanthoria elegans,* jewel lichen; *Thamnolia vermicularis,* worm lichen), whole flowers (*Saxifraga oppositifolia,* purple saxifrage; *Saxifraga caespitose,* tufted saxifrage), and fungi were collected in 50 mL falcon tubes that were pre-rinsed with acetone and hexane, or in sterile Whirlpaks®. Three falcon tubes of each lichen species were collected near the 13 ponds in 2006. In 2007, samples of worm and jewel lichen were taken from varying altitudes along the seabird cliff and at control sites CV1 and Cape Herschel on Ellesmere Island. *X. elegans* was scraped off of flat rocks using field knives that were wiped clean and dry between pond sites. *T. vermicularis* were collected using

stub-ended large tweezers. Samples were put on sea ice in a cooler until they were transferred to the freezer room at the Polar Continental Shelf Project (PCSP) base at Resolute Bay, Nunavut.

Approximately two tubes of each saxifrage species were collected near each pond at Cape Vera (n=13) in 2006. In 2007, additional samples from the cliffs, CV1, and Cape Herschel were collected. Samples were stored on sea ice in a cooler until they were transferred to a freezer room at the PCSP at Resolute Bay, and then were shipped frozen to Ottawa. Saxifrage and lichen samples were weighed and freeze-dried for 48 hours. They were then homogenized using a Magic Bullet® blender in preparation for total mercury (THg) and stable isotope analysis. The blender blade and plastic bowl were cleaned and rinsed with distilled water and ethanol, then dried completely between samples.

From each pond, periphyton, mixed samples of zooplankton and phytoplankton, and chironomids samples were collected. Periphyton samples were collected in 2007 from 13 ponds at Cape Vera and two from Cape Herschel. Before sampling, GF/F 47 mm filters were ashed in a muffle furnace at 500 °C for 5 hours and sealed in Petri dishes. Rocks were collected along the shoreline of each pond in water 0.01 to 0.5 m deep. Rocks were scrubbed on site vigorously in a 9"x9" steel coated baking pan filled with 250 mL of pond water using a nail brush specific to each pond. Surface areas of the periphyton were determined by wrapping the rocks with tinfoil and using the surface area to mass ratio calculated for the foil. The periphyton mixture was then filtered through a GF/F 47 mm filter using an electric pump. The filters were placed in a Petri dish and sealed in a Whirl-Pak® bag. Samples were placed on sea ice in a cooler until they were transferred to the freezer room at PCSP. At the University of Ottawa, samples were weighed and freeze-dried for 48 hours, scraped from filters, and homogenized using a clay mortar and pestle.

Zooplankton and phytoplankton samples were collected by horizontal hauls at depths of approximately 1 m using a plankton net (mesh size 61 μm) and placed in 50 mL falcon tubes that were pre-rinsed with acetone and hexane. Three falcon tubes were collected from each pond at Cape Vera (n=13) and Cape Herschel in 2006. Chironomid samples were collected from 2005 to 2007 from eleven ponds at Cape Vera using emergent and malaise traps as well as an aerial insect net. The malaise trap was placed by the edge of a pond, entrapping newly emerged adult chironomids. The aerial insect net was used to catch adult chironomid swarms at a pond. Upon collection, both chironomid and zooplankton samples were put on sea ice in a cooler until they were transferred to PSCP. Sample identification was conducted using a dissection microscope at the University of Ottawa, and a subset of each sample was preserved in alcohol.

Several small animals were collected from Cape Vera. Fifty Victor® snap traps were set in 2006 and 2007 beside burrows of *Dicrostonyx groenlandicus*, the northern collared lemming, and checked every morning and evening. Weight, sex, mass and body length of all lemmings were recorded.

We captured 25 snow buntings (*Plectrophenax nivalis)*, 11 in 2006 and 14 in 2007, in Victor® traps or by shooting with a 12 gauge shot gun using steel pellets. All buntings were sexed and sealed in Ziploc freezer bags. In 2007, five buntings were captured from CV1 as controls. In 2007, two ermine (*Mustela erminea arctica)* were captured (one by snap trap and the other shot). We took GPS coordinates at all capture sites, and put carcasses on sea ice in a cooler until they were transferred to freezers at PCSP.

At the University of Ottawa, animal samples were dissected and prepared for THg and isotope analysis. To verify trophic links within our food web, stomach content identifications

were performed on all animal samples. Mammals were weighed, sexed, and skinned: the gastrointestinal tract was removed for stomach content analysis. Birds were weighed, and plucked of feathers; the gastrointestinal tract was removed for stomach content analysis. Animal samples were homogenized using liquid nitrogen in the M20 IKA Works® Universal Mill. After homogenization, 1-2 g gram subsamples were placed in microcentrifuge tubes for THg and stable isotope analysis. The mill was cleaned with distilled water and ethanol and dried in between samples. All samples were freeze-dried for 72 hours and re-homogenized.

2.3.3-Stable Isotope Analyses

Freeze-dried whole body tissue was used for stable isotope analyses after running a preliminary test between different tissues which showed the stable isotope values for liver to be the same as for whole body (Appendix A). Samples were analyzed for carbon and nitrogen stable isotopes at the G.G. Hatch Isotope Lab at the University of Ottawa. Samples were flash combusted at 1800°C in an elemental analyser (EA) (EA 1110, CE Instruments, Italy). The resulting gases were carried via helium through the EA to purify and separate into N_2 and CO_2. Gases were carried from the EA into an isotope ratio mass spectrometer (DeltaPlus Advantage IRMS, ThermoFinnigan, Germany) for isotope analysis via a Conflo interface (Conflo III). Stable isotope values were reported in δ notation using per mil units (‰), which are defined as follows:

$$\delta^{15}N \text{ or } \delta^{13}C = [(R_{sample}/R_{standard})-1] \times 1000 \quad \text{(Peterson and Fry 1987)}$$

Analytical precision was based on the internal standards Nicotiamide (C-51), ammonium sulphate + sucrose (C-52), caffeine (C-54), and the blind standard L-glutamic acid (C-55).

Carbon stable isotope values were calculated relative to Peedee belemnite (PDB) carbonite normalized to internal standards calibrated to international standards IAEA-CH-6(-10.4‰), NBS-22(-29.91‰), USGS-40(-26.24‰) and USGS-41(37.76‰) with an analytical precision of ±0.2‰. Nitrogen stable isotope values were calculated relative to atmospheric nitrogen (N_2) normalized to internal standards calibrated to international standards IAEA-N1(+0.4‰), IAEA-N2(+20.3‰), USGS-40(-4.52‰) and USGS-41(47.57‰). Triplicate assays were run every sixth sample.

A subset of carbon isotope samples for lichen, saxifrage, periphyton, and zooplankton samples were pretreated for carbonates via acid fumigation to make sure the carbonates of rocks, sediment, and carapaces did not interfere with the isotope values of the organisms. Samples were moistened using high-performance liquid chromatography–grade water and placed in a sealed vessel with an open beaker of HCl for 48 hours. The samples were freeze-dried, re-homogenized, and weighed for isotope analysis. Slight and insignificant differences were observed between carbonate-treated and untreated samples, and only treated samples were used for further analyses.

2.3.4-THg Analysis

Freeze-dried whole body tissue was analyzed for THg concentrations at the University of Ottawa using a Nippon Hg Analyser SP-3D (Nippon Instruments Corporation, Osaka, Japan) with a detection limit of 0.01 ng/sample. Each sample was analyzed with 0.1 M NaOH buffer, calcium hydroxide [$Ca(OH)_2$], activated alumina (Al_2O_3), and 1:1 sodium carbonate (Na_2CO_3) as additive agents. Approximately 10 to 20 mg of lichen, saxifrage, periphyton, fungi, zooplankton,

and stomach contents; and approximately 5 to 10 mg of chironomid, lemming, bunting, and ermine samples were analyzed.

All steel utensils used for dissections (weighing implements, scissors, tweezers, and scalpels) were rinsed with distilled water and American Chemical Society (ACS) grade acetone and hexane before being heated at 200°C in a glassware oven for 12 hours prior to use. Following every fifth sample, a check standard was run for quality control. The mean recovery concentration for the check standard run for lichens and saxifrage was 25.8 out of 25 ng/g (n=16). Mean recovery concentrations for the check standard spanning a period of five run dates was 47.3 out of 50 ng/g (n =38) and 54.2 out of 56 ng/g (n=5). Every sixth sample was run in triplicate. The mean CV for lichen triplicates was 5.39% (n=18) and the mean CV for saxifrage was 5.28% (n=18). The mean CVs for periphyton was 4.1 % (n=6), 2.8% for zooplankton (n=3), and 6.32 for chironomids (n=12). The mean CV for collared lemmings was 3.09 % (n=6), 6.08 % for snow buntings (n=15), and 1.87% for ermines (n=6). All CVs were below 10%.

Each day, replicates of certified reference materials DORM-2 (4.64 ± 0.26 mg/kg; National Research Council of Canada, Ottawa, ON) were run for quality control. Due to the lower than desired recoveries of DORM-2 (89.9%, n=8, CV=7.15 %) and its expiration as a reference material, three replicates of DORM-3 certified reference material (0.382 ± 0.06 mg/kg; National Research Council of Canada, Ottawa, ON) were run with triplicates of each sample type (buntings, ermine, and lemmings) and DORM-2. The mean recovery of DORM-3 was 0.363 mg/kg (95%, n=3) with a CV of 1.6%. In comparison, DORM-2 had a mean recovery of 1429 mg/g (n=4) with a CV of 73.3%, demonstrating its high variability as a reference material. All triplicates of each sample type had CVs less than 6%.

2.3.5-Statistical Analyses

All data were analyzed using Systat® 12 and SigmaPlot® 10 (Systat Software, Point Richmond, CA, USA). Linear regressions in SigmaPlot were used to analyze the relationship between stable isotopes and THg. One-way analyses of variance (ANOVAs) were performed using Systat®12. Distance measurement calculations of the Cape Vera ponds to the seabird cliffs were taken from Brimble (2008). Cape Herschel was not included in the analyses involving distance.

2.4-Results and Discussion

2.4.1-Stable Isotopes and Food Web Structure

Significant differences in $\delta^{13}C$ values were detected between organisms that feed from terrestrial versus the aquatic ecosystems at Cape Vera (ANOVA, $F_{(11,137)}=80.7$, $p<0.001$). Therefore, we reject our first null hypothesis that there are no significant differences in $\delta^{13}C$ values among species in this ecosystem. Tukey HSD pairwise comparisons among species reveal that $\delta^{13}C$ values differ significantly between several species (Appendix Table A.1). Most terrestrial-based organisms (collared lemmings, purple and tufted saxifrage, worm lichen, ermines, and fungi) had similar $\delta^{13}C$ values which were significantly lower than the values associated with aquatic-based organisms (chironomids, zooplankton, and periphyton). Buntings and jewel also had $\delta^{13}C$ values that were significantly lower than aquatic-based species; however, with the exception of ermines and fungi, their $\delta^{13}C$ values were significantly higher than the previously listed terrestrial organisms. Zooplankton and chironomids had similar $\delta^{13}C$ values that were significantly different from the other species. Periphyton $\delta^{13}C$ values were

significantly different from all species. There seems to be greater variation in $\delta^{13}C$ values among freshwater species than terrestrial organisms (Figs. 2.4).

Results made using stable isotope analyses support trophic relationships discussed in the literature on trophic relationships and stomach content analyses. One ermine contained stomach contents of feathers and bones (Table 2.1). It was observed to be raiding a nest before capture, and therefore, its stomach contents are assumed to be a young snow bunting. Although they eat buntings, ermines primarily prey on collared lemmings (Gilg et al. 2006). Similarities between the $\delta^{13}C$ values of ermines and both lemmings and buntings support the ermine's consumption of either prey. Stomach contents of collared lemmings were well digested and difficult to identify, but appeared to be moss (Table 2.1). Based on their very low $\delta^{13}C$ values, collared lemmings feed from the terrestrial ecosystem (Fig 2.3-2.4). The majority of snow bunting stomachs at Cape Vera contained small rocks, seeds, and the remains of macroinvertebrates, were likely chironomids (based on literature and field observations) (Falconer *et al.* 2008). The range of $\delta^{15}N$ values for bunting stomach contents was 5.62 to 20.9 ‰ and from -9.59 to -24.3‰ for $\delta^{13}C$. Snow buntings shot near the control site CV1 had significantly lower $\delta^{15}N$ values (t-test, t_{23}=-3.46, p=0.002) and $\delta^{13}C$ values (t-test, t_{23}=-3.28, p=0.003) than those from the affected ponds at Cape Vera, which may contribute to the high variability of $\delta^{13}C$ values (Fig 2.4). There were no significant differences in $\delta^{15}N$ values among age classes of snow buntings, but hatch-year buntings had significantly higher $\delta^{13}C$ values than adults, implying possible carryover from migration (ANOVA, $F_{2,22}$=5.38, p=0.01).

2.4.2-Stable Isotopes as Indicators of Seabird Derived Nutrients

Nitrogen in seabird guano has undergone several trophic transfers in the marine food web and therefore, will enrich $\delta^{15}N$ signatures of baseline primary producers that acquire this source (Evenset et al. 2007). The mean $\delta^{15}N$ value for chironomids, snow buntings, and ermines was higher than the mean value for northern fulmars (Figure 2.4B). In our assessment of the effect of distance from the seabird colony on $\delta^{15}N$, we have found that half of our species have significant negative relationships between $\delta^{15}N$ and distance from the seabird colony (Fig. 2.5). $\delta^{15}N$ in jewel (Fig 2.5A; r^2 =0.35, p=0.02, n=16) worm lichen (Fig. 2.5B; r^2 =0.38, p=0.02, n=16), and tufted saxifrage (Fig 2.5C; r^2 =0.37, p=0.02, n=14) increased significantly with decreasing distance from the seabird colony. Nitrogen stable isotope values in the other species increased with decreasing distance from the colony (Fig 2.5). Although individually not significant, the observed trends in six species is significant according to a binomial test (p=0.02).

As an additional analysis, we compared the $\delta^{15}N$ values of organisms to the $\delta^{15}N$ values of sediment from the ponds they were collected from/near. Sediment $\delta^{15}N$ data were provided by Brimble (2008), and were not available for every pond. The $\delta^{15}N$ values of primary producers, phyto/zooplankton and chironomids were significantly related to $\delta^{15}N$ values in pond sediment (Figure 2.6; r^2 =0.37, p<0.001, n=87). The $\delta^{15}N$ values in pond sediment were also significantly related to distance from the seabird cliffs (r^2 =0.30, p=0.04, n=14), supporting an overall gradient of $\delta^{15}N$. We can therefore, reject our second hypothesis that $\delta^{15}N$ values will not increase with decreasing distance from the seabird cliff within a localized species.

We did not find significant relationships between $\delta^{13}C$ and $\delta^{15}N$ values in most species to demonstrate a gradient of seabird influence. There was a positive relationship between $\delta^{13}C$ and $\delta^{15}N$ values in jewel lichen (Table 2.2, Fig 2.7A; r^2 =0.36, p=0.01, n=18) and in

zoo/phytoplankton (Table 2.2, Fig 2.7F; r^2 =0. 29, p= 0.05, n=14) from Cape Vera and Cape Herschel. There was also a positive relationship between $\delta^{13}C$ and $\delta^{15}N$ values in chironomids (Table 2.2). Since carbon stable isotopes had little variation outside of the aquatic environment and showed no relationship to $\delta^{15}N$, they may not be good indicators of seabird influence for terrestrial ecosystems. Similarly, Cocks *et al.* (1998) found little variation in carbon stable isotopes among terrestrial primary producers (lichens and moss) and soil samples collected from nunataks with and without seabirds. Carbon stable isotopes have been useful indicators of seabird influence for aquatic environments, as marine primary producers collected near seabird colonies have expressed gradients of both $\delta^{13}C$ and $\delta^{15}N$ values from offshore to inshore (Wainwright et al. 1998).

In our comparison between Cape Vera and reference site Cape Herschel, nitrogen stable isotope values of organisms collected from Cape Vera did not coincide with those from Cape Herschel. Jewel, worm lichen, and periphyton from Cape Vera had significantly higher $\delta^{15}N$ values than corresponding species (two-sample t-test, jewel: t_{17}=-4.22, p=0.001; worm: t_{15}=-4.62, p<0.001; periphyton: t_{13}=-1.99, p=0.07) from Cape Herschel. Although highly variable, $\delta^{13}C$ values from species at Cape Vera were not significantly different from those species at Cape Herschel (Table 2.3).

In comparison to other Arctic studies, $\delta^{15}N$ and $\delta^{13}C$ values for periphyton, zooplankton, and terrestrial plants from Cape Vera were elevated. In Arctic Lakes on the Mackenzie Delta, periphyton had a $\delta^{15}N$ range of 2.39 to 4.03‰, and $\delta^{13}C$ values ranging from -30.1 to -28.5‰. Zooplankton occupied a secondary trophic position with a $\delta^{15}N$ range of 1.57 to 6.13‰, and $\delta^{13}C$ values from -32.7 to -24.5‰ across different lakes on the Mackenzie River delta (Hecky and Hesslein 1995). These values are considerably lower than the mean $\delta^{15}N$ and $\delta^{13}C$ values of

periphyton and phyto/zooplankton at Cape Vera (Table 2.2). With a mean value of 13.7±1.04‰, collared lemmings at Cape Vera had significantly higher $\delta^{15}N$ values compared to other lemming populations across the Canadian High Arctic. At Bylot Island, the mean $\delta^{15}N$ value for collared lemmings was 1.42‰ (n=18; Giroux 2007, Tarroux 2008) and 4.3 ±0.8 (n=8) at Karrak Lake from 2000 to 2004 (Samelius et al. 2007). However, there was little variation in $\delta^{13}C$ values among collared lemmings.

2.4.3-THg Concentrations and Food Web Structure

Of all the organisms, jewel lichen and fungi had the highest mean concentrations of THg at Cape Vera (Table 2.4). Lichens lack an external root system and absorb most of their nutrients from the atmosphere and are commonly used to monitor spatial and temporal patterns of contaminant concentrations (Nash and Gries 1995, Poissant et al. 2008). Snowmelt has also been cited as a significant source of contaminants to lichen (Ford et al. 1995). Age may be a contributing factor to mercury concentrations in lichen since they are long-lived, have a vegetative thallus they do not shed, and therefore, may be accumulating Hg over a long period of time (Dr. Irwin Brodo, personal communication). Mercury concentrations in lichen can vary greatly by species (Dr. Jesse Ford, personal communication). Soil contamination is the main source of mercury to mushrooms and fungi, which are also effective indicators of local contamination. However, similar to lichen, the ability of fungi to act as point source bioindicators varies by species (Falandysz et al. 2003).

Ermine (mean: 202±29.6 ng/g dw) and snow buntings (mean: 181±27.0 ng/g dw) had the next highest concentrations in THg. However, with a range from 45.9 to 570 ng/g (dw), 30% of the buntings studied from Cape Vera surpassed the mean THg concentration of ermines

(202±29.6 ng/g). There was no difference in THg concentrations between the buntings from CV1 and at Cape Vera; however, age/sex class had a significant effect on THg concentrations (ANOVA, $F_{(2,22)}$=4.09, p=0.03, df=2), with adult males having significantly higher THg concentrations than hatch-year buntings (Tukey HSD test, p=0.031). Unfortunately, ours seems to be the first and only study to report THg levels in snow buntings, so we are unable to compare our results to other sites (AMAP 1998). Based on the available data, there appears to be no THg enrichment of Cape Vera buntings.

2.4.4-THg Concentrations in relation to Seabird Influence

There does not appear to be any relationship between THg concentrations in localized species and distance from the seabird colony. There was a positive significant relationship between distance from the seabird colony and THg concentration in periphyton (Figure 2.8E; r^2 =0.49, p=8.0 x 10^{-3}, n=15), which was opposite of expected. Three other species have positive yet insignificant relationships with THg and distance (Fig 2.8). The only positive significant relationship between THg concentrations and $\delta^{15}N$ values was in worm lichen (Figure 2.9B; r^2 =0.46, p=3.0 x 10^{-3}, n=17). Of the species, four of the six had slightly positive yet insignificant relationships between THg concentrations and $\delta^{15}N$ values, whereas the remaining two had negative trends (Fig 2.8). According to a binomial test, the odds of 4 out of 6 positive relationship was not any more significant than expected by chance (p=0.23), and we cannot reject our null hypothesis that THg concentrations do not increase with $\delta^{15}N$ values within a localized species.

There appears to be no relationship between THg concentrations in localized species with distance or $\delta^{15}N$ values and we must accept both null hypotheses. Some of our results may have

been confounded by "biodilution", where increasing biomass and productivity rates of algae can reduce the uptake of methyl mercury to higher trophic levels (Pickhardt et al. 2002). Ponds closer to the seabird colony are characterized by higher primary productivity rates (Brimble 2008). On the other hand, there are many mercury pathways, and it is difficult to distinguish fulmar guano as a main source. Ocean aerosols have been found to contribute THg concentrations to lichen and vegetation of coastal ecosystems such as Cape Vera (Bargagli et al. 1998, Bargagli et al. 2008).

2.4.5-Total Hg at Cape Vera and Other Regions of the Arctic

THg concentrations in species from Cape Vera coincide with concentrations in species from Cape Herschel, with only worm lichen having significantly higher concentrations at Cape Vera (Table 2.2). Mean THg concentrations in jewel (225$\pm$15.9 ng/g) and worm lichen (161 $\pm$ 18.9 ng/g) from Cape Vera are slightly higher than other Arctic sites (Table 2.3). For example, lichen species collected across the Arctic in Canada, Greenland, Russia, and Finland averaged between 10 and 100 ng/g (dw), and ranged from 72 to 255 ng/g (dw) for 12 lichen species collected from the Central Barrenlands, Nunavut (AMAP 1998, Chiarenzelli et al. 2001). *Cetraria nivalis,* a fructicose lichen had a range of THg concentrations from 10 to 270 ng/g, with a mean value of 90 $\pm$10 ng/g (dw) within a 64,000 km^2 area in Northern Quebec and median values of THg concentrations ranged from 34 to 61 ng/g (dw) for *C. nivalis* from four locations in Greenland (Crête et al. 1992, Riget et al. 2000). Unfortunately, there are no contaminant studies specifically on jewel or worm lichen.

Heavy metal concentrations in the vegetation of the Canadian Arctic is considered low and therefore, THg data for vascular plants such as *Saxifraga oppositifolia* and *S. caespitosa* is

limited (Fisk et al. 2003). Root uptake is the main route of mercury transport for vascular plants. Most THg concentrations for vascular plants across the Arctic are below or near the detection limit (Ford et al. 1995, AMAP 1998). Although it appears saxifrage at Cape Vera have elevated THg concentrations, it is difficult to form a strong conclusion since background data are scarce (AMAP 1998). *Daphnia* from Cape Vera are elevated in THg compared to those from the Arctic National Wildlife Refuge in Alaska, where most had THg concentration below detection limit (20 ng/g) (n=16). There are no available data on Hg concentrations for Arctic microorganisms and insects (AMAP 1998).

THg concentrations of small animals collected from Cape Vera are similar to other Arctic areas. THg concentrations in muscle tissue of collared lemmings averaged 110 ng/g (dw) (2-220 ng/g, n=9) at Baikada River and 70 ng/g (dw) (20-110, n=4) at Lake Nyagamya in the Taimyr Peninsula of Russia (Allen-Gil et al. 2003). Unfortunately, Hg data for ermines is limited, but THg concentrations in ermines from Cape Vera coincide with those found in ermine livers (n=8) from Banks and Victoria Island [range: 80 to 650 ng/g (ww)] (AMAP 1998). However, THg concentrations vary among animal tissues and this must be considered when comparing whole body tissue to liver and muscle (Goldstein et al. 1996, Strom 2008).

2.5-Conclusions and Future Directions

High nitrogen stable isotopes among species at Cape Vera may be the result of seabird-derived nutrients to the ecosystem. The $\delta^{15}N$ values of many organisms were enriched with values that coincided with top predators and mammals in the marine ecosystem of the High Arctic (Dehn et al. 2006). Carbon stable isotopes did not demonstrate enrichment, showing little variation among terrestrial organisms. Total Hg concentrations in worm lichen increased

significantly with $\delta^{15}N$ values across a gradient of seabird influence, but was the only primary producer to do so. There was no relationship between distance or $\delta^{15}N$ values and THg in species, and THg concentrations in species coincide with concentrations found in other High Arctic regions.

Unexpectedly, reference sites CV1 and CV40 had high THg concentrations in most samples. These results were corroborated by Brimble (2008), who reported high concentrations of other trace metals at CV1 and CV40; however, removal of these controls did not improve the THg and $\delta^{15}N$ relationship. Interestingly, samples from the ledge at CV43 had the highest concentration of THg for jewel lichen (369 ng/g), purple saxifrage (140 ng/g), and tufted saxifrage (70.8 ng/g); whereas Cape Herschel had the lowest THg concentrations for tufted saxifrage (15.2 ng/g), periphyton (3.42 ng/g), and worm lichen (72.5 ng/g) (Table 2.3). There could still be a seabird influence on mercury, and perhaps we are not taking into consideration other factors that may be affecting the relationships with distance and $\delta^{15}N$. Future research should examine mercury speciation and measure the concentration of methyl mercury in samples, which would provide clues on other potential sources of mercury.

2.6-Acknowledgements

This study was funded by the Natural Sciences and Engineering Research Council of Canada (NSERC), the Polar Continental Shelf Project, the Canadian Wildlife Service and the Northern Scientific Training Program grants. All collections were made with appropriate animal care permits (University of Ottawa), and territorial and federal research permits. Thanks to Drs. Irwin Brodo, Laurie Consaul and Kamal Khidas at the Canadian Musuem of Nature, who

confirmed identifications. We would also like to thank our colleagues who helped us collect samples.

Table 2.1. Total mercury concentrations [ng/g dw] and carbon and nitrogen isotope values of species collected from Cape Vera and the THg [ng/g dw], carbon and nitrogen isotopes values of their stomach contents.

Sample	Pond	$\delta^{15}N$ (‰)	$\delta^{13}C$(‰)	THg	Stomach Contents	$\delta^{15}N$ (‰)	$\delta^{13}C$(‰)	THg
Bunting	CV1	13.9	-26.3	69.4	80% seeds	7.16	-24.3	N/A
Bunting	CV7	21.1	-19.7	100	60% sand/sediments	14.5	-9.59	16.5
					15% seeds	14.1	-22.2	N/A
Bunting	CV8	19.7	-21.5	272	85% sand	18.6	-6.93	13.4
					15% chironomids	15.5	-23.7	N/A
Bunting	Edge of CV8	16.8	-25.1	116	40% chironomids	18.9	-24.0	N/A
Bunting	Near glacial stream	10.9	-22.3	570	50% chironomids	5.62	-19.9	175
Bunting	CV1	13.1	-21.8	307	30% chironomids	13.1	-19.7	56.8
Bunting	CV10	23.0	-20.8	425	70% chironomids	20.9	-15.9	188
Bunting	CV10	22.2	-13.5	80.8	70% chironomids	19.8	-13.9	86.2
Bunting	CV10	21.0	-15.4	79.9	35% sand/plant material	19.2	-9.67	16.9
Bunting	CV10	21.6	-17.7	86.0	95% chironomids	18.3	-19.3	42.0
Bunting	CV12	15.2	-16.0	57.7	75% chironomids	13.9	-14.8	41.4
Bunting	CV7	20.9	-15.2	84.2	70% chironomids	17.5	-11.3	36.2
Bunting	CV7	16.7	-18.3	106	40% chironomids	13.3	-20.1	66.0
Bunting	CV8	23.2	-19.2	306	25% chironomids	18.7	-19.2	N/A
Bunting	CV8	17.0	-18.1	92.3	80% chironomids	16.9	-22.7	53.4
Lemming	near CV 10	13.3	-28.5	32.1	100% moss	12.5	-28.8	130
Lemming	CV8	13.9	-28.1	65.7	100% moss	12.6	-28.9	81.7
Lemming	CV9	14.3	-27.4	24.1	100% moss	13.6	-29.0	110
Lemming	CV7	10.4	-28.4	10.3	100% moss	9.8	-28.9	132
Lemming	CV8	16.8	-29.2	348	100% moss	15.0	-29.1	57.2
Ermine	CV8	20.4	-25.5	231	50% feathers	19.2	-19.3	320
					50% bunting tissue	20.1	-20.1	203

Table 2.2: Carbon and nitrogen isotope mean values of several species from Cape Vera, Devon Island, Nunavut and Cape Herschel, Ellesmere Island from 2005-2007 (n=147). Correlation analysis was performed between $\delta^{15}N$ and $\delta^{13}C$ values and* indicates significance.

Species	$\delta^{15}N$ (‰)		$\delta^{13}C$ (‰)		r^2	P	n
	Mean ± SE	Range	Mean ± SE	Range			
Worm Lichen	4.14±0.88	-2.62-9.07	-26.3±0.18	-27.5- (-24.8)	0.12	0.18	17
Jewel Lichen	9.37±1.19	-0.62-14.9	-22.1±0.34	-24.2-(-19.2)	0.36	0.01*	18
Purple Saxifrage	7.14±1.10	0.76-13.4	-29.0±1.74	-30.7- (-25.0)	0.11	0.20	16
Tufted Saxifrage	8.60±1.19	0.17-16.6	-28.6±0.47	-30.3- (-23.3)	0.02	0.63	16
Fungi	10.7±1.71	6.4-16.8	-24.7±0.19	-25.1-(-23.9)	0.53	0.10	6
Periphyton	9.94±1.94	0.79-20.4	-9.56±0.74	-13.5-(-3.13)	0.03	0.57	15
Phyto/Zooplankton	12.3±1.66	2.03-21.8	-15.3± 1.28	-25.3- (-8.65)	0.29	0.05*	14
Chironomids	16.5±1.18	9.71-22.7	-15.3±0.67	-20.6- (-13.1)	0.29	0.06	13
Collared Lemming	13.7±1.04	10.4-16.8	-28.3±0.27	-29.1-(-27.4)	0.08	0.65	5
Snow Bunting	18.1±0.73	10.9-23.2	-19.7±0.70	-26.7-(-13.5)	0.04	0.31	25
Ermines	20.3±0.18	20.1-20.4	-25.4±0.08	-25.5-(-25.3)	N/A	N/A	2

Table 2.3: Summary of stable isotope, THg mean concentrations and standard errors of several species from Cape Vera, Devon Island, Nunavut and control site Cape Herschel, Ellesmere Island collected from 2005-2007 (n=96). * indicates significantly higher mean concentration based on t–test ($p<0.05$).

Sample	n	$\delta^{15}N$ (‰)	$\delta^{13}C$(‰)	THg [ng/g dw]
Cape Vera **(Seabird colony)**				
Jewel Lichen	15	10.8±0.98*	-21.9±0.37	231±19.0
Worm Lichen	14	5.38±0.68*	-26.5±0.19	176 ±20.8*
Purple Saxifrage	15	7.66±1.03	-29.0±0.46	47.9±10.1
Tufted Saxifrage	15	9.16±1.12	-28.6±0.50	33.3±3.40
Phyto/Zooplankton	13	13.1±1.72	-14.5±1.11	70.8± 18.6
Periphyton	13	9.94±1.97*	-9.39±0.82	33.9±6.15
Cape Herschel **(Control site)**				
Jewel Lichen	4	1.56±2.18	-23.3±0.50	199 ±10.3
Worm Lichen	3	-1.66±0.49	-25.9±0.52	92.8±11.1
Purple Saxifrage	1	-0.76	-30.1	35.1
Tufted Saxifrage	1	0.17	-29.1	15.2
Phyto/Zooplankton	1	2.03	-25.3	34.6
Periphyton	2	1.01±-0.22	-10.7± 2.11	13.0±9.58

Table 2.4: Mean total Hg and nitrogen isotope mean values of several species from Cape Vera, Devon Island, Nunavut from 2005-2007 (n=147). Regression analysis was performed between THg concentrations and $\delta^{15}N$ values and* indicates significance.

Species	THg [ng/g dw]		$\delta^{15}N$ (‰)		r^2	P	n
	Mean ± SE	Range	Mean ± SE	Range			
Worm Lichen	161 ±18.9	72.5-366	4.14±0.88	-2.62-9.07	0.46	0.003*	17
Jewel Lichen	226 ±16.0	133-370	9.37±1.19	-0.62-14.9	0.05	0.37	18
Purple Saxifrage	47.1 ±9.50	15.3-140	7.14±1.10	0.76-13.4	0.02	0.65	16
Tufted Saxifrage	32.2 ±3.38	15.2-70.8	8.60±1.19	0.17-16.6	0.05	0.41	16
Fungi	247 ±46.0	151-437	10.7±1.71	6.4-16.8	0.10	0.54	6
Periphyton	31.1±5.71	3.42-68.4	9.94±1.94	0.79-20.4	0.06	0.39	15
Phyto/Zooplankton	68.2±17.4	29.9-262	12.3±1.66	2.03-21.8	0.18	0.13	14
Chironomids	58.8±7.17	25.5-101	16.5±1.18	9.71-22.7	0.06	0.44	13
Collared Lemming	96.1±63.7	10.3-348	13.7±1.04	10.4-16.8	0.64	0.11	5
Snow Bunting	181±27.0	45.9-570	18.1±0.73	10.9-23.2	<0.001	0.96	25
Ermines	202±29.6	172-231	20.3±0.18	20.1-20.4	N/A		2

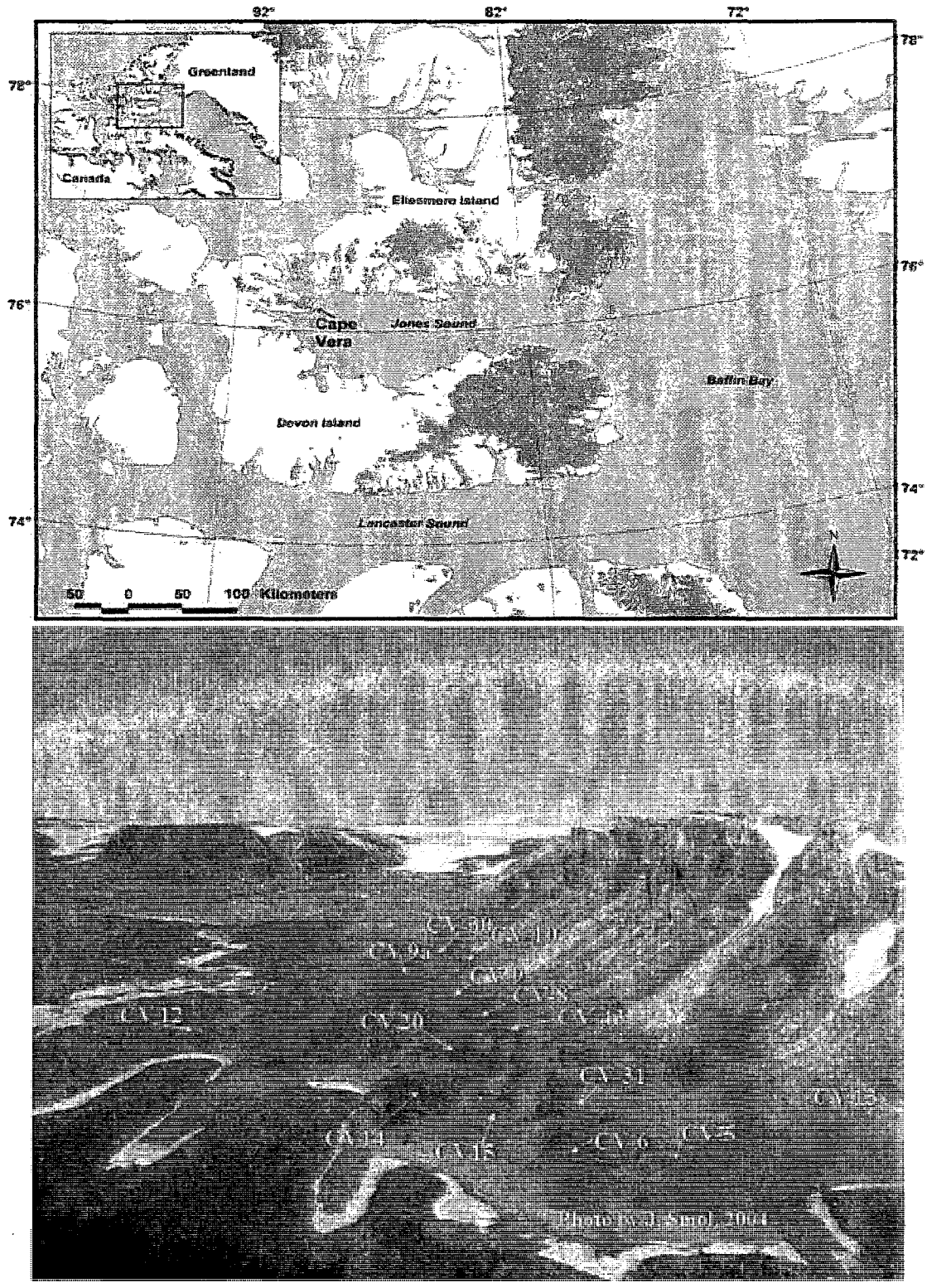

Figure 2.1 Main study site at Cape Vera, Devon Island, Nunavut (76°15' N, 89°15'W). Arrows and labels indicate ponds where samples were collected at the base of the seabird cliffs

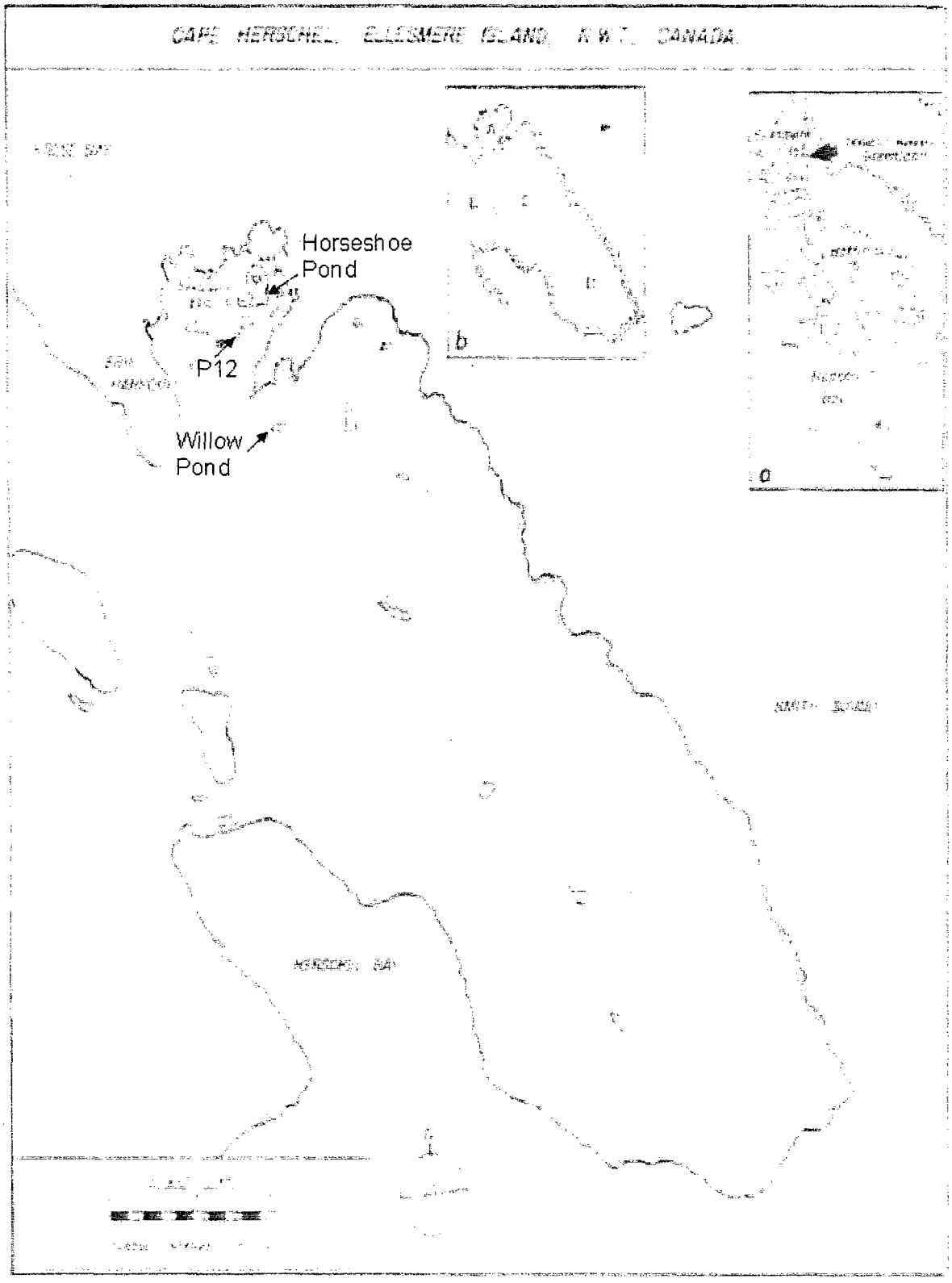

Figure 2.2 Map of control ponds [Willow, Pond 12 (P12), and Horseshoe] sampled from Cape Herschel, Ellesmere Island, Nunavut (78°37'N, 74°42'W) (Douglas and Smol 1994)

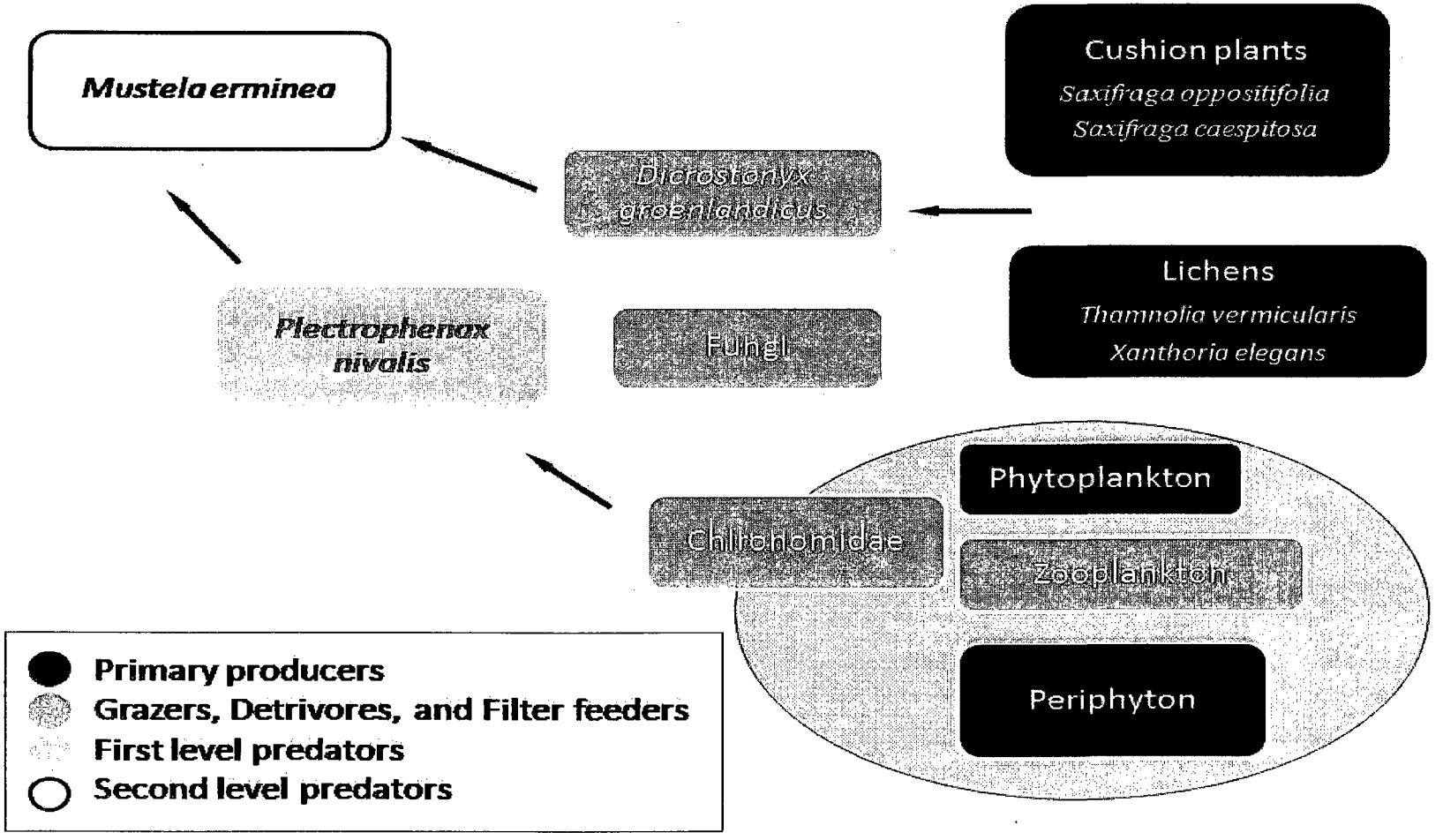

Figure 2.3 Trophic linkages among organisms collected from the coastal ecosystem at Cape Vera, Devon Island, Nunavut, Canada. Trophic linkages are represented by arrows and are supported by stomach content analysis and literature (Krebs et al. 2003, Falconer et al. 2008). The oval represents the ponds at Cape Vera and encompasses the organisms that inhabit it.

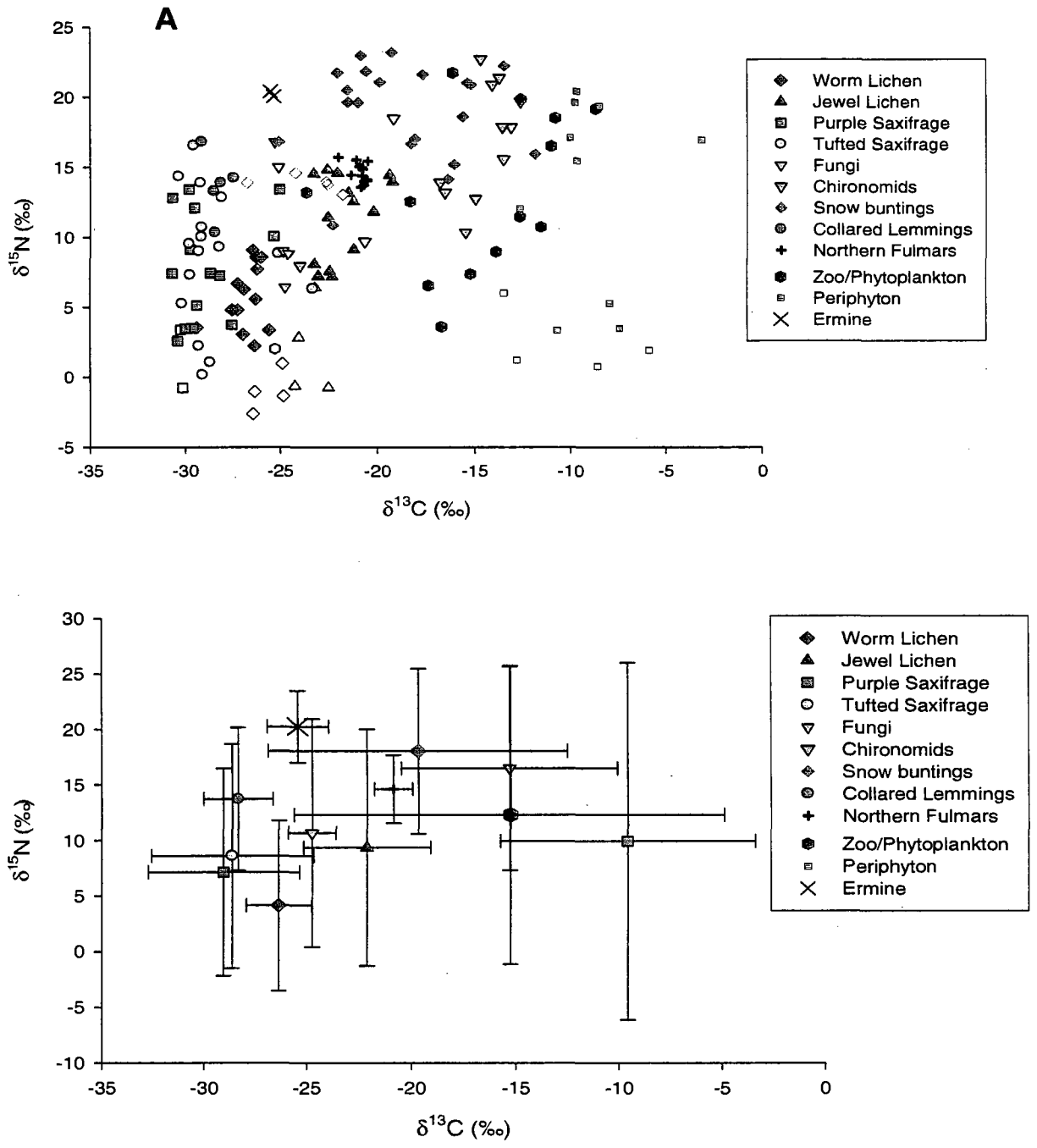

Figure 2.4 A. Carbon and nitrogen isotope values of several species from Cape Vera, Devon Island, and Cape Herschel, Ellesmere Island from 2005-2007 (n=180). Open symbols represent samples from Cape Herschel **B.** The mean carbon and nitrogen isotope values of several species from Cape Vera, Devon Island, and Cape Herschel, Ellesmere Island from 2005-2007 (n=180). Error bars represent the 95% confidence limits. Northern fulmar data are representative of the

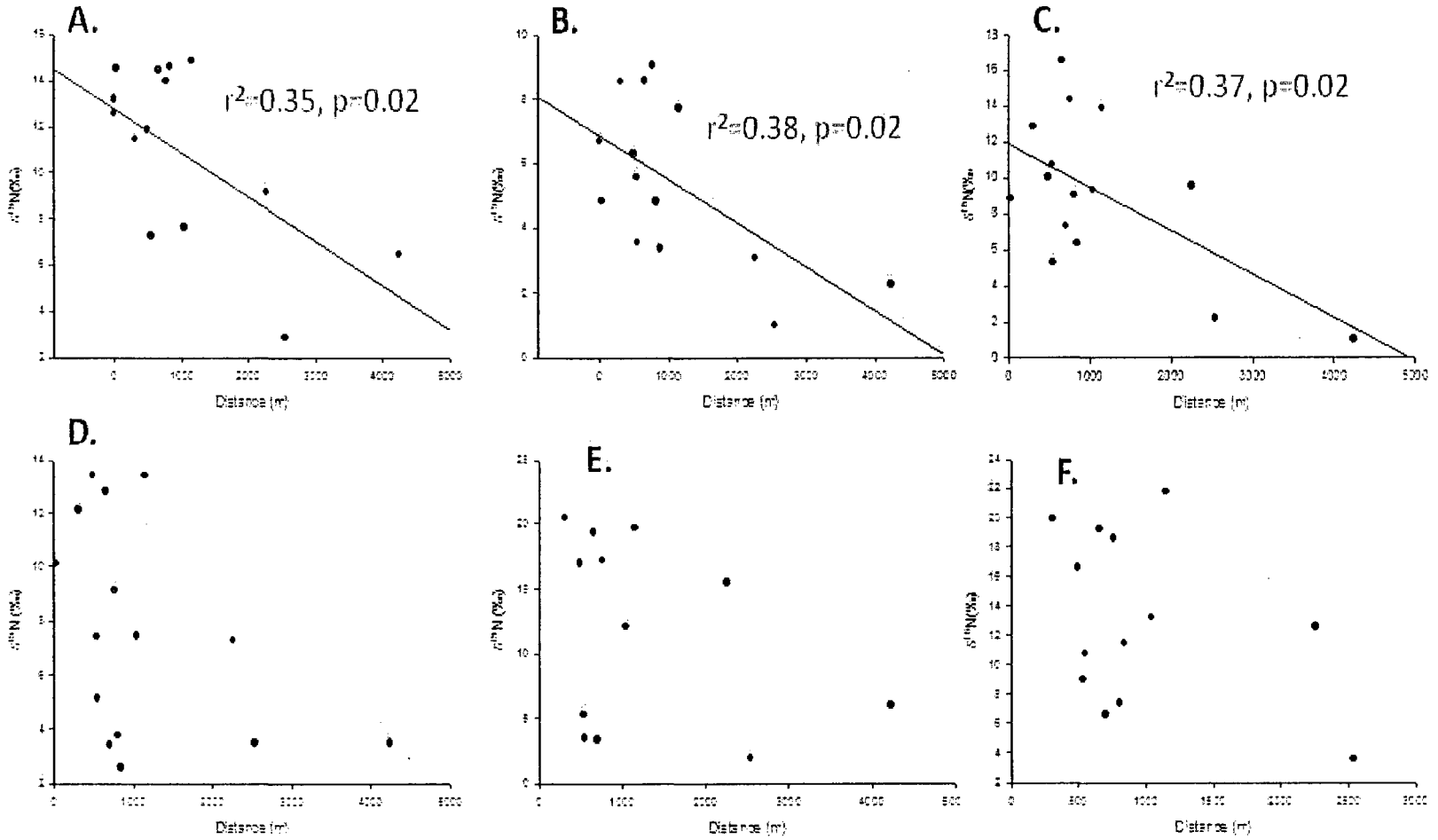

Figure 2.5. The relationship between distance from the cliffs and $\delta^{15}N$ values for A) Jewel lichen B) Worm lichen C) Tufted Saxifrage D) Purple Saxifrage E) Periphyton F) Zooplankton from Cape Vera.

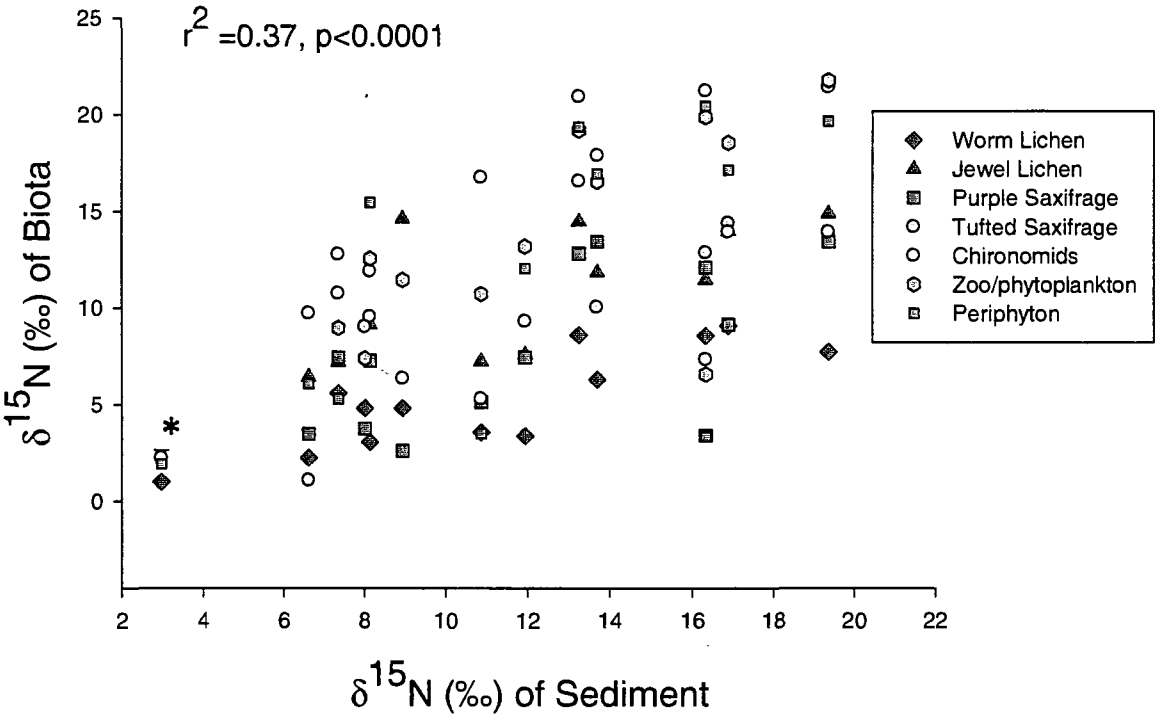

Figure 2.6 The relationship between the $\delta^{15}N$ values of organisms and the sediment from the ponds they were collected from or near at Cape Vera. Sediment $\delta^{15}N$ values were provided by Brimble (2008). * indicates samples collected near reference pond CV 1.

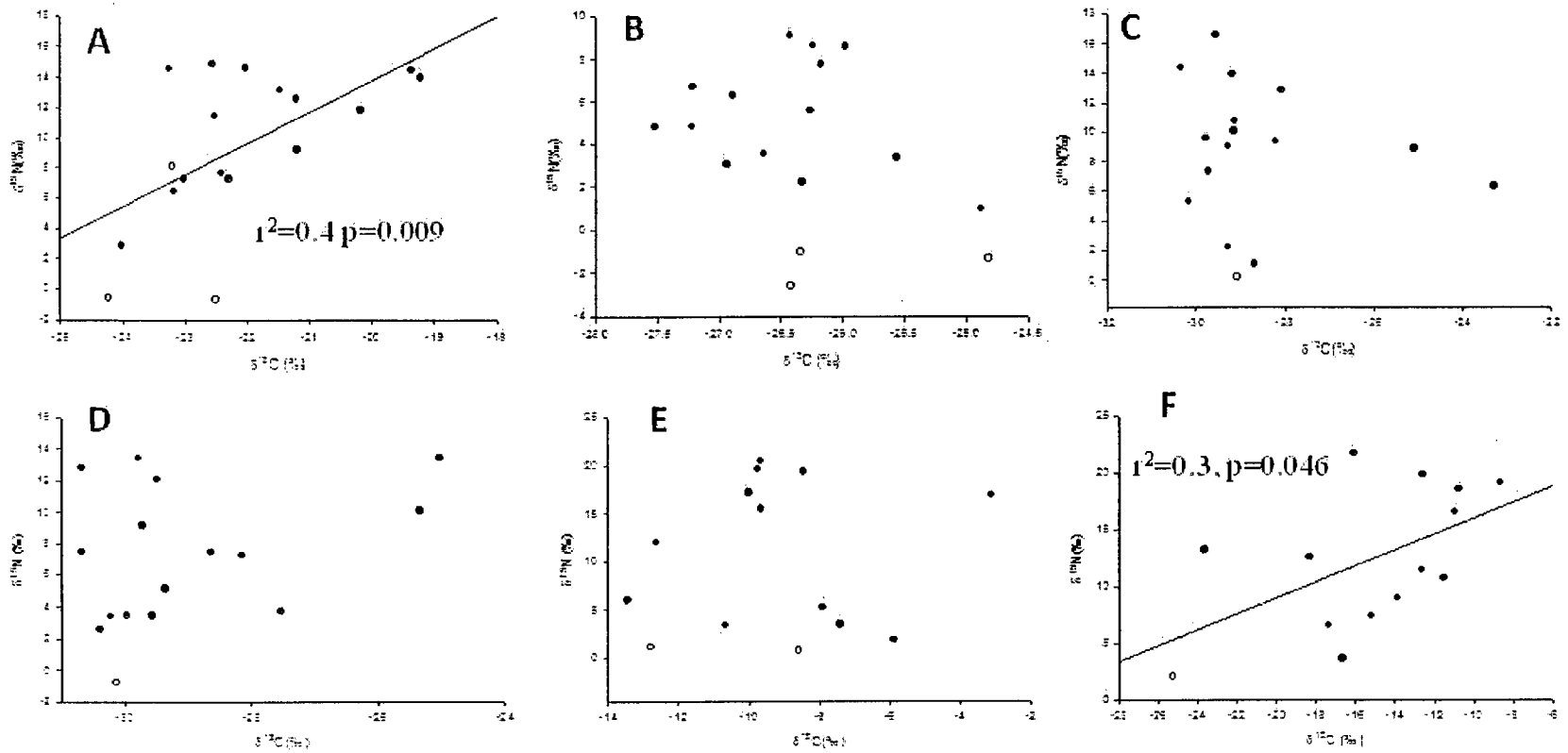

Figure 2.7. The relationship between $\delta^{15}N$ and $\delta^{13}C$ values for A) Jewel lichen B) Worm lichen C) Tufted Saxifrage D) Purple Saxifrage E) Periphyton F) Zooplankton from Cape Vera. Open symbols represent samples from Cape Herschel.

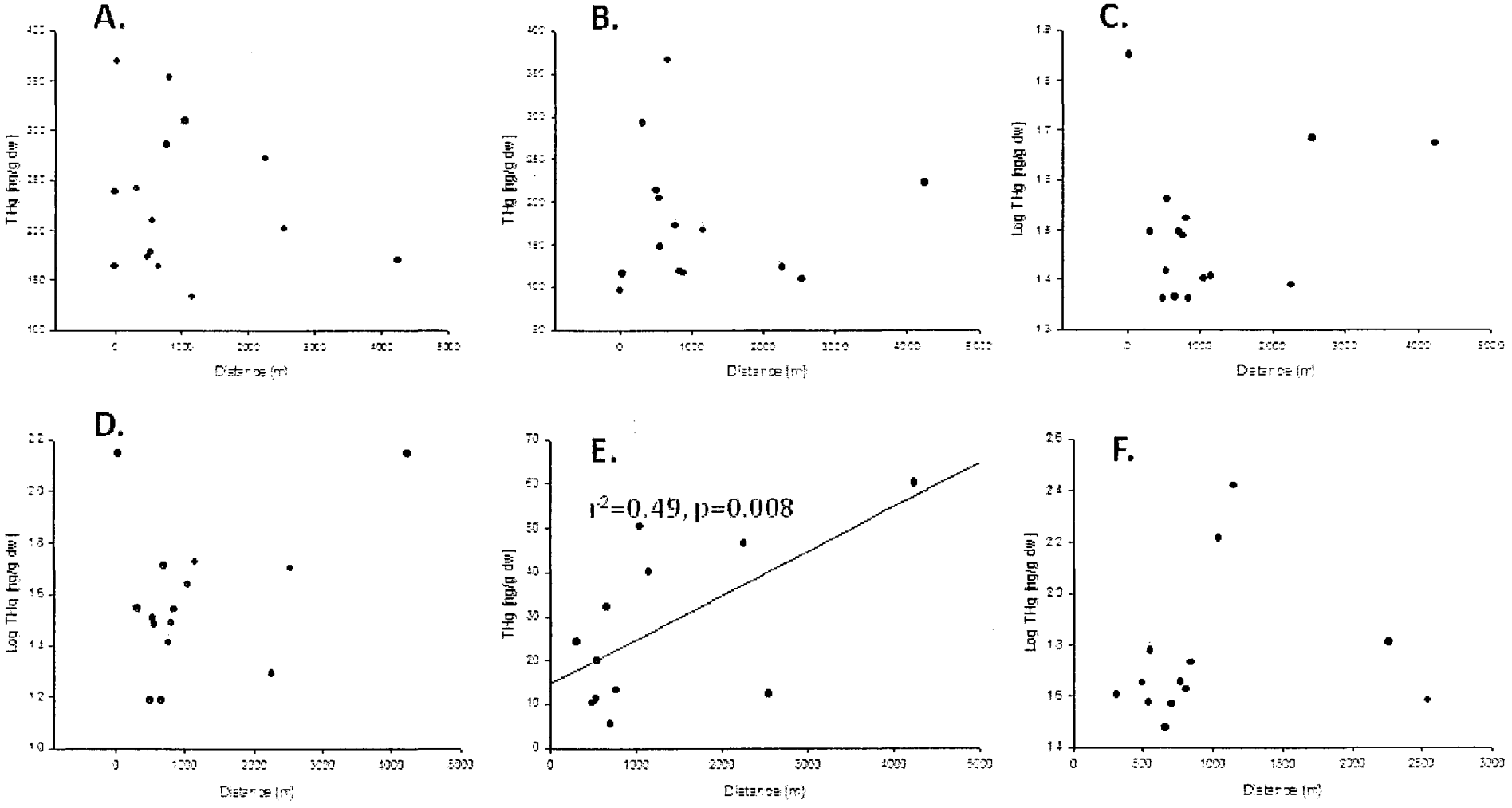

Figure 2.8. The relationship between distance from the cliffs and THg concentrations for A) Jewel lichen B) Worm lichen C) Tufted Saxifrage D) Purple Saxifrage E) Periphyton F) Zooplankton from Cape Vera.

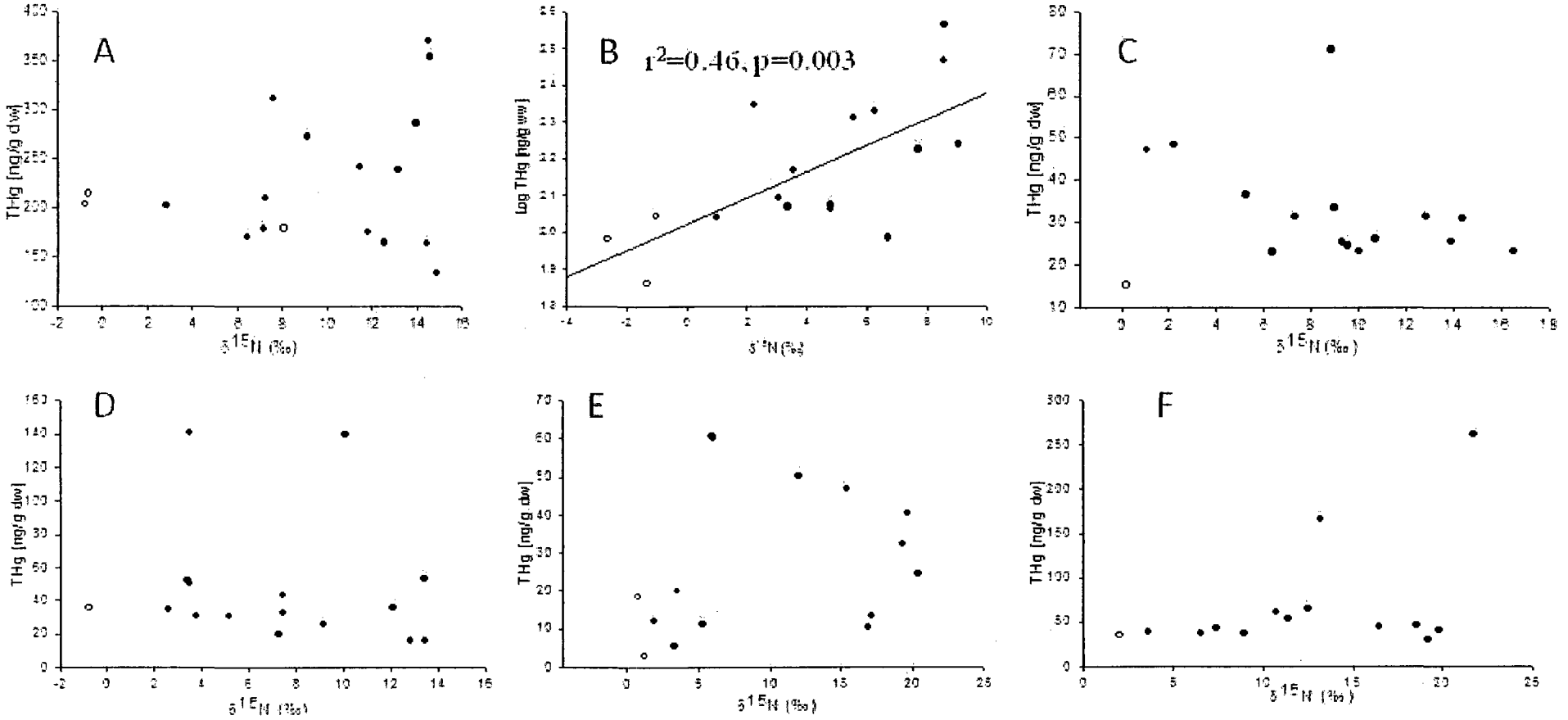

Figure 2.9. The relationship between the concentrations of THg [ng/g dw] and $\delta^{15}N$ values for A) Jewel lichen B) Worm lichen C) Tufted Saxifrage D) Purple Saxifrage E) Periphyton F) Zooplankton from Cape Vera. Open symbols represent samples from Cape Herschel.

3.0 - Spatial Patterns of Organic Pesticides and PCBs in the food webs linked to seabird-derived nutrients at Cape Vera, Devon Island, Nunavut, Canada

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3.1-Abstract

At Cape Vera, Devon Island, Nunavut, Canada, a seabird colony of northern fulmars (*Fulmarus glacialis)* concentrates and releases nutrients through the deposition of guano to the coastal environment, thus creating habitats important to insects, birds, and mammals by fertilizing the ecosystem. However, high concentrations of DDT and HCB were also detected in the sediments of ponds located below colonies of nesting fulmars relative to reference ponds. It is unknown whether these contaminants are transferred to food webs. The purpose of this study was to determine whether PCB and DDT concentrations were transferred from a large seabird colony to coastal food webs. Snow buntings (*Plectrophenax nivalis)* were the most contaminated species at Cape Vera, having ∑PCB (mean: 168 ng/g ww) and ∑DDT (mean: 106 ng/g ww) concentrations that were high relative to other Arctic bunting populations and surpassed environmental guidelines for protecting wildlife. In jewel lichen, several biomagnifying congeners (CB-153, 118, 138/163, 180, 99, 128, 170, 195, 194), *p'p*-DDE to ∑DDT ratio, and ∑DDT concentrations increased inversely with distance from the seabird cliffs, and increased with increasing $\delta^{15}N$ values, supporting the idea of seabird-derived contamination. Although not all relationships were significant, all biomagnifying congeners, *p'p*-DDE to ∑DDT ratio, and ∑DDT in jewel lichen displayed the expected trends with distance, which is significantly greater than what would be expected by chance. We were unable to show that contaminant concentrations in ermines, collared lemmings, and worm lichen were affected by seabirds, and therefore, cannot conclude that the effects of biovector transport extend to the entire ecosystem. We conclude that biovector transport may be a source of organic contaminants to certain species at Cape Vera, such as jewel lichen and snow buntings.

3.2-Introduction

Despite strict restrictions on the production and usage of persistent contaminants and pesticides across North America and Europe, contaminant concentrations remain high in the marine mammal and indigenous populations of the Arctic (AMAP 1998). Arctic residents do not enjoy many of the benefits for which these pollutants are produced yet their health and traditions are compromised by these chemicals. The process of cold condensation or global fractionation explains the tendency of contaminants to gradually migrate to the polar regions (Wania et al. 1998). Organic contaminants (OCs) volatize in the atmosphere of the warmer southern climates and are carried by long range transport of air and ocean currents to colder climates where they enter the environment. The progressive movement of these contaminants to polar regions is known as global distillation, and is dependent on several chemical properties such as a chemical's volatility and persistence (AMAP 1998).

The air-plant-animal pathway is the main route of OCs to Arctic terrestrial food webs, as illustrated in studies of the lichen→ reindeer → wolf food chain (Thomas et al. 1992, AMAP 1998, Kelly and Gobas 2001). However, local sources through biovector transport, the transfer of contaminants by migratory species, may also be important pathways of contaminants to Arctic food webs. Biovector transport is efficient at transferring high concentrations of organic contaminants to neighbouring ecosystems. Most of the candidates for biovector transport are top predators or high order consumers, and therefore, their contaminants have already undergone food web biomagnification processes (Blais et al. 2007).

At Cape Vera, Devon Island, Nunavut, a colony of 10,000 breeding pairs of northern fulmars (*Fulmarus glacialis*) may heavily concentrate and release contaminants through their

guano to the coastal ecosystem. Concentrations of hexachlorobenzene (HCB), total mercury (THg) and total dichlorodiphenyltrichloroethane (DDT) in sediment of ponds below nesting colonies are 10 to 60 times higher than in ponds outside of the range of ornithogenic input (Blais et al. 2005). Cape Vera is a polar oasis rich with green moss, emergent insects, and small birds and mammals at the base of the seabird cliffs. It remains unclear whether the effects of these contaminants are localized to the ponds or whether they enter the food chain and pose a threat to coastal species.

This study was designed to determine if organic contaminants from a seabird colony were transferred through biovector transport to food webs. We examined polychlorinated biphenyl (PCB) and DDT concentrations in selected food web components at Cape Vera and compared those from Arctic areas without the presence of seabird colonies. Contaminants were measured in five species: jewel lichen (*Xanthoria elegans*), worm lichen (*Thamnolia vermicularis*), northern collared lemming (*Dicrostonyx groenlandicus*), snow bunting (*Plectrophenax nivalis)* and ermine (*Mustela erminea arctica*)

We first determined if PCB and DDT concentrations increase with trophic level among the species at Cape Vera. Nitrogen stable isotopes ($\delta^{15}N$) have been used to assess the trophic transfer of organic contaminants (Kidd et al. 1995). Strong positive relationships have been found between $\delta^{15}N$ values and organochlorine compounds in Arctic freshwater and marine food webs, indicating biomagnification (AMAP 1998, Fisk et al. 2001). We predicted a positive relationship between $\delta^{15}N$ and PCB/DDT concentrations among our five organisms. Our specific null hypothesis was that $\delta^{15}N$ values should not increase with contaminant concentrations among all species at Cape Vera.

Typically, terrestrial plants and species in the High Arctic have low levels of organic contaminants levels (Thomas et al. 1992, Braune et al. 1999). Since there is no local industrial source, Cape Vera should not have higher contaminant levels relative to other High Arctic areas. However, since northern fulmars are top predators and scavengers in the marine food web, we expected PCB and DDT concentrations in species affected by fulmar guano to be significantly higher than those from reference sites. The specific null hypothesis was: the contaminant concentrations in species at Cape Vera should not be higher than other regions in the Arctic.

As long-lived top predators in the Arctic, high concentrations of biomagnifying congeners accumulate in northern fulmars. In order of decreasing contributions, CB- 153, 180, 118, 138, 99, and 128 were reported as the predominant congeners found in northern fulmars and Arctic marine top predators (Elliott 2005). In fulmar eggs, PCB congeners that constituted over 5% of total PCBs were 153, 180, 138, 118, and 170/190 (Braune 2007). The PCB congeners most abundant in northern fulmars along with CB-195 and CB-194 predominate the top trophic levels of Arctic marine and terrestrial food webs (AMAP 1998).

p'p-DDE, a DDT metabolite with a high biomagnification potential, concentrates in top predators and was found to compose 86% to 88% of ∑DDT in northern fulmars (Buckman et al. 2004). It is estimated that *p'p*-DDE composes 98.7 to 100% of ∑DDT in seabird guano (Evenset et al. 2004a) Similarly, the ratio of DDT to its metabolites, such as *p'p*-DDT/*p'p*-DDE and DDE to ΣDDT, can identify if sources have been processed by the marine food web (Bidleman et al. 2005, Roosens et al. 2007). Only trace amounts of DDT-related compounds have been measured in Arctic air (Barrie et al. 1992, Su et al. 2008). At High Arctic monitoring stations, the summer *p'p*-DDT/*p'p*-DDE ratios of air has been measured at 1.8, and between 1 to

1.5 in Alert and 3 in Amderma (Barrie et al. 1992, AMAP 2002). The *p'p*-DDT/(*p'p*-DDT+ *p'p*-DDE) for ambient air concentration in the Arctic is estimated at 0.30 $\pm$0.1 (Bidleman et al. 2005). At Cape Vera, DDT related compounds were very low and DDE concentrations were not detected in passive air samplers (Foster et al. 2009). However, at Cape Vera, the *p'p*-DDE to *p'p* ΣDDT ratio in pond sediment increased with proximity to the seabird cliffs (Blais et al. 2007).

Using lichens as bioindicators, we predicted an increase in the concentrations of PCB congeners common in fulmars and top predators (CB-153, 180, 138, 99, 118, 128, 170/190, 194, and 195) with increasing seabird influence. Seabird influence was measured using distance and $\delta^{15}N$ values. The specific null hypotheses were: biomagnifying PCBs and ΣDDT concentrations, and the ratio of *p'p*-DDE to ΣDDT will increase inversely with distance from the seabird colony in lichens and biomagnifying PCBs and ΣDDT concentrations, and the ratio of *p'p*-DDE to ΣDDT will not increase with $\delta^{15}N$ values in lichens. Since lichens acquire airborne contaminants, lower chlorinated PCB congeners (CB 66/95, 70, 101, and 52) are typically most abundant in Arctic lichens (AMAP 1998). To strengthen our hypothesis, we also analyzed lower-chlorinated PCB congeners (CB-18, 31-28, 44, 49, 52, 87, 101, 105, 110) that are typically metabolized and eliminated by seabirds (Elliott 2005) to see if our predicted relationships were unique to biomagnifying congeners.

3.3-Methods

3.3.1-Study Area

Cape Vera is located on Devon Island, Nunavut (Figure 3.1; 76°15' N, 89°15'W). Cliffs run along the coastline of Cape Vera 245 to 313 metres above sea level. Approximately 11, 000 breeding pairs of northern fulmars have built nests along a 6.4 km stretch of the cliffs (Gaston et al. 2006). A series of 12 sites adjacent to ponds (CV5, 6, 8, 9, 9a, 10, 13-15, 20, 30, 31) and on cliffs at different elevations located below the seabird cliffs and spanning a 4 km gradient of ornithogenic influence were sampled at Cape Vera (Figure 3.1).

Samples of lichen were collected at different elevations and from rocky ledges at the base of the seabird cliff. Jewel lichen samples were collected on the cliffs at elevations of 119 and 140 metres above sea level. Worm lichen was collected at 65 metres. Both lichen samples were also collected along a rocky ledge 6 metres high at the base of the cliff, next to CV43. Unlike the other cliff samples, lichens from CV43 were collected on a horizontal rocky surface approximately 34 metres from main cliff of the colony.

Reference sites

Reference (background) sites (CV 1, 12) were located away from the immediate influence of the seabird colony, and other sites were located at Cape Herschel on Ellesmere Island (Figure 3.2; 78°37'N, 74°42'W).

3.3.2-Sample Collection and Preparation

All food web samples were collected between July 1 to July 20, 2006, and July 8 to July 21, 2007. Lichens were collected near ponds along a gradient of seabird influence spanning approximately 4 km (Brimble 2008). Jewel (*Xanthoria elegans)* and worm lichens *(Thamnolia vermicularis*) were collected in 50 mL falcon tubes that were pre-rinsed with acetone and hexane. Three falcon tubes of each lichen species were collected from the 13 ponds in 2006. In 2007, samples of worm and jewel lichen were taken from varying altitudes along the seabird cliff and at reference sites CV1 and Cape Herschel on Ellesmere Island. Jewel lichens were scraped off of flat rocks using field knives that were wiped clean and dry between pond sites. Worm lichens were collected using stub-ended large tweezers. Samples were put on sea ice in a cooler until they were transferred to the freezer room at the Polar Continental Shelf Project (PCSP) base at Resolute Bay, Nunavut.

Several small animals were collected from Cape Vera. Fifty vector snap traps were set in 2006 and 2007 beside burrows of *Dicrostonyx groenlandicus*, the northern collared lemming. Traps were checked every morning and evening for lemmings. A total of five lemmings were collected in 2006. Weight, sex, mass and body length of all lemmings were recorded.

Twenty-five snow buntings (*Plectrophenax nivalis)*, 11 in 2006 and 14 in 2007 were killed by a vector trap or 12 gauge shot gun, sexed, and sealed in Ziploc freezer bags. In 2007, five buntings were captured from CV1 as controls. In 2007, two ermines (*Mustela erminea arctica)* were captured (one by snap trap and the other shot). All lemming, snow bunting and ermine samples were removed from snap traps using nitrile gloves, placed in Whirl-Pak® and Ziploc bags, and labelled with the GPS or closest pond were put on sea ice in a cooler until they

were transferred to PCSP. In 2007, animal samples were stored in a small freezer supported by a generator, before being transferred to PCSP. All methods for the capture of lemmings and snow buntings in 2007 were approved by the Animal Care Committee of the University of Ottawa.

At the University of Ottawa, animal samples were dissected and prepared for isotope analysis. To verify trophic links within our food web, stomach content identifications were performed on all animal samples. Mammals were weighed, sexed, and skinned; the gastro-intestinal tract was removed for stomach content analysis. Birds were weighed and plucked of feathers; the gastro-intestinal tract (GI tract) was removed for stomach content analysis. Animal samples were homogenized using liquid nitrogen in the M20 IKA Works® Universal Mill. After homogenization, one to two gram subsamples were placed in microcentrifuge tubes for stable isotope analysis and the remaining homogenate was stored in the freezer for organochlorine analysis. The mill was cleaned with distilled water and ethanol and dried in between samples. Samples for stable isotope analyses were freeze-dried for 72 hours and re-homogenized.

3.3.3-Stable Isotope Analyses

Freeze-dried whole body tissue was used for stable isotope analyses. Samples were analyzed for carbon and nitrogen stable isotopes at the G.G. Hatch Isotope Laboratory at the University of Ottawa. Samples were flash combusted at 1800°C in an elemental analyser (EA) (EA 1110, CE Instruments, Italy). The resulting gases were carried via helium through the EA to purify and separate into N_2 and CO_2. Gases were carried from the EA into an isotope ratio mass spectrometer (DeltaPlus Advantage IRMS, ThermoFinnigan, Germany) for isotope analysis via a

Conflo interface (Conflo III). Stable isotope values were reported in δ notation using per mil units (‰), which are defined as follows:

$$\delta^{15}N = [(R_{sample}/R_{standard})-1] \times 1000 \text{ (Peterson and Fry 1987)}$$

Analytical precision was based on the internal standards Nicotiamide (C-51), ammonium sulphate + sucrose (C-52), caffeine (C-54), and the blind standard L-glutamic acid (C-55). Nitrogen stable isotopes values were calculated relative to atmospheric nitrogen (N_2) normalized to internal standards calibrated to international standards IAEA-N1(+0.4‰), IAEA-N2(+20.3‰), USGS-40(-4.52‰) and USGS-41(47.57‰). Triplicate assays were run every sixth sample.

3.3.4-Contaminant and Lipid Analysis

Only wet tissue samples were used for organochlorine and lipid analysis. Sample preparation of the animals for PCB and pesticides analyses were based on methods used by Johnstone et al.1996. Methods for PCB and DDT analysis followed the National Laboratory for Environmental Testing (NLET) protocol. Sample extraction was done by species in a randomized order to reduce any chance of analytical bias. Lichen samples were ground and approximately 8 to 10 grams were placed into 33 mL cells for the accelerated solvent extractor (ASE200, Dionex, Sunnyvale CA, USA). Less than one falcon tube was required to achieve the minimum mass requirements (8 grams) for jewel lichens, whereas two falcon tubes were combined for worm lichens. Eight grams, wet weight, whole body tissues were homogenized in Hydromatrix® (Varian, Harbour City, CA, USA) and packed into 33mL cells. A set of recovery

surrogates were added to each sample which consisted of PCBs 30, 205, as well as 1, 3, dibromobenzene (DBB), δ-hexachlorohexane (HCH), endrine ketone, 1,2,4,5, tetrabromobenzene (TBB) and 1,3,5, tetrabromobenzene (TBB). Surrogate standards were obtained from Ultra Scientific, North Kingston, RI, USA.

The samples were extracted in the ASE200 with methylene chloride (Omnisolv®, Fisher Scientific, Ottawa, ON, Canada) at 2000psi, 125°C, with a 6 min heat cycle, and 3 min static for 3 cycles. Followed by hexane (Omnisolv®, Fisher Scientific, Ottawa, ON, Canada) at 2000psi, 100°C, with a 5 min heat cycle, and 5 min static for 2 cycles. The 2 sample extracts were combined and poured over a glass funnel lined with fluted filter paper holding 25 g of sodium sulphate ($NaSO_4$) to remove water. The vials were rinsed twice with 2mL of 1:1 methylene chloride: hexane poured over the $NaSO_4$ and added to the sample. After a final rinse of 10mL of 1:1 methylene chloride:hexane, the sample was evaporated to 1 mL.

The extract was placed in a 6 ml vial, and the volume adjusted to 4 ml with methylene chloride, mixed and filtered at 0.2 µm. Lipid removal was completed using a preparative liquid-chromatograph coupled with a photo diode array and fraction collector (Agilent Technologies, Mississauga, ON, Canada) on 2 Waters Envirogel columns (Waters, Mississauga, ON, Canada) with a methylene chloride mobile phase with a flow rate of 7ml/min and monitored at a wavelength of 254 nm. Fractionation and instrument performance was determined by repeated injections of a GPC Calibration Standard containing corn oil and methoxychlor (CLP-340, Ultra Scientific, North Kingston, RI, USA). The collected sample fractions were evaporated to 1 ml in Iso-Octane (Fisher Scientific, Mississauga, ON, Canada).

A 250 mm x 12 mm chromatographic column was wet packed in hexane with 8 grams of activated silica gel (Davisil 635, Fisher Scientific, Mississauga, ON, Canada) for the final clean-up step. Non-polar organochlorine compounds and PCBs were eluted using 50 mL of hexane, followed by 80 mL of 1:1 hexane:methylene chloride to elute polar organochlorines. Samples were evaporated down to 500µl in iso-octane and 2.5 pg of octachloronapthalelene (Ultra Scientific, North Kingston, RI, USA) was added as an internal standard. To determine lipid content, 1g of whole body tissue was placed into 11 mL ASE cells and extracted using methylene chloride. The extraction was left to evaporate and oven dried at 60°C for 48 hours. Afterwards, lipid weight was determined gravimetrically using the following equation:

Lipid %= [(initial vial weight- final vial weight)/sample weight] * 100

PCBs and OCs were determined using an Agilent 6890 gas chromatograph with a ^{63}Ni micro electron-capture detector (Agilent Technologies, Mississauga, ON, Canada). One microlitre of extract was injected, using a splitless injection, with an inlet temperature of 280°C, pressure of 35.56 psi, constant flow of helium at 33 cm/second on a 60 m x 250 µm x 0.25 µm DB-5MS capillary column (Agilent Technologies, Mississauga, ON, Canada). The initial oven temperature was 80 °C for two minutes, 110°C ramped at a rate of 7°C/min held for seven minutes, 280°C ramped at a rate of 5°C/min held for five minutes. The total run time was 50 minutes. The µECD was held at 350 °C with a combined flow of 30 mL/minute. Compounds were identified by running a set of standards and the compound response factors to the internal standard to determine concentrations. Chromatograms were screened for 72 peaks consisting of for 41 PCB congeners and 25 pesticides. The quantification of sum PCB was the total of 39 PCB congeners (5, 8, 14, 18, 19, 28, 29, 31, 32, 44, 49, 52, 66, 87, 99, 101, 105, 110, 118, 128, 132, 138, 146,

149, 153, 155, 156, 157, 163, 170, 180, 183, 187, 194, 195, 200, 203, 206, 209). Sum DDT was the total of four DDT congeners (*p'p*-DDE, *p'p*-DDD, *p'p*-DDT, *o'p*-DDT).

3.3.5-Quality Control

All glassware was washed with industrial grade detergent, triple rinsed with distilled water, American Chemistry Society (ACS) grade acetone and hexane before being heated at 200°C in an oven for 12 hours. The surrogate recovery standards were used to determine the recoveries of the analyzed compounds. Recovery corrections were made on each sample, and the average percent recoveries for each species matrix are listed in Table B.1 of the Appendix section. Mussel Standard Reference Material 2978 (National Institute of Standards and Technology, Gaithersburg, MD, USA) was run routinely with sample batches. Using approximately 0.25 grams of dry weight sample, the average recovery for the Standard Reference Material® 2978 for 22 PCB congeners was 72.2$\pm$ 24.5% SD (n=6) and for 5 pesticides was 65$\pm$31% SD (n=5). The mean coefficient of variation (CV) for ΣPCB duplicates was 7.91% for lichens (n=2), 0.53% for collared lemmings (n=2), 10.8 % for snow buntings (n=4), and 6.54% for ermines (n=4). The mean CV for ΣOC duplicates was 12.8% for lichens, (n=2), 3.74% for collared lemmings (n=2), 10.5 % for snow buntings (n=4), and 5.25% for ermines (n=4).

Method blanks (n=12) consisting of pre-cleaned Hydromatrix® were packed in 11 mL cells and were run with every sample set. Method blanks represented background contamination levels associated with the analytical process. Background concentrations were removed from samples by subtracting concentrations in method blanks from samples on a compound-to-

compound basis using the blank run within its sample batch. The method detection limits were calculated as the standard deviation of the average concentration in method blanks multiplied by 2 to achieve a 95% confidence level and since blanks were subtracted upon analysis (Gouin et al. 2005). The detection limits for ΣPCB was 291 pg/g and was 195 pg/g for ΣDDT. Detection limits (DL) for individual congeners and metabolites can be found in Table B.2 and Table B.3. Since the frequency of values below detection limit was low (<15%), values below the limit of detection were converted to DL/2 for statistical analysis (Baccarelli et al. 2005).

Interference with toxaphene and chlordane congeners was a concern for particular or suspicious PCB congeners (CB-128, 146, 32, 99, 52). The ratios of the congeners of concern to CB153 and/or CB99 in samples were compared to the ratios found in Aroclor 1254. Sample ratios for CB-128, 52, and 99 were not significantly higher than those found in Aroclor 1254, and were assumed to have no interference by toxaphene or other congeners. CB-146 and CB-32 had higher ratios than expected from Aroclor 1254 and were removed from the analysis.

3.3.6-Statistical Analysis

All data were analyzed using Systat® 12, SigmaPlot® 10 (Systat Software, Point Richmond, CA, USA), and Canonical Community Ordination (CANOCO) software 4.5 (Biometris, Wageningen, the Netherlands. Analysis of covariance (ANCOVAs), t-tests, and linear regressions were performed using Systat®12.

Regression analyses were run on our lower-chlorinated PCBs (CB-18, 28-31, 44, 49, 52, 87 and 101) and our biomagnifying PCBs (CB-99, 118, 138-163, 153, 170, 180, 194, and 195) ΣPCB, ΣDDT, and DDE:ΣDDT ratio. PCBs that were not detected in our lichen samples (CB 5-

8, 14, 19) or were only measured in one sample (CB-29, 66) were not analyzed. Log or square root transformations (if the data set contained zeros) were performed on data until acceptable levels of normality and constant variance were achieved. CL642 was not used for regressions involving DDT since one column fraction did not work, resulting in loss of the compounds. CV9 was not used for regressions involving the DDE: ΣDDT ratio, since both compounds were below the detection limit and wasn't possible to get an accurate estimate. The distance measurements of the Cape Vera ponds to the seabird cliffs were used from Brimble (2008). Principal components analyses of the PCB congener concentrations in jewel lichen were performed using CANOCO®4.5. The statistical tests used to create our model for predicting PCB concentration in jewel were run using S-Plus®7 (general additive model and chi-square) and Sigmaplot®10 (t-test and linear regression).

3.4-Results and Discussion

3.4.1-Contaminants in the Cape Vera Ecosystem

Since PCBs and DDT are both lipophilic contaminants, we first determined if it was necessary to lipid-normalize our data (Hebert and Keenleyside 1995). No relationship was found between % lipid and log ΣPCB or log ΣDDT for any species. Since the relationship between % lipid and contaminant concentrations was not isometric and to avoid introducing more variance to the results, data were analyzed using analysis of covariance (ANCOVA) with lipid as the covariate as discussed by Hebert and Keenleyside (1995).

There was a significant relationship between $\delta^{15}N$ values and log ΣPCB [ng/g ww] (r^2=0.49, p<0.001, n=49) as well as $\delta^{15}N$ values and log ΣDDT [ng/g ww] (r^2=0.56, p<0.001,

n=46) among all organisms (Figures 3.3 and 3.4). The relationship remains significant when using lipid normalized contaminant data. There were no relationships found between $\delta^{15}N$ values and individual species.

Of all the organisms, snow buntings were the most contaminated at Cape Vera, followed by the ermines, lichens, and collared lemmings (Table 3.1; Figure 3.3 and 3.4). Unlike the other organisms that feed from the terrestrial food web, snow buntings feed on chironomids from the ponds (Choy et al. 2009). The sediment-chironomid pathway has been found to be a main route for PCB contamination to tree swallows, with 94% of PCB concentrations in nestlings accumulated through diet (Maul et al. 2006). The concentrations of ΣPCB and ΣDDT in snow buntings exceed many Canadian and American environmental guidelines. For example, mean ΣDDT concentrations in snow buntings [106±29.2 ng/g (ww)] as well as ermines [37.3±8.7 ng/g(ww)] exceeded Canadian environmental quality guidelines of 14 [ng/g ww] for the protection of wildlife. Bunting ΣDDT concentrations surpassed US Environmental Protection Agency (USEPA) guidelines of 39 [ng/g ww]. Mean ΣPCB concentrations in snow buntings [168.0±43.1 (ng/g ww)] also exceeded USEPA guidelines of 160 [ng/g ww] and International Joint Commission guidelines for the protection of aquatic life and wildlife of 100 [ng/g ww] (Braune et al. 1999). There was no significant difference in ΣPCB concentrations among age classes (ANOVA, $F_{(2,15)}=2.88$, p=0.09, df=2) and concentrations above contaminant guidelines were found in both hatch year and adult buntings. There was a significant difference in ΣDDT concentrations among sex classes (ANOVA,$F_{(2,14)}=4.29$, p=0.04, df=2), with contaminant

concentrations in hatch year buntings significantly lower than adult females (post-hoc, tukey test, $p=0.04$).

To determine if buntings from Cape Vera were highly contaminated, we compared ΣPCB and ΣDDT to other Arctic populations. ΣDDT, DDE, and ΣPCB concentrations in snow buntings from Cape Vera were higher than concentrations of buntings from Rankin Inlet, West inland and coastal East Greenland (Table 3.2). Buntings from Cape Vera had approximately 5 to 8 times higher ΣPCB concentrations than detectable concentrations in buntings from Greenland and Rankin Inlet. The ranges of ΣPCB and DDE concentrations in buntings from Cape Vera overlap with those from Greenland. However, the range concentrations from Cape Vera include hatch year buntings, which have significantly lower ΣDDT and almost significantly lower ΣPCB concentrations than adult female buntings. The ages of the snow buntings from Greenland were not indicated, and it is unclear whether age was a confounding factor.

The higher ΣPCB and ΣDDT concentrations in buntings was surprising since the ermine is the top predator at Cape Vera, and stomach contents indicated they consume buntings (Choy et al. 2009). Although ermine prey on buntings at Cape Vera, collared lemmings are their main prey (Gilg et al. 2006). In the High Arctic of Greenland, the remains of collared lemmings were found to comprise 98.5% of the dry weight of ermine scat during the winter, whereas 50% of their scat dry weight during the summer contained the remains of birds, insects, muskox, and plants (Gilg et al. 2006). As a year-round inhabitant of Cape Vera, ermines may attain most of their organic contaminants from lemmings, feeding on snow buntings when they arrive for nesting during the summer. Based on the mean contaminant values, the ermine at Cape Vera is

approximately 60 to 170 fold higher in ΣPCB and ΣDDT than lemmings (Table 3.1). Comparisons for PCB and OCs in ermines were limited. ΣDDT concentrations in ermine muscle from Grande Baleine, Quebec were below 1 ng/g, and ΣPCB were 13.7 ng/g (AMAP 1998).

Many of the PCB congener and DDT compound concentration for lemmings were at or below the method detection limits. In comparison to other Arctic collared lemming populations, ΣDDT concentrations in collared lemmings from Cape Vera were higher than lemmings from Rankin Inlet (Table 3.2). The contaminant concentrations listed from Rankin Inlet were based on one lemming, and the other 12 had levels below their detection limit (PCBs: 0.1 mg/kg, OCs: 0.02 mg/kg; Johnstone et al.1996). ΣPCB concentrations in the five collared lemmings from Cape Vera are approximately 10 times higher than the lemming from Rankin Inlet.

3.4.2-Biomagnifying Congeners and Metabolites in relation to Seabird Influence

Biomagnifying PCBs (CB-153, 118, 138/163, 180, and 99) were the most dominant congeners in snow buntings and ermines (Figure 3.5). Ermines and other weasels have the ability to metabolize congeners that have no chlorine substitutions in the meta and para-position (Leonards et al. 1998). Collared lemmings also had high proportions of CB-153, 138/163, and 180, but had more variation in their congener profiles (Figure 3.5). Lichen expressed highly variable congener profiles which were not dominated by lower chlorinated compounds (CB-66/95, 52, 101) as found in other Arctic studies of lichen (AMAP 1998). In order of decreasing contributions, the most abundant congeners found in jewel and worm lichen at Cape Vera were CB-153, 163/138, 180 and 118, each comprising 4.4 to 14.1 % of ΣPCB.

Many compounds were below the detection limit or were not detected at all in worm lichen, and we are uncertain of what may have caused such low concentrations. Lichens vary with their response to pollutants, restricting the use of some species to monitor contaminant levels (Rossbach and Lambrecht 2006). Prior to this study, there have been no studies that have used worm lichen to measure organic contaminants, whereas jewel lichen has been used successfully to monitor spatial patterns of trace elements and organohalogens (Matschullat et al. 1999). Despite our best efforts, we also had difficulty getting enough tissue for our sample extraction of worm lichen. Therefore, we decided to focus our statistical analyses on jewel lichen.

p'p-DDE: ΣDDT in jewel lichen had significant negative relationships with distance from the seabird cliffs (Fig. 3.7). The square-root concentration of CB-95 also had a significant negative relationship with distance from the cliffs, but 7 of the 13 points had values of zero. Jewel lichen showed no other significant trends with distance, but all regressions showed decreasing contaminant concentrations with increasing distance from the cliffs. There was also a significant positive relationship between $\delta^{15}N$ values and log PCB-138/163 concentrations in jewel lichens (Fig. 3.8). There were no other significant trends with $\delta^{15}N$ values, but all regressions showed increasing contaminant concentrations with increasing $\delta^{15}N$ values. We cannot reject our null hypotheses that PCB and DDT concentrations do not increase significantly with decreasing distance from the colony and with increasing $\delta^{15}N$ values (Figs 3.6-3.9). Although not significant, all jewel lichen samples did show the predicted trends with distance. According to a binomial test, the predicted trends occurring in all 12 regressions is significant ($p=2.0 \times 10^{-4}$).

In contrast to our biomagnifying congeners, there were no relationships between distance and the concentrations of lower chlorinated PCBs in jewel lichen (Fig 3.10). Six of the nine congeners showed slightly increasing concentrations with increasing distance. The patterns of lower chlorinated congeners in relation to $\delta^{15}N$ values also contrasted those of biomagnifying congeners in jewel lichen (Fig 3.11). Concentrations in eight of the nine congeners increased inversely with $\delta^{15}N$ values and three of the relationships were significant (Fig 3.11; CB-18, 31-28, 44, 52). However, CB-105 concentrations did not decrease with increasing $\delta^{15}N$ values and increased inversely with distance. Although not a major congener, CB-105 has been detected in marine seabirds including fulmars, accounting for less than 5% of ΣPCB (Elliott 2005).

A principal components analysis (PCA) of PCB congener data normalized to CB-153 was performed to discern how specific congeners partitioned in jewel lichen collected from sites of varying contamination (Figure 3.12). Normalizing the congeners to CB-153 creates a relative index of biomagnification. Several tri-, tetra-, and pentachlorobiphenyls (CB-18, 31-28, 44, 49, 52, 99, 101) were located at one extreme of the first axis whereas hepta- and octachlorobiphenyls (CB-170, 194) were at the other, representing a gradient of chlorine substitution. The first axis explained 80.1% of the total variance whereas the second axis explained 11.3%, for a combined total of 91.4%. Lichens collected from Cape Herschel (reference site) were separated from those collected at Cape Vera, indicating different sources of contamination. CV9, with very low concentrations of PCBs, was also isolated from the other lichens at the extreme of the second axis. Most of the samples from Cape Vera were clustered together, indicating similar congener patterns. There were differences among lichens collected from cliffs and CV10, CV8, and CV20, which had a greater contribution of higher chlorinated PCBs (Figure 3.12). Both jewel and worm lichen collected from the ledge (CL43) had the highest concentration of ΣPCB (14.8

and 1.96 ng/g ww) and DDT (8.97 and 0.75 ng/g ww) of all samples (Table 3.3; Table 3.4). The remaining jewel lichen (CV13, 5/6, 14, 30, 15-31, 9a) from Cape Vera clustered near CB-153, the congener with the highest concentration for most lichens from Cape Vera. Foster et al. (2009) found that in Northern Fulmar guano, congeners CB-153, 138, 118, and 180 were the main constituents while CB-18, 31-28, and 49 composed 35 to 40% of the ΣPCB of gaseous concentrations in air.

To test our hypothesis that log PCB congeners were a function of seabird influence and to determine what factors were significant predictors of log PCB congener concentrations in jewel lichen, we ran a general additive model using the scores of axis 1 and 2 from our PCA (Fig 3.12), $\delta^{15}N$, and distance as variables, along with several chemical properties (Henry's Law Constant, log Kow, and chlorine substitution) as independent variables to log PCB congener concentrations. $\delta^{15}N$ and distance from the seabird colony were used as metrics of seabird influence and were also used as independent variables. We found that Henry's law constant, scores of axis 1 and 2, and chlorine substitution did not explain variance in log PCB concentrations above that which was already explained by log Kow and distance, or log Kow and $\delta^{15}N$. After determining which factors were most influential, we ran a regression which included log Kow and either distance or $\delta^{15}N$. Using a chi square test, we found no significant difference between using distance or $\delta^{15}N$ when included with logKow in the model ($p=0.001$). In our distance and log Kow model, distance and $[\log Kow]^2$ were significant variables ($t_{partial}=-2.9$, $p=0.004$; $t_{partial}=-6.43$, $p<0.001$), whereas distance^2 and log Kow were not. In our $\delta^{15}N$ and log Kow model, $[\delta^{15}N]^2$ and $[\log Kow]^2$ were significant variables ($t_{partial}=-4.0$, $p<0.001$; $t_{partial}=-6.48$, $p<0.001$), whereas $\delta^{15}N$ and log Kow were not. Both models were significant in predicting log concentrations of PCB congeners ($p<0.001$) (Figs 3.13 and 3.14).

3.5-Conclusions and Future Directions

Among the organisms studied from Cape Vera, snow buntings and jewel lichen appear to have enriched concentrations of PCBs and DDT. Since snow buntings are seasonal migrants, it is unclear if they are obtaining their contaminants from Cape Vera or their winter grounds. Although snow buntings from most Arctic regions migrate from Southern Ontario and the United States, the snow buntings at Cape Vera are believed to migrate from Greenland due to their early arrival in April before other Arctic snow bunting populations south of Cape Vera (Mark Mallory, personal communication). However, migration does not explain some of the high PCB and DDT concentrations found in nestlings and hatch year buntings. Future analysis on contaminant concentrations in chironomids, the main prey of snow buntings at Cape Vera, will be vital for strengthening support for guano as the source of contamination to buntings. Relative to other populations, the snow buntings at Cape Vera are severely contaminated surpassing Canadian and American environmental guidelines for protecting wildlife.

Our models showed that distance and $[\delta^{15}N]^2$ alongside log Kow were significant factors for predicting PCB congener concentrations in jewel lichen. However, most of our regressions were not significant, and the correlations in our linear models were not strong. There may have been other external factors or influences we did not consider that were affecting these relationships. Lichens were collected from a variety of surfaces (cliffs, ponds, plateaus), and we have observed that two of the cliff concentrations (CL590 and 642) have low $\delta^{15}N$ and PCB concentrations despite their proximity to the bird colony. Since these lichens were collected on a steep side of the cliff, we expect that most contaminants would run off these surfaces whereas by the ponds, they would collect and accumulate. CL43, the site with the most contaminant lichen, was flat ledge near the base of the cliff. Unfortunately, the literature available on organic

contaminants in lichen is limited and therefore, we do not know the effect different surfaces may have on the accumulation of contaminants. However, the expected relationships between biomagnifying PCBs in jewel lichen with our indicators of seabird influence may support biovector transport as a potential route of contaminants.

Although PCB and DDT concentrations in ermines and lemmings from Cape Vera were higher than concentrations from other areas of the Arctic, data were very limited and we are unable to conclude if contaminant concentrations in these species were affected by biovector transport. Similarly, worm lichens were not affected by biovector transport to the extent of jewel lichens. Therefore, we cannot conclude the effect of biovector transport extends to the entire Cape Vera ecosystem, but it does appear to affect certain species such as jewel lichen and snow buntings.

3.6- Acknowledgements

This study was funded by the Natural Sciences and Engineering Research Council of Canada (NSERC), the Polar Continental Shelf Project, the Canadian Wildlife Service and the Northern Scientific Training Program grants. All collections were made with appropriate animal care permits (University of Ottawa), and territorial and federal research permits. Thanks to Drs. Irwin Brodo, Laurie Consaul and Kamal Khidas at the Canadian Musuem of Nature, who confirmed species identifications. We would also like to thank our colleagues who helped us sample the ponds.

Table 3.1. Summary of mean and standard error (SE) of stable isotope and contaminant data for organisms collected from Cape Vera

Species	N	% Lipid	$\delta^{15}N$ (‰)	$\delta^{13}C$ (‰)	ΣDDT [ng/g ww]	ΣPCB [ng/g ww]	PCB-153 [ng/g ww]
Worm Lichen	11	4.19	4.14±0.88	-26.3±0.18	0.31±0.07	0.94±0.14	0.12±0.03
Jewel Lichen	14	1.69	9.37±1.19	-22.1±0.34	2.04±0.60	3.28 ±0.93	0.54±0.21
Collared Lemming	5	2.36	13.7±1.04	-28.3±0.27	0.69±0.33	0.76±0.37	0.11±0.07
Snow Bunting	18	2.91	18.1±0.73	-19.7±0.70	105.9±29.2	168±43.1	63.9±16.8
Ermine	2	6.5	20.3±0.18	-25.4±0.08	37.3±8.72	53.8±12.9	18.4±7.69

Table 3.2: Mean contaminant whole body data for lemmings and snow buntings from Cape Vera and areas regions of the High Arctic.

Species	Location	Year	N	ΣDDT [ng/g ww]	DDE [ng/g ww]	DDE range [ng/g]	DDE [lipid wt]	ΣPCB [ng/g ww]	ΣPCB range [ng/g]	ΣPCB [lipid wt]	Study
Collared Lemming	Cape Vera	2006	5	0.69	0.105	ND-0.27	--	0.76	0.33-1.86		This study
Collared *Lemming	Rankin Inlet	1993 -94	13	ND	ND	--	--	ND		--	(Johnstone et al. 1996)
Snow Bunting	Cape Vera	2006 -07	18	106	98.4	4.3-380	4.80×10^3	168.0	11.7-601	8.23×10^3	This study
Snow Bunting	Rankin Inlet	1993 -94	2	--	NO	0- 70	--	ND		--	(Johnstone et al. 1996)
Snow Buntings	Rankin Inlet	1982 -83	5	ND	ND	--	--	ND	--	--	(Court et al. 1990)
Snow Buntings	West Greenland - inland survey	1973	1	--	80	--	1900	NO	--	--	(Burnham and Mattox 1984)
Snow Buntings	West Greenland -inland survey	1979	4	--	80	32-110	1640	20	18-30	470	(Burnham and Mattox 1984)
Snow Bunting	Coastal East Greenland	1973	2	--	70	60-70	1700	NO	--	ND	(Burnham and Mattox 1984)

* only 1 lemmings had detectable contaminant levels (ΣPCB of 4.17 ng/g, DDE=0.11, DDD=0.70, and DDT=0.80 ng/g).

ND means calculated mean is below detection limit (PCBs: 0.1 ng/g, DDT: 0.02 ng/g Johnstone *et al.* 1996). Sample concentrations for snow buntings from Court et al. (1990) were labelled "not detected" but no detection limit was provided. NO means no analytical response.

Table 3.3: Summary of nitrogen stable isotope values, distances, and contaminant data for jewel lichen collected from Cape Vera and Cape Herschel (CV=Cape Vera, CL= cliffs at Cape Vera, CH=Cape Herschel, CP=Central Plateau, P12= Pond 12). GPS and distance values for Cape Vera were provided by Brimble (2008).

Pond	Latitude	Longitude	Distance from cliffs (m)	$\delta^{15}N$ (‰)	ΣPCB [ng/g ww]	ΣDDT [ng/g ww]	DDE/ ΣDDT	*p'p*-DDT/ *p'p*-DDE	*p,p*-DDT/ [*p'p*-DDE+ *p'p*-DDT]
CV5-6	76°13'49.2"	89°12'55.5"	827	14.6	2.02	2.01	0.28	0.97	0.49
CV8	76°13'46.8"	89°14'07.5"	313	11.4	3.56	3.43	0.32	1.86	0.65
CV9	76°13'45"	89°14'25.6"	496	11.8	0.66	ND	ND	ND	ND
CV9A	76°13'44"	89°14'33"	552	7.23	2.50	1.23	0.37	0.57	0.36
CV10	76°13'45.8"	89°14'47"	660	14.5	4.30	2.50	0.44	0.60	0.37
CV13	76°14'0.4"	89°12'29.5"	1152	14.9	1.10	0.77	0.44	0.30	0.23
CV14	76°12'42"	89°13'13"	2260	9.14	1.65	0.96	0.26	0	0
CV15-31	76°13'49.2"	89°12.5'4"	876	7.59	2.41	0.87	0.26	0.85	0.46
CV20	76°13'42"	89°13'31"	539	7.19	4.05	2.10	0.58	0.22	0.18
CV30	76°14'41.6"	89°15'1.5"	767	14.0	1.18	0.64	0.21	0.78	0.44
CL43	76°13'46.2"	89°13'23.7"	34.2	14.5	14.8	8.97	0.73	0.15	0.13
CL590	76°13'56.6"	89°14'2.6"	0	12.6	2.75	1.58	0.72	0.05	0.04
CL642	76°13'52.5"	89°14'51.7"	0	13.2	1.65	0.94*	0.64*	0*	0*
CHP12	78°37'35.9"	74°43'23.8"	N/A	-0.73	0.94	0.73	0.15	1.03	0.51
CHCP	78°36'7.8"	74°41'42.1"	N/A	-0.49	3.04	0.93	0.19	1.20	0.55

* ND indicates concentrations were below detection limit (Appendix B.2 and B.3). * indicates concentrations were based on only 1 fraction and contaminant data was lost.

Table 3.4: Summary of nitrogen stable isotope values, distances, and contaminant data for worm lichen collected from Cape Vera and Cape Herschel (CV=Cape Vera, CL= cliff at Cape Vera, CH=Cape Herschel, M=Moraine Pond, P12= Pond 12). GPS and distance values for Cape Vera were provided by Brimble (2008).

Pond	Latitude	Longitude	Distance from cliffs (m)	$\delta^{15}N$ (‰)	ΣPCB [ng/g ww]	ΣDDT [ng/g ww]	DDE/ ΣDDT	*p'p*-DDT/ *p'p*-DDE	*p,p*-DDT/ [*p'p*-DDE+ *p'p*-DDT]
CV1	76°15'51"	89°14'17	4238	2.24	0.61	ND	--	--	--
CV9A	76°13'44"	89°14'33"	552	3.55	0.82	0.34	0.29	0.1	0.34
CV10	76°13'45.8"	89°14'47"	660	8.59	1.13	ND	--	--	--
CV12	76°12'32"	89°13'42"	2541	0.99	0.78	ND	--	--	--
CV13	76°14'0.4"	89°12'29.5"	1152	7.72	0.67	ND	--	0	--
CV14	76°12'42"	89°13'13"	2260	3.06	1.67	0.71*	0.38*	0.66*	0.40*
CV20	76°13'42"	89°13'31"	539	5.58	0.67	0.39	0.38	0.34	0.77
CV30	76°14'41.6"	89°15'1.5"	767	9.07	0.77	0.51	0.18	3.35	0.77
CL43	76°13'46.2"	89°13'23.7"	34.2	4.82	1.96	0.75	0.61	0.41	0.29
CHP12	78°37'35.9"	74°43'23.8"	N/A	-0.73	0.47	ND	--	--	--
CHM	78°37'2.8"	74°41'11.4"	N/A	-0.49	0.79	ND	0	--	--

ND indicates concentrations were below detection limit (Appendix Table B.2 and B.3) * indicates concentrations were based on only 1 fraction and contaminant data was lost.

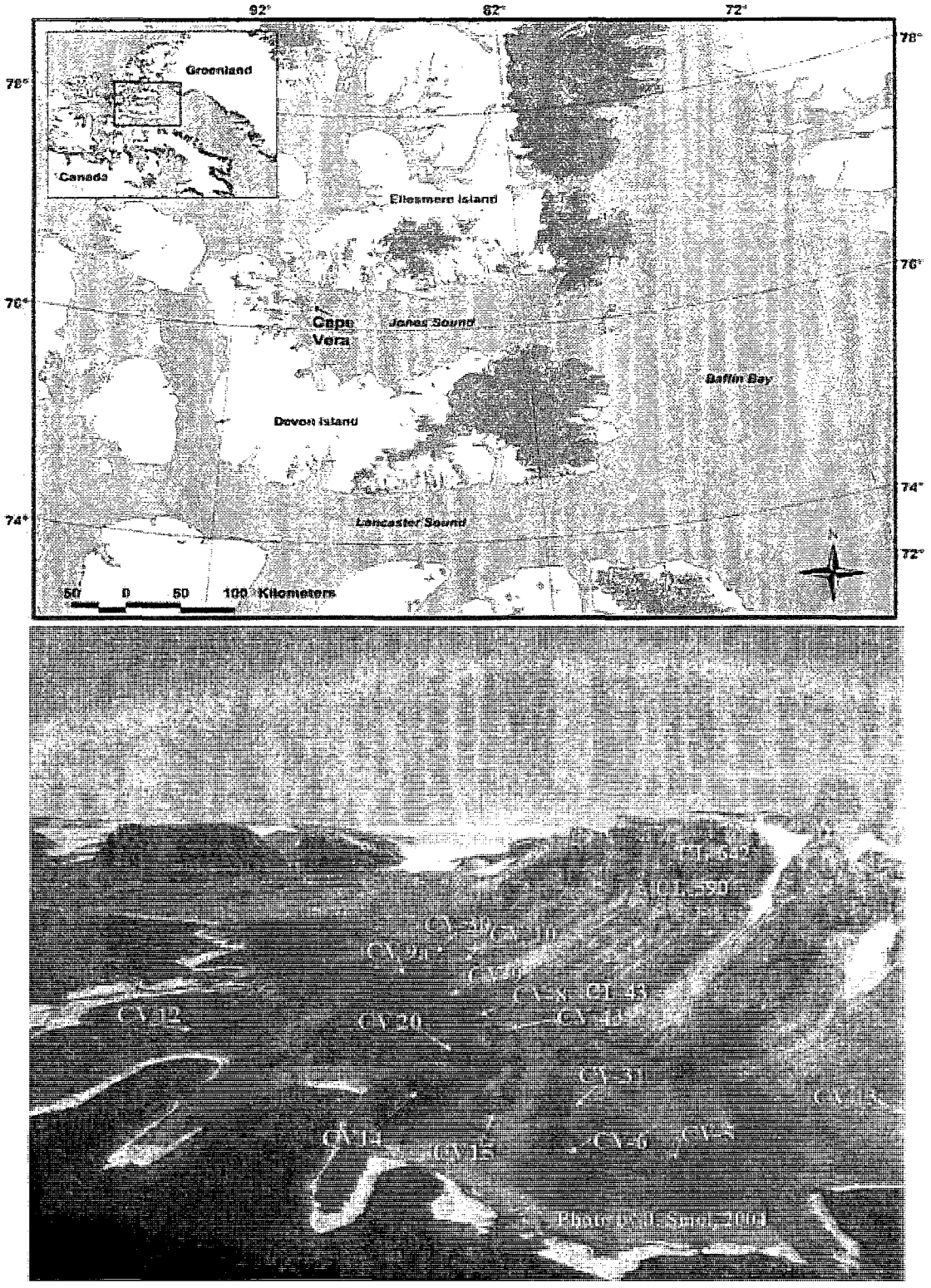

Figure 3.1 Main study site at Cape Vera, Devon Island, Nunavut (76°15' N, 89°15'W). Arrows and labels indicate ponds (CV) or cliffs and ledges (CL) where samples were collected.

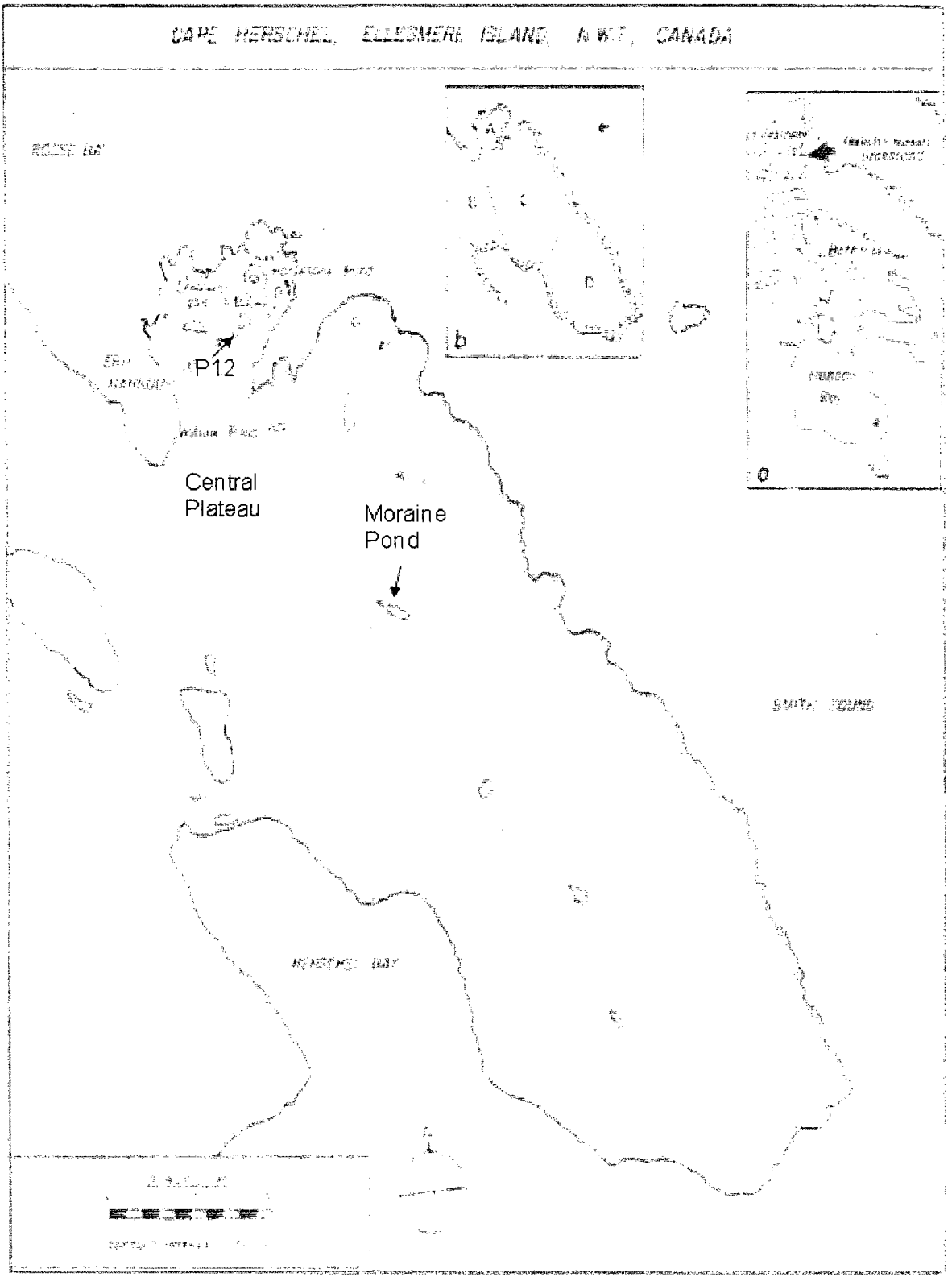

Figure 3.2 Map of control ponds [Moraine, Pond 12 (P12), and Central Plateau] sampled from Cape Herschel, Ellesmere Island, Nunavut (Douglas and Smol 1994).

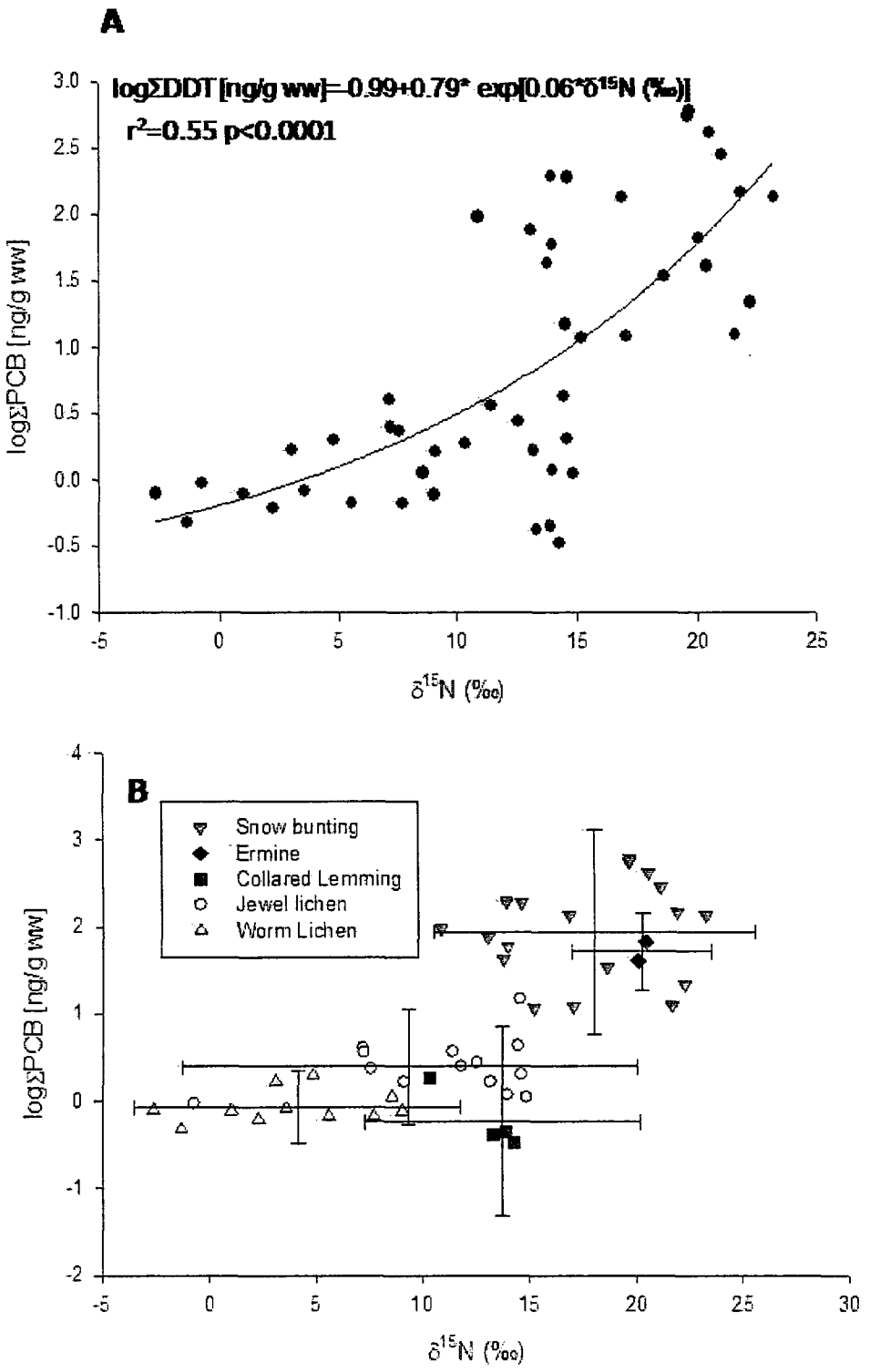

Figure 3.3 The non-linear relationship (f=y0+a*exp(b*x)) between log ΣPCB [ng/g ww] and $\delta^{15}N$ values among members of the ecosystem at Cape Vera, Devon Island, Nunavut. Errors bars represent the 95% confidence intervals surrounding the means of log ΣPCB [ng/g ww] and $\delta^{15}N$ for each species.

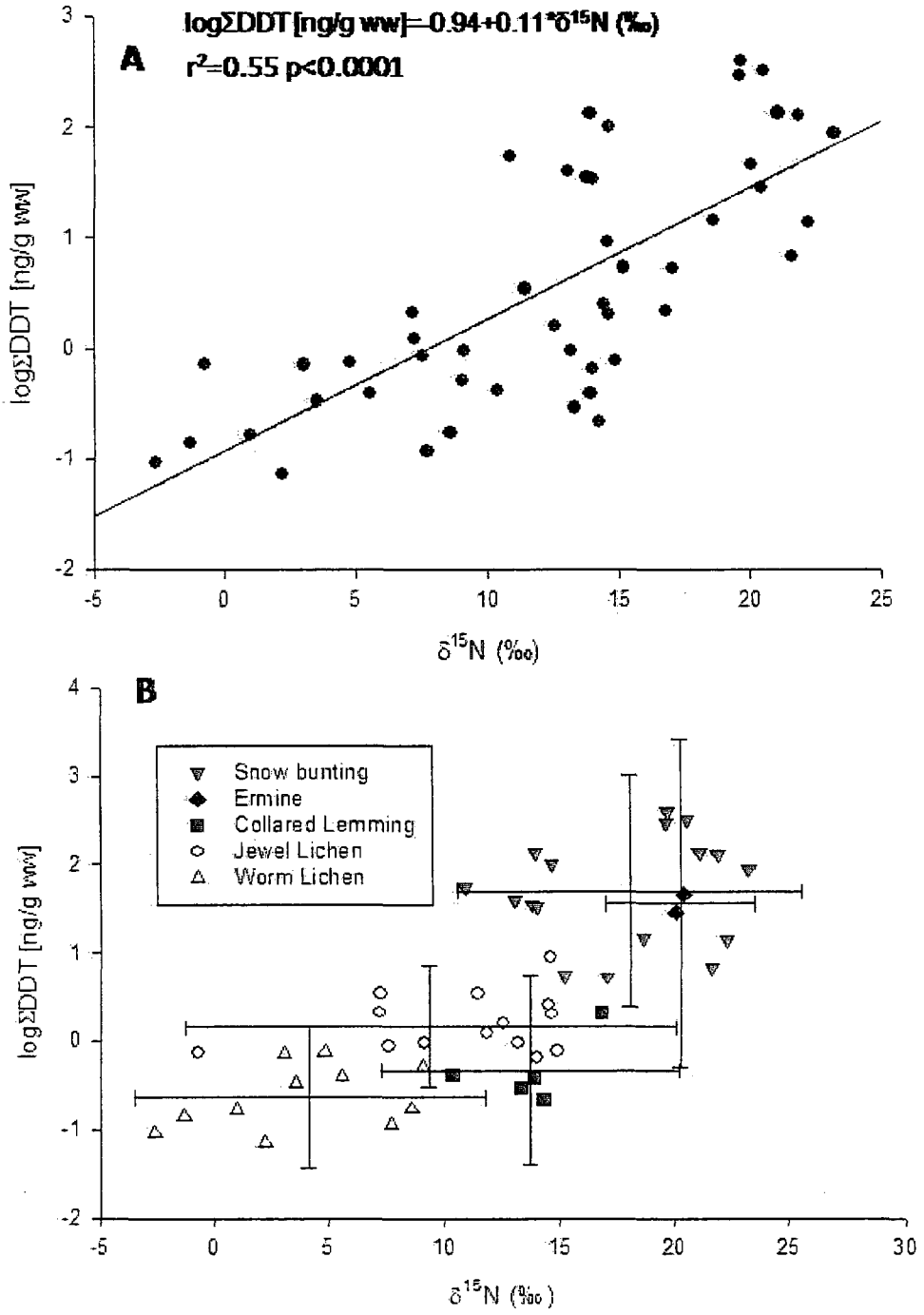

Figure 3.4A The relationship between log ΣDDT [ng/g ww] and $\delta^{15}N$ values among members of the ecosystem at Cape Vera, Devon Island, Nunavut. **B.** Errors bars represent the 95% confidence intervals surrounding the species means of log ΣDDT [ng/g ww] and $\delta^{15}N$ values for each species.

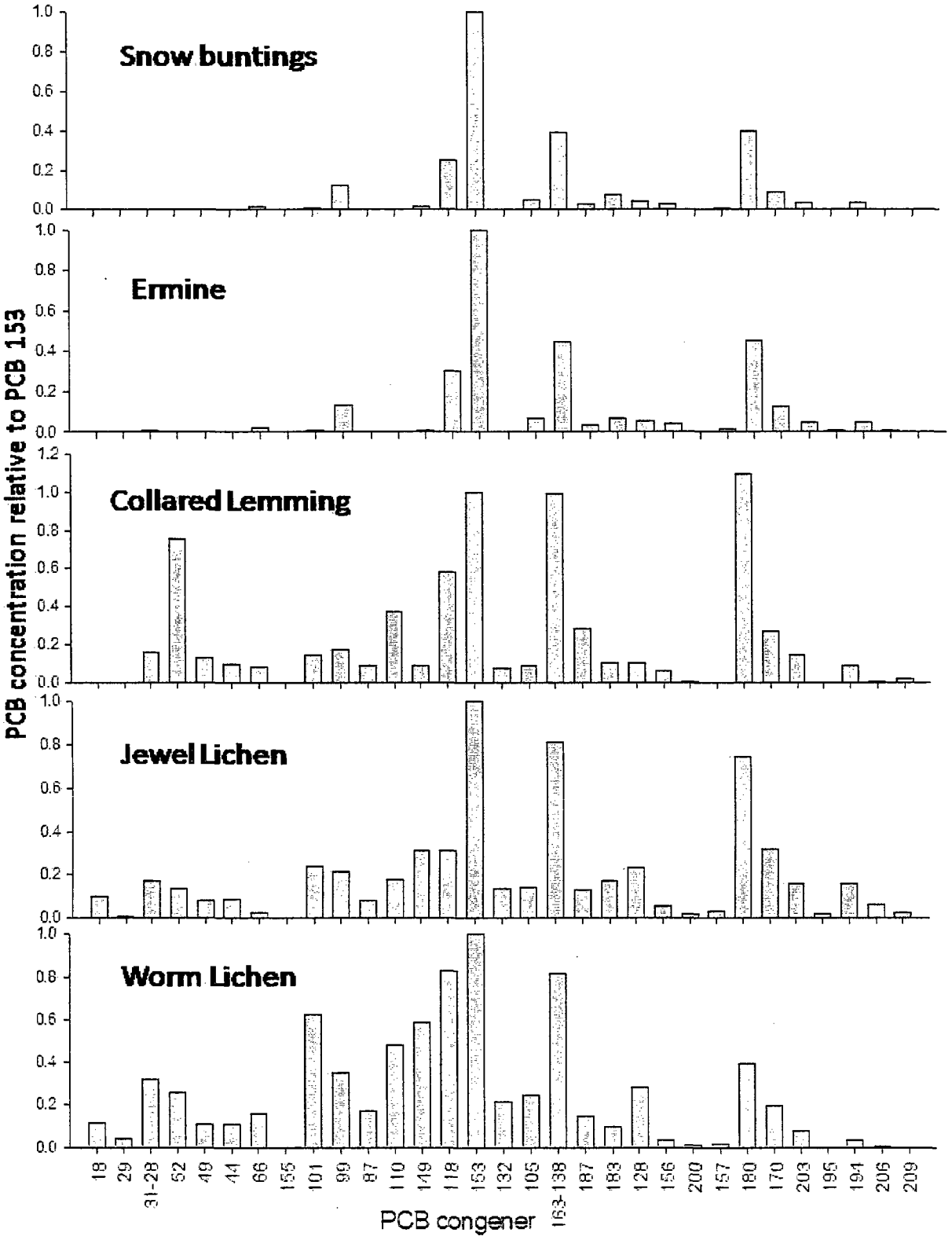

Figure 3.5 Mean PCB congener concentrations normalized to PCB-153 for each species collected from the Cape Vera food web (2006-2007).

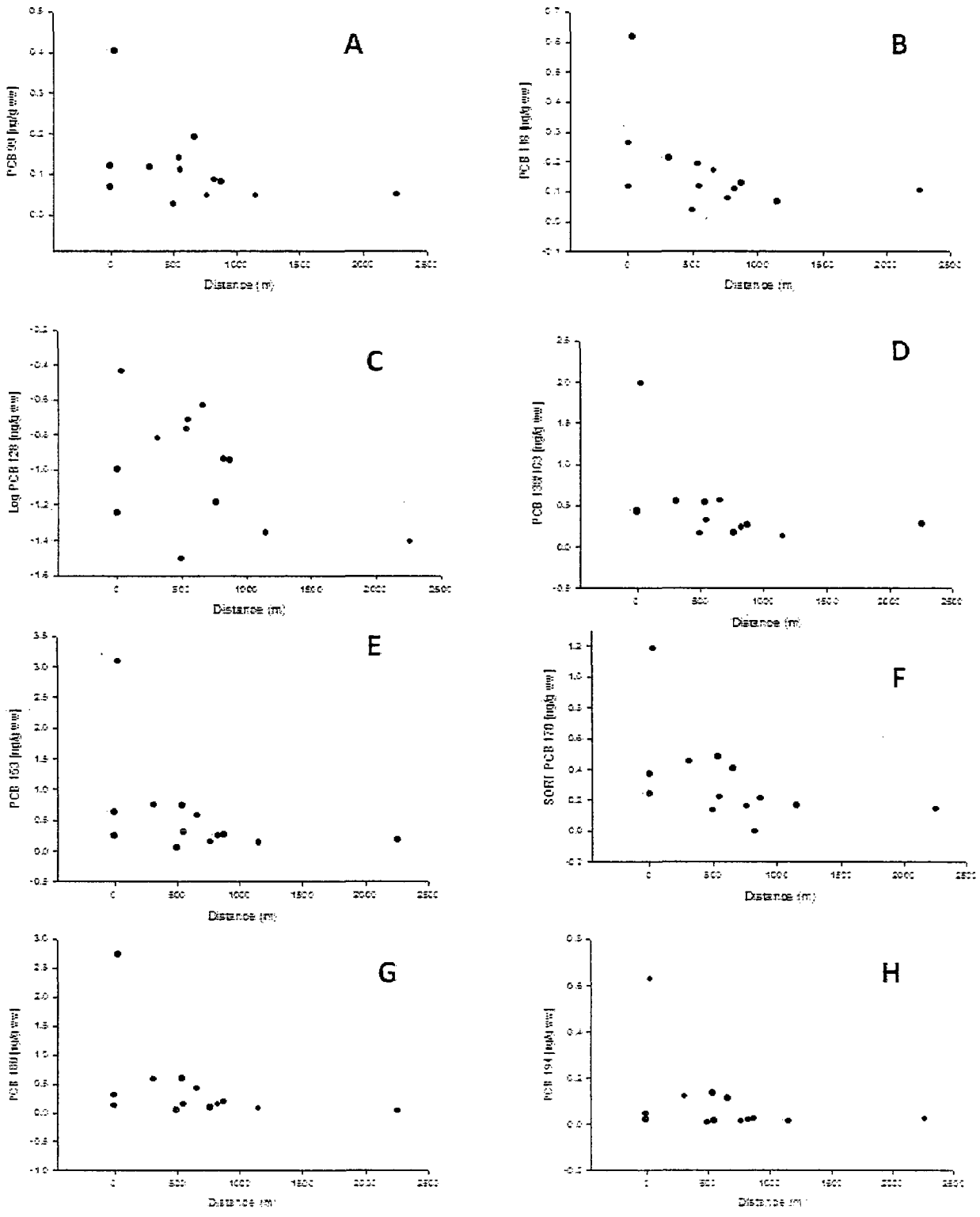

Figure 3.6 The relationship between distance (m) from the seabird cliffs and (A) PCB 99 [ng/g ww] (B) PCB 118 [ng/g ww] (C) Log PCB 128 [ng/g ww] (D) PCB 138/163 [ng/g ww] (E) PCB 153 [ng/g ww] (F) Square-root PCB 170 [ng/g ww] (G) PCB 180 [ng/g ww] (H) PCB 194 [ng/g ww] in jewel lichen (n=13).

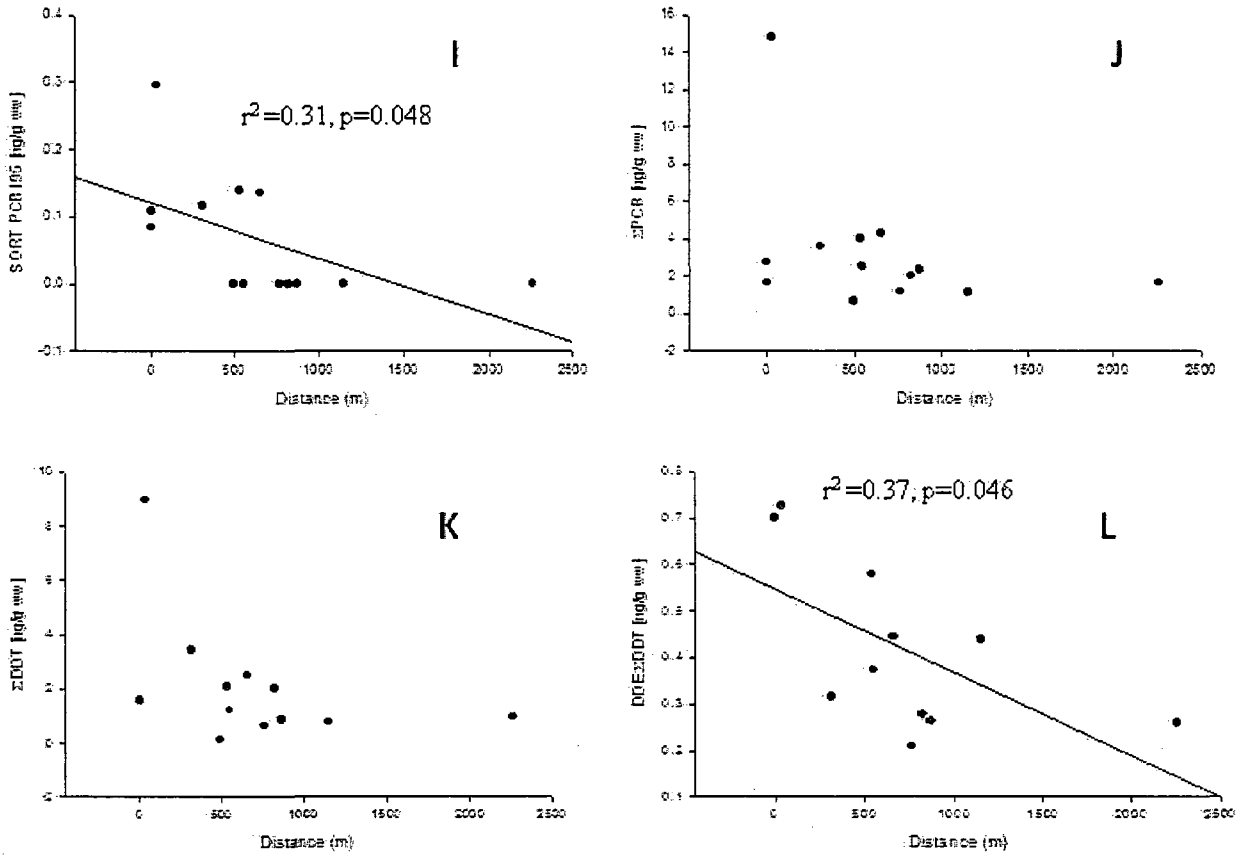

Figure 3.7 The relationship between distance (m) from the seabird cliffs and (I) Square root PCB 195 [ng/g ww] (J) ΣPCB [ng/g ww] (K) ΣDDT [ng/g ww] (L) DDE:ΣDDT [ng/g ww] in jewel lichen (n=13).

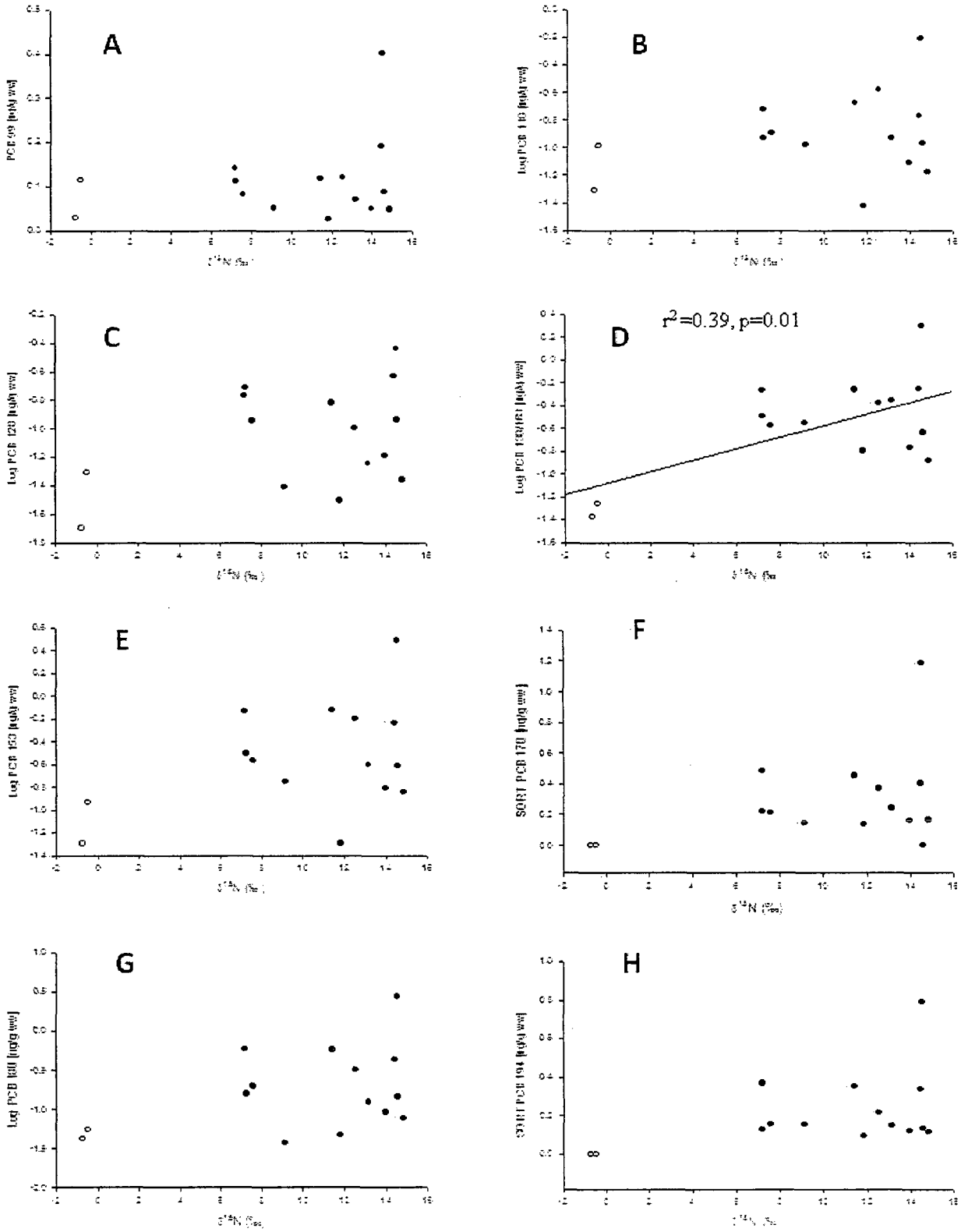

Figure 3.8 The relationship between $\delta^{15}N$ (‰) and (A) PCB 99 [ng/g ww] (B) Log PCB 118 [ng/g ww] (C) Log PCB 128 [ng/g ww] (D) Log PCB 138/163 [ng/g ww] (E) Log PCB 180 [ng/g ww] (F) Square-root Log PCB 153 [ng/g ww] (G) PCB 180 [ng/g ww] (H) Square root PCB 194 [ng/g ww] in jewel lichen from Cape Vera. Open symbols represent samples from Cape Herschel.

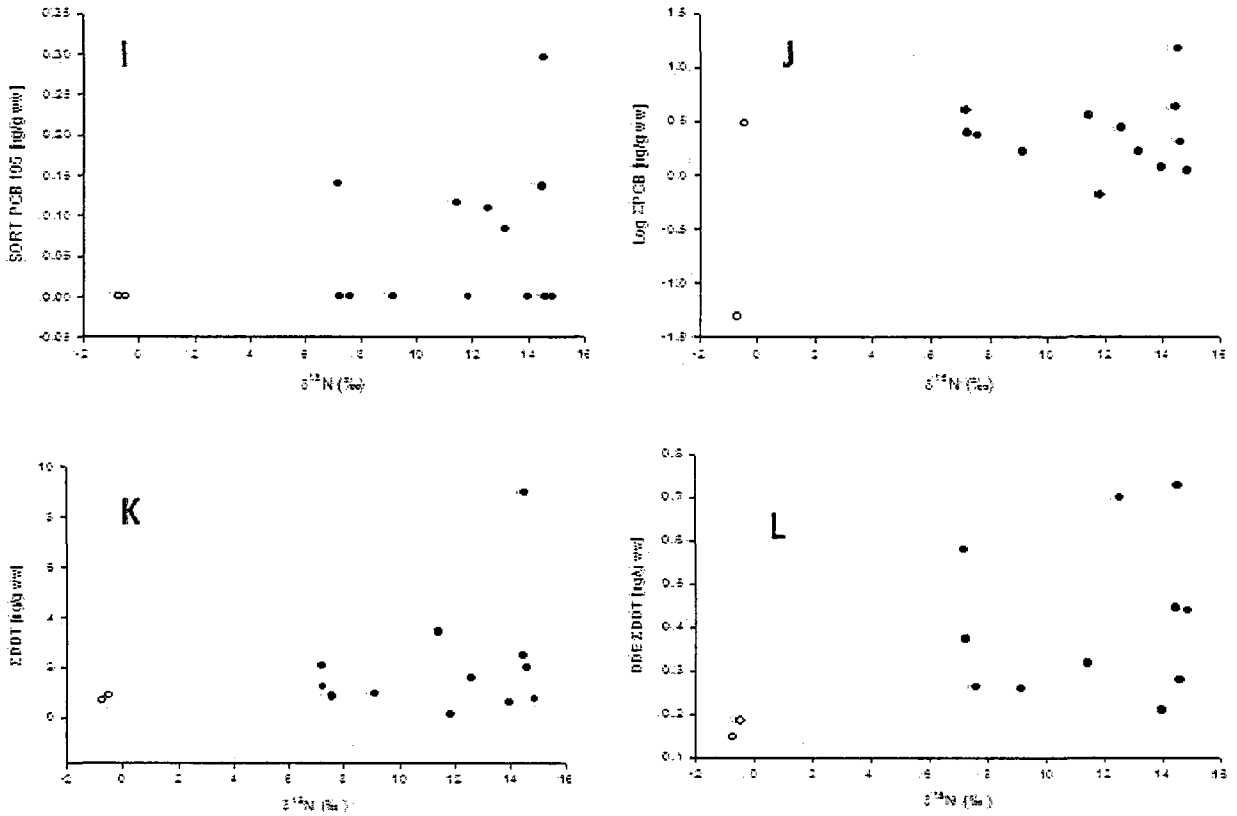

Figure 3.9 The relationship between $\delta^{15}N$ (‰) and (I) square root PCB 195 [ng/g ww] (J) Log ΣPCB [ng/g ww] (K) ΣDDT [ng/g ww] (L) DDE: ΣDDT [ng/g ww] in jewel lichen (n=13). Open symbols represent samples from Cape Herschel.

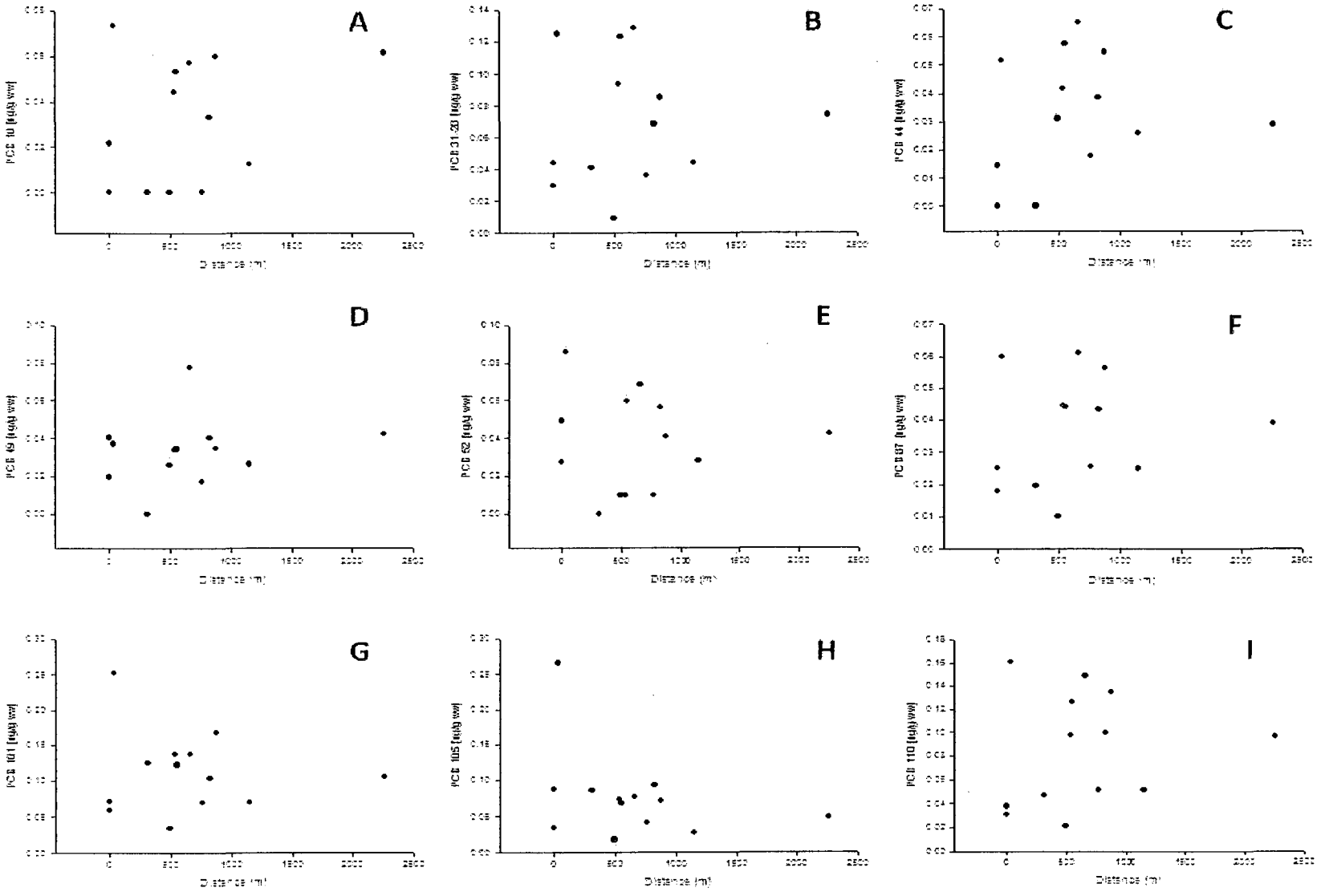

Figure 3.10 The relationship between distance (m) from the seabird cliffs and (A) PCB 18 [ng/g ww] (B) PCB 31-28 [ng/g ww] (C) PCB 44 [ng/g ww] (D) PCB 49 [ng/g ww] (E) PCB 52 [ng/g ww] (F) PCB 87 [ng/g ww] (G) PCB 101 [ng/g ww] (H) PCB 105 [ng/g ww] (I) PCB 110 [ng/g ww] in jewel lichen (n=13).

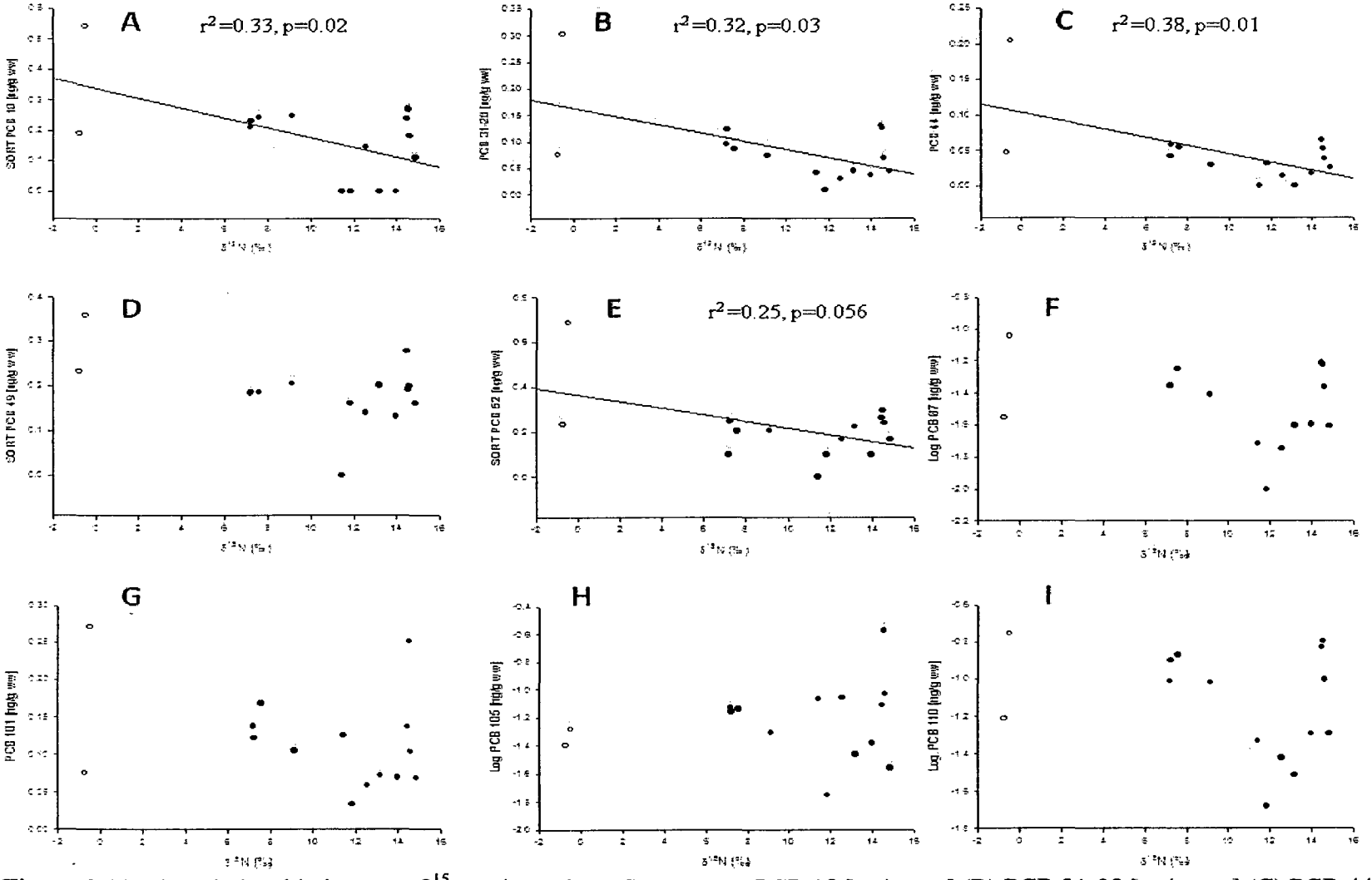

Figure 3.11. The relationship between $\delta^{15}N$ (‰) and (A) Square-root PCB 18 [ng/g ww] (B) PCB 31-28 [ng/g ww] (C) PCB 44 [ng/g ww] (D) Square-root PCB 49 [ng/g ww] (E) Square-root PCB 52 [ng/g ww] (F) Log PCB 87 [ng/g ww] (G) PCB 101 [ng/g ww]] (H) Log PCB 105 [ng/g ww] (I) Log PCB 110 [ng/g ww] in jewel lichen from Cape Vera. Open symbols represent samples from Cape Herschel.

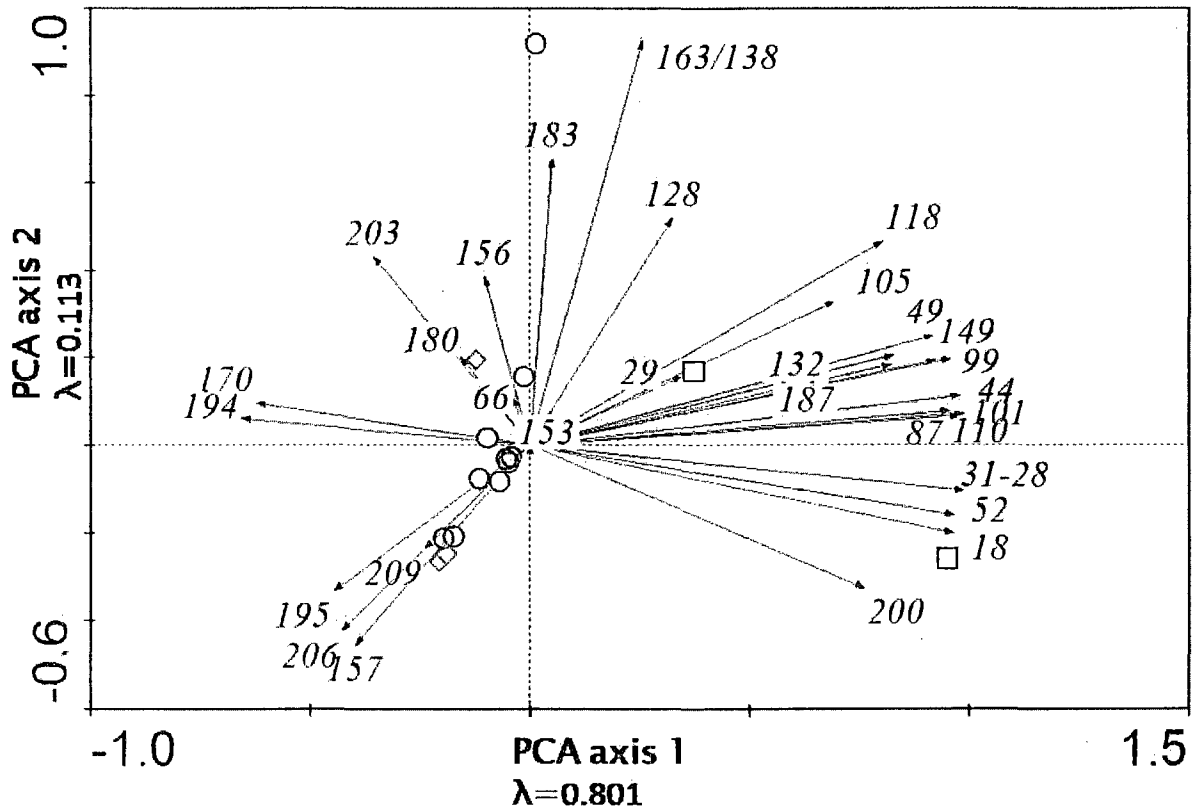

Figure 3.12 PCA biplot of PCB congeners normalized to PCB-153 in jewel lichen from 15 sites at Cape Herschel and Cape Vera. Numbers represent different congeners (eg. 200 refers to CB-200). Lichens collected near reference ponds at Cape Herschel are represented by squares, near affected ponds at Cape Vera by circles and on cliffs by diamonds.

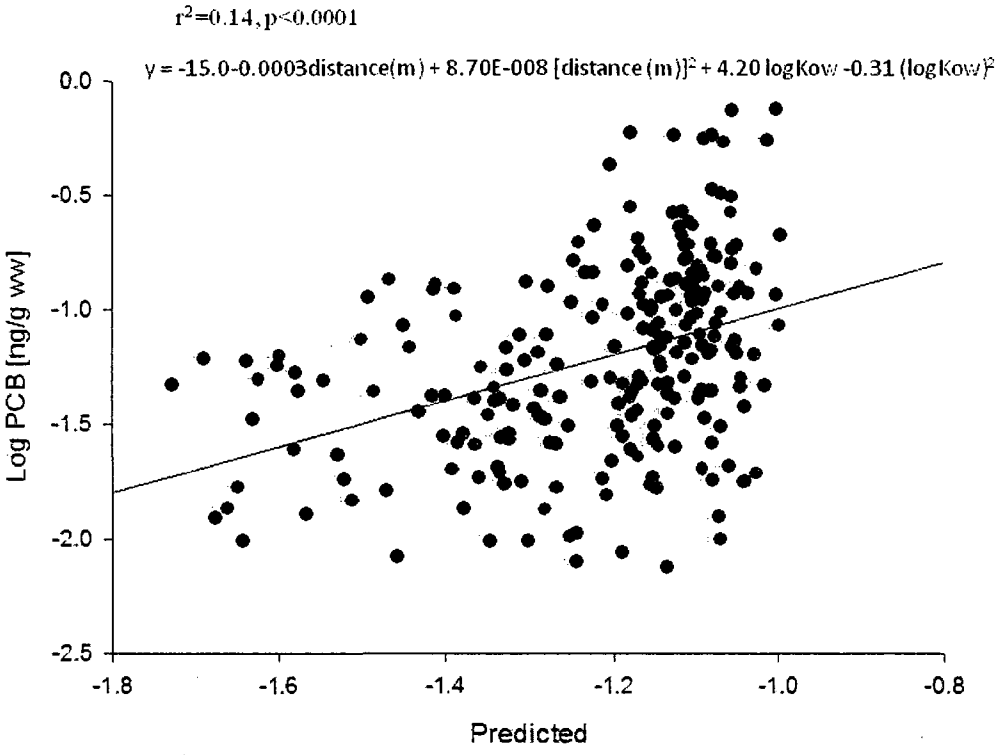

Figure 3.13 The relationship between observed and predicted log PCB congener concentrations. Predicted values generated from our model specific for each congener: Log PCB_{Lichen} = -15 – 0.0003 x distance (m) + 8.7E-008 x $[distance(m)]^2$ + 4.2 x log Kow – 0.31 x $[log\ Kow]^2$. The line represents the line of best fit.

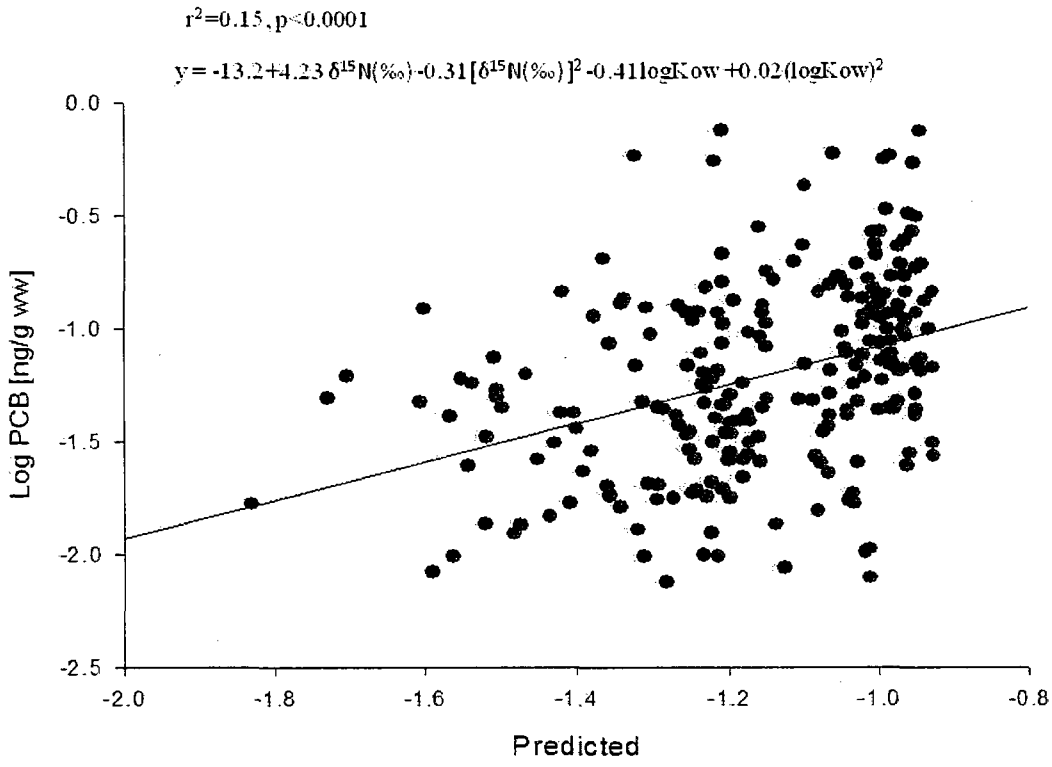

Figure 3.14. The relationship between observed and predicted log PCB congener concentrations. Predicted values generated from our model specific for each congener: Log PCB_{Lichen} = -13.2 + 4.23 x $\delta^{15}N$ (‰) - 0.31 x $[\delta^{15}N$ (‰)$]^2$ – 4.1 x log Kow + 0.02 x [log Kow]^2. The line represents the line of best fit.

4.0-Discussions and Conclusions

Biovector transport is an important process for delivering allochthonous nutrients and contaminants to coastal ecosystems. Cape Vera is a rich polar oasis that serves as important habitat to many species, and the fulmars play a critical role in fertilizing the ecosystem. The contribution of the fulmars in sustaining the ecosystem is evident by their dependence as prey by Arctic foxes, the extensive coverage of ornithocophilous lichen on the cliffs, and the high abundance of plant and animal populations next to the colony. Near other colonies in the High Arctic, the influence of fulmar fertilization on the primary productivity of local environments can be seen by chlorophyll reflectance on satellite Landsat imagery (Blais et al. 2007).

In our study, we tested to see if biovector transport was a major source of contamination to the neighbouring food webs at Cape Vera. We first established the trophic structure of the food web using carbon and nitrogen stable isotopes, and then determined whether marine-derived nutrients were transferred to the local ecosystem. Nitrogen stable isotopes values in primary producers, zooplankton, and small animals from Cape Vera were elevated relative to those from reference sites and other High Arctic areas. These differences in isotope values were very similar to those between organisms collected from seabird-affected Lake Ellasjøen and reference Lake Øyangen on the island Bjørnøya in Norway. Chironomid larvae and zooplankton from Lake Ellasjøen had mean $\delta^{15}N$ values that were approximately 3 to 4 times higher than Lake Øyangen (Evenset et al. 2004a). Species at Cape Vera had mean $\delta^{15}N$ values that were 6 to 10 times higher than those from Cape Herschel (Table 2.2). Although carbon stable isotopes showed little variation among terrestrial species, organisms from the freshwater food web had higher $\delta^{13}C$ values in ponds of close proximity to the colony (CV8, CV9, and CV10), which may have been caused by the increase in primary productivity in response to fertilization (Table 2.1).

Other studies have also shown carbon isotopes to be useful indicators of bird influence in aquatic ecosystems but not the terrestrial environment (Cocks et al. 1998, Wainwright et al. 1998).

We also tested if mercury and organochlorine concentrations in local food webs were transferred via biovector transport. We were unable to conclude that biovector transport was a major source of total mercury (THg) to the food web at Cape Vera. There was a significant relationship between total mercury concentrations and $\delta^{15}N$ values in worm lichen at Cape Vera; however, that was the only relationship among our species. The other organisms did not show relationship with THg concentrations and our seabird indicators. We found that in some cases, PCB and DDT concentrations in species may be affected by biovector transport, but these effects did not extend to the entire food web. PCB and DDT concentrations showed positive correlations $\delta^{15}N$ values in jewel lichen, but only one relationship was significant. PCB-195 and DDE:ΣDDT ratio showed significant relationships with distance. Although the relationships were not all significant, all jewel lichens displayed the expected trends with distance, which was significantly greater than what would be expected from by chance. These relationships were unique to biomagnifying congeners. Snow buntings, a small passerine had the highest concentrations of PCBs and DDT, with concentrations higher than other Arctic populations that surpassed environmental guidelines for protecting wildlife (Braune et al. 1999). However, we were unable to demonstrate that organic contaminant concentrations in ermines, collared lemmings, and worm lichen were influenced by biovector transport.

The delivery of allochthonous nutrients to coastal environments by seabirds has been observed in several species and studied extensively all over the world, from the Gulf of California to the South China Sea, the High Arctic in Norway to the Antarctic (Sanchez-Pinero

and Polis 2000, Evenset et al. 2004b, Liu et al. 2006, Roosens et al. 2007). Only recently have studies examined the possibility of contaminant transfer by seabirds. Approximately 10 million seabirds including 500 000 northern fulmars nest in the Canadian Arctic each year (Mallory 2006). The 500 000 fulmars that nest in the Canadian Arctic make up only 2% of the North Atlantic population, the rest of which migrate elsewhere. Furthermore, global annual food consumption by seabirds is estimated at 70 million tonnes (Blais et al. 2007). If biovector transport by seabirds is an important pathway of marine-derived contaminants to coastal species, its impact may be very widespread in the Arctic. This paper adds to the growing understanding of the effects biovector transport may have on coastal ecosystems, as well as sources of contamination to the Arctic.

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6.0-Appendix A

Two-sample t-test results on $\delta^{15}N$ values between tissues

Two-sample t-test on D15N Grouped by TISSUE$ vs Alternative = 'not equal'

GROUP	N	Mean	Standard Deviation
Liver	24	18.292	3.729
whole body	25	18.049	3.650

Separate Variance

Difference in Means	:	0.243
95.00% Confidence Interval	:	-1.879 to 2.365
T	:	0.231
Df	:	46.814
p-value	:	0.819

Pooled Variance

Difference in Means	:	0.243
95.00% Confidence Interval	:	-1.878 to 2.364
T	:	0.231
Df	:	47.000
p-value	:	0.819

Two-sample t-test on D13C Grouped by TISSUE$ vs Alternative = 'not equal'

GROUP	N	Mean	Standard Deviation
Liver	24	-19.013	3.872
whole body	25	-19.677	3.524

Separate Variance

Difference in Means	:	0.663
95.00% Confidence Interval	:	-1.468 to 2.795
T	:	0.626
Df	:	46.152
p-value	:	0.534

Pooled Variance

Difference in Means	:	0.663
95.00% Confidence Interval	:	-1.463 to 2.790
T	:	0.628
Df	:	47.000
p-value	:	0.533

Table A.1. Tukey HSD test results for $\delta^{13}C$ values among organisms at Cape Vera

Tukey's Honestly-Significant-Difference Test					
SPECIES$(i)	SPECIES$(j)	Difference	p-value	95.0% Confidence Interval	
				Lower	Upper
Buntings	Chironomids	-4.314	0.000	-7.080	-1.548
Buntings	Collared lemming	8.738	0.000	4.776	12.701
Buntings	Fungi	5.160	0.000	1.483	8.838
Buntings	Jewel	2.287	0.168	-0.355	4.929
Buntings	Northern fulmars	1.283	0.937	-1.483	4.049
Buntings	P Sax	9.395	0.000	6.753	12.036
Buntings	Periphyton	-10.189	0.000	-12.954	-7.423
Buntings	Tufted Sax	9.014	0.000	6.372	11.656
Buntings	Worm	7.066	0.000	4.366	9.766
Buntings	Zooplankton	-5.097	0.000	-7.863	-2.331
Buntings	ermines	5.845	0.059	-0.099	11.790
Chironomids	Collared lemming	13.052	0.000	8.795	17.309
Chironomids	Fungi	9.474	0.000	5.482	13.466
Chironomids	Jewel	6.601	0.000	3.536	9.666
Chironomids	Northern fulmars	5.596	0.000	2.424	8.769
Chironomids	P Sax	13.708	0.000	10.643	16.773
Chironomids	Periphyton	-5.875	0.000	-9.048	-2.702
Chironomids	Tufted Sax	13.328	0.000	10.263	16.393
Chironomids	Worm	11.380	0.000	8.264	14.495
Chironomids	Zooplankton	-0.783	1.000	-3.956	2.390
Chironomids	ermines	10.159	0.000	4.015	16.303
Collared lemming	Fungi	-3.578	0.415	-8.476	1.320
Collared lemming	Jewel	-6.451	0.000	-10.628	-2.274
Collared lemming	Northern fulmars	-7.456	0.000	-11.712	-3.199
Collared lemming	P Sax	0.656	1.000	-3.521	4.833
Collared lemming	Periphyton	-18.927	0.000	-23.184	-14.670
Collared lemming	Tufted Sax	0.276	1.000	-3.901	4.453
Collared lemming	Worm	-1.672	0.980	-5.886	2.542
Collared lemming	Zooplankton	-13.835	0.000	-18.092	-9.578
Collared lemming	ermines	-2.893	0.964	-9.660	3.875
Fungi	Jewel	-2.873	0.404	-6.781	1.034
Fungi	Northern fulmars	-3.878	0.066	-7.870	0.115
Fungi	P Sax	4.234	0.020	0.327	8.141
Fungi	Periphyton	-15.349	0.000	-19.341	-11.357
Fungi	Tufted Sax	3.854	0.057	-0.054	7.761
Fungi	Worm	1.906	0.917	-2.041	5.853

Tukey's Honestly-Significant-Difference Test					
SPECIES$(i)	SPECIES$(j)	Difference	p-value	95.0% Confidence Interval	
				Lower	Upper
Fungi	Zooplankton	-10.257	0.000	-14.249	-6.265
Fungi	ermines	0.685	1.000	-5.920	7.290
Jewel	Northern fulmars	-1.004	0.996	-4.069	2.061
Jewel	P Sax	7.108	0.000	4.154	10.061
Jewel	Periphyton	-12.476	0.000	-15.541	-9.410
Jewel	Tufted Sax	6.727	0.000	3.773	9.681
Jewel	Worm	4.779	0.000	1.773	7.785
Jewel	Zooplankton	-7.384	0.000	-10.449	-4.318
Jewel	ermines	3.558	0.753	-2.531	9.648
Northern fulmars	P Sax	8.112	0.000	5.047	11.177
Northern fulmars	Periphyton	-11.471	0.000	-14.644	-8.299
Northern fulmars	Tufted Sax	7.731	0.000	4.666	10.797
Northern fulmars	Worm	5.783	0.000	2.668	8.899
Northern fulmars	Zooplankton	-6.379	0.000	-9.552	-3.207
Northern fulmars	ermines	4.563	0.388	-1.581	10.707
P Sax	Periphyton	-19.583	0.000	-22.648	-16.518
P Sax	Tufted Sax	-0.381	1.000	-3.334	2.573
P Sax	Worm	-2.329	0.320	-5.335	0.677
P Sax	Zooplankton	-14.491	0.000	-17.556	-11.426
P Sax	ermines	-3.549	0.757	-9.638	2.540
Periphyton	Tufted Sax	19.203	0.000	16.138	22.268
Periphyton	Worm	17.255	0.000	14.139	20.370
Periphyton	Zooplankton	5.092	0.000	1.919	8.265
Periphyton	ermines	16.034	0.000	9.890	22.178
Tufted Sax	Worm	-1.948	0.610	-4.954	1.058
Tufted Sax	Zooplankton	-14.111	0.000	-17.176	-11.046
Tufted Sax	ermines	-3.169	0.868	-9.258	2.920
Worm	Zooplankton	-12.163	0.000	-15.278	-9.047
Worm	ermines	-1.221	1.000	-7.335	4.894
Zooplankton	ermines	10.942	0.000	4.798	17.086

Table A.2 Total mercury and stable isotope data for primary producers and macroinvertebrates from Cape Vera, Devon Island, and Cape Herschel, Ellesmere Island (CV= Cape Vera, CL=cliff at Cape Vera, CH- Cape Herschel, P12= Pond 12, CP= Central Plateau, HP= Horseshoe Pond, M=Moraine Pond, WP= Willow Pond).

Pond	Species	Latitude	Longitude	Distance from cliffs (m)	$\delta^{15}N$ (‰)	$\delta^{13}C$ (‰)	THg [ng/g dw]
CV1	Jewel Lichen	76°15'51"	89°14'17	4238	6.43	-23.2	170
CV5-6	Jewel Lichen	76°13'49.2"	89°12'55.5"	827	14.6	-22.0	354
CV8	Jewel Lichen	76°13'46.8"	89°14'7.5"	313	11.4	-22.5	242
CV9	Jewel Lichen	76°13'45"	89°14'25.6"	496	11.8	-20.2	174
CV9A	Jewel Lichen	76°13'44"	89°14'33"	552	7.23	-23.0	203
CV10	Jewel Lichen	76°13'45.8"	89°14'47"	660	14.5	-19.4	163
CV12	Jewel Lichen	76°12'32"	89°13'42"	2541	2.85	-24.0	201
CV13	Jewel Lichen	76°14'0.4"	89°12'29.5"	1152	14.9	-22.6	133
CV14	Jewel Lichen	76°12'42"	89°13'13"	2260	9.14	-21.2	272
CV31	Jewel Lichen	76°13'54.4"	89°12'30.9"	1045	7.59	-22.4	312
CV20	Jewel Lichen	76°13'42"	89°13'31"	539	7.19	-22.3	178
CV30	Jewel Lichen	76°14'41.6"	89°15'1.5"	767	14.0	-19.2	285
CL43	Jewel Lichen	76°13'46.2"	89°13'23.7"	34.2	14.5	-23.3	369
CL590	Jewel Lichen	76°13'56.6"	89°14'2.6"	0	12.6	-21.2	164
CL642	Jewel Lichen	76°13'52.5"	89°14'51.7"	0	13.2	-21.5	239
CHP12	Jewel Lichen	78°37'35.9"	74°43'23.8"	N/A	-0.73	-22.5	210
CHP12	Jewel Lichen	78°37'35.9"	74°43'23.8"	N/A	-0.62	-24.2	214
CHCP	Jewel Lichen	78°36'7.8"	74°41'42.1"	N/A	8.09	-23.2	179
CV1	Worm Lichen	76°15'51"	89°14'17	4238	2.24	-26.3	222
CV5-6	Worm Lichen	76°13'49.2"	89°12'55.5"	827	4.81	-27.5	118
CV8	Worm Lichen	76°13'46.8"	89°14'7.5"	313	8.55	-26.0	293
CV9	Worm Lichen	76°13'45"	89°14'25.6"	496	6.29	-26.9	213
CV9A	Worm Lichen	76°13'44"	89°14'33"	552	3.55	-26.6	147
CV10	Worm Lichen	76°13'45.8"	89°14'47"	660	8.59	-26.2	366
CV12	Worm Lichen	76°12'32"	89°13'42"	2541	0.99	-24.9	109
CV13	Worm Lichen	76°14'0.4"	89°12'29.5"	1152	7.72	-26.2	167
CV14	Worm Lichen	76°12'42"	89°13'13"	2260	3.06	-26.9	123
CV20	Worm Lichen	76°13'42"	89°13'31"	539	5.58	-26.3	204
CV30	Worm Lichen	76°14'41.6"	89°15'1.5"	767	9.07	-26.4	172
CV15-31	Worm Lichen	76°13'49.2"	89°12.5'4"	876	3.37	-25/6	117
CL43	Worm Lichen	76°13'46.2"	89°13'23.7"	34.2	4.82	-27.2	116
CHP12	Worm Lichen	78°37'35.9"	74°43'23.8"	N/A	-1.32	-24.8	72.5
CHHP	Worm Lichen	78°37'26.4"	74°42'57.2"	N/A	-1.03	-26.3	111
CHM	Worm Lichen	78°37'2.8"	74°41'11.4"	N/A	-2.62	-26.4	95.3
CV1	Purple Saxifrage	76°15'51"	89°14'17	4238	3.48	-30.0	140
CV5	Purple Saxifrage	76°13'49.2"	89°12'55.5"	827	2.6	-30.4	34.8
CV6	Purple Saxifrage	76°13'47"	89°12'54"	811	3.75	-27.5	30.8
CV8	Purple Saxifrage	76°13'46.8"	89°14'7.5"	313	12.1	-29.5	35.0
CV9	Purple Saxifrage	76°13'45"	89°14'25.6"	496	13.4	-25.0	15.3
CV9A	Purple Saxifrage	76°13'44"	89°14'33"	552	5.14	-29.4	30.6
CV10	Purple Saxifrage	76°13'45.8"	89°14'47"	660	12.8	-30.7	15.4
CV12	Purple Saxifrage	76°12'32"	89°13'42"	2541	3.49	-29.57	50.5
CV13	Purple Saxifrage	76°14'0.4"	89°12'29.5"	1152	13.4	-29.8	53.3
CV14	Purple Saxifrage	76°12'42"	89°13'13"	2260	7.27	-28.2	19.6
CV15	Purple Saxifrage	76°13'44"	89°13'7"	706	3.4	-30.2	50.6
CV20	Purple Saxifrage	76°13'42"	89°13'31"	539	7.42	-30.7	32.3
CV30	Purple Saxifrage	76°14'41.6"	89°15'1.5"	767	9.14	-39.7	25.8
CV31	Purple Saxifrage	76°13'54.4"	89°12'30.9"	1045	7.44	-28.6	43.9

CL43	Purple Saxifrage	76°13'46.2"	89°13'23.7"	34.2	10.1	-25.3	140
CH	Purple Saxifrage	76°36'10.3"	74°38'6.6"	N/A	-0.76	-30.1	35.1
CV1	Tufted Saxifrage	76°15'51"	89°14'17	4238	1.07	-28.7	47.1
CV5	Tufted Saxifrage	76°13'49.2"	89°12'55.5"	827	6.34	-23.3	22.9
CV6	Tufted Saxifrage	76°13'47"	89°12'54"	811	9.01	-29.3	33.3
CV8	Tufted Saxifrage	76°13'46.8"	89°14'7.5"	313	12.85	-28.1	31.3
CV9	Tufted Saxifrage	76°13'45"	89°14'25.6"	496	10.0	-29.1	26.0
CV9A	Tufted Saxifrage	76°13'44"	89°14'33"	552	5.28	-30.2	36.4
CV10	Tufted Saxifrage	76°13'45.8"	89°14'47"	660	16.6	-29.6	23.1
CV12	Tufted Saxifrage	76°12'32"	89°13'42"	2541	2.22	-29.3	48.6
CV13	Tufted Saxifrage	76°14'0.4"	89°12'29.5"	1152	13.9	-29.2	25.4
CV14	Tufted Saxifrage	76°12'42"	89°13'13"	2260	9.53	-29.8	24.4
CV15	Tufted Saxifrage	76°13'44"	89°13'7"	706	7.32	-29.7	31.2
CV20	Tufted Saxifrage	76°13'42"	89°13'31"	539	10.7	-29.1	26.0
CV30	Tufted Saxifrage	76°14'41.6"	89°15'1.5"	767	14.4	-30.3	30.8
CV31	Tufted Saxifrage	76°13'54.4"	89°12'30.9"	1045	9.30	-28.2	25.2
CL43	Tufted Saxifrage	76°13'46.2"	89°13'23.7"	34.2	8.85	-25.1	70.8
CHWP	Tufted Saxifrage	78°37'26.4"	74°42'57.2"	N/A	0.17	-29.1	15.2
CV5	Phyto/Zooplankton	76°13'49.2"	89°12'55.5"	827	11.5	-12.6	53.9
CV6	Phyto/Zooplankton	76°13'47"	89°12'54"	811	7.39	-15.2	42.4
CV8	Phyto/Zooplankton	76°13'46.8"	89°14'7.5"	313	19.9	-12.6	40.2
CV9	Phyto/Zooplankton	76°13'45"	89°14'25.6"	496	16.5	-11.0	44.8
CV9A	Phyto/Zooplankton	76°13'44"	89°14'33"	552	10.7	-11.5	60.3
CV10	Phyto/Zooplankton	76°13'45.8"	89°14'47"	660	19.2	-8.65	29.9
CV12	Phyto/Zooplankton	76°12'32"	89°13'42"	2541	3.61	-16.7	38.3
CV13	Phyto/Zooplankton	76°14'0.4"	89°12'29.5"	1152	21.8	-16.1	262
CV14	Phyto/Zooplankton	76°12'42"	89°13'13"	2260	12.6	-29.8	64.6
CV15	Phyto/Zooplankton	76°13'44"	89°13'7"	706	6.56	-17.4	37.0
CV20	Phyto/Zooplankton	76°13'42"	89°13'31"	539	8.96	-13.9	37.4
CV30	Phyto/Zooplankton	76°14'41.6"	89°15'1.5"	767	18.5	-10.8	45.1
CV31	Phyto/Zooplankton	76°13'54.4"	89°12'30.9"	1045	13.2	-23.6	165
CHWP	Phyto/Zooplankton	78°37'26.4"	74°42'57.2"	N/A	2.03	-25.3	34.6
CV1	Periphyton	76°15'51"	89°14'17	4238	6.06	-13.4	65.5
CV8	Periphyton	76°13'46.8"	89°14'7.5"	313	20.4	-9.65	27.4
CV9	Periphyton	76°13'45"	89°14'25.6"	496	16.9	-3.13	12.7
CV9A	Periphyton	76°13'44"	89°14'33"	552	3.49	-7.4	23.4
CV10	Periphyton	76°13'45.8"	89°14'47"	660	19.4	-8.45	35.5
CV12	Periphyton	76°12'32"	89°13'42"	2541	1.92	-5.88	13.6
CV13	Periphyton	76°14'0.4"	89°12'29.5"	1152	19.6	-9.74	45.5
CV14	Periphyton	76°12'42"	89°13'13"	2260	15.5	-9.66	55.0
CV15	Periphyton	76°13'44"	89°13'7"	706	3.35	-10.7	6.33
CV20	Periphyton	76°13'42"	89°13'31"	539	5.28	-7.92	13.6
CV30	Periphyton	76°14'41.6"	89°15'1.5"	767	17.1	10.0	15.4
CV31	Periphyton	76°13'54.4"	89°12'30.9"	1045	12.0	-12.6	58.4
CV40	Periphyton	76°15'51"	89°14'17	4238	5.99	-13.5	68.4
CHHP	Periphyton	78°37'26.4"	74°42'57.2"	N/A	1.23	-12.8	3.42
CHP12	Periphyton	78°37'35.9"	74°43'23.8"	N/A	0.79	-8.58	22.6
CV1	Chironomids	76°15'51"	89°14'17	4238	9.71	-20.6	101
CV8	Chironomids	76°13'46.8"	89°14'7.5"	313	19.7	-12.6	63.3
CV8	Chironomids	76°13'46.8"	89°14'7.5"	313	22.7	-14.7	68.4
CV9	Chironomids	76°13'45"	89°14'25.6"	496	17.9	-13.1	87.1
CV9A	Chironomids	76°13'44"	89°14'33"	552	17.9	-13.5	38.3
CV9A	Chironomids	76°13'44"	89°14'33"	552	15.6	-13.5	25.5
CV10	Chironomids	76°13'45.8"	89°14'47"	660	20.9	-14.1	44.7
CV13	Chironomids	76°14'0.4"	89°12'29.5"	1152	21.4	-13.7	36.1
CV14	Chironomids	76°12'42"	89°13'13"	2260	10.4	-15.5	41.6

CV14	Chironomids	76°12'42"	89°13'13"	2260	13.2	-16.5	34.0
CV20	Chironomids	76°13'42"	89°13'31"	539	12.8	-14.9	44.0
CV30	Chironomids	76°14'41.6"	89°15'1.5"	767	13.9	-16.8	88.1
CV41	Chironomids	76°15'51"	89°14'17	4238	18.5	-19.0	91.3
CV9	Fungi	76°13'45"	89°14'25.6"	496	16.8	-25.3	215
CV9A	Fungi	76°13'44"	89°14'33"	552	9.02	-24.8	437
CV10	Fungi	76°13'45.8"	89°14'47"	660	15.0	-25.1	125
CV14	Fungi	76°12'42"	89°13'13"	2260	8.83	-24.6	295
CV20	Fungi	76°13'42"	89°13'31"	539	6.40	-24.7	151
CV31	Fungi	76°13'54.4"	89°12'30.9"	1045	7.98	-23.9	260

Table A.3 Total mercury and stable isotope data for small animals from Cape Vera, Devon Island.

Location	Species	Latitude	Longitude	Age/Sex Class	$\delta^{15}N$ (‰)	$\delta^{13}C$ (‰)	THg [ng/g dw]
CV1	Snow bunting	76°15'47.3"	89°15'26.3"	Female	13.9	-26.7	69.4
CV1	Snow bunting	76°15'45.7"	89°14'26.5"	Male	14.6	-24.2	107
CV1	Snow bunting	76°15'47.3"	89°15'26.3"	Male	14.0	-22.6	146
CV1	Snow bunting	76°15'45.7"	89°14'26.5"	Male	13.1	-21.8	310
CV1	Snow bunting	76°15'47.3"	89°15'26.3"	Hatch Year	13.8	-22.6	104
CV7	Snow bunting	76°13'48"	89°13'32"	Female	21.1	-19.7	100
CV7	Snow bunting	76°13'48"	89°13'32"	Hatch Year	20.9	-15.2	84.2
CV7	Snow bunting	76°13'48"	89°13'32"	Hatch Year	16.7	-18.3	106
CV8	Snow bunting	76°13'47.5"	89°14'14.1"	Female	19.7	-21.5	272
CV8	Snow bunting	76°13'47.5"	89°14'14.1"	Female	16.8	-25.1	116
CV8	Snow bunting	76°13'47.5"	89°14'14.1"	Male	19.6	-21.0	374
CV8	Snow bunting	76°13'47.8"	89°14'2.1"	Male	20.5	-21.5	319
CV8	Snow bunting	76°13'46.8"	89°14'7.5"	Hatch Year	23.2	-19.2	306
CV8	Snow bunting	76°13'46.8"	89°14'7.5"	Hatch Year	17.0	-18.1	92.3
CV9a	Snow bunting	76°13'46.8"	89°14'7.5"	Female	15.9	-14.5	132
CV10	Snow bunting	76°13'46.8"	89°14'7.5"	Hatch Year	23.0	-20.8	425
CV10	Snow bunting	76°13'42.4"	89°14'59.5"	Hatch Year	22.2	-13.5	80.8
CV10	Snow bunting	76°13'45.8"	89°14'47"	Hatch Year	21.0	-15.4	79.9
CV10	Snow bunting	76°13'45.8"	89°14'47"	Hatch Year	21.6	-17.7	86.0
CV12	Snow bunting	76°13'45.8"	89°14'47"	Hatch Year	15.2	-16.0	57.8
CV14	Snow bunting	76°12'42"	89°13'13"	Nestling	14.2	-16.3	45.9
near cabin	Snow bunting			Male	10.9	-22.4	570
near cabin	Snow bunting			Hatch Year	18.6	-15.6	196
	Snow bunting	76°13'49.1"	89°13'41.0"	Hatch Year	21.9	-20.6	223
	Snow bunting	76°13'47.1"	89°14'1.5"	Hatch Year	21.8	-22.0	133
CV7	Collared Lemming	76°13'48"	89°13'32"	Female	10.4	-28.4	10.3
CV8	Collared Lemming	76°13'46.8"	89°14'7.5"	Female	13.9	-28.1	65.7
CV8	Collared Lemming	76°13'46.8"	89°14'7.5"	Male	16.8	-29.1	348
CV9	Collared Lemming	76°13'45"	89°14'25.6"	Male	14.3	-27.4	24.1
CV10	Collared Lemming	76°13'45.8"	89°14'47"	Female	13.3	-28.5	32.1
CV8	Ermine	76°13'46.8"	89°14'7.5"	Juvenile	20.1	-25.3	172
CV8	Ermine	76°13'47.5"	89°14'14.1"	Male	20.4	-25.5	231

Appendix B. Organochlorine data for species from Cape Vera, Devon Island and Cape Herschel, Ellesmere Island

Table B.1 The mean percent recoveries of PCB and OC standards for each sample type. Buntings were run with a standard that did not include PCB-205.

Species	N	PCB-30	PCB-205	1, 3- DBB	1,3,5-TBB	1,2,4,5-TBB	δ-HCH	Endrine Ketone
Snow Bunting	20	69.8 ± 13.5	N/A	48.4± 16.6	35.0±6.0	36.5±10.4	33.5±7.8	11.4 ±7.3
Collared Lemming	5	89.1±15.3	74.5±12.0	56.6±12.3	42.0±11.5	39.3±8.9	44.1±6.5	10.9±5.7
Ermine	4	79.5±9.4	65.8±3.7	49.8±4.7	36.1±5.6	34.8±5.9	33.8±2.7	7.3±1.0
Lichen	29	52.8±19.0	40.6±16.4	24.9±12.5	18.6±7.4	20.3±8.5	22.0±9.0	4.8±5.2

Table B.2 Method detection limits of PCB congeners for organisms collected from Cape Vera, Devon Island, Nunavut (data is in pg/g wet weight and is based on 12 method blanks).

PCB	Amount	PCB	Amount	PCB	Amount
5-8	0.00	99	16.7	156	2.70
14	0.00	87	5.45	200	0.00
19	0.00	110	8.52	157	0.00
18	0.00	149	9.48	180	37.0
29	0.00	118	33.9	170	11.2
31-28	18.0	153	101	203	7.12
52	19.6	132	3.35	195	0.00
49	4.74	105	5.60	194	4.26
44	7.00	163/138	49.1	206	0.00
66	0.00	187	6.29	209	0.00
155	0.00	183	8.81		
101	9.84	128	0.00	Sum	291

Table B.3 Method detection limits of OC pesticides for organisms collected from Cape Vera, Devon Island, Nunavut (data is in pg/g wet weight and is based on 12 method blanks).

Compound	Amount	Compound	Amount	Compound	Amount
1,3-DCB	0.00	HCB	55.8	Endrin	28.4
1,4-DCB	0.00	g-HCH	86.6	b-Endosulfan	17.2
1,2-DCB	0.00	Hepatchlor	0.00	p,p'-DDD	12.5
1,3,5-TCB	0.00	Aldrin	0.00	o,p'-DDT	66.0
1,2,4-TCB	36.1	Hep. Epoxide	29.1	p,p'-DDT	99.8
1,2,3-TCB	0.00	g-Chlordane	0.00	Methoxyclor	340.0
1,2,3,4-TTCB	49.4	a-Endosulfan & a-Chlordane	0.00	Mirex	10.9
PECB	92.7	p,p'-DDE	78.2		
a-HCH	43.0	Dieldrin	23.8	ΣDDT	257

Table B.4 PCB congener concentration for worm lichen collected from Cape Vera and Cape Herschel (CV=Cape Vera, CL= Cliff at Cape Vera, CH-Cape Herschel, M=Moraine Pond, P12= Pond 12).

PCB	CV12	CV1	CHP12	CV43	CV13	CV10	CV30	CV20	CV14	CV9A	CHM
5-8	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
18	0.000	0.000	0.054	0.000	0.000	0.000	0.000	0.026	0.034	0.043	0.000
29	0.000	0.000	0.000	0.000	0.000	0.051	0.000	0.000	0.000	0.000	0.000
31-28	0.060	0.050	ND	0.052	0.050	0.051	0.000	0.047	0.057	0.049	0.000
52	0.056	ND	0.021	0.036	0.000	0.030	0.023	0.034	0.054	0.069	ND
49	0.000	0.018	0.015	0.000	0.030	0.049	0.000	0.013	0.020	0.000	0.000
44	0.022	0.032	0.012	0.016	0.000	0.016	0.000	0.025	0.026	0.000	0.000
66	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.053	0.086	0.071	0.000
101	0.097	0.116	0.106	0.082	0.069	0.045	0.057	0.041	0.073	0.050	0.099
99	0.035	0.036	0.008	0.091	0.053	0.040	0.043	0.027	0.068	0.038	0.034
87	0.026	0.020	0.000	0.025	0.028	0.013	0.000	0.000	0.038	0.028	0.051
110	0.065	0.052	0.025	0.061	0.067	0.055	0.045	0.040	0.080	0.057	0.098
149	0.066	0.053	0.044	0.106	0.074	0.077	0.053	0.049	0.113	0.072	0.080
118	0.082	0.058	0.017	0.190	0.120	0.104	0.110	0.069	0.152	0.084	0.127
153	ND	ND	ND	0.422	0.105	0.168	0.154	ND	0.190	ND	ND
132	0.026	0.017	0.016	0.033	0.000	0.029	0.019	0.016	0.067	0.022	0.041
105	0.031	0.007	0.012	0.057	0.015	0.028	0.035	0.021	0.066	0.023	0.034
163/138	0.085	0.052	0.000	0.301	0.000	0.116	0.107	0.087	0.159	0.065	0.122
187	0.015	0.006	0.015	0.036	0.000	0.063	0.000	0.003	0.033	0.021	0.000
183	0.018	0.000	0.017	0.044	0.000	0.000	0.000	0.010	0.028	0.015	0.000
128	0.030	0.010	0.029	0.071	0.024	0.043	0.029	0.023	0.063	0.027	0.026
156	0.000	0.000	0.000	0.026	0.000	0.000	0.000	0.008	0.012	0.000	0.000
200	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.015	0.000	0.000
157	0.000	0.000	0.000	0.007	0.000	0.000	0.000	0.000	0.013	0.000	0.000
180	0.000	ND	0.000	0.178	ND	0.121	0.049	ND	0.067	0.038	ND
170	ND	ND	ND	0.058	0.013	0.018	0.016	ND	0.131	0.000	0.000
203(PRC)	0.010	0.000	0.016	0.030	0.000	0.009	0.021	0.000	0.016	0.000	0.000
195	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
194	0.000	0.000	0.000	0.030	0.000	0.000	0.009	0.000	0.007	0.000	0.000
206	0.000	0.000	0.000	0.008	0.000	0.000	0.000	0.000	0.000	0.000	0.000
209	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
ΣPCB	**0.779**	**0.614**	**0.473**	**1.96**	**0.667**	**1.13**	**0.767**	**0.667**	**1.67**	**0.824**	**0.790**

ND indicates concentrations were below detection limit (Appendix Table B.2 and B.3).

Table B.5 PCB congener concentrations for jewel lichen collected from Cape Vera and Cape Herschel (CV=Cape Vera, CL=cliffs at Cape Vera, CH= Cape Herschel, CP=Central Plateau, P12= Pond 12).

	CV13	CV5-6	CV10	CV20	CV14	CHCP	CL43	CL590	CHP12	CL642	CV30	CV15-31	CV9	CV9A	CV8
5-8	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
18	0.012	0.033	0.057	0.044	0.061	0.294	0.073	0.022	0.037	0.000	0.000	0.060	0.000	0.053	0.000
29	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.041	0.000	0.000	0.000	0.000	0.000	0.000
31-28	0.044	0.069	0.129	0.094	0.074	0.304	0.125	0.030	0.075	0.044	0.036	0.085	0.009	0.123	0.041
52	0.028	0.056	0.068	0.010	0.042	0.469	0.086	0.027	0.054	0.049	0.010	0.041	0.010	0.060	0.000
49	0.026	0.040	0.078	0.034	0.042	0.129	0.037	0.020	0.054	0.040	0.017	0.035	0.026	0.034	0.000
44	0.026	0.038	0.065	0.042	0.029	0.204	0.052	0.014	0.047	0.000	0.018	0.054	0.031	0.057	0.000
66	0.000	0.000	0.000	0.000	0.108	0.000	0.000	0.058	0.000	0.000	0.000	0.000	0.000	0.000	0.000
101	0.069	0.104	0.137	0.138	0.105	0.272	0.252	0.059	0.075	0.072	0.069	0.168	0.034	0.122	0.125
99	0.048	0.087	0.192	0.141	0.051	0.114	0.403	0.121	0.029	0.069	0.048	0.082	0.026	0.111	0.118
87	0.025	0.043	0.061	0.044	0.039	0.090	0.060	0.018	0.028	0.025	0.025	0.056	0.010	0.044	0.019
110	0.051	0.099	0.149	0.097	0.096	0.176	0.161	0.038	0.061	0.031	0.051	0.135	0.021	0.126	0.046
149	0.099	0.192	0.333	0.184	0.117	0.233	0.248	0.085	0.084	0.077	0.096	0.211	0.046	0.266	0.117
118	0.067	0.109	0.169	0.192	0.105	0.103	0.619	0.264	0.049	0.117	0.078	0.129	0.038	0.117	0.213
153	0.144	0.242	0.577	0.742	0.178	0.115	3.086	0.630	0.051	0.249	0.155	0.267	0.051	0.311	0.748
132	0.031	0.144	0.087	0.065	0.083	0.095	0.202	0.021	0.043	0.024	0.043	0.086	0.018	0.071	0.000
105	0.027	0.092	0.077	0.074	0.049	0.052	0.266	0.087	0.040	0.034	0.041	0.072	0.018	0.069	0.086
163/138	0.131	0.230	0.557	0.539	0.280	0.164	1.983	0.419	0.064	0.437	0.169	0.265	0.159	0.321	0.550
187	0.041	0.076	0.115	0.066	0.031	0.061	0.212	0.034	0.031	0.042	0.041	0.076	0.012	0.065	0.064
183	0.028	0.059	0.165	0.118	0.022	0.018	0.463	0.070	0.013	0.038	0.035	0.068	0.018	0.070	0.118
128	0.044	0.115	0.234	0.171	0.039	0.049	0.366	0.100	0.020	0.057	0.065	0.113	0.031	0.193	0.151
156	0.011	0.000	0.037	0.047	0.000	0.007	0.178	0.042	0.000	0.012	0.009	0.016	0.008	0.017	0.045
200	0.010	0.000	0.035	0.019	0.000	0.025	0.050	0.000	0.000	0.000	0.000	0.000	0.000	0.017	0.000
157	0.008	0.000	0.023	0.025	0.000	0.000	0.116	0.016	0.000	0.000	0.000	0.000	0.000	0.000	0.020
180	0.078	0.145	0.427	0.591	0.037	0.055	2.737	0.314	0.042	0.125	0.092	0.197	0.047	0.156	0.577
170	0.027	0.000	0.163	0.233	0.020	0.000	1.407	0.135	0.000	0.058	0.026	0.044	0.018	0.049	0.204
203	0.014	0.028	0.133	0.126	0.020	0.010	0.536	0.052	0.000	0.024	0.029	0.046	0.017	0.033	0.144
195	0.000	0.000	0.019	0.019	0.000	0.000	0.087	0.012	0.000	0.007	0.000	0.000	0.000	0.000	0.013
194	0.013	0.018	0.113	0.135	0.025	0.000	0.628	0.047	0.000	0.021	0.015	0.023	0.008	0.016	0.122
206	0.000	0.000	0.050	0.063	0.000	0.000	0.282	0.010	0.000	0.000	0.010	0.014	0.000	0.000	0.049
209	0.000	0.000	0.047	0.000	0.000	0.000	0.108	0.005	0.000	0.000	0.000	0.000	0.000	0.000	0.017
ΣPCB	2.02	4.30	4.05	1.65	3.04	14.8	2.75	0.940	1.65	1.18	2.34	0.66	2.50	3.59	0.291

ND indicates concentrations were below detection limit (Appendix Table B.2 and B.3)

Table B.6 PCB congener concentrations in snow buntings collected from Cape Vera (m=male, F=female, HY= hatch year).

Date	17/07	12/06	19/07	17/07	17/07	18/07	17/07	17/07	17/07	17/07	16/07	16/06	15/06	14/06	17/07	17/06	17/07	17/07
Sex	M	HY	HY	M	F	HY	F	F	HY	HY	M	HY	HY	HY	M	HY	M	M
Location	CV1	CV12	near cabin	CV8	CV1		CV8	CV8	CV1	CV8	near cabin	CV7	CV14	CV10	CV1	CV10	CV8	CV1
Mass (g)	7.88	6.44	5.19	7.79	7.75	7.78	7.95	7.82	5.87	8.05	8.11	8.22	7.96	7.91	5.93	5.94	5.03	4.87
5-8	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
18	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
29	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
31-28	0.119	0.064	0.107	0.569	0.183	0.617	0.259	0.445	0.220	0.345	0.451	0.42	0.058	0.11	0.135	0.095	0.584	0.146
52	0.060	0.065	0.083	0.072	0.112	0.132	0.116	0.214	0.085	0.123	0.327	0.07	0.062	0.05	0.038	0.004	0.079	0.020
49	0.000	0.008	0.017	0.000	0.000	0.034	0.031	0.000	0.028	0.022	0.071	0.00	0.023	0.01	0.009	0.000	0.061	0.042
44	0.000	0.000	0.013	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.047	0.07	0.000	0.000	0.000	0.000	0.060	0.031
66	0.744	0.18	0.323	3.62	1.25	2.09	0.888	3.67	0.432	1.45	0.914	2.03	0.132	0.24	0.513	0.138	2.66	0.434
155	0.093	0.000	0.000	0.531	0.000	0.000	0.000	0.000	0.069	0.000	0.000	0.40	0.000	0.03	0.000	0.000	0.000	0.000
101	0.000	0.26	0.526	1.77	0.923	1.54	0.759	1.61	0.649	1.12	1.77	0.000	0.163	0.000	0.605	0.209	0.66	0.389
99	7.63	0.61	1.43	26.1	10.2	9.74	5.28	30.9	1.93	7.51	3.26	14.0	0.476	0.95	3.09	0.682	18.6	2.46
87	0.000	0.017	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.031	0.000	0.081
110	0.000	0.071	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.62	0.000	0.066	0.000	0.000	0.086	0.000	0.138
149	0.498	0.221	0.454	1.70	0.542	1.90	0.966	1.17	0.670	1.35	1.52	1.82	0.151	0.31	0.57	0.183	1.29	0.460
118	13.5	1.05	3.53	58.2	17.3	17.7	14.1	62.6	3.77	16.2	6.03	29.4	0.921	2.08	5.42	1.30	35.1	4.21
153	72.4	3.77	13.0	213	73.7	52.9	53.2	234	14.2	50.9	32.9	110	4.46	7.74	28.4	4.50	160	20.9
132	0.00	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.00	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
105	2.75	0.259	0.779	10.6	3.78	3.95	2.78	11.5	0.76	3.47	1.37	6.24	0.196	0.47	1.05	0.266	6.69	0.842
163	1.61	0.246	0.406	3.50	1.93	1.28	1.18	3.77	0.630	1.03	1.49	1.97	0.135	0.30	0.000	0.135	2.97	0.783
138	27.1	1.55	4.37	77.0	31.3	22.1	17.7	86.6	5.94	19.1	12.0	39.6	1.60	2.84	10.8	1.51	57.9	7.24
187	2.37	0.315	0.546	5.42	2.57	1.63	1.76	5.62	0.792	1.38	1.98	2.62	0.212	0.36	1.13	0.204	4.33	1.52
183	6.10	0.298	1.07	15.2	5.32	3.57	3.78	17.1	1.02	3.43	3.20	7.42	0.370	0.61	2.55	0.338	12.5	1.86
128	2.70	0.231	0.474	8.26	3.37	3.81	1.84	8.82	1.31	2.45	1.60	6.07	0.194	0.44	1.08	0.204	6.47	1.22
156	1.79	0.154	0.442	5.65	1.99	1.29	1.77	6.59	0.428	1.37	1.05	2.53	0.144	0.27	0.75	0.150	3.55	0.675
200	0.094	0.016	0.031	0.187	0.000	0.065	0.054	0.000	0.070	0.060	0.112	0.12	0.008	0.02	0.05	0.000	0.172	0.084
157	1.24	0.000	0.000	2.84	0.000	0.000	0.000	0.000	0.979	0.00	0.000	1.72	0.000	0.69	0.312	0.049	1.46	0.28
180	34.9	1.43	4.41	84.0	28.2	16.3	19.74	88.9	5.62	16.9	17.4	41.7	1.82	2.71	13.7	1.53	72.7	9.91
170	7.30	0.463	1.09	19.1	6.71	4.05	4.40	20.6	1.54	4.05	3.63	9.75	0.480	0.78	3.03	0.412	15.1	2.47
203	2.88	0.167	0.48	7.01	2.25	1.36	1.70	7.36	0.648	1.39	1.76	3.01	0.187	0.31	1.32	0.163	6.07	1.10
195	0.316	0.028	0.083	0.742	0.275	0.178	0.273	0.86	0.065	0.201	0.223	0.32	0.027	0.05	0.142	0.033	0.552	0.132
194	3.15	0.183	0.550	6.95	2.11	1.31	1.87	7.05	0.655	1.49	1.76	3.56	0.176	0.33	1.32	0.167	6.00	0.549
206	0.462	0.046	0.109	1.02	0.355	0.198	0.313	1.07	0.131	0.23	0.315	0.51	0.034	0.05	0.22	0.000	0.891	0.241
209	0.083	0.014	0.026	0.159	0.067	0.037	0.083	0.18	0.000	0.042	0.102	0.09	0.011	0.02	0.043	0.000	0.159	0.025
ΣP[illegible]	190	11.7	34.4	553	194	148	135	601	42.6	136	95.9	286	12.1	21.8	76.2	12.4	417	58.2

Table B.7 PCB congener concentrations in small animals at Cape Vera (M=male, f=female, J=juvenile).

Sample	Ermine	Ermine	Lemming	Lemming	Lemming	Lemming
Sample Date	07/17/07	07/10/07	07/16/06	07/15/06	07/14/06	07/14/05
Sex	M	J	F	F	F	M
Location	CV8	CV8	CV7	CV10	CV8	CV9
Mass extracted wet (g)	8.29	8.13	2.98	8.20	8.09	8.10
5-8	0.000	0.000	0.000	0.000	0.000	0.000
18	0.010	0.000	0.000	0.000	0.000	0.000
29	0.000	0.000	0.000	0.000	0.000	0.000
31-28	0.165	0.208	0.033	0.018	ND	ND
52	0.055	0.021	0.223	0.032	0.042	0.029
49	0.005	0.013	0.026	0.013	0.012	0.007
44	0.005	0.000	0.027	0.000	ND	0.010
66	0.466	0.368	0.000	0.000	0.019	0.016
101	0.247	0.128	0.025	0.019	0.016	ND
99	2.95	1.87	0.039	0.021	ND	ND
87	0.030	0.033	0.015	0.006	0.010	0.007
110	0.050	0.053	0.116	0.031	0.010	ND
149	0.284	0.139	0.021	0.008	ND	ND
118	7.12	4.12	0.165	0.053	ND	ND
153	23.8	13.0	0.307	0.025	ND	ND
132	0.000	0.000	0.020	0.002	0.007	0.004
105	1.48	0.975	0.022	0.009	0.003	0.007
163	0.498	0.225	0.024	0.031	ND	ND
138	9.77	6.03	0.179	0.037	0.040	ND
187	0.854	0.442	0.030	0.012	0.078	ND
183	1.64	0.934	0.027	0.009	ND	ND
128	1.14	0.821	0.026	0.004	0.01	0.006
156	0.831	0.612	0.017	0.003	0.000	0.006
200	0.000	0.000	0.000	0.000	0.000	0.004
157	0.292	0.199	0.000	0.000	0.000	0.000
180	10.0	6.67	0.389	0.047	ND	ND
170	2.61	2.00	0.070	0.014	0.019	0.014
203	0.922	0.796	0.042	0.009	ND	0.011
195	0.217	0.127	0.000	0.000	0.000	0.000
194	0.953	0.813	0.007	0.003	0.010	0.018
206	0.181	0.197	0.000	0.000	0.003	0.000
209	0.057	0.067	0.007	0.003	0.000	0.000
ΣPCB	66.7	40.8	1.86	0.410	0.446	0.332

ND indicates concentrations were below detection limit (Appendix Table B.2 and B.3)

Table B.8. DDT compound concentration for worm lichen collected from Cape Vera and Cape Herschel (CV=Cape Vera, CL= Cliff at Cape Vera, CH-Cape Herschel, M=Moraine Pond, P12= Pond 12).

Pond	CV12	CV1	CHP12	CV10	CL43	CV13	CV10	CV30	CV20	CV14	CV9A	CHM
Mass extracted wet (g)	9.21	5.39	7.51	8.94	7.80	9.02	3.22	7.11	3.57	7.32	6.19	11.0
p,p'-DDE	0.080	0.000	ND	0.127	0.457	ND	ND	0.094	0.148	0.269	0.098	0.000
p,p'-DDD	0.035	0.072	0.051	0.027	0.076	0.077	0.050	0.105	0.021	0.000	0.014	0.044
o,p'-DDT	0.000	0.000	0.000	0.000	ND	0.000	0.000	0.000	0.173	0.262	0.172	0.000
p,p'-DDT	ND	0.000	ND	ND	0.186	0.000	ND	0.315	ND	0.177	ND	ND
ΣDDT	0.165	0.072	0.140	0.204	0.751	0.116	0.139	0.514	0.392	0.708	0.335	0.094

ND indicates concentrations were below detection limit (Appendix Table B.2 and B.3)

Table B.9. DDT compound concentrations for jewel lichen collected from Cape Vera and Cape Herschel (CV=Cape Vera, CL=cliffs at Cape Vera, CH= Cape Herschel, CP=Central Plateau, P12= Pond 12).

Pond	CV13	CV5-6	CV10	CV20	CV14	CHCP	CL43	CL590	CHP12	CL642	CV30	CV15-31	CV9	CV9A	CV8
Mass extracted wet (g)	8.39	8.26	6.79	8.29	7.56	8.49	8.75	10.4	10.6	10.5	7.97	8.10	8.84	7.37	8.03
p,p'-DDE	0.337	0.558	1.11	1.22	0.248	0.172	6.53	1.10	0.106	0.599	0.134	0.228	ND	0.457	1.08
p,p'-DDD	0.021	0.089	0.150	0.064	0.104	0.042	0.175	0.064	0.035	0.000	0.234	0.210	0.035	0.172	0.229
o,p'-DDT	0.308	0.821	0.577	0.547	0.607	0.511	1.32	0.360	0.477	0.341	0.171	0.236	0.000	0.337	0.099
p,p'-DDT	0.102	0.543	0.663	0.270	0.000	0.207	0.950	ND	0.109	0.000	0.104	0.193	ND	0.259	2.01
ΣDDT	0.769	2.01	2.50	2.10	0.960	0.931	8.972	1.58	0.727	0.939	0.643	0.868	0.128	1.23	3.43

ND indicates concentrations were below detection limit (Appendix Table B.2 and B.3)

Table B.10. PCB congener concentrations in snow buntings from Cape Vera (m=male, F=female, HY= hatch year).

Sample Date	17/07	12/06	19/07	17/07	17/07	18/07	17/07	17/07	17/07	17/07	16/07	16/06	15/06	14/06	17/07	16/06	17/07	17/07
Sex	**M**	**HY**	**HY**	**M**	**F**	**HY**	**F**	**F**	**HY**	**HY**	**M**	**HY**	**HY**	**HY**	**M**	**HY**	**M**	**M**
Location		**CV12**	**near cabin**	**CV8**	**CV1**		**CV8**	**CV8**	**CV1**	**CV8**	**near cabin**	**CV7**	**CV 14**	**CV10**	**CV1**	**CV 10**	**CV8**	**CV1**
Mass extracted wet (g)	7.88	6.44	5.19	7.79	7.75	7.78	7.95	7.82	5.87	8.05	8.11	8.22	7.96	7.91	5.93	5.94	6.47	6.58
p,p'-DDE	95.2	4.34	12.1	276	126	117	66.2	380	19.0	79.9	48.9	127	4.65	6.31	35.0	5.88	307	28.2
p,p'-DDD	0.635	0.220	0.420	0.000	0.697	1.30	0.000	0.085	0.057	0.000	0.27	0.000	0.09	0.000	0.077	0.107	1.63	0.376
o,p'-DDT	1.23	0.245	0.431	5.06	1.64	2.80	2.10	6.51	0.762	3.45	0.943	2.80	0.16	0.444	1.69	0.197	3.73	1.52
p,p'-DDT	4.07	0.536	1.42	9.68	5.56	6.0	3.41	9.23	15.1	3.43	4.43	4.178	0.42	7.16	3.04	0.457	9.47	3.09
ΣDDT	101	5.34	14.3	291	134	127	71.7	396	35.0	86.7	54.5	134	5.33	13.9	39.8	6.64	322	33.2

Table B.11. DDT compound concentrations in small animals at Cape Vera (M=male, f=female, J=juvenile).

Sample	Ermine	Ermine	Lemming	Lemming	Lemming	Lemming	Lemming
Sample Date	07/17/07	07/10/07	07/16/06	07/15/06	07/14/06	07/14/06	07/16/06
Sex	M	F	F	F	F	M	M
Location	CV8	CV8	CV7	CV10	CV8	CV9	CV8
Mass extracted wet (g)	8.13	8.13	2.98	8.20	8.09	8.10	3.99
p,p'-DDE	42.0	26.8	0.083	ND	0.096	ND	0.27
p,p'-DDD	0.257	0.115	0.000	0.051	0.206	0.14	0.29
o,p'-DDT	1.46	0.64	0.173	0.188	ND	ND	1.57
p,p'-DDT	2.30	1.04	0.165	ND	ND	ND	0.000
ΣDDT	46.0	28.6	0.420	0.330	0.385	0.258	2.13

ND indicates concentrations were below detection limit (Appendix Table B.2 and B.3)

Statement of Contributions of Collaborators

Two co-authored articles are included in this Master's thesis. Data for this Master's was collected over a period of three summers (2005-2007) at Cape Vera, Devon Island and Cape Herschel, Ellesmere Island. The collection of samples in 2005 and 2006 were made by other members of the Blais lab (Huijin Liu, Karen Foster, Linda Kimpe, Jules Blais) and from the Paleoecological Environmental Assessment and Research Lab (PEARL) at Queen's University. Sample collections at Cape Herschel were made exclusively by PEARL led by Dr. John Smol at Queen's University.

Identification and stable isotope analysis of snow bunting stomach contents was performed by Martine Gauthier in the Blais lab. Linda Kimpe completed the lipid removal of samples using the Prep-LC and interpreted chromatograms for OCs and PCBs.

The analyses of mercury, PCBs/OC's, and stable isotopes, data analysis, and composition of the articles are my work. Co-authors provided feedback and suggestions to improve the articles. Jules Blais was responsible for conceptual development, project inception, design, management, as well as logistical planning for the field work at Cape Vera.