Arctic Species Trend Index

2010

Tracking Trends in Arctic Wildlife

CAFF CBMP Report No. 20

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Acknowledgements

CAFF Designated Agencies:

- Directorate for Nature Management, Trondheim, Norway
- Environment Canada, Ottawa, Canada
- Faroese Museum of Natural History, Tórshavn, Faroe Islands (Kingdom of Denmark)
- Finnish Ministry of the Environment, Helsinki, Finland
- Icelandic Institute of Natural History, Reykjavik, Iceland
- The Ministry of Infrastructure and Environment, the Environmental Agency, the Government of Greenland
- Russian Federation Ministry of Natural Resources, Moscow, Russia
- Swedish Environmental Protection Agency, Stockholm, Sweden
- United States Department of the Interior, Fish and Wildlife Service, Anchorage, Alaska

CAFF Permanent Participant Organisations:

- Aleut International Association (AIA)
- Arctic Athabaskan Council (AAC)
- Gwich'in Council International (GCI)
- Inuit Circumpolar Conference (ICC) Greenland, Alaska and Canada
- Russian Indigenous Peoples of the North (RAIPON)
- The Saami Council

This publication should be cited as: Louise McRae, Christoph Zöckler, Michael Gill, Jonathan Loh, Julia Latham, Nicola Harrison, Jenny Martin and Ben Collen. 2010. *Arctic Species Trend Index 2010: Tracking Trends in Arctic Wildlife*. CAFF CBMP Report No. 20, CAFF International Secretariat, Akureyri, Iceland.

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Cover photo courtesy of Joelle Taillon.

March 2010

— CAFF Designated Area

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This report was commissioned by the Circumpolar Biodiversity Monitoring Program (CBMP) with funding provided by the Government of Canada. The 2010 Biodiversity Indicators Partnership provided funding to assist in the printing of the report.

Content

Foreword

TOM BARRY

Many people view the Arctic as a vast and barren expanse—an intimidating and hostile environment devoid of wildlife and people. Fortunately this myth is being dispelled with the growing voice of Arctic indigenous peoples and other residents, and the growing focus on such issues as climate change and its disproportionate impact on high-latitude regions. The Arctic not only is a highly productive system that plays host to a vast array and abundance of unique wildlife, but it acts as a critical component in the Earth's physical, chemical and biological regulatory system. Perturbations to this system are expected to not only have consequences for the Arctic itself, but will be felt globally.

Arctic residents in particular, but also the world at large, have been increasingly demanding timely and accurate information on how the Arctic is responding to pressures such as climate change. Until now, these demands have largely been met with silence. To date, we have mostly relied on climate information and sea-ice extent as indicators of how the Arctic is changing. But what of the wildlife that inhabits the Arctic? How are they responding to these pressures?

With the Arctic Species Trend Index (ASTI) we can now begin to track how the Arctic's ecosystems and the living resources dependent upon them are responding to change. Almost 1,000 datasets for the past four decades representing 35% of all known Arctic vertebrate species are found in the ASTI—a significant accomplishment and recognition of the sustained effort and dedication of Arctic researchers and communities who have been tracking wildlife populations in a remote and challenging environment.

While the data found in the ASTI are impressive, more are needed to understand how the Arctic's ecosystems and the living resources they support are responding and will respond to growing and cumulative pressures. Information on invertebrates is particularly scarce, as is the tracking of large-scale vegetation changes. A growing awareness that changes are occurring faster than modelled predictions reminds us that minimal datasets can have limited value. An enhanced effort is needed from all Arctic countries to further invest in monitoring and associated research. The results have to be effectively delivered to Arctic residents, governments and the world in order to help us conserve the Arctic's living resources and adapt to changes to these resources in a changing world.

Dr. Aevar Petersen

Chair, Arctic Council Conservation of Arctic Flora and Fauna (CAFF) Working Group

WE CAN NOW BEGIN TO TRACK HOW THE ARCTIC'S ECOSYSTEMS AND THE LIVING RESOURCES DEPENDENT UPON THEM ARE RESPONDING TO CHANGE

JOELLE TAILLON

Summary

The contribution of Arctic wildlife to global biodiversity is substantial. The region supports globally significant populations of birds, mammals and fish. For example, over half of the world's shorebirds and 80% of the global goose population breed in Arctic and Sub Arctic regions. Dramatic changes (e.g., sea-ice loss) in the Arctic's ecosystems are predicted to occur over the next century. Arctic species that have adapted to these extreme environments are expected to be displaced by the encroachment of more southerly (Sub Arctic) species and ecosystems. Continued, rapid change in the Arctic ecosystems will have global repercussions affecting the planet's biodiversity as a whole. Understanding how the Arctic's living resources, including its vertebrate species, are responding to these changes is essential in order to develop effective conservation and adaptation strategies.

In this report, vertebrate population-abundance data were used to produce an indicator of the trends in Arctic biodiversity over the past 34 years (1970 as the baseline[1]). This index tracks 965 populations of 306 species, representing 35% of all known vertebrate species found in the Arctic. Vertebrate abundance in High Arctic species declined 26% between 1970 and 2004. Low and Sub Arctic species have fared better over this time period: Low Arctic species experienced increasing abundance and Sub Arctic species showed a decline since the mid-1980s, but no overall change over the 34-year period. These observed trends are largely consistent with current predictions regarding the response of Arctic wildlife to climate change and expected increases in previously over-harvested species, and suggest that human-induced changes in Arctic ecosystems are already resulting in winners and losers. Dramatic growth of certain populations of migratory Arctic-nesting geese species, for instance, shows a contrast with a steady decline in other herbivorous species, most of which are not migratory.

While this report highlights trends seen over 34 years, further work is needed to produce a more robust index that adequately represents all taxa, biomes and regions and to develop a better understanding of how the Arctic's wildlife is responding to both natural and human-induced changes. The remoteness of the region means certain species and populations (e.g., fish populations and High Arctic populations) have limited data coverage. Current research and monitoring efforts are insufficient, limiting our ability to detect and understand changes in population abundance. Better designed, more widely distributed and more integrated research and monitoring schemes need to be implemented. The resulting information must be delivered using effective formats to decision-makers at all levels (national, regional and local authorities) in order to facilitate more effective and timely conservation and adaptation responses in a rapidly changing system.

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1. 1970 was used as the baseline as pre-1970 data in the ASTI was limited making trend results uncertain for years preceding 1970. Likewise, 2004 was used as the cut-off year as sample size declined dramatically after 2004 due to recent, updated datasets not yet being available.

Introduction

MONITORING ARCTIC BIODIVERSITY

This year, all signatory nations will be reporting to the Convention on Biological Diversity (CBD) on their progress towards the 2010 target of reducing the rate of biodiversity loss. Biodiversity indicators have been developed to assess whether or not this target has been met and to demonstrate the changing state of nature over time. To track status and trends in Arctic biodiversity for the 2010 target, the Circumpolar Biodiversity Monitoring Program (CBMP) has identified a number of indices and indicators, one of which is the Arctic Species Trend Index (ASTI). This index, like the global Living Planet Index (LPI), illustrates overall vertebrate population trends by integrating vertebrate population trend data of an appropriate standard [1] from across the Arctic and over the last 34 years. An increasing index indicates that, overall, more vertebrate populations in the Arctic are increasing than decreasing. Whereas a decreasing index, indicates the opposite situation. This index not only allows for a composite measure of the overall trajectory of Arctic vertebrate populations, but can be disaggregated to display trends based on taxonomy, ecosystem, region, time period and other categories.

Measuring change in Arctic biodiversity is all the more pertinent given evidence emerging of Arctic ecosystems already responding, in some cases quite dramatically, to climatic changes [2, 3]. Predictions are of substantial shifts in this environment in the near future (e.g., encroachment of more southerly species and ecosystems) [4, 5] and recent changes in physical elements such as sea ice have outpaced predicted changes [6]. Limited functional redundancy in Arctic ecosystems poses a particular risk as the loss of a single species could have dramatic and cascading effects on an ecosystem's state and function [3]. Our current, mostly, single-species approach to monitoring with a bias towards charismatic species over functional species limits our ability to detect and understand critical changes in the Arctic's ecosystems. A broader and more integrated approach is needed to facilitate a better understanding of how the Arctic's living resources, including its vertebrate species, are responding to a changing Arctic and how these changes might reflect or counter global biodiversity trends. This information is essential in order to develop effective conservation and adaptation strategies.

Results presented in this report from the analysis of Arctic vertebrate population data are used to examine overall trends in population abundance in a changing Arctic ecosystem. An overall ASTI is presented as an indicator of Arctic biodiversity at the ecosystem level, followed by a number of species- and system-based themes illustrated to reveal trends in abundance at smaller scales. These disaggregations identify patterns in Arctic vertebrate population trends,

CARSTEN EGEVANG

THIS INFORMATION IS ESSENTIAL IN ORDER TO DEVELOP EFFECTIVE CONSERVATION AND ADAPTATION STRATEGIES.

CARSTEN EGEVANG

thereby facilitating a greater understanding of the potential drivers of these trends. Over time, tracking this index will help reveal patterns in Arctic wildlife response to growing pressures, thereby facilitating a better predictive ability on the trajectory of Arctic ecosystems.

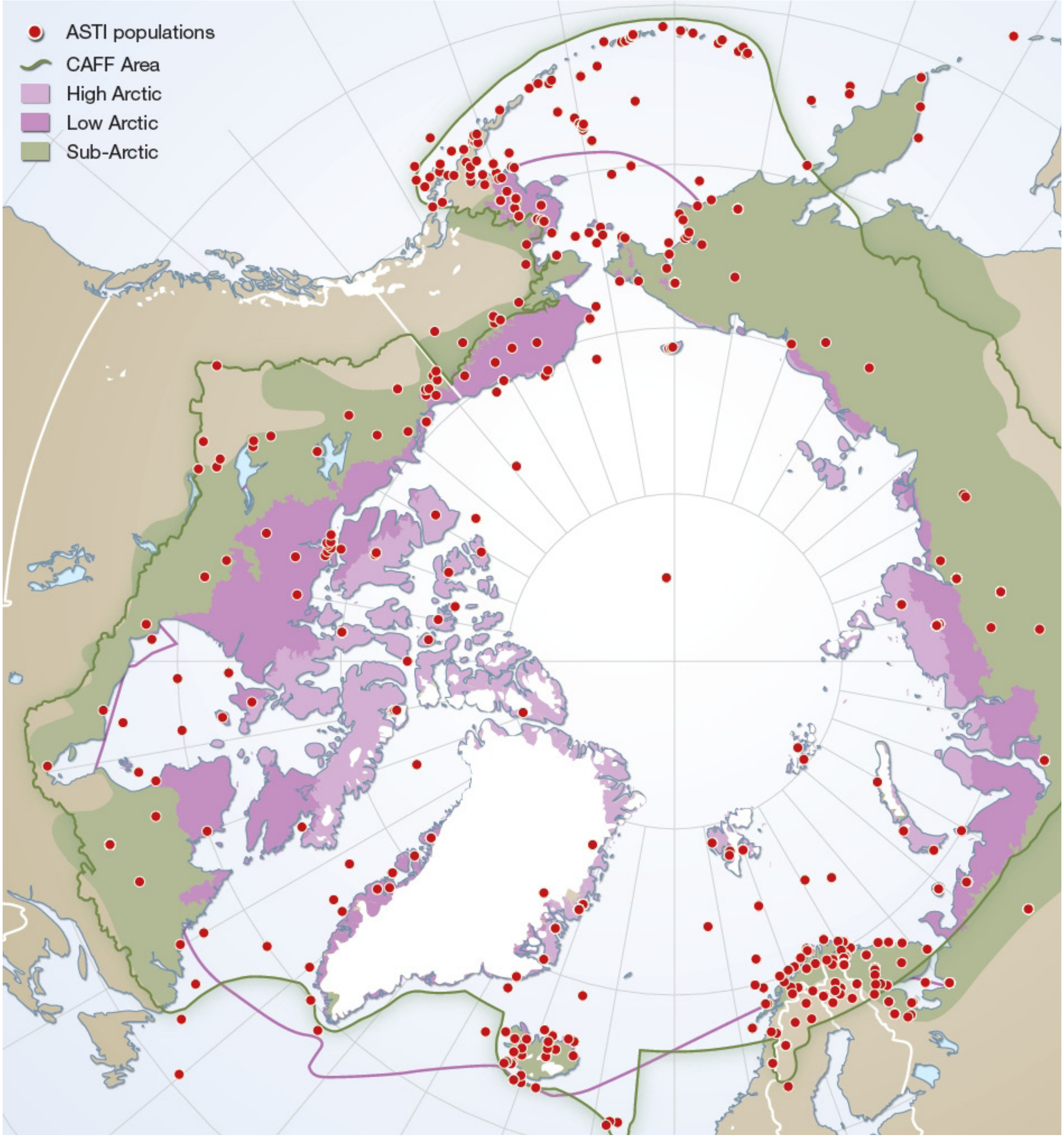


Figure 1: Arctic boundaries The Arctic as defined by the Conservation of Arctic Flora and Fauna [7] and the High, Low and Sub Arctic regions according to floristic boundaries [8]. The red dots represent vertebrate populations included in the ASTI data analysis.

Data Coverage


PETER E. STEENSTRA/USFWS

The delineation of the High, Low and Sub Arctic boundaries was used to classify Arctic populations (Figure 1) giving a total of 965 time series for 306 species of birds, mammals and fish. The total number of species in the ASTI represents 35% of the known Arctic vertebrate species and the proportion of each taxonomic class represented is shown in Figure 2. Representative coverage was good for bird species, moderate for mammals and poor for fish.

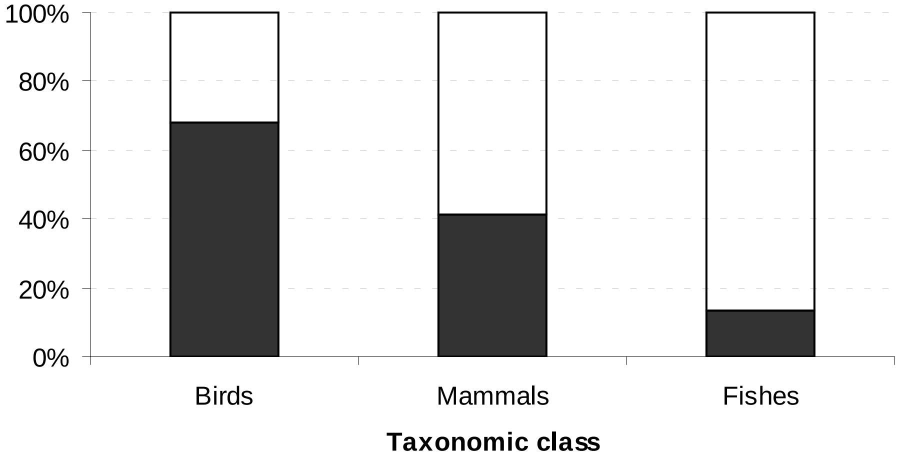


Figure 2: Data Coverage by Taxonomic Class. The coverage of species represented in the ASTI. Black bars represent proportion of Arctic species in each class for which there are population data available. White bars are the proportion of Arctic species with no available population-trend data.

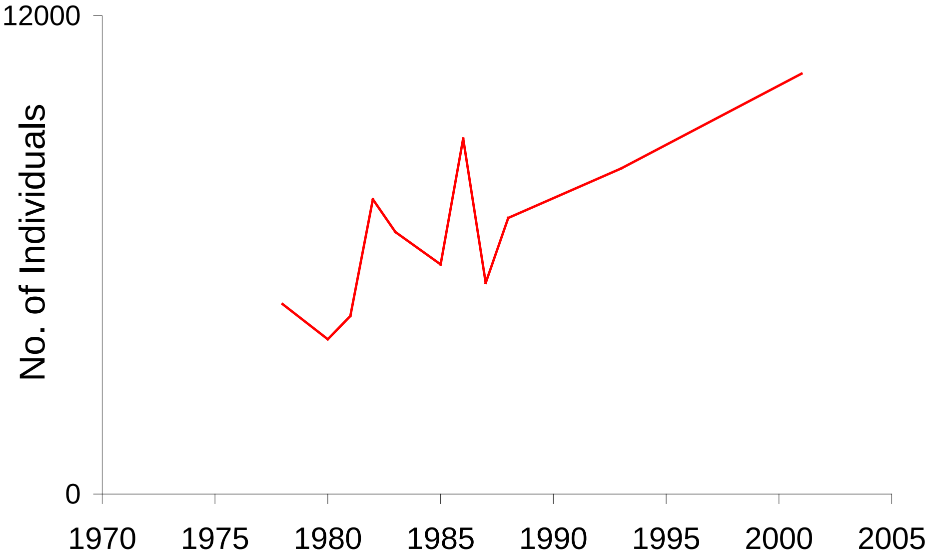
Data were collated from across the Arctic representing contributions from various individuals and organizations (see Acknowledgements) in all eight Arctic nations and from marine, terrestrial and freshwater systems (see Appendix II). A few examples of the composition of the ASTI data set are on the following pages. The trends in abundance in each subset of data were averaged to produce the results that follow.

TRENDS IN SAMPLE POPULATIONS OF SELECTED SPECIES

The population trends for the 10 terrestrial, marine and freshwater species shown in Figure 3 illustrate the kinds of data that have been used to calculate the Arctic Species Trend Index. The example set spans a range of classes, locations and Arctic regions to illustrate how different populations are faring across the Arctic region, but does not necessarily represent the picture for an entire species or region.

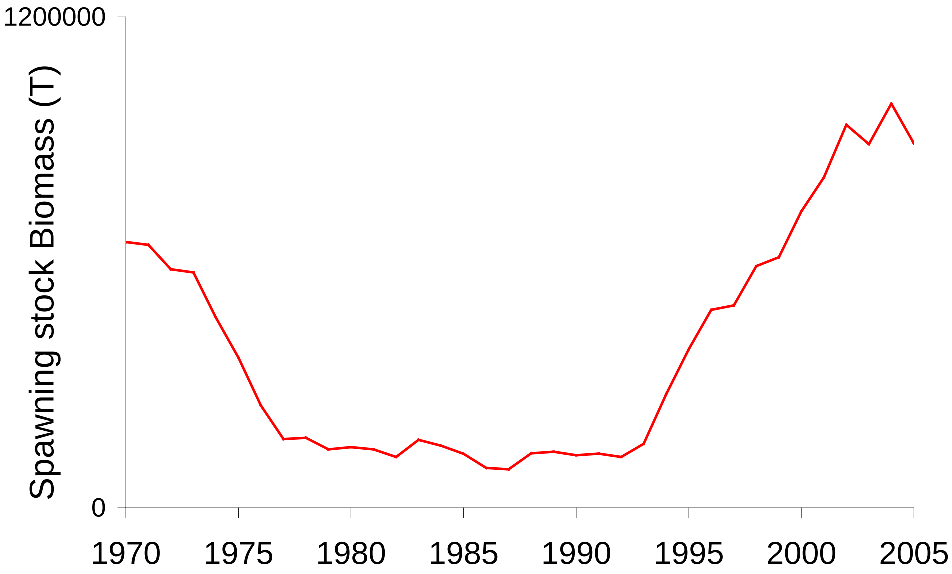
Some populations are either stable or increasing, representing conservation successes such as the Alaskan Bowhead Whale population that is benefitting from the removal of hunting pressure. Greenland Cod that declined to a very low level by the early 1990s due to deterioration of the environmental conditions and high fishing mortality, shows indications of improving, with influx of cod from Icelandic waters as one contributing factor.

ANSGAR WALK



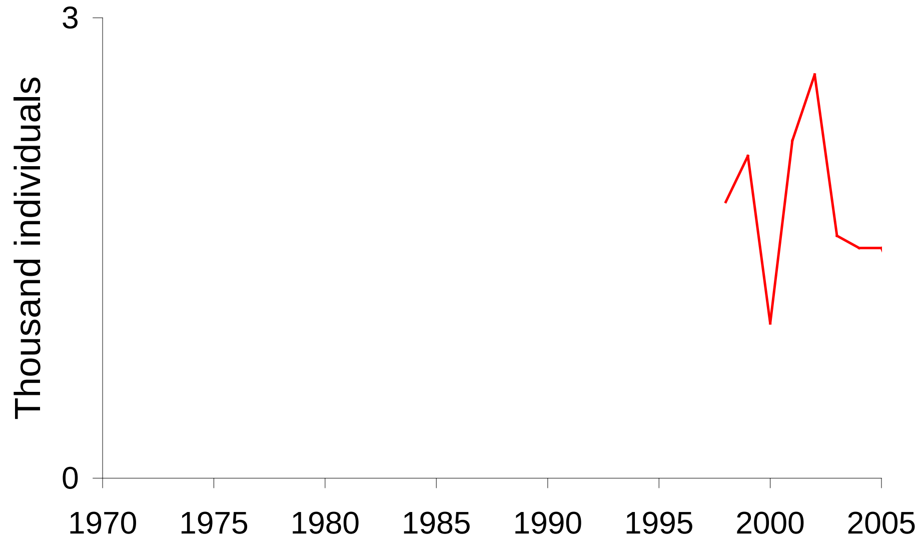
Bowhead Whale (*Balaena mysticetus*)

SUSAN DALY



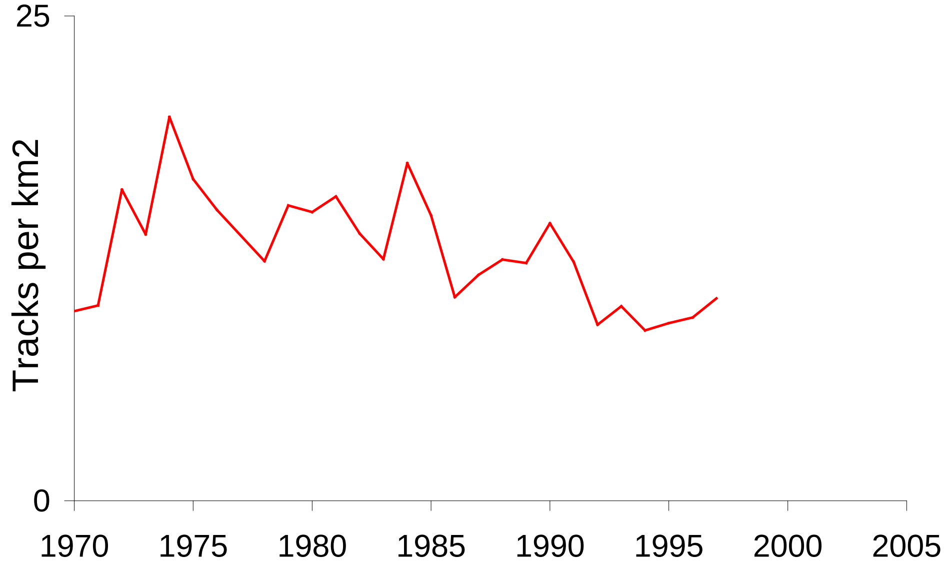
Pollock (*Pollachius virens*)

Figure 3: Sample Populations



WOLVERINE (*GULO GULO*)

MATTHIAS HILLEBRAND



ARCTIC HARE (*LEPUS TIMIDUS*)

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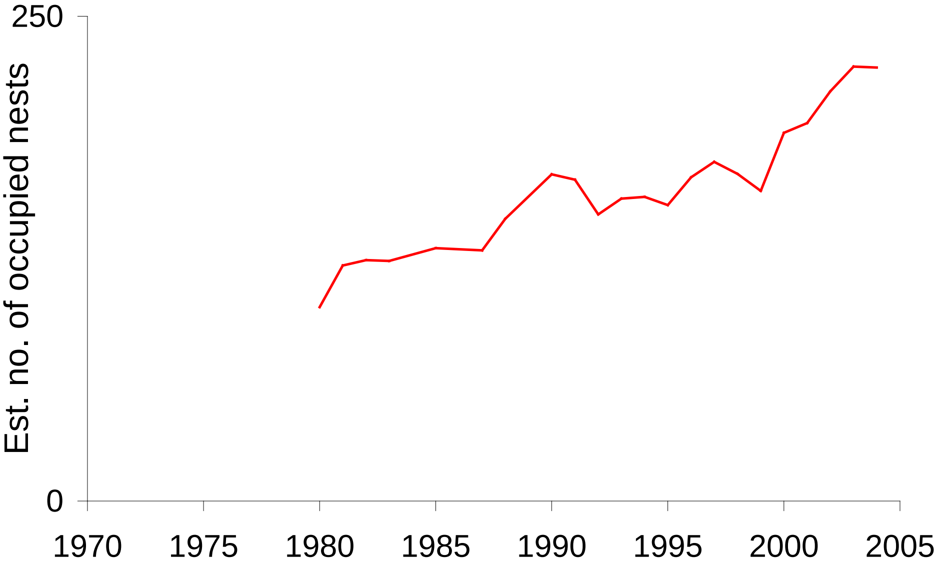
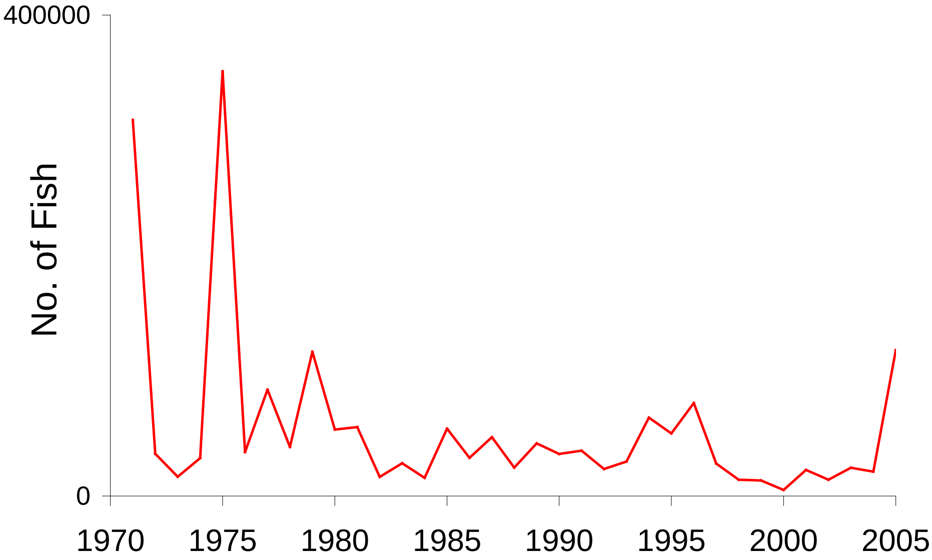


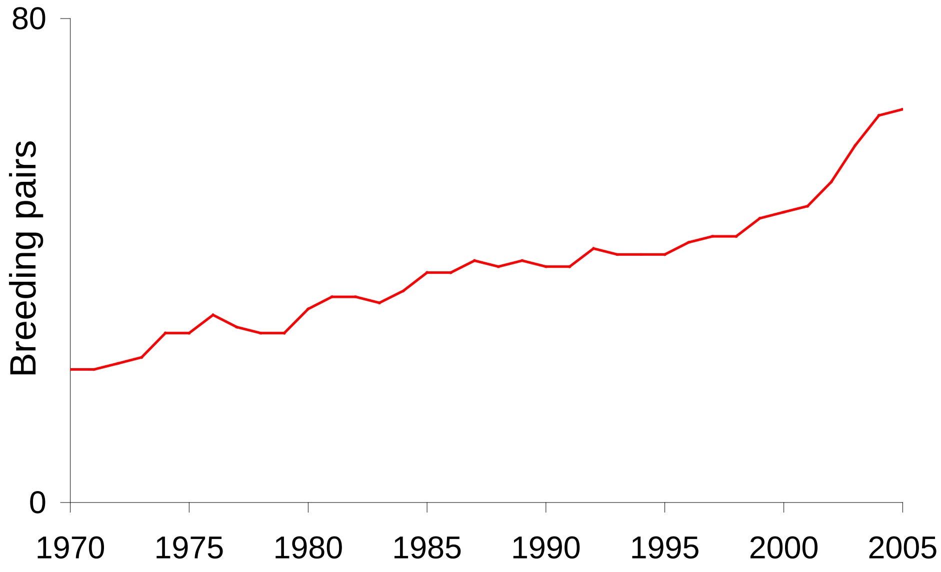
Atlantic Puffin (*Fratercula artica*)

RUTH FOSTER



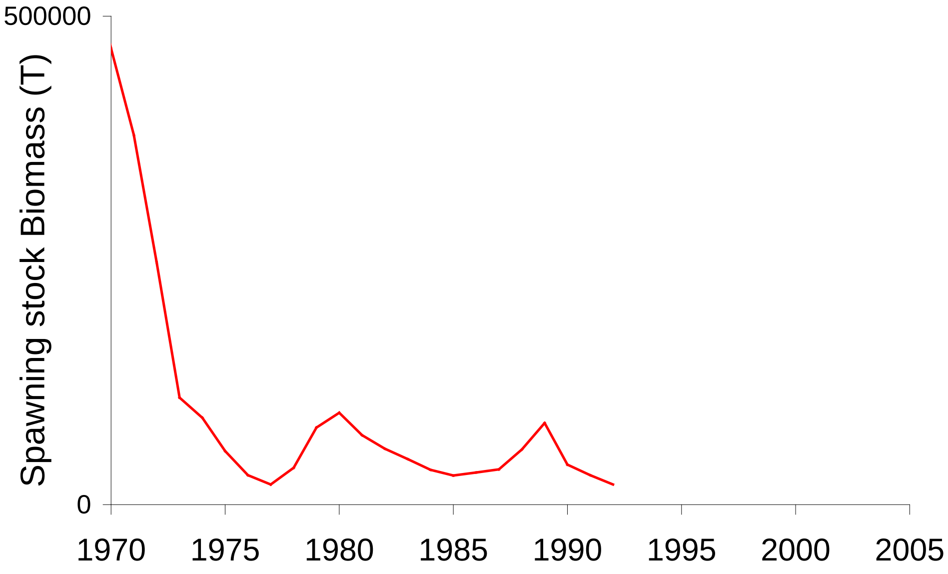
Chum Salmon (*Oncorhynchus keta*)

Continued … Figure 3: Sample Populations




MIKE BROWN

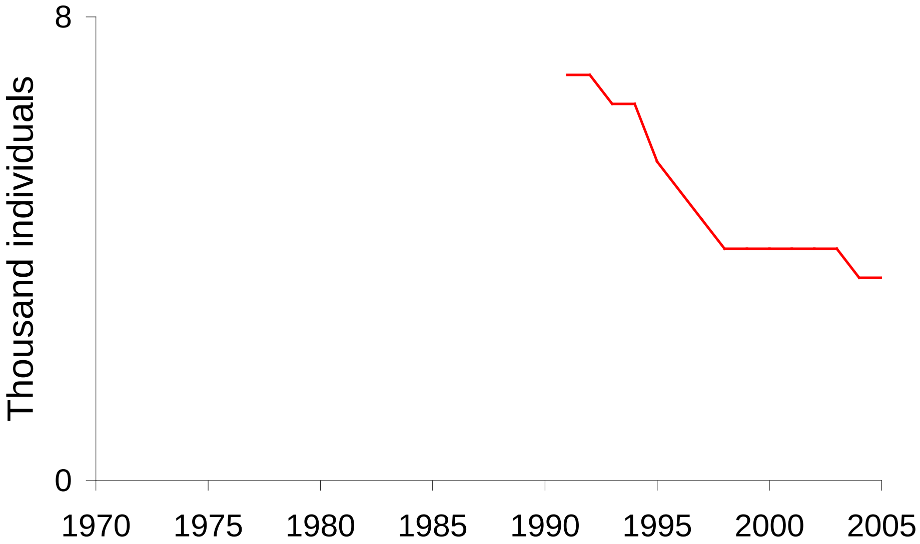
WHITE-TAILED EAGLE (*HALIAEETUS ALBICILLA*)




HANS-PETTER FJELD/WIKIPEDIA

GREENLAND COD (*GADUS MORHUA*)

MALENE THYSSEN/WIKIPEDIA



BROWN BEAR (*URSUS ARCTOS*)

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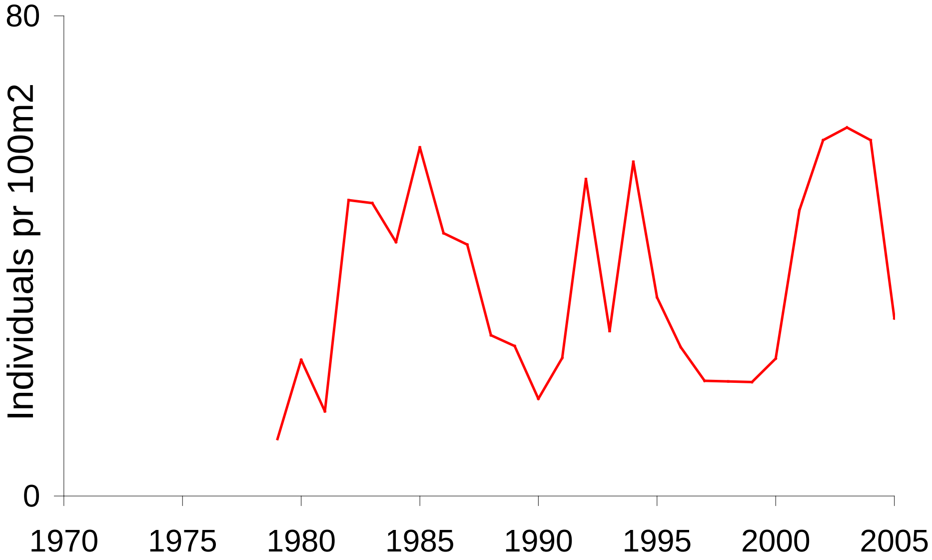

ATLANTIC SALMON (*SALMO SALAR*)

CONTINUED ... FIGURE 3: SAMPLE POPULATIONS

Arctic Species Trend Index (ASTI)

USFWS

The average trend in 965 populations of 306 Arctic vertebrate species indicates an increase in abundance from 1970 until 1984, then the index remains relatively stable up to 2004 (Figure 4). Overall, the index has increased by 16% over the time period (1970-2004). The confidence intervals[2] show that the overall increase in vertebrate abundance was between 2 and 32%. The number of Arctic populations contributing to the index over the 34 years ranged from 266 to 666 time series for a single year. The number of populations has increased steadily up until 1998 indicating that data availability has improved either as a result of more monitoring schemes, or by data becoming more widely available, or both. Declines in sample size in recent years is thought to be due to new data not yet being available, rather than representing a reduction in monitoring effort. Population trends within the Arctic boundary as defined by CAFF (see Figure 1) were almost identical to those of the Arctic boundaries used in this analysis. Although the CAFF dataset contains 133 fewer populations, there was only one species difference between the two indices, so they are qualitatively very similar (see Appendix II and III).

Although the overall ASTI is increasing, the following sub-indices reveal that the same trend is not consistent among all regions, systems or groups of species.[2]

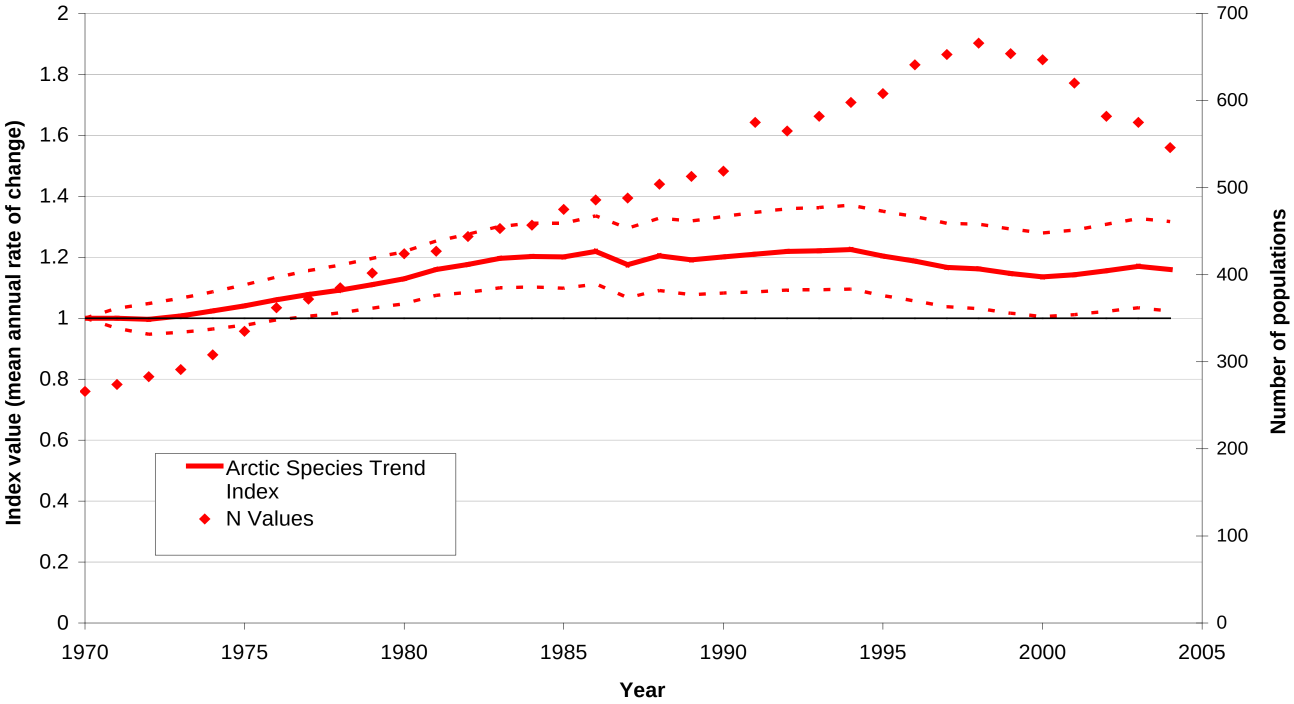

Figure 4: Arctic Species Trend Index (with 95% confidence intervals) for all species within the Arctic boundaries and total population (N) values for that year, for the period 1970-2004. (ASTI, n=306 species, 965 populations).

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[2] Confidence intervals were generated for each index and the values are found in Appendix III of this report. They are not displayed in most figures in order to maintain the clarity of the graphs.

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REGIONAL RESULTS: ARCTIC BOUNDARIES

Populations in the High, Low and Sub Arctic boundaries show markedly different trends (Figure 5). High Arctic species show an overall decline in abundance of 26% with populations levelling off in the mid-1990s. Similarly, after an initial growth period, Sub Arctic species appear to have declined in abundance from around the mid 1980s (overall decline of 3%). Low Arctic species on the other hand have increased by an average of 46% over the same time period.

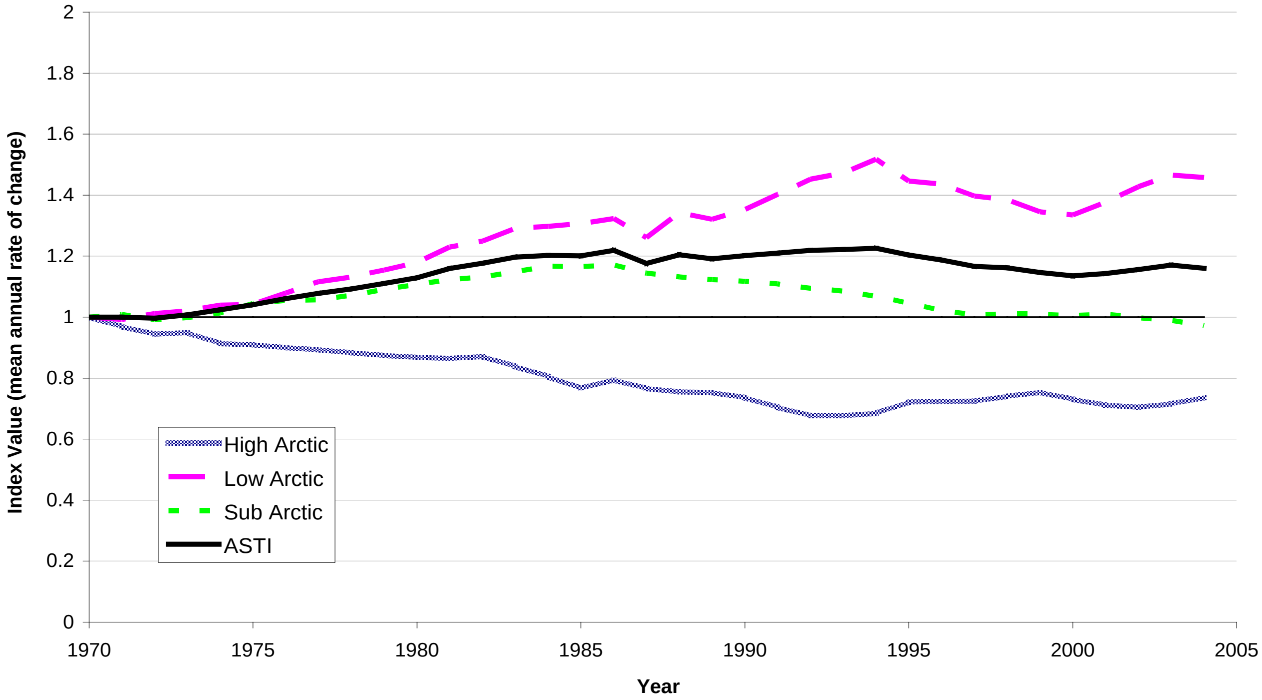

FIGURE 5: ARCTIC SPECIES TREND INDEX FOR ALL ARCTIC SPECIES (BLACK LINE) DISAGGREGATED INTO HIGH ARCTIC SPECIES, LOW ARCTIC SPECIES AND SUB ARCTIC SPECIES for the period 1970-2005. (All species, n =306 species, 965 populations; High Arctic, n =47 species, 114 populations; Low Arctic, n=194 species, 545 populations; Sub Arctic n=155 species, 306 populations.)

The High Arctic index combines trends in 47 species and includes sea-ice-associated species, such as narwhal and polar bear. This region of the Arctic has experienced the largest increase in temperature change to date [5] and has already experienced dramatic reductions in sea-ice extent (Figure 6) with further contraction of sea ice predicted in the near future [9]. Reduction in sea-ice extent limits the habitat available for many sea-ice dependent High Arctic species and these species are expected to decline with declining sea-ice cover [10]. However, we are unable to ascertain the extent to which sea-ice associated species, such as polar bear, have already been affected by these changes. The trend data for most High Arctic species are available for only a few selected populations (see Box 1) and there are other factors influencing species abundance (e.g., natural cycles) that need to be considered. For example, some terrestrial mammal populations are known to cycle naturally and some of these populations have recently been experiencing a period of decline (e.g., Brown and Collared Lemming populations in Greenland and Canada; Caribou populations from the northern territories in Canada). These recent declines are thought to be part of a natural cycle and are contributing to the decreasing High Arctic index.


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The Sub Arctic area predominantly covers terrestrial and freshwater systems with very few coastal and no marine populations. This is the most accessible region in the Arctic, and consequently human impact and land-use change have been greater than in the High Arctic, although still relatively low compared to non-Arctic regions. With climate change and increased resource development coupled with invasive species, contaminants and possible overharvesting, the Sub Arctic may face increasing, cumulative pressures that result in negative impacts on wildlife populations. However, it is unclear at this time what might be driving the steady decline in vertebrate abundance since 1986.

The index of Low Arctic species is predominantly a reflection of the marine environment and shows an average increase in abundance over the time period. The species included in this data set are primarily marine fish, some of which (such as Pollock) change in abundance in accordance with sea-temperature fluctuations [11], and marine mammal species (many of which have shown recoveries from previously high levels of exploitation [12]). These increases are largely found in the Pacific waters of the Low Arctic in the Eastern Bering Sea, thus demonstrating the need for careful interpretation of the Low Arctic index. They also reveal the shortcomings that a restricted timeline of biodiversity change presents. If populations had been monitored since the early 1900s, the small recovery in some of the large marine-mammal species over the past few decades would be dwarfed by the extensive declines that marked the decades preceding 1970.

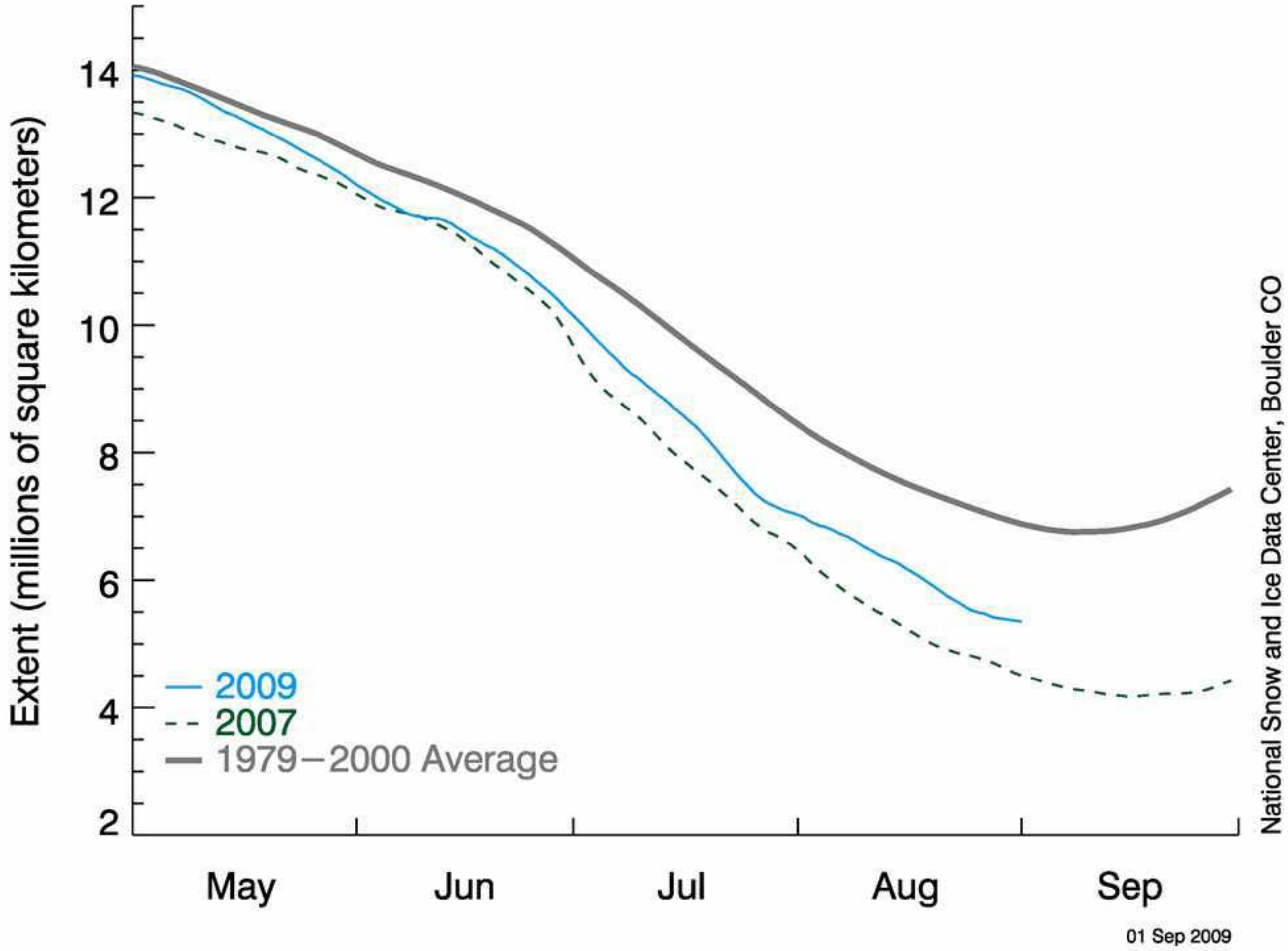

Figure 6: Trends in Arctic summer sea-ice extent. Comparison between 1979 to 2000 average, 2007 and 2009 (up to August 31). Source: National Snow and Ice Data Center. Digital media.

Box 1: Sea-ice-associated species

Arctic summer sea-ice extent reached a record minimum (see Figure 6) in 2007 (39% below the 1979 to 2000 average) and 2008 was the second-lowest record (reaching 34% below average). In conjunction with these surprising losses in sea-ice extent is the loss of multi-year ice which makes the current thinner, single-year ice much more vulnerable to further reductions in extent. It is well established that further losses in sea-ice extent are to be expected over the coming decades [9]. How this loss of sea ice will impact marine species is less clear. Not all High Arctic species are equally reliant on this rapidly changing habitat, so the strength of this relationship and the plasticity of the species will dictate the ability of any given species to adapt to future changes in the distribution of sea ice [10]. The ice represents a habitat that many species depend on, from Polar Bears to Ringed Seals, seabirds to fish, and even algae and invertebrates directly associated with multi-year ice. Species such as the Polar Bear, Narwhal and Ringed Seal are highly adapted to this habitat for foraging, birthing or predator evasion [13]. Polar Bears, for example, rely almost entirely on the marine sea-ice environment for their survival, therefore large-scale changes in their habitat are expected to have dramatic impacts on population sizes [14]. In the case of the Western Hudson Bay Polar Bear population, the increasingly long ice-free season is directly correlated with reduced body condition of Polar Bears in this population, thereby initiating the observed population declines [14, 15]. However, the lack of a linear relationship between this changing habitat and population abundance makes it difficult to predict exact effects. The extent to which the majority of species can adapt to the loss of sea ice and associated prey species remains largely unclear [10]. There is great uncertainty in how species interactions will be affected by these dramatic changes and even baseline data on population size in sea-ice-dependent species is largely lacking.

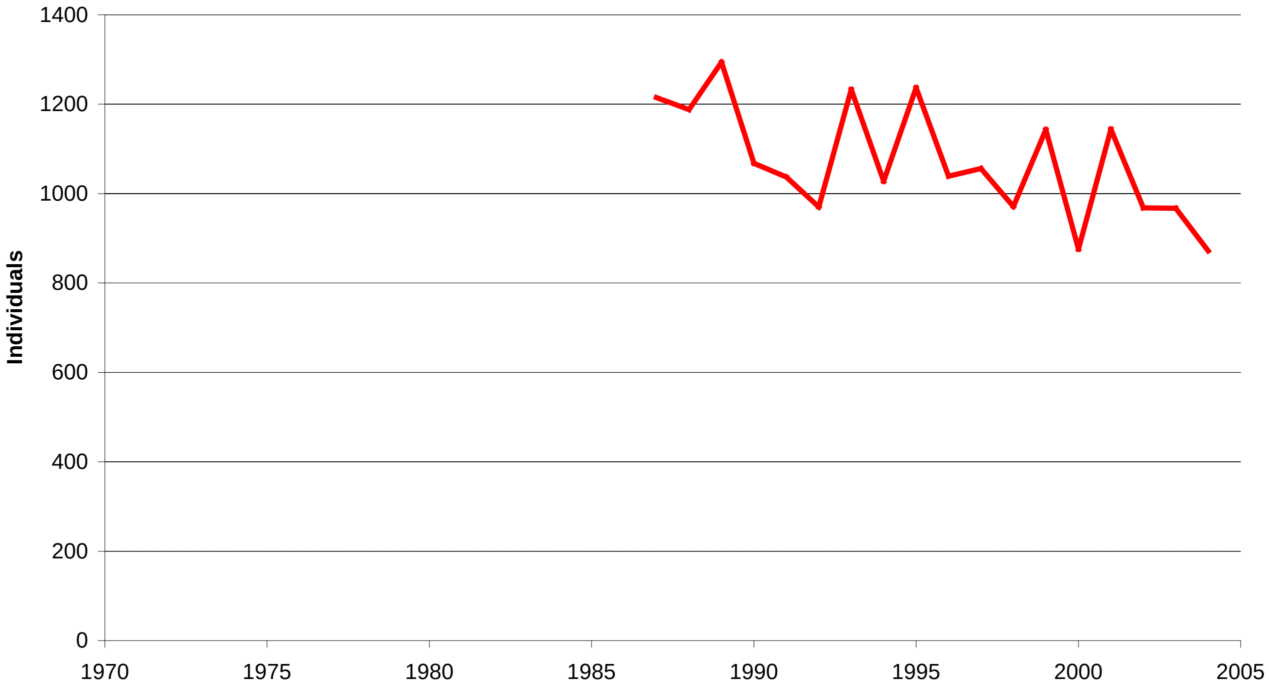

Figure 7: Trends in the Western Hudson Bay Polar Bear (*Ursus maritimus*) populations [15].

System Results

OVERVIEW


HANNES GROBE/AWI/WIKIPEDIA

Divergent patterns are also observed between the different systems (marine, freshwater and terrestrial). Whereas the freshwater and marine indices increase over the time period (52% and 53% respectively), the terrestrial index shows an overall decline of 10%, despite increasing in the late 1970s to mid-1980s (Figure 8). However, the data behind the freshwater index is currently too sparse (51 species; 132 populations) to fully reflect the circumpolar freshwater situation. The marine index is robust (107 species; 390 populations), but it is largely driven, as is the Low Arctic index, by an overweighting of population data from the eastern Bering Sea. More robust and balanced datasets are needed for these systems. The terrestrial index, however, does have relatively balanced and decent data and it comprises the largest dataset with 46% of the total number of ASTI populations compared to marine (40%) and freshwater with only 14%.

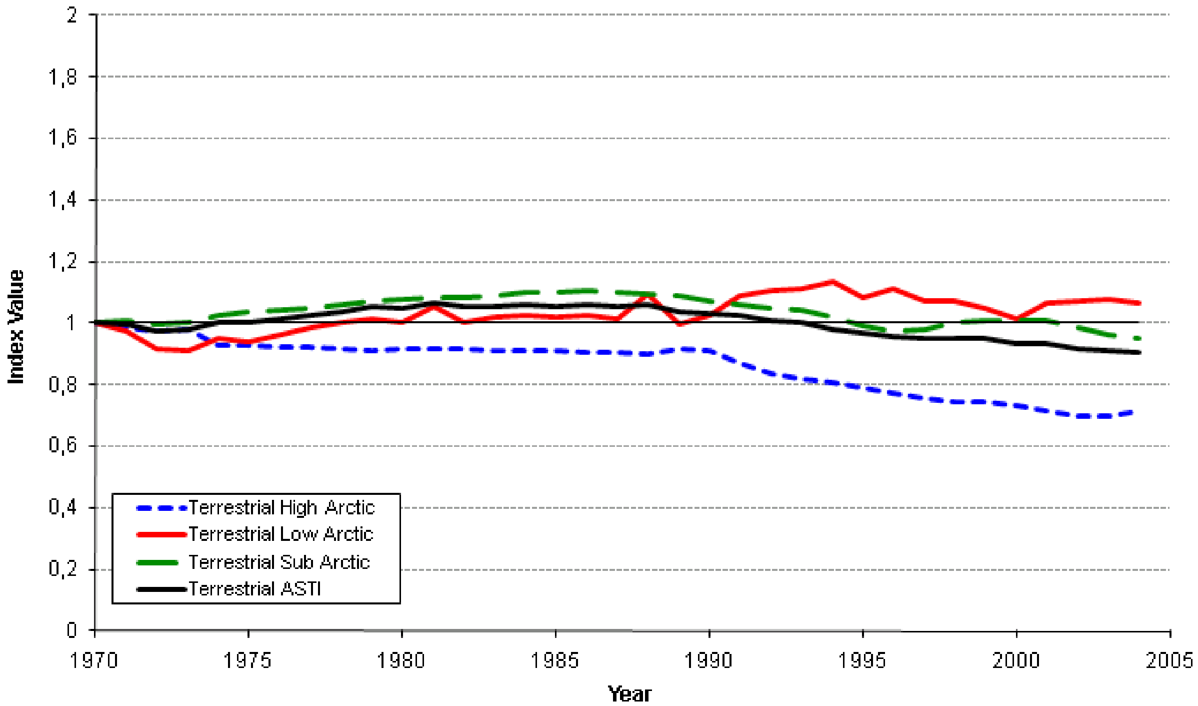

FIGURE 8: INDEX OF TERRESTRIAL SPECIES DISAGGREGATED BY ARCTIC BOUNDARY for the period 1970-2004 (High Arctic, n=25 species, 73 populations; Low Arctic, n=66 species, 166 populations; Sub Arctic, n=102 species, 204 populations.)

The terrestrial index is fairly stable until the early 1990s, after which there is a steady decline, despite an overall dramatic increase in goose populations over the same time period (Figure 8). The overall moderate decline in the terrestrial index is largely a reflection of declines (-28%) in terrestrial High Arctic populations (mostly herbivores, e.g., caribou, lemmings), whereas terrestrial Low Arctic populations (e.g., Lesser Snow Geese [16]) have increased by 7% and Sub Arctic populations have declined (-5%) slightly (Figure 8). The increase in the Low Arctic is, in part, due to the strong increase of goose populations. It could also reflect ecological responses to climatic changes whereby species with more southerly distributions have moved north and are now thriving, while the northernmost typical High Arctic species have nowhere to move to. However, evidence for this is not conclusive and cumulative factors might be involved.

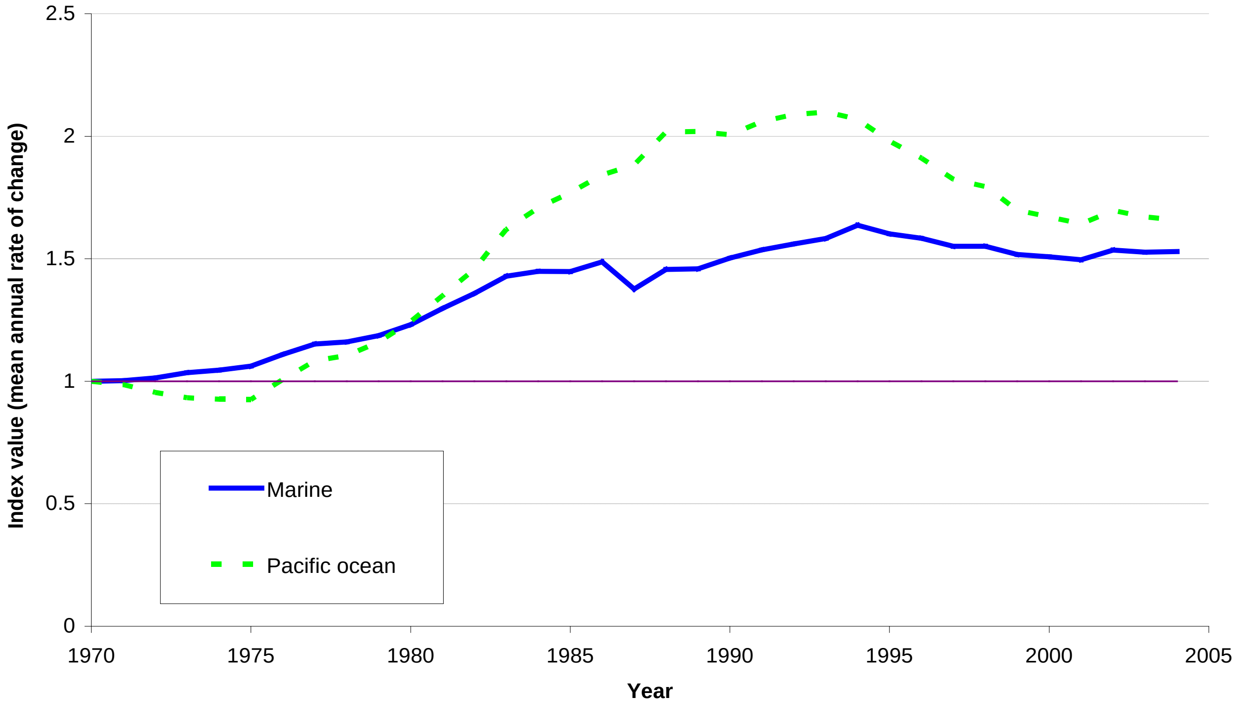

Figure 9: Overall index of marine species and index of north Pacific Ocean species for the period 1970-2004. (Marine, n=107 species, 390 populations; Pacific, n=69 species, 176 populations.)

As mentioned, the marine index was overweighted by population data from the eastern Bering Sea. The increasing trend found in Figure 9 for Pacific marine populations, is largely driven by mammal and fish populations. This dramatically increasing trend is largely driving the overall marine index. Many marine vertebrate populations (e.g., marine mammals) in the Bering Sea are recovering from historical overharvesting [17], as well as from recent changes in environmental conditions (e.g., Bering Sea Pollock [18]) resulting in dramatic increases in some species' populations.

Further analysis was conducted for the terrestrial system due to the larger data collections. These smaller scale indices that result reveal intriguing underlying trends within the terrestrial system.

Trophic Level

All species in the ASTI were assigned a category according to their trophic level: primary consumer (herbivores), secondary consumer (carnivores preying on invertebrates, fish, small birds and/or mammals) or tertiary consumers (top predators). Figure 10 illustrates the trends in abundance for the primary consumers, 85% of which are terrestrial. Substantial increases in some populations of the Anatidae family (geese, ducks and swans) have been observed [19], so trends in primary consumers were analysed with and without species from the Anatidae family. While herbivores as a whole increased slowly in abundance from 1970 to 1990, most of the increase was due to large increases in Anatidae populations. By removing the ducks, geese and swans it can be seen that there was an overall downward trend in other primary consumers by 30% between 1984 and 2004. The reasons for this decline are not known and may be due, in part, to the cyclical nature of some species and populations (e.g., Barren Ground Caribou). It may, however, be also attributed to changing conditions in tundra vegetation and more variable spring weather conditions. In many parts of the Arctic, shrubs have increased in abundance and cover in tundra systems as the climate has warmed and the adjacent sea-ice cover has declined[20][21][22]. Experimental warming of vegetation plots in tundra systems has shown the same effect with a corresponding decrease in lichen and bryophyte biomass [23]. These changes are expected to be unfavourable for many existing tundra herbivorous species such as Barren Ground Caribou [24]. Also, the incidence of icing events due to spring rainfall or increased freeze-thaw cycles are thought to be on the rise and represent a negative impact on Arctic herbivores as the ice makes it more difficult for grazers to access forage with potentially catastrophic results. For example, during two winters in the 1990s, the Peary Caribou population in the western Queen Elizabeth Islands was reduced by more than 95%. This was due to heavy snow conditions and the presence of ice layers in the snow that made it difficult for the Caribou to reach ground forage [25].

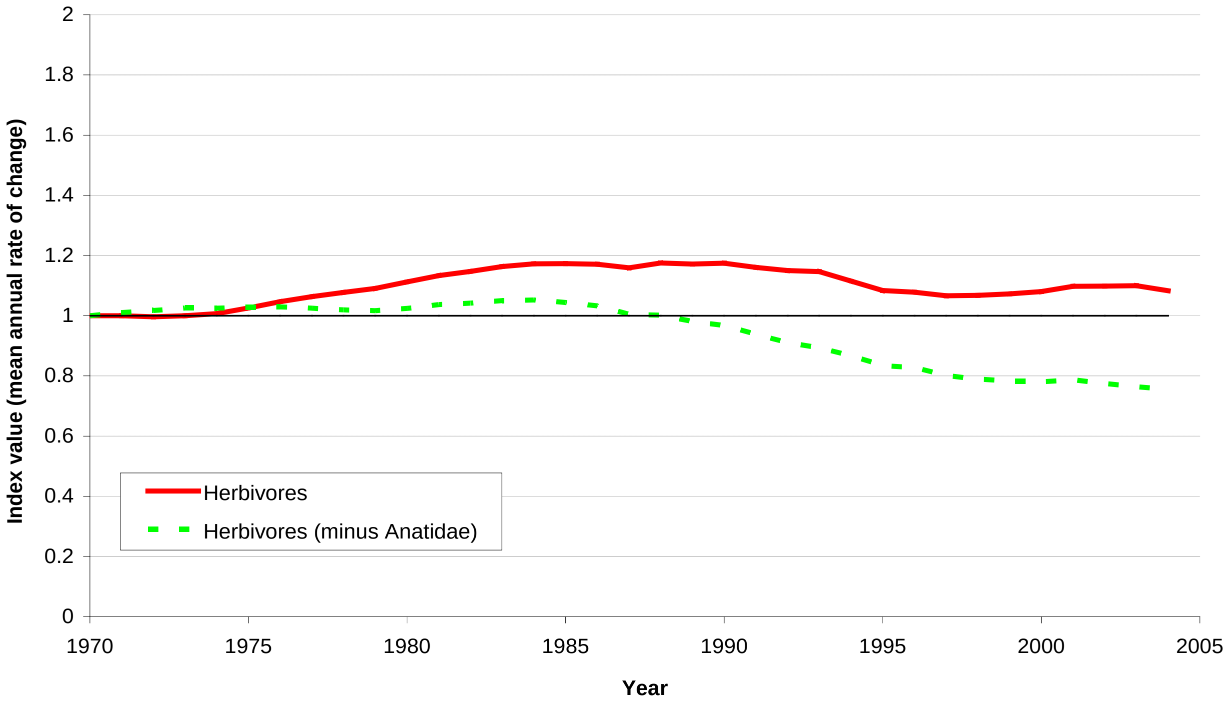

FIGURE 10: INDICES OF ALL HERBIVORE SPECIES AND ALL HERBIVORES EXCLUDING THE WATERBIRD SPECIES (ducks, geese and swans) for the period 1970-2004. (All herbivores, n=66 species, 220 populations; herbivores minus waterbird species, n=55 species, 182 populations.)

BOX 2: CARIBOU/REINDEER

Humans have had a relationship with Caribou stretching back to Upper Palaeolithic times, as the 20,000-year-old cave paintings in Cantabria, northern Spain, testify. Europe was in the grip of the last glacial period, the landscape of northern Spain and southern France was boreal tundra, Mammoths and Woolly Rhinoceros were abundant, and Reindeer were among the most important food species for the Cro-Magnon hunter-gatherer people who lived there. Today that relationship continues in the Arctic and Sub Arctic regions, where indigenous peoples such as the Saami of Scandinavia and the Inuit in Canada depend on domesticated and wild herds for meat, milk and hides.

Figure 11 shows average trends in 25 North American and 21 Eurasian Caribou/Reindeer populations, and the average trend across all 46 populations. The total population of wild herds peaked at about 5.6 million in the early 1990s and 2000s, and since then declined by about a third overall [26]. The largest herd in Russia, the Taimyr, peaked at around one million animals in 2000. Although recent declines are part of a natural cycle, there is growing concern about the current impacts of global change on Rangifer populations [27]. Three factors differentiate the recent period of low abundance from previous declines in populations: climate change, increased industrial development and more efficient harvesting. Geographically variable climate-change trends and characteristic extremes in weather patterns have direct impacts, both positive and negative, on birth and survival rates, and ultimately on herd

JOELLE TAILLON

productivity. Increased industrial development in the North alters activity and distribution patterns. Greater access to caribou and improved mobility of hunters results in consistently high harvests even when population numbers are low. All three factors have the potential to affect current declines and prolong recovery times. It will be important to understand what drivers are responsible for population declines and to monitor the outcome of recovery strategies [27].

The population trends shown in Figure 11 are clearly cyclical and also show striking similarities between Eurasia and North America, suggesting that there may be circumpolar factors underlying these trends. Although the cyclical patterns have been attributed to climatic patterns in some populations [28], the relationship between climate and Rangifer abundance is complex. Rather than having a direct causal effect, decadal variation in climate is likely to have a cumulative influence on abundance through successive generations by affecting extrinsic and intrinsic factors such as forage availability and fecundity [29]. Recent advances in estimating long-term trends in Barren Ground Caribou abundance [30] may help to shed some more light on these complex interactions.

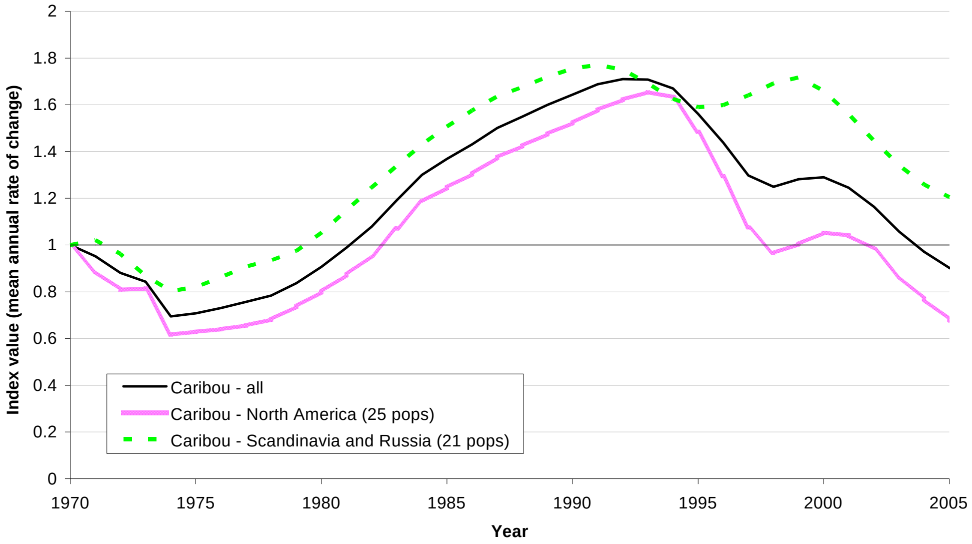

Figure 11: Indices for all Caribou (Rangifer tarandus) populations, disaggregated into North American and European populations. (All Caribou populations=46, North America=25, Scandinavia and Russia=21).

Taxonomic Results

Overview

Like the systems, the analysis of the ASTI by taxonomic class also reveals contrasting trends between each species group. Birds comprise 52% of the ASTI populations and show a flat trend overall with a slight decline in later years, until 2004. Mammal populations increased, on average, over the 34-year period. The fluctuations during the mid-1980s are due to rapid changes in abundance of a small set of marine-mammal populations in the Arctic Ocean (Killer, Sperm, Fin and Humpback whales). This is mostly a reflection of a limited number of datasets with limited time-series data rather than an accurate depiction as large-bodied marine mammals generally don't exhibit such marked annual changes in population size. The fish index is not shown as it is heavily skewed by marine fish populations from the Bering Sea, an effect which has been discussed in the systems section (p. 19) of this report.

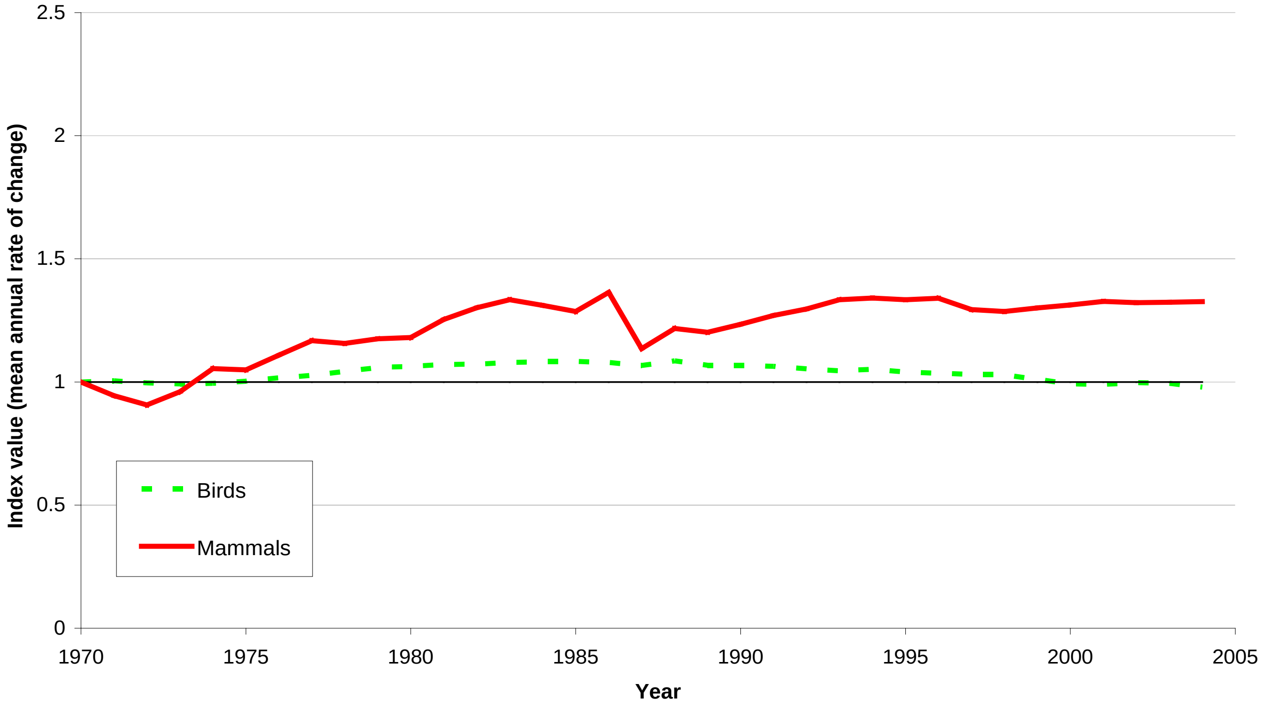

FIGURE 12: INDEX OF ASTI SPECIES DISAGGREGATED BY TAXONOMIC CLASS for the period 1970-2004. (Birds, n=190 species, 503 populations; mammals, n=53 species, 275 populations.)

Birds are the best studied of the taxonomic classes, covering a large number of species, populations and geographic areas over relatively long time periods, thus allowing for more detailed analyses to be conducted.

BIRDS

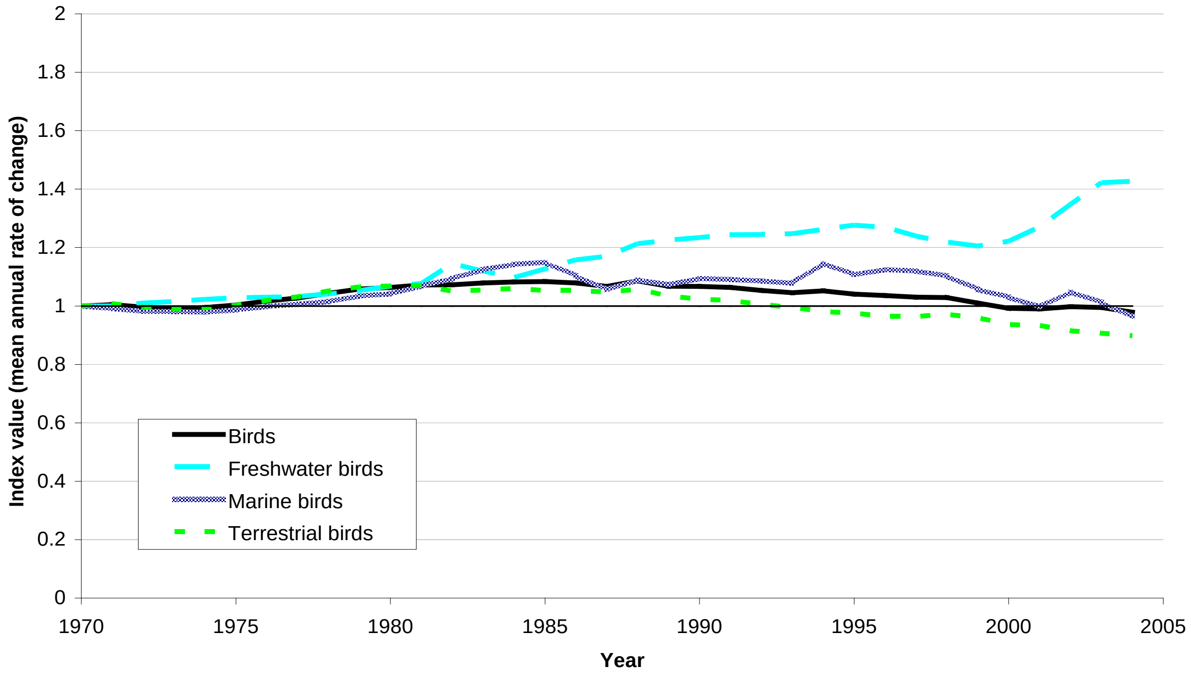

FIGURE 13: INDEX OF ALL BIRD SPECIES DISAGGREGATED INTO INDICES OF FRESHWATER, MARINE AND TERRESTRIAL BIRDS FOR THE PERIOD 1970-2004. (All birds, n=190 species, 503 populations; freshwater, n=35 species, 54 populations; marine, n=37 species, 214 populations; terrestrial, n=118 species, 235 populations.)

An analysis of Arctic bird trends by biome (Figure 13) shows that the relatively stable pattern is somewhat consistent in both marine- and terrestrial-bird populations thereby reinforcing the trend seen in the overall Arctic bird index. Freshwater-bird populations have increased overall between 1970 and 2004. This positive trend in abundance in many of the freshwater-bird populations, and particularly in the case of some duck species, could reflect the implementation of stricter hunting regulations and more-abundant wintering-ground food sources that have allowed these species to increase in number [19].

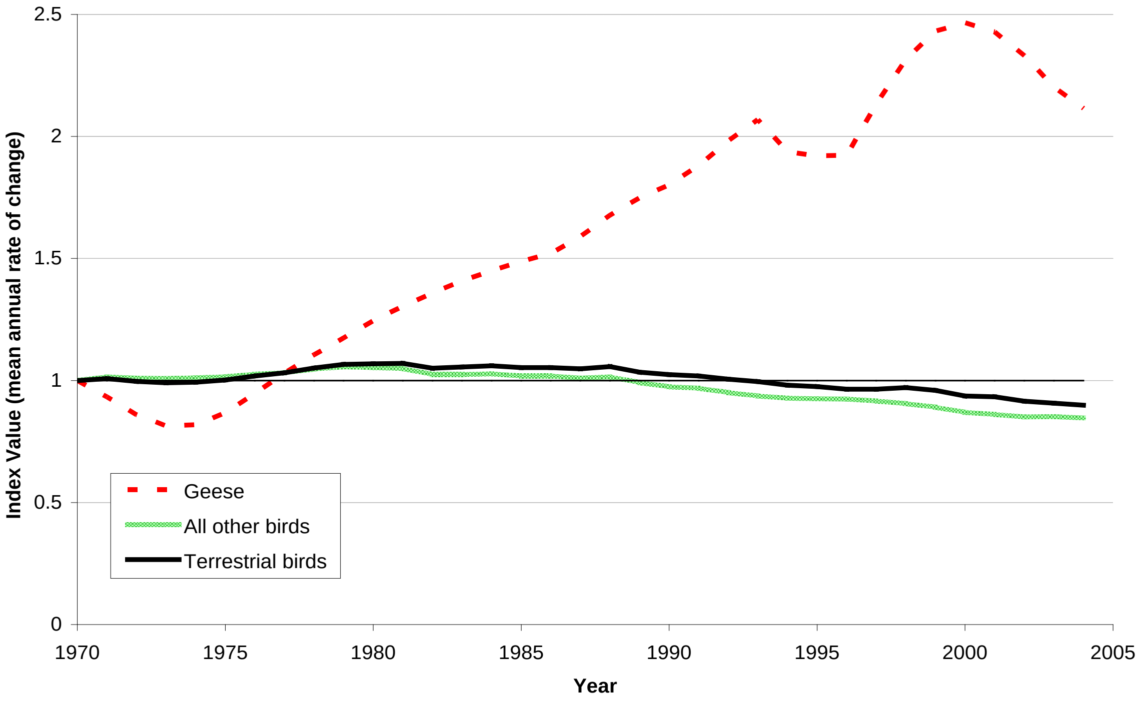

FIGURE 14: INDEX OF ALL TERRESTRIAL BIRDS DISAGGREGATED INTO AN INDEX WITHOUT GOOSE SPECIES AND AN INDEX OF GOOSE SPECIES ALONE. (All terrestrial birds, n=122 species, 236 populations; Anatidae only, n=13 species, 46 populations; non-Anatidae, n=109 species, 190.)

BOX 3: TERRESTRIAL BIRDS

Figure 14 shows trends in geese compared to other terrestrial birds. Many goose populations have benefited from both a reduction in the level of hunting and also land-use changes on over-wintering sites which has provided better forage.

These sometimes rapidly increasing populations are driving the goose index in Figure 14. However, this is not a uniform trend across all species of geese. A recent synthesis of Arctic-breeding geese monitoring suggests that 23% of these populations are actually in decline [19].

MIGRATORY BIRDS

Millions of birds migrate from around the Earth to breed in the Arctic each year. A total of over 450 bird species are known to breed in Arctic and Sub Arctic areas. Of these, 395 species regularly migrate outside the Arctic and Sub Arctic, linking these regions with almost all areas of the planet (except inland Antarctica) via their migratory route. Four species migrate within the region [31]. More than half of the world's shorebirds and almost 80% of the world's geese breed in the Arctic and Sub Arctic [32] [19]. The indices above (Figure 15) indicate an overall increase in non-migrant populations, whereas migratory populations slightly decreased (-6%). But there is no significant difference between the trends in the two groups (see Appendix III). The decline in migratory bird populations would be more

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pronounced if the increasing geese shown in Figure 14 are not included. As well, long-term monitoring of Arctic migrants takes place across the Earth at wintering and staging sites. Although the migratory index involves 170 species comprising 424 populations, many shorebird data from monitoring stations outside the Arctic (the majority of which are declining [33]) have not yet been included.

Unlike resident species, population sizes of migratory species can be influenced by conditions at any stage of migration with impacts only becoming apparent after monitoring at subsequent stages [34]. Many waders or shorebirds are in decline, but the reasons are not fully understood ([35][36][33]). Although changes in the Arctic, such as snow cover, humidity and increasing shrub cover may impact shorebirds [37], there are many other factors inside (e.g., changing distribution and extent of tundra wetlands) and outside the Arctic to consider in explaining the trends. For example, pre-nesting and egg-laying periods are major energetic bottlenecks across the entire Arctic region [38]. Warmer temperatures in spring and summer over large parts of the Arctic tundra can be largely beneficial for shorebird populations, however, the recent observed declines are mostly attributed to threats outside the Arctic region. Changes in habitat and food availability on key stopover sites are crucial for the survival of shorebird populations.

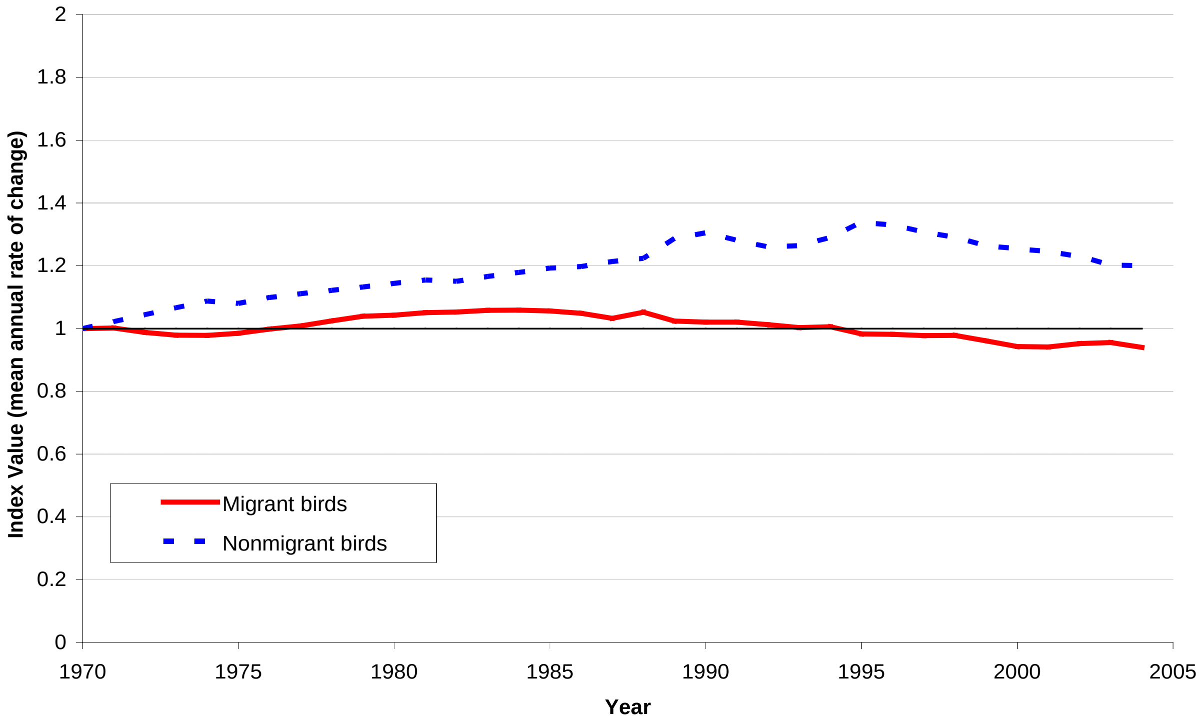

Figure 15: Index of all bird species disaggregated into indices of migrant and non-migrant bird populations for the period 1970-2004. (All birds, n=190 species, 503 populations; migrants, n=170 species, 424 populations; non-migrants, n=29 species, 79 populations.)

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ASTI in the Global Context

The Living Planet Index (LPI), which provides a measure of the trends in vertebrate abundance across the globe, has been steadily declining since the early 1980s. The difference between the Global LPI and the ASTI is largely due to recent declines in the tropics. The temperate LPI shows a very similar trend to the Arctic Species Trend Index with an overall increase of almost 20% since 1970. These varying regional trajectories are thought to be a reflection of recent human-use and development patterns. Tropical regions prior to 1970 experienced relatively little development pressures. Since the early 1960s, this region has experienced rapidly increasing development pressures largely resulting in large-scale habitat conversion and loss. In contrast, the majority of large-scale habitat loss and conversion in temperate regions took place prior to 1950, with conversion to agriculture among the main drivers. The increasing trend in the temperate LPI is likely to reflect recovery of some temperate vertebrate species from these historical pressures and increasing abundance of species benefitting from these land-use changes. While most of the Arctic has not experienced large-scale habitat conversion or loss, the increase in the ASTI is thought to be partly due to the recovery of some vertebrate populations (e.g., marine mammals and geese) from historical overharvesting, as well as increases in some fish populations, particularly in the Bering Sea. The decline in the High Arctic index, where development and harvesting pressures are virtually non-existent is a concern and could be an early indication of the response of High Arctic vertebrate populations to a changing climate and its consequent changes, such as in the physical structure of High Arctic habitats (e.g., sea ice).

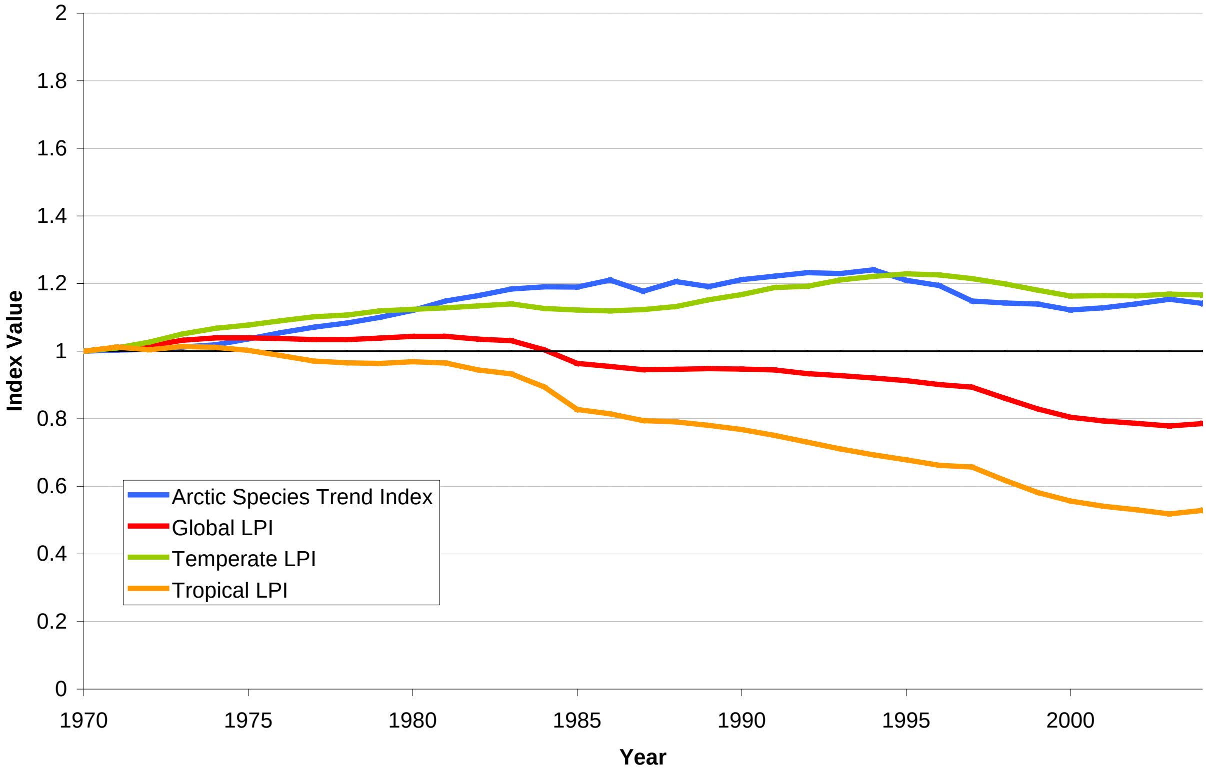

Figure 16: Global Living Planet Index (LPI) disaggregated into temperate and tropical indices and the Arctic Species Trend Index for the period 1970-2004. (Global LPI, n=2093 species, 6,433 populations; temperate LPI, n=1,329 species, 4,638 populations; tropical LPI, n=858 species, 1,795 populations; ASTI, n=306 species, 965 populations.)

Discussion

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This report describes the average trends in 965 populations of 306 vertebrate species to give an initial indicator of changes in Arctic biodiversity over 34 years. There was a mean overall increase in abundance between 1970 and 2004. This increasing trend, however, is not consistent across all species, systems or regions. Declines were evident in the High Arctic among terrestrial populations and herbivores (excluding waterbirds).

The taxonomic spread of data in the ASTI (for mammals and birds) sets a very good baseline with populations from 35% of all known Arctic vertebrate species represented. However, spatial and temporal coverage varies widely and a more comprehensive dataset is needed in order to reduce bias and to allow for finer-scale analysis. Where there is an imbalance in coverage in a subset of data, the resulting trends may be driven by the dominant region or species. For example, the increase in the marine index is skewed towards trends from Alaskan waters where monitoring efforts have yielded far more data than in other Arctic seas. Therefore, cautious interpretation of the results is required. It is anticipated that, with greater data contributions, future ASTI reports will be able to provide a more robust and accurate depiction of overall and regional trends.

These initial results suggest that impacts of changing land use, climate change, invasive species and exploitation have not negatively impacted overall vertebrate abundance in the Arctic during the past 34 years. However, the overall increase in vertebrate abundance masks underlying trends where some species and populations during this period have thrived or remained relatively flat while others have declined, possibly in response to human-induced changes. In particular, the High Arctic and terrestrial trends are of concern as they may reflect early response to expected changes in these ecosystems. Indeed, the observed declining trends in these systems are broadly consistent with predicted ecosystem and wildlife response to climate change. These predictions include reductions in abundance of High Arctic species dependent on sea ice, reductions in extent of High Arctic terrestrial ecosystems (e.g., tundra) and increased overall abundance of Sub Arctic wildlife as more southerly distributed species move northwards [5]. Future analyses must pay close attention to these systems. Despite this overall trend, accelerating changes in the Arctic's physical system largely attributed to climate change are expected to cause fundamental changes to the Arctic's ecosystems and the biodiversity these support. Increasing and accelerating pressures highlight the importance of enhancing current monitoring programs, integrating these programs to research and expanding coverage to less well-covered species and regions. Certain regions, such as the High Arctic, are showing populations already in decline. Climatic changes already occurring in the Arctic are likely to be one of the processes behind these declines, but further research is needed to establish the precise mechanism or mechanisms in force and their relative influence on these declining trends. Monitoring species abundance in the remote Arctic environment presents a number of logistical obstacles that need to be overcome. This is critical for groups such as sea-ice-associated species, for which obtaining regular population-trend data will be of paramount importance as the region warms [39].

The Arctic is an environment where pronounced, prolonged and often synchronous population cycles are a natural phenomena—in some cases associated with natural climate fluctuations [28]. This can make direct interpretation difficult when looking at trends among groups of species and over a limited time-frame (34 years). But with a comprehensive dataset that is broad in taxonomic, geographic and temporal scope, the index can be disaggregated to help elucidate patterns outside of natural variation. These patterns can shed light upon possible casual mechanisms and their relative influence. This report has illustrated many of these patterns and highlights the opportunities for enhanced understanding that future analysis can provide.

As with other Arctic environmental indices (e.g., sea-ice cover), the ASTI represents an important indicator of the state of the Arctic. With increasing data coverage, it is expected to provide an early warning system for the world with regard to the impacts of climate change and other human stressors on biodiversity. A robust ASTI will be able to depict at an early stage system responses, ecological regime shifts and subtle changes in the Arctic environment that would otherwise not be noticed. Its ability to serve as an early warning system very much depends on the number of participating monitoring networks and adequate data coverage.

Acknowledgements

We would like to thank Foreign Affairs and International Trade Canada and Environment Canada for providing the funding for this project. We'd also like to thank all CAFF country representatives for their help in facilitating the delivery of data to make the Arctic Species Trend Index more robust. In particular we'd like to thank Tom Barry from the CAFF secretariat, Aevar Petersen (Iceland) and Sune Sohlberg (Sweden) for their active role in providing data for the ASTI. This report and the index would not have been possible to compile without numerous contributors. We are extremely grateful to the following organizations and individuals that helped and contributed with published and unpublished data and in many cases comments on the draft report.

United States: Sue Moore, Tim Ragen, Scott Schliebe, Simon Tokumine, Vernon Byrd, Jennifer Boldt, Don Dragoo, David Irons and Richard Lanctot

Canada: Villy Christensen, Kathy Dickson, Gilles Gauthier, Grant Gilchrist, Anne Gunn, Trish Hayes, Charles Krebs, Guy Morrison, Dave Mossop, Jim Reist, Don Russell, Rick Ward and Dirk Zeller

Russia: Alexander Kondratiev, Elena Lappo, Mikhail Soloviev and Vassily Spiridonov

Greenland: Jannik Hansen, Flemming Merkel and Hans Meltofte

Norway: Per Arneberg, Stein Nilsen, Knut Sunnanaa and Dag Vongraven

Sweden: Johan Bodegard and Robert Franzen

Finland: Jaako Erkinaro

Germany: Helmut Kruckenberg

References

1. Collen, B., J. Loh, S. Whitmee, L. McRae, R. Amin, and J.E.M. Baillie. "Monitoring change in vertebrate abundance: the Living Planet Index". Conservation Biology 23(2) 2009: p. 317-327.
2. Hinzman, L.D., Neil D. Bettez, W. Robert Bolton, F. Stuart Chapin, Mark B. Dyurgerov, Chris L. Fastie, Brad Griffith, Robert D. Hollister, Allen Hope, Henry P. Huntington, Anne M. Jensen, Gensuo J. Jia, Torre Jorgenson, Douglas L. Kane, David R. Klein, Gary Kofinas, Amanda H. Lynch, Andrea H. Lloyd, A. David Mcguire, Frederick E. Nelson, Walter C. Oechel, Thomas E. Osterkamp, Charles H. Racine, Vladimir E. Romanovsky, Robert S. Stone, Douglas A. Stow, Matthew Sturm, Craig E. Tweedie, George L. Vourlitis, Marilyn D. Walker, Donald A. Walker, Patrick J. Webber, J.M. Welker, K.S. Winker, and K. Yoshikawa. "Evidence And Implications Of Recent Climate Change In Northern Alaska And Other Arctic Regions". Climate Change 72 2005: p. 251-298.
3. Post, E., M.C. Forchhammer, M.S. Bret-Harte, T.V. Callaghan, T.R. Christensen, B. Elberling, A.D. Fox, O. Gilg, D.S. Hik, T.T. Hoye, R.A. Ims, E. Jeppesen, D.R. Klein, J. Madsen, A.D. McGuire, S. Rysgaard, D.E. Schindler, I. Stirling, M.P. Tamstorf, N.J.C. Tyler, R. van der Wal, J. Welker, P.A. Wookey, N.M. Schmidt, and P. Aastrup. "Ecological dynamics across the Arctic associated with recent climate change". Science 325 2009: p. 1355-1358.
4. IPCC. Cambridge University Press, Ed. "Fourth Assessment Report of the Intergovernmental Panel on Climate Change, IPCC (WG I&II)". Cambridge: Cambridge University Press, 2007.
5. ACIA. Arctic Climate Impact Assessment. Cambridge, UK: Cambridge University Press:, 2005. Page 1042.
6. Stroeve, J., M.M. Holland, W. Meier, T. Scambos, and M. Serreze, "Arctic Sea Ice Decline: Faster than forecast". Geophysical Research Letters 34(L09501) 2007.
7. CAFF International Secretariat. "Arctic Flora and Fauna: Status and Conservation" in Chapter 9 Status and Trends in Species and Populations. 2005.
8. AMAP. "AMAP Assessment Report: Arctic Pollution Issues". Arctic Monitoring and Assessment Programme (AMAP): Oslo, Norway. 1998. Pages. Xii+859.
9. Holland, M.M., C.M. Bitz, and B. Tremblay. "Future Abrupt Reductions in the Summer Arctic Sea Ice". Geophysical Research Letters 33(L23503) 2006.
10. Moore, S.E. and H.P. Huntington. "Arctic Marine Mammals and Climate Change: Impacts and Resilience". Ecological Applications. 2008 18(sp2). Pages S157-S165.
11. NPFMC. "North Pacific Fishery Management Counci, Ecosystem Considerations for 2009". Joint Institute for the Study of the Atmosphere and Ocean (JISAO) and the School of Aquatic and Fishery 2008. Pages 77-80.
12. Reeves, R.R., B.D. Smith, E.A. Crespo, and G. Notarbartolo di Sciara. I.S.C.S. Group, ed. Dolphins, Whales and Porpoises: 2002–2010 Conservation Action Plan for the World's Cetaceans. Gland, Switzerland & Cambridge, UK, 2003. Pages ix+139.
13. Laidre, K.L., I. Stirling, L.F. Lowry, O. Wiig, M.P. Heide-Jorgensen, and S.H. Ferguson, "Quantifying The Sensitivity of Arctic Marine Mammals to Climate-Induced Habitat Change". Ecological Applications. 18. 2 (2008): S97-S125.

14. Stirling, I., N.J. Lunn, and J. Iacozza, "Long-Term Trends in the Population Ecology of Polar Bears in Western Hudson Bay in Relation to Climatic Change". Arctic, 1999. 52(3): p. 294-306.

15. Aars, J., N.J. Lunn, and A.E. Derocher. "Polar Bears: Proceedings of the 14th Working Meeting of the IUCN/SSC Polar Bear Specialist Group". 2005. Seattle, Washington, USA: IUCN, Gland, Switzerland and Cambridge, UK.

16. Abraham, K.F. and R.L. Jefferies. 1997. "High Goose Populations: Causes, Impacts and Implications". Batt, B. (Ed.), "Arctic Ecosystems in Peril: Report of the Arctic Goose Habitat Working Group", Arctic Goose Joint Venture Special Publication, U.S. Fish and Wildlife Service, Washington DC and Canadian Wildlife Service, Ottawa, Ontario, pp. 7–72.

17. George, J.C., J. Zeh, R. Suydam, and C. Clark. "Abundance and Population Trend of Western Arctic Bowhead Whales Surveyed Near Barrow, Alaska". 2006. Marine Mammal Science. 20(4): p. 755-773.

18. Overland, J. 2008. "Fisheries in the Bering Sea". In J. Richter-Menge, J. Overland, M. Svoboda, J. Box, M.J.J.E. Loonen, A. Proshutinsky, V. Romanovsky, D. Russell, C.D. Sawatzky, M. Simpkins, R. Armstrong, I. Ashik, L.-S. Bai, D. Bromwich, J. Cappelen, E. Carmack, J. Comiso, B. Ebbinge, I. Frolov, J.C. Gascard, M. Itoh, G.J. Jia, R. Krishfield, F. McLaughlin, W. Meier, N. Mikkelsen, J. Morison, T. Mote, S. Nghiem, D. Perovich, I. Polyakov, J.D. Reist, B. Rudels, U. Schauer, A. Shiklomanov, K . Shimada , V. Sokolov, M. Steele, M.-L. Timmermans, J. Toole, B. Veenhuis, D. Walker, J. Walsh, M. Wang, A. Weidick, C. Zöckler (2008). "Arctic Report Card 2008".

19. Zöckler, C., "The Role of the Goose Specialist Group in the Circumpolar Biodiversity Monitoring Programme (CBMP)". Vogelwelt, 2008. 129: p. 127-130.

20. Lantz, T.C. and S.V. Kokelj, "Increasing Rates of Retrogressive Thaw Slump Activity in the Mackenzie Delta Region, NWT, Canada". Geophysical Research Letters, 2008. 35.

21. Sturm, M., Charles Racine, and K. Tape, "Climate Change: Increasing Shrub Abundance in the Arctic". Nature, 2001. 411: p. 546-547.

22. Wahren, C.-H.A., M. D. Walker, and M.S. Bret-Harte, Vegetation Responses in Alaskan Arctic Tundra After 8 Years of a Summer Warming and Winter Snow Manipulation Experiment. Global Change Biology, 2005. 11: p. 537–552.

23. Arft, A.M., M.D. Walker, J. Gurevitch, J.M. Alatalo, M.S. Bret-Harte, M. Dale, M. Diemer, F. Gugerli, G.H.R. Henry, M.H. Jones, R.D. Hollister, I.S. Jonsdottir, K. Laine, E. Levesque, G.M. Marion, U. Molau, P. Molgaard, U. Nordenhall, V. Raszhivin, C.H. Robinson, G. Starr, A. Stenstrom, M. Stenstrom, O. Totland, P.L. Turner, L.J. Walker, P.J. Webber, J.M. Welker, and P.A. Wookey, Responses of Tundra Plants to Experimental Warming: Meta-Analysis of the International Tundra Experiment. Ecological Monographs, 1999. 69(4): p. 491-511.

24. Rees, W.G., F.M. Stammler, F.S. Danks, and P. Vitebsky, Vulnerability of European Reindeer Husbandry to Global Change. Climate Change, 2007. 87(1-2): p. 199-217.

25. Miller, F.L. and A. Gunn, "Catastrophic Die-off of Peary Caribou on the Western Queen Elizabeth Islands, Canadian High Arctic". Arctic, 2003. 56: p. 686-702.

26. Russell, D. and A. Gunn, "2010 Biodiversity Indicator—Wild Reindeer and Caribou. 2009: Coordinator CircumArctic Rangifer Monitoring and Assessment Network (CARMA)", Northern Research Institute, Yukon College, Yukon, Canada.

27. Gunn, A., Don Russell, Robert G. White and Gary Kofinas.2009. "Facing a future of change: Wild migratory caribou and reindeer". Arctic. Vol. 62, No. 3 (September 2009) P. iii–vi.
28. Aanes, R., B.-E. Saether, F.M. Smith, E.J. Cooper, P.A. Wookey, and N.A. Oritsland, "The Arctic Oscillation Predicts Effects of Climate Change in Two Trophic Levels in a High Arctic Ecosystem". Ecology Letters, 2002. 5(3): p. 445-453.
29. Gunn, A., "Voles, Lemmings and Caribou—Population Cycles Revisited?" Rangifer, 2003. 14: p. 105-111.
30. Zalatan, R., A. Gunn, and G.H.R. Henry, "Long-Term Abundance Patterns of Barren-Ground Caribou Using Trampling Scars on Roots of Picea Mariana in the Northwest Territories, Canada". Arctic, AntArctic, and Alpine Research, 2006. 38(4): p. 624-630.
31. Scott, D., "Global Overview of the Conservation of Migratory Arctic Breeding Birds Outside the Arctic", in "CAFF Tech Rep. No. 4". 1998. p. 133p.
32. Delany, S. and D. Scott, Waterbird Population Estimates Fourth Edition. 2006: Wetlands International, Wageningen. 239p.
33. Stroud, D.A., A. Baker, D.E. Blanco, N.C. Davidson, S. Delany, B. Ganter, R. Gill, P. González, L. Haanstra, R.I.G. Morrison, T. Piersma, D.A. Scott, O. Thorup, R. West, J. Wilson, and C. Zöckler, "The Conservation and Population Status of the World's Waders at the Turn of the Millennium", in Waterbirds Around the World, G.C. Boere, C.A. Galbraith, and D.A. Stroud, Editors. 2006, The Stationery Office, Edinburgh, UK. p. pp. 643-648.
34. Newton, I., "Population Limitation in Migrants". Ibis, 2004. 146: p. 197-226.
35. Morrison, G.R.I., Y. Aubry, R.W. Butler, G.W. Beyresbergen, G.M. Donaldson, C.L. Gratto-Trevor, P.W. Hicklin, V.H. Johnston, and R.K. Ross, "Declines in North American Shorebird Populations". "Wader Study Group Bulletin", 2001. 94: p. 34-38.
36. Zöckler, C., S. Delany, and W. Hagemeijer, "Wader Populations Are Declining—How Will We Elucidate the Reasons?". "Wader Study Group Bulletin", 2003. 100: p. 202-211.
37. Johnson, J.A., R.B. Lanctot, B.A. Andres, J.R. Bart, S.C. Brown, S.J. Kendall, and D.C. Payer, "Distribution of Breeding Shorebirds on the Arctic Coastal Plain of Alaska". Arctic, 2007. 60(3): p. 277-293.
38. Meltofte, H., T. Piersma, H. Boyd, B. Mccaffery, B. Ganter, V.V. Golovnyuk, K. Graham, T. Gratto-, C. L, R.I.G. Morrison, E. Nol, H.-U. Rösner, D. Schamel, H. Schekkerman, M.Y. Soloviev, P.S. Tomkovich, D.M. Tracy, I. Tulp, and L. Wennerberg, "Effects of Climate Variation in the Breeding Ecology of Arctic Shorebirds". MoG Bioscience, 2007. 59: p. 48p.
39. Simpkins, M., K.M. Kovacs, K. Laidre, and L.Lowry, "A Framework for Monitoring Arctic Marine Mammals—Findings of a Workshop Sponsored by the U.S. Marine Mammal Commission and U.S. Fish and Wildlife Service", Valencia, March 2007, in "CAFF CBMP Report No. 16". 2007, CAFF International Secretariat.
40. Loh, J., R.E. Green, T. Ricketts, J.F. Lamoreux, M. Jenkins, V. Kapos, and J. Randers, "The Living Planet Index: Using Species Population Time Series To Track Trends in Biodiversity". Philosophical Transactions of the Royal Society of London B, 2005. 360: p. 289-295.

41. International Hydrographic Organisation, Limits of the Oceans and Seas, 3rd Edition, in Special Publication no. 23. 1953, International Hydrographic organization: Monte-Carlo. p. 1-42.

42. Fisheries Centre, "Sea Around Us, 2009. A global database on marine fisheries and ecosystems". 2009, Fisheries Centre, University of British Columbia, Vancouver.

Appendix I: Technical Notes

Arctic Species Trend Index

The species population data used to calculate the Arctic indices are gathered from a variety of sources primarily published in scientific journals, but also from grey literature where studies meet the appropriate standard [1]. All data used in constructing the indices are time series of either population size, density, abundance or a proxy of abundance. The period covered by the data runs between 1950 and 2004. Annual data points were interpolated for time series with six or more data points using a generalized additive modelling framework or by assuming a constant annual rate of change for time series with less than six data points [1][40]. The average rate of change in each year across all species was calculated. The average annual rates of change in successive years were chained together to make an index, with the index value in 1970 set to 1. We used a bootstrap re-sampling technique to generate confidence limits around the index values; these are not shown to avoid over-complicating the figure. The indices were aggregated according to the hierarchy of indices shown in Figure 17. Methods are described in detailed in Collen et al. (2009) [1] and Loh et al. (2005) [40].

Data tagging

Arctic location

Each species population was assigned to a division of the Arctic system depending on its geographic location. The Arctic system was classified into two divisions: CAFF boundary and Arctic boundaries (see Figure 1). The Arctic region was subdivided into three further divisions of High, Low and Sub Arctic based on floristic boundaries [8]. A species population could be assigned to a single division or both, i.e., a species population may be present within an Arctic boundary and the CAFF boundary or in one or the other. Arctic division indices were calculated giving equal weight to each species.

System

Each species population was classified as being terrestrial, freshwater or marine, according to which system it is most dependent on for survival and reproduction. Populations were divided by the ocean basin (Arctic, Atlantic, Pacific) they inhabit for the marine analysis. The divisions for these were based on the boundary of the Arctic Ocean [41].

Trophic level

Each species was assigned to a trophic level: primary consumers, secondary consumers and tertiary consumers. Marine fish species were categorised based on the trophic level assigned for the Marine Trophic Index [42].

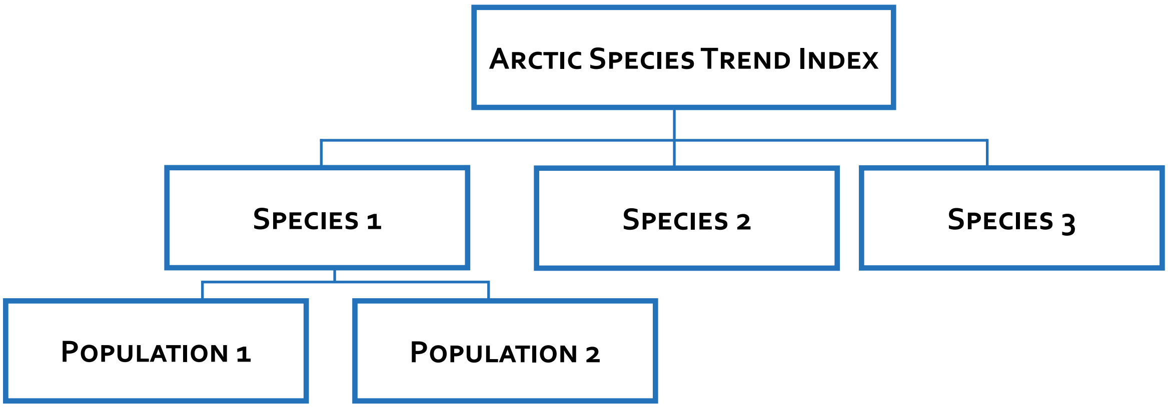

Figure 17: Hierarchy of indices within the Arctic Species Trend Index. Each population carries equal weight within each species and each species carries equal weight within the Arctic Species Trend Index.

Appendix II:
Species and Population Numbers in the ASTI Dataset

CAFF BOUNDARY

1. Populations

	FRESHWATER	MARINE	TERRESTRIAL	TOTAL
FISH	60	94		154
AMPHIBIAN	3			3
BIRD	57	188	233	478
MAMMAL	3	54	140	197
TOTAL	123	336	373	832

2. Species

	FRESHWATER	MARINE	TERRESTRIAL	TOTAL
FISH	13	48		61
AMPHIBIAN	2			2
BIRD	34	37	118	189
MAMMAL	1	22	30	53
TOTAL	50	107	148	305

HIGH/LOW/SUB ARCTIC BOUNDARIES COMBINED

3. Populations

	FRESHWATER	MARINE	TERRESTRIAL	TOTAL
FISH	72	112		184
AMPHIBIAN	3			3
BIRD	54	214	235	503
MAMMAL	3	64	208	275
TOTAL	132	390	443	965

4. Species

	FRESHWATER	MARINE	TERRESTRIAL	TOTAL
FISH	13	48		61
AMPHIBIAN	2			2
BIRD	35	37	118	190
MAMMAL	1	22	30	53
TOTAL	51	107	148	306

High/Low/Sub Arctic disaggregated by class

5. Populations

	HIGH ARCTIC	LOW ARCTIC	SUB ARCTIC
FISH	3	158	23
AMPHIBIAN		1	2
BIRD	81	243	179
MAMMAL	30	143	102
TOTAL	114	545	306

6. Species

	HIGH ARCTIC	LOW ARCTIC	SUB ARCTIC
FISH	3	58	10
AMPHIBIAN		1	1
BIRD	36	88	122
MAMMAL	8	47	22
TOTAL	47	194	155

High/Low/Sub Arctic disaggregated by system

7. Populations

	HIGH ARCTIC	LOW ARCTIC	SUB ARCTIC
FRESHWATER	8	68	56
MARINE	33	311	46
TERRESTRIAL	73	166	204
TOTAL	114	545	306

8. Species

	HIGH ARCTIC	LOW ARCTIC	SUB ARCTIC
FRESHWATER	6	27	35
MARINE	16	101	18
TERRESTRIAL	25	66	102
TOTAL	47	194	155

MARINE OCEANS BY CLASS

9. Populations

	ARCTIC	ATLANTIC	PACIFIC	TOTAL
FISH	18	21	73	112
BIRD	112	31	71	214
MAMMAL	29	3	32	64
TOTAL	159	55	176	390

10. Species

	ARCTIC	ATLANTIC	PACIFIC	TOTAL
FISH	11	7	37	55
BIRD	28	13	18	59
MAMMAL	16	2	14	32
TOTAL	55	22	69	146

REGIONS (GREENLAND AND NORTH AMERICA)

11. Populations

	NORTH AMERICA	EUROPE/ASIA
HIGH ARCTIC	98	16
LOW ARCTIC	282	263
SUB ARCTIC	112	194
TOTAL	492	473

12. Species

	NORTH AMERICA	EUROPE/ASIA
HIGH ARCTIC	45	10
LOW ARCTIC	118	117
SUB ARCTIC	88	72
TOTAL	251	199

Appendix III:
Index and Confidence Interval Values for Each of the Indices

Index		1970	1975	1980	1985	1990	1995	2000	2004
ASTI	Index	1.00	1.04	1.13	1.20	1.20	1.20	1.14	1.16
	Lower C.L.	1.00	0.98	1.05	1.10	1.08	1.07	1.01	1.02
	Upper C.L.	1.00	1.11	1.22	1.31	1.33	1.35	1.28	1.32
CAFF Boundary	Index	1.00	1.04	1.13	1.18	1.18	1.19	1.14	1.17
	Lower C.L.	1.00	0.98	1.05	1.08	1.06	1.07	1.01	1.03
	Upper C.L.	1.00	1.11	1.21	1.29	1.31	1.34	1.29	1.33
High Arctic	Index	1.00	0.91	0.87	0.77	0.74	0.72	0.73	0.74
	Lower C.L.	1.00	0.80	0.76	0.65	0.60	0.58	0.57	0.57
	Upper C.L.	1.00	1.01	0.98	0.89	0.90	0.91	0.94	0.96
Low Arctic	Index	1.00	1.04	1.18	1.31	1.35	1.45	1.33	1.46
	Lower C.L.	1.00	0.93	1.03	1.11	1.12	1.16	1.07	1.15
	Upper C.L.	1.00	1.17	1.35	1.53	1.62	1.78	1.66	1.83
Sub Arctic	Index	1.00	1.04	1.11	1.17	1.12	1.05	1.00	0.97
	Lower C.L.	1.00	0.98	1.02	1.06	1.00	0.93	0.89	0.85
	Upper C.L.	1.00	1.13	1.22	1.29	1.25	1.18	1.14	1.11
Marine	Index	1.00	1.06	1.23	1.45	1.50	1.60	1.51	1.53
	Lower C.L.	1.00	0.94	1.06	1.21	1.23	1.27	1.19	1.19
	Upper C.L.	1.00	1.20	1.45	1.75	1.86	2.00	1.89	1.96
Terrestrial	Index	1.00	1.00	1.05	1.06	1.03	0.97	0.93	0.90
	Lower C.L.	1.00	0.94	0.97	0.96	0.92	0.85	0.81	0.78
	Upper C.L.	1.00	1.07	1.14	1.17	1.15	1.11	1.08	1.05
Freshwater	Index	1.00	1.19	1.28	1.31	1.31	1.43	1.25	1.52
	Lower C.L.	1.00	0.91	0.95	0.96	0.95	1.02	0.87	1.03
	Upper C.L.	1.00	1.60	1.76	1.81	1.85	2.07	1.83	2.26
Birds	Index	1.00	1.00	1.06	1.08	1.07	1.04	0.99	0.98
	Lower C.L.	1.00	0.96	1.00	0.99	0.96	0.93	0.88	0.86
	Upper C.L.	1.00	1.05	1.13	1.18	1.17	1.17	1.12	1.11
Fishes	Index	1.00	1.16	1.35	1.70	1.88	1.93	1.68	1.96
	Lower C.L.	1.00	0.87	0.99	1.20	1.30	1.32	1.12	1.28
	Upper C.L.	1.00	1.59	1.89	2.44	2.77	2.86	2.56	3.01
Mammals	Index	1.00	1.05	1.18	1.29	1.23	1.33	1.31	1.33
	Lower C.L.	1.00	0.84	0.90	0.96	0.87	0.93	0.90	0.91
	Upper C.L.	1.00	1.28	1.53	1.71	1.74	1.92	1.90	1.93
Arctic Ocean	Index	1.00	1.10	1.07	0.94	0.89	1.03	1.07	1.07
	Lower C.L.	1.00	0.99	0.91	0.77	0.67	0.76	0.78	0.77
	Upper C.L.	1.00	1.23	1.23	1.13	1.16	1.39	1.47	1.48
Atlantic Ocean	Index	1.00	1.22	1.15	1.13	1.04	1.00	0.97	0.96
	Lower C.L.	1.00	0.85	0.77	0.74	0.67	0.64	0.61	0.60
	Upper C.L.	1.00	1.83	1.83	1.81	1.66	1.62	1.59	1.58
Pacific Ocean	Index	1.00	0.93	1.24	1.77	2.01	1.98	1.67	1.66
	Lower C.L.	1.00	0.79	1.01	1.39	1.53	1.50	1.24	1.19
	Upper C.L.	1.00	1.10	1.54	2.26	2.63	2.65	2.30	2.30
Terrestrial Birds	Index	1.00	1.00	1.07	1.05	1.02	0.98	0.94	0.90
	Lower C.L.	1.00	0.94	0.99	0.96	0.91	0.84	0.80	0.76
	Upper C.L.	1.00	1.07	1.15	1.17	1.17	1.14	1.11	1.07
Terrestrial Mammals	Index	1.00	1.00	0.96	1.09	1.08	0.94	0.94	0.98
	Lower C.L.	1.00	0.75	0.69	0.76	0.75	0.65	0.64	0.66
	Upper C.L.	1.00	1.30	1.31	1.52	1.51	1.33	1.38	1.44
Terrestrial High Arctic	Index	1.00	0.93	0.91	0.91	0.91	0.79	0.73	0.72
	Lower C.L.	1.00	0.80	0.79	0.78	0.77	0.66	0.60	0.58
	Upper C.L.	1.00	1.02	1.02	1.02	1.04	0.93	0.88	0.87

Terrestrial Low Arctic	Index	1.00	0.94	1.00	1.02	1.03	1.09	1.01	1.07
	Lower C.L.	1.00	0.78	0.79	0.72	0.66	0.64	0.57	0.59
	Upper C.L.	1.00	1.14	1.28	1.44	1.62	1.86	1.76	1.87
Terrestrial Sub Arctic	Index	1.00	1.04	1.08	1.10	1.07	0.99	1.01	0.95
	Lower C.L.	1.00	0.97	0.99	1.00	0.96	0.89	0.89	0.84
	Upper C.L.	1.00	1.11	1.17	1.20	1.18	1.10	1.14	1.09
Herbivores	Index	1.00	1.03	1.11	1.17	1.17	1.08	1.08	1.08
	Lower C.L.	1.00	0.94	1.02	1.06	1.04	0.94	0.93	0.92
	Upper C.L.	1.00	1.12	1.23	1.32	1.33	1.25	1.27	1.28
Herbivores (Minus Anatidae)	Index	1.00	1.03	1.02	1.04	0.97	0.83	0.78	0.75
	Lower C.L.	1.00	0.95	0.93	0.94	0.85	0.72	0.66	0.63
	Upper C.L.	1.00	1.12	1.13	1.17	1.10	0.97	0.92	0.90
Freshwater Birds	Index	1.00	1.03	1.07	1.13	1.23	1.28	1.22	1.43
	Lower C.L.	1.00	0.81	0.82	0.84	0.91	0.93	0.88	0.99
	Upper C.L.	1.00	1.33	1.39	1.55	1.71	1.80	1.72	2.06
Marine Birds	Index	1.00	0.99	1.04	1.15	1.09	1.11	1.03	0.96
	Lower C.L.	1.00	0.92	0.94	1.00	0.93	0.88	0.81	0.72
	Upper C.L.	1.00	1.06	1.15	1.32	1.32	1.40	1.34	1.27
Terrestrial Birds	Index	1.00	1.00	1.07	1.05	1.02	0.98	0.94	0.90
	Lower C.L.	1.00	0.94	0.99	0.96	0.91	0.84	0.80	0.76
	Upper C.L.	1.00	1.07	1.15	1.17	1.17	1.14	1.11	1.07
Terrestrial Geese	Index	1.00	0.87	1.24	1.49	1.80	1.92	2.47	2.12
	Lower C.L.	1.00	0.60	0.82	0.99	1.15	1.26	1.55	1.30
	Upper C.L.	1.00	1.19	1.78	2.11	2.66	2.92	4.02	3.53
Terrestrial Birds (Minus Geese)	Index	1.00	1.02	1.05	1.02	0.97	0.93	0.87	0.85
	Lower C.L.	1.00	0.97	0.99	0.92	0.86	0.79	0.74	0.71
	Upper C.L.	1.00	1.07	1.12	1.13	1.10	1.09	1.03	1.01
Migrant Birds	Index	1.00	0.98	1.04	1.06	1.02	0.98	0.94	0.94
	Lower C.L.	1.00	0.93	0.97	0.97	0.92	0.86	0.82	0.81
	Upper C.L.	1.00	1.04	1.12	1.16	1.14	1.12	1.08	1.09
Non-Migrant Birds	Index	1.00	1.08	1.14	1.19	1.30	1.34	1.25	1.20
	Lower C.L.	1.00	1.01	1.06	1.09	1.16	1.11	1.03	0.96
	Upper C.L.	1.00	1.15	1.23	1.30	1.47	1.64	1.56	1.51
Caribou	Index	1.00	0.71	0.91	1.37	1.64	1.56	1.29	0.90
	Lower C.L.								
	Upper C.L.								
Nearctic Caribou	Index	1.00	0.63	0.80	1.25	1.52	1.48	1.05	0.68
	Lower C.L.								
	Upper C.L.								
Palearctic Caribou	Index	1.00	0.82	1.05	1.51	1.75	1.59	1.66	1.20
	Lower C.L.								
	Upper C.L.								