"All of the plants, all of the animals, the water, the air, the land is all of what we are… It is who we are. This is our understanding. People making decisions have a different understanding."

- *Quote from interviews, meetings, and workshops (Inuit Circumpolar Council- Alaska, 2015).*

Introduction

The Arctic is the fastest warming region in the world which causes severe and immediate changes of ecosystems, Inuit cultures, fauna disturbance, and landscape alterations. Since the warming Arctic temperatures are more prevalent, the sea-ice extent and weather changes are highly visible to Inuit people. Arctic temperature rates are increasing almost twice as much as the global average ("Satellite Observations of Arctic Change Overview | National Snow and Ice Data Center :: Satellite Observations of Arctic Change" 2019). The rising Arctic temperatures are thawing the permafrost on shorelines, riverbanks, and below houses which leads to erosion, vegetation loss, animal habitat degradation, and stability for Inuit (Romero Manrique, Corral, and Guimarães Pereira 2018). As a result of warming Arctic temperatures, global temperatures increased by 1.4° F since 1880 and in the past decade, North America experienced unpredictable weather events (NOAA 2019). Global warming is an issue that requires a strong understanding of the matter in order to implement policies, strategies, and enhance cooperation between countries. The Arctic is the forefront of climate change and must be thoroughly studied and observed in order to protect and preserve what is left of the Arctic's ecosystem, cultural traditions, and abundance of wildlife.

The Arctic is experiencing climate change first-hand. Inuit subsistence practices are jeopardized because the animals' habitats are eroding, melting, or depleting. Inuit are utilizing traditional ecological knowledge to adapt to land, ocean, and animal disturbances. Indigenous knowledge holders know how important ecosystems are because of the many years of observing their land (Sakakibara 2017). In Alaska's North Slope, the changing climate will result in physiological changes in avian, terrestrial, marine, and freshwater fauna. Landforms, hydrology, and vegetation will alter wildlife's habitats and ecosystems (Kittel et al. 2011). Due to the increased Arctic temperatures, Canadian Arctic caribou, a source of protein for Inuit, are experiencing a population decline (Mallory and Boyce 2018). Utilizing traditional ecological knowledge and science, subsistence hunters could predict future ecosystem and faunal disturbances in the Arctic. Understanding how animals behave in the changing Arctic will preserve subsistence hunting and potentially protect the wildlife from future habitat destruction.

Lesser Snow Geese

The Lesser Snow Geese are one of the many avian species that utilize the Arctic's resources to nest, molt, raise young, and forage. Inuit hunt Lesser Snow Geese and other types of geese to eat for feasts, such as Nalukataq and Kivgiq and to fill up freezers at home for winter. Lesser Snow Geese (*Chen caerulescens caerulescens*) are migratory birds that are in the duck and geese family. The Lesser Snow Geese spend the summer on the tundra by marshes, grain fields, lakes, ponds, and bays, and overwinters in California, Gulf Coast of Louisiana, Texas, and the Atlantic Coast (Kaufman 2014). Lesser Snow Geese diet consists of seeds, leaves, and roots of wild grasses, sedges, bulrushes, and horsetail. The foraging habits of the geese prohibits regrowth of grasses and flowering plants which can alter ecosystems (Kaufman 2014). The Lesser Snow Goose colony of interest is the Ikpikpuk Snow Goose colony. The Ikpikpuk Snow Goose colony nests and molts on the Teshekpuk Lake and Ikpikpuk River.

Caribou

Caribou is located throughout the Circumpolar North. One of the Iñupiaq values is to use all or most parts of the animal Inuit hunted. Caribou's fur, skin, and sinew are used to make traditional clothing, their antlers are used for art and medicine. Lastly, Inuit people rely on caribou as a main source of protein. Caribou (*Rangifer tarandus granti*), often do not migrate; rather, caribou move to locations for better foraging, a safe place to calf, and to find insect relief (Kaufman 2014). Caribou seek locations with cold winds and waterbodies to escape from the intense summer heat and overpopulation of insects that could make caribou sick, destroy their fur, and irritate the caribou's foraging and calving (Witter et al. 2012). Caribou summer diet consists of leaves from willow, sedges, flowering tundra plants, and mushrooms and winter diet consist of lichen, dried sedges, and small shrubs (Kaufman 2014). The Alaskan caribou herd of interest is the Teshekpuk Caribou Herd (TCH). The TCH is located at the Teshekpuk Lake area year-round, but moves to different locations for insect relief, calving, and foraging.

The focus of the study is to observe the potential effects on how the increasing Ikpikpuk Snow Goose population can affect Teshekpuk Caribou Herd's insect relief habitats in the Teshekpuk Lake and Ikpikpuk River Delta. The overpopulation of Lesser Snow Geese increases habitat loss and depletion of resources for other species in the habitat by disrupting ponds, lakes, vegetation biodiversity, ground-temperatures, and soil nutrients. The destruction of the Ikpikpuk River Delta and the Teshekpuk Lake could impact caribou insect relief habitats by increasing near-surface ground temperatures that later results in drying ponds and small bodies of water (Campbell, Lantz, and Fraser 2018), and further results in an increase of insect populations. Vegetation comparisons, waterbodies levels, Teshekpuk Caribou Herd distribution, and Ikpikpuk Snow Goose population data will answer the focus of the study. Geographic Information System (GIS) was utilized to create a map of the two locations. The population data and maps were collected from the North Slope Borough Department of Wildlife Management and Alaska Biological Research. If the Ikpikpuk Snow Geese are creating disturbances for caribou, the caribou distribution and population can fluctuate due to the increased insect populations and the lack of vegetation and water. The potential caribou population decline, or distribution shifts of caribou is a problem for Inuit hunters and native communities in Alaska because the caribou will not be easily accessible, or the overall population will be too low to fulfill subsistence needs.

Literature Review

The Arctic is home to caribou, moose, fish, migratory birds, bears, and different types of marine mammals. The abundance of animals requires scientists and Inuit to understand how the Arctic fauna interact and respond in habitats to help predict and protect future ecological disasters in the Arctic. In previous studies, wildlife biologists studied how migratory birds interact with competition between different species, vegetation types, water, climate change, and human activity. In a study about bird nest densities and nest survivorship in the Teshekpuk Lake, nests were more abundant in areas with little to no human-activity compared to Prudhoe Bay, Alaska where oil development takes place (Liebezeit, White, and Zack 2011). In previous research conducted in Banks Island, Canada, the overgrazing caused by the Lesser Snow Geese (*Chen caerulescens caerulescens)* reduced the waterbody resilience of drying and draining (Campbell, Lantz, and Fraser 2018). Lastly, in a study conducted in the Teshekpuk Lake, vegetation and landscape changes were more of a factor for Greater White-Fronted Geese, Black Brant, and Lesser Snow Geese rather than interspecific competition (Flint et al. 2008). The birds in the Arctic are valuable indicators of how fast the Earth is changing. With increasing Arctic temperatures, Lesser Snow Geese may be forced to find new habitats and migration routes in order to properly forage, nest, and brood-rear. The fauna, vegetation, and ecosystems are at risk due to the destruction of habitat created by Lesser Snow Geese.

Climate change is not only altering lands and oceans but the distribution and abundance of animals. Climate change is manipulating the distribution and abundance of Arctic migratory birds. Wildlife biologists in the Arctic are examining the distributions, migrations, and populations of migratory birds and determining how fast these processes occur. Previous research on shorebirds in the Teshekpuk Lake Special Area concluded the Teshekpuk Lake has the overall highest density of shorebirds in the world (Andres et al. 2012). In a study conducted in Banks Island, Canada, there was an increase in avian herbivore populations, and as a result, the increasing populations were contributing to climate-driven changes in high-Arctic ponds (Campbell, Lantz, and Fraser 2018). Studies on the Ikpikpuk Snow Goose population concluded the rapid increase of the Ikpikpuk Snow Goose population is potentially due to the habitat and food availability in the Northwest Territories and continental United States (Burgess et al. 2017). The populations of migratory birds are indications of how previous habitats and breeding grounds are changing. Migratory birds travel to the Arctic to nest, molt, and raise the young before migrating South and other animals use the Arctic as breeding grounds, foraging, and calving. Therefore, developing an understanding of migratory birds and other species interactions in Arctic habitats could help analyze the overpopulation of Lesser Snow Geese and determine if the geese will negatively impact other species in the area.

The study fits with existing research because the study focuses on the high Arctic and climate change. Furthermore, the vegetation and water issues caused by the abundance of Lesser Snow Geese are similar in the other Arctic regions. Biologists studying Lesser Snow Geese in Canada also acknowledge that snow geese are destructive to other ecosystems. The research I am conducting will not only add another geographic location but will provide further explanation on how caribou are behaving and adapting to the habitat changes caused by snow geese and climate change. The research will help identify how fast the climate is changing with the increase of Lesser Snow Goose populations and help analyze the potentials risks other Arctic fauna will experience. The significance of my research will incorporate Indigenous knowledge into western science by adding the Indigenous perspective that all things; land, sea, and people, are connected and if one aspect is disrupted, the Arctic system will not be synced. My research will further explain the vulnerability of the caribou and how sensitive Arctic coastal regions and ecosystems are.

Methods

To answer the research question, a comparative analysis was conducted between the literature from Canadian Arctic Lesser Snow Goose studies and North Slope Alaska snow goose studies. The Ikpikpuk Snow Goose population data from years 1995-2015, United States Geological Survey's Normalized Difference Vegetation Index (NDVI) data from years 1984-2012, Teshekpuk Caribou Herd population from 1978 to 2017, and insect relief locations for caribou from years 2000-2016 were used for this study. The United States Geological Survey's Earth Explorer provided other vegetation maps in forms of .TIF and .DBF. For the Teshekpuk Caribou Herd's insect relief locations and Earth Explorer maps, the month of July is highlighted because it is the peak insect harassment month and July has the highest summer temperatures. The North Slope Borough Department of Wildlife Management and various Canadian Arctic wildlife journal articles provided the Ikpikpuk Snow Goose and Teshekpuk Caribou Herd population data, Lesser Snow Goose foraged tundra photos and information, and caribou distribution maps. The data collected from journal articles from the Canadian studies and North

Slope observations were synthesized using quantitative analysis, summarization, and comparative analysis. Geographic Information System (GIS) was utilized to map vegetation changes on the Teshekpuk Lake and Ikpikpuk River. A statistical analysis and programming tool, R-Studio, created a line graph of the increasing adult Ikpikpuk Snow Goose population. Microsoft Excel created the Teshekpuk Caribou Herd population line graph.

Analysis

Warming Arctic - Increase of Vegetation:

The Arctic, specifically coastal regions, is experiencing climate change at an alarming rate. Due to climate change, the land, ocean, vegetation, and wildlife are projecting negative and positive feedbacks. An example of a positive feedback is vegetation growth and abundance. The warming Arctic temperatures are contributing to the increasing vegetation abundance (van der Kolk et al. 2016). The warming Arctic temperatures causes earlier snow melt and a sooner breakup season, which allows vegetation to grow faster, earlier, and prolongs greening throughout the spring and summer (Hogrefe et al. 2017). Vegetation is a key component to answering the research question. Furthermore, vegetation abundance is one of the results of climate change. Understanding how and why vegetation abundance grew over the years helps researchers, scientists, and Inuit answer questions about how Arctic ecology and animal behavior and populations will alter. Figure 1 is a visualization of vegetation abundance changes in Alaska from July 2003 and July 2018. Figure 2 displays the greening trend from 1984 through 2012.

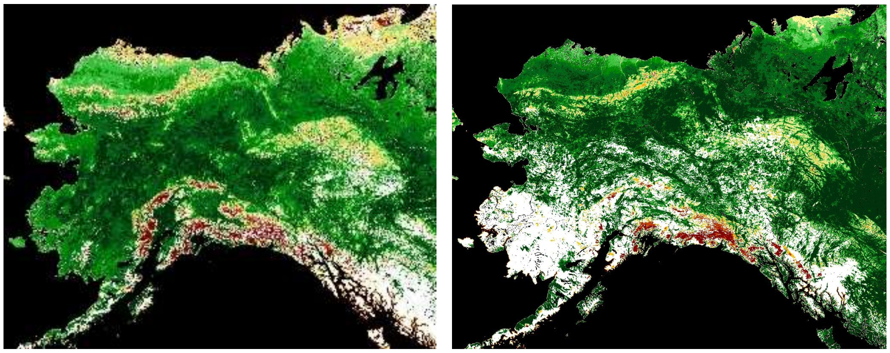


Figure 1. Photo 1 is from July 2003. Photo 2 is from July 2018 (“EarthExplorer - Alaska” 2019).

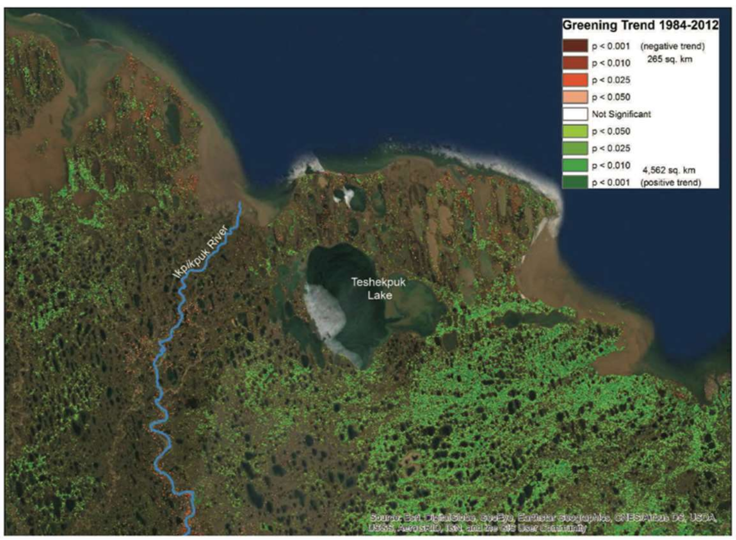


Figure 2. Study area of the Ikpikpuk River and Teshekpuk Lake. Map displays the greening trend from 1984 to 2012. The green regions indicate vegetation growth of 4,562 square kilometers and the brown/orange regions indicate vegetation loss of 265 square kilometers. The p-values indicate the significance of growth.

Warming Arctic – Increased Wildlife Populations:

Another positive feedback from climate change is the Arctic wildlife population fluctuations. Focusing on a few decades, terrestrial and marine animal populations are fluctuating. Because of the population fluctuations, it is difficult to predict wildlife populations. However, due to the increasing Arctic temperatures and vegetation, migratory wildlife populations, such as Alaska caribou herds and migratory birds are increasing (Liebezeit, White, and Zack 2011; Mallory and Boyce 2018). Unfortunately in the Canadian Arctic, caribou populations are declining and the cause is unknown (Mallory, Campbell, and Boyce 2018). Analyzing wildlife population fluctuations can determine how vulnerable and adaptable Arctic wildlife are to the changing climate and landscapes. However, the overabundance of certain species can disrupt another specie's behavior. Therefore, determining the rate of population increase and observing and quantifying the landscape and ecology damages caused by the overpopulation of a species can help determine what can happen to other species in the ecosystem. Figure 3 and Figure 4 shows the population trends of the Ikpikpuk Snow Goose colony and the Teshekpuk Caribou Herd.

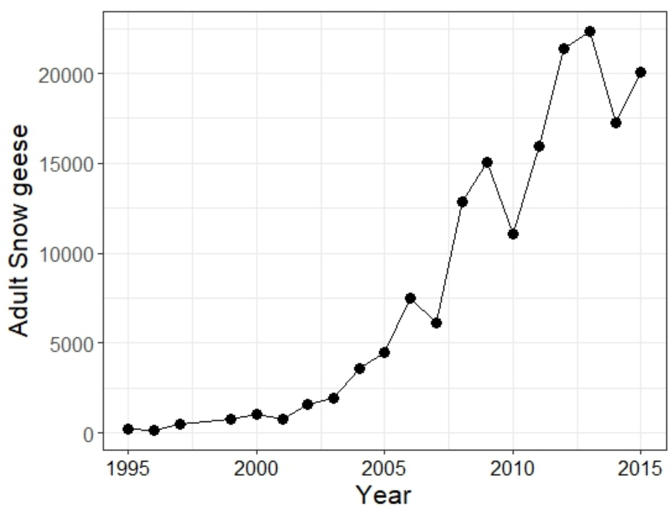


Figure 3. Adult Ikpikpuk Snow Goose population trend from years 1995 to 2015. Since 1995, the adult Ikpikpuk Snow Goose population increased by a rate of 10,222%. Data came from Burgess et al. 2017, R Studio created the line graph using ggplot2 functions.

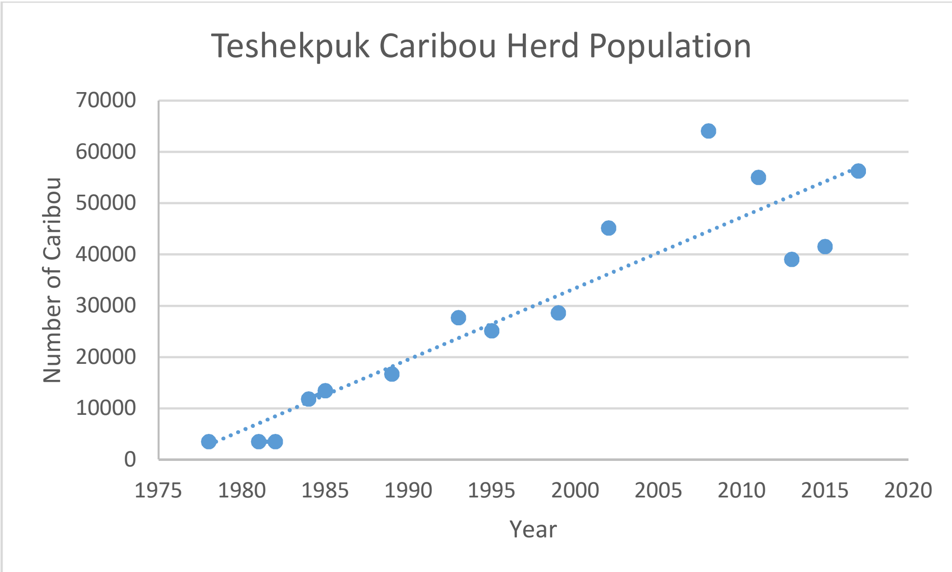


Figure 4. Teshekpuk Caribou Herd population trend from years 1978 to 2017. Several years were not sampled due to government and North Slope Borough funding. From 1978 to 1982, sampling methods were not well developed. Since 1978, the Teshekpuk Caribou Herd increased by a rate of 160.7%.

Teshekpuk Caribou Herd Insect Relief Habitats:

Throughout the year, Arctic caribou herds utilizes certain terrains for specific needs such as insect relief, calving, and foraging. Locations for these purposes rarely change. The Teshekpuk Caribou Herd uses the Teshekpuk Lake and Ikpikuk River Delta for mosquito insect relief (Wilson et al. 2012; ConocoPhillips Alaska et al. 2017). The river delta and lake is the preferred locations for insect relief because of the abundance of water, the waterbodies are along the coast which has the most winds, and vegetation length and abundance is ideal for protection from insects and is good for foraging (Liebezeit, White, and Zack 2011). Since the TCH utilizes certain areas during certain times of the year, determining what caribou behavior and system will be disrupted by snow geese leads to further analyses on what can happen to the caribou's system and behavior. Identifying TCH locations helps determine where TCH and Ikpikpuk Snow Geese overlap. Figure 5 displays the TCH insect relief locations.

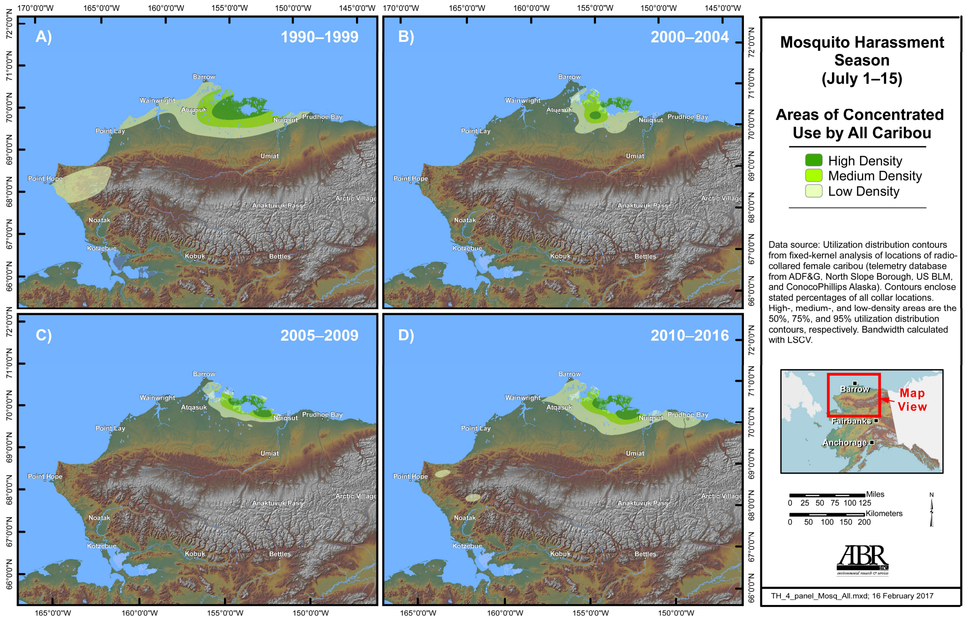


Figure 5. Teshekpuk Caribou Herd's mosquito relief locations from years 1990 to 2016. The dark green regions indicate locations where there is a high density of Teshekpuk Caribou. The lightest green shade indicates a low density of Teshekpuk Caribou. Map is from ConocoPhillips Alaska. Study conducted by Alaska Biological Research and the North Slope Borough Department of Wildlife Management.

Ikpikpuk Snow Goose Colony Locations:

Ikpikpuk Snow Geese are migratory birds. The Ikpikpuk Snow Goose colony, along with other geese such as the Greater White-Fronted Geese and Pacific Black Brants migrates to the Teshekpuk Lake and Ikpikpuk River every summer to nest and brood-rear (Liebezeit, White, and Zack 2011; Flint et al. 2008). The map below represents the Ikpikpuk Snow Goose colony locations during the Lesser Snow Geese summer breeding on the North Slope. The Ikpikpuk River Delta and the Teshekpuk Lake are inhabited by the Ikpikpuk Snow Geese. Comparing the Teshekpuk Caribou Herd insect relief locations and Ikpikpuk Snow Goose colony locations, there is an overlap between the two species.

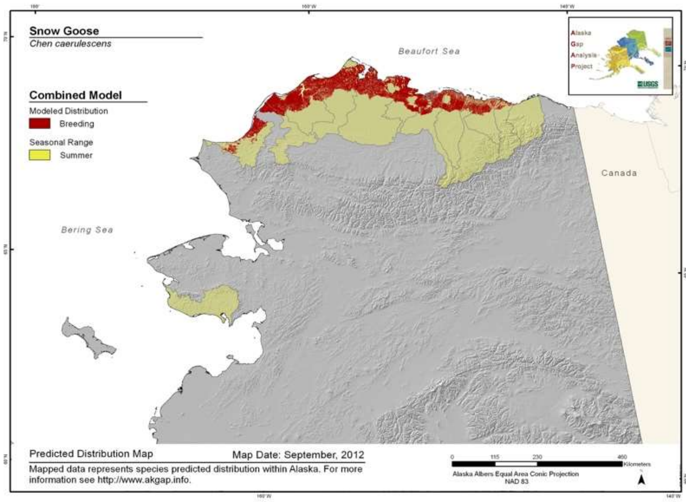


Figure 6. Ikpikpuk Snow Goose colony locations. Map created by the University of Alaska Southeast.

Snow Goose and Vegetation:

The overpopulation of Lesser Snow Geese is destructive to Arctic tundra and recolonization of tundra plants. Since the 1970's, Canadian biologists conducted research on the vegetation, soil, water, and landscape changes caused by Lesser Snow Geese. Their results concluded that the overpopulation of snow geese resulted in severe population reduction of forage species in freshwater wetlands, especially sedges, grasses, and tundra flowering plants (Kotanen and Abraham 2013). In areas with high levels of vegetation, Lesser Snow Geese overexploited the vegetation and increased the size of barren-grounds. The barren-grounds caused soil water salinity to increase, which created a feedback that limits recolonization of shrub and graminoid growth (Peterson et al. 2013). Tundra vegetation stabilizes the Arctic's near-surface ground temperatures, controls pH and water of soil, and protects permafrost from melting (van der Kolk et al. 2016). Arctic avian and terrestrial fauna relies on tundra to forage, nest or calf, and utilize the land as home or for safety from insects, predators, and hunters. Without vegetation, the land and fauna are at risk for distribution shifts, population fluctuations, and illness. Figure 7 shows vegetation changes over time based off of a snow goose study conducted in Canada.

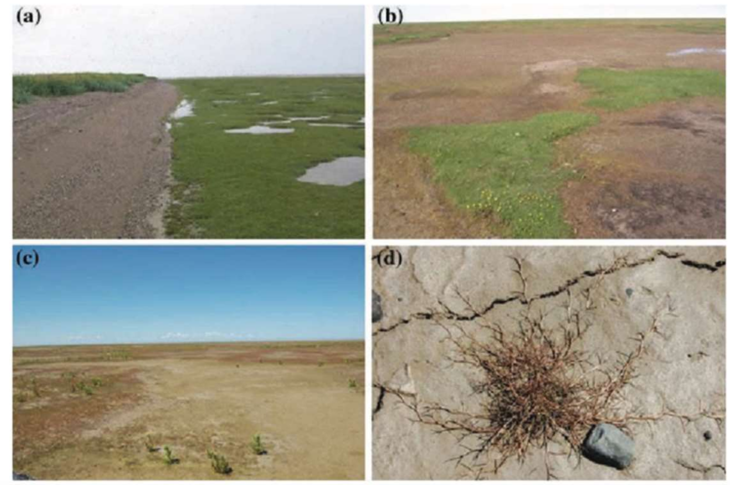


Figure 7**.** Results of grazing Lesser Snow Geese in Hudson Bay Lowlands in Canada: a) no Lesser Snow Geese present; b) Lesser Snow Goose brood-rearing location; c) barren-grounds from (a); d) barren-ground from (b) (Kotanen and Abraham 2013).

Snow Goose and Waterbodies:

Vegetation loss caused by Lesser Snow Geese takes a toll on surface water resilience. A lack of vegetation around surface water and waterbodies can dry the water or make the waterbody less resilient to changes of pH, salinity, and can also alter the water's nutrients (Campbell, Lantz, and Fraser 2018). Figure 8 shows how Lesser Snow Geese altered waterbodies in the Canadian Arctic.

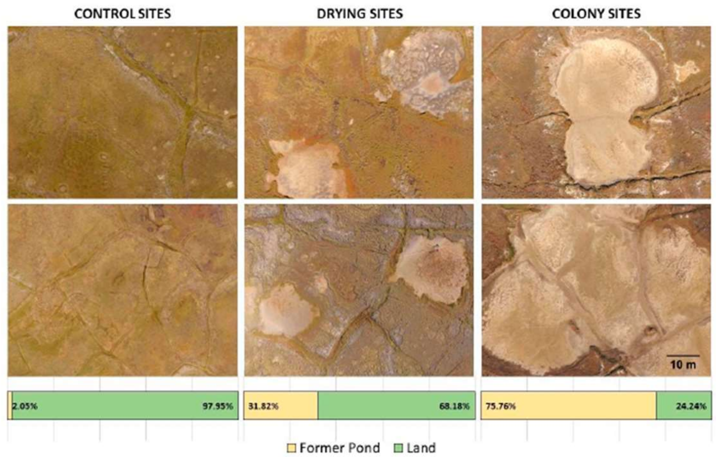


Figure 8. Results of overabundant snow geese in high Arctic lakes and ponds in Canada. The bars below the image indicate proportion of field transects classified as former pond basins and land (Campbell, Lantz, and Fraser 2018).

Potential Impacts to Caribou Insect Relief Habitats

The rapid increase of Ikpikpuk Snow Geese (Figure 3) alters Teshekpuk Caribou's insect relief habitats by creating plots of barren-ground (Figure 7). Caribou's preferred vegetation will become less abundant, water will dry up (Figure 8), and near-surface ground temperatures will rise, causing insect populations to increase. The loss of insect relief habitats could shift the caribou's distributional patterns or make caribou ill, which is a problem for subsistence hunters.

Counterpoints

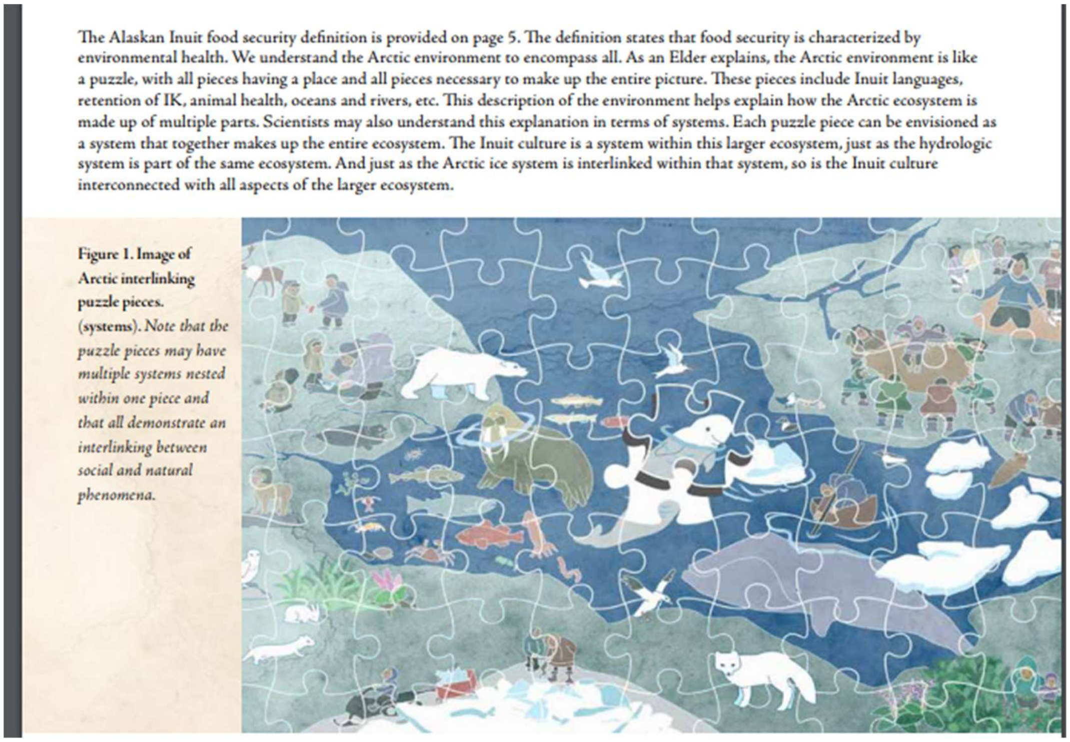
Climate Change and Weather Changes:

Snow geese are not the only source contributing to habitat loss and ecosystem alterations. The changing seasonal weather, increased precipitation, and heavier storms are a major factor in altering ecosystems and wildlife habitats. The Arctic has a sensitive ecosystem that changes rapidly causing detrimental effects to the land, wildlife, ocean, and people (Sakakibara 2017; Ford et al. 2018).

Counterargument – Can Lesser Snow Geese Reverse the Effects of Climate Change on Coastal Arctic Regions?

Discussion

My research project fills in a gap of determining interspecies behavior on the changing climate. Scientists overlook the different animal behaviors in shared habitats and may focus on the species direct impact on landscapes. In Canada, there are now studies that focus on how animal behavior can disrupt another species' nesting or population density (McFarland, Kendall, and Powell 2017). Furthermore, Lesser Snow Geese contributed to the population decrease of lemmings and voles (Samelius and Alisauskas 2009). Furthering the study of interspecies behavior connects with the indigenous perspective on how everything is connected. There is not enough research on the damages of habitats caused by a certain species and how it effects another species' resource selection process. Figure 9 illustrates Inuit's connection with the land, sea, animals, and people.



The Alaskan Inuit food security definition is provided on page 5. The definition states that food security is characterized by environmental health. We understand the Arctic environment to encompass all. As an Elder explains, the Arctic environment is like a puzzle, with all pieces having a place and all pieces necessary to make up the entire picture. These pieces include Inuit languages, retention of IK, animal health, oceans and rivers, etc. This description of the environment helps explain how the Arctic ecosystem is made up of multiple parts. Scientists may also understand this explanation in terms of systems. Each puzzle piece can be envisioned as a system that together makes up the entire ecosystem. The Inuit culture is a system within this larger ecosystem, just as the hydrologic system is part of the same ecosystem. And just as the Arctic ice system is interlinked within that system, so is the Inuit culture interconnected with all aspects of the larger ecosystem.

Figure 1. Image of Arctic interlinking puzzle pieces. (systems). *Note that the puzzle pieces may have multiple systems nested within one piece and that all demonstrate an interlinking between social and natural phenomena.*

Figure 9. Inuit perspective. (Inuit Circumpolar Council-Alaska, 2015).

The increasing Ikpikpuk Snow Geese population in the Teshekpuk Lake and Ikpikpuk River region are exacerbating climate change impacts on tundra and soil. In coastal Arctic regions, vegetation shifts resulting from climate change and avian herbivores impacts both the land and sea. Studies have shown that vegetation abundance, growth, and floral health is linked to sea ice extent (Bhatt et al. 2010). If Snow Geese are contributing to drying waterbodies and raising Arctic temperatures (Schreiber 2019), the Teshekpuk Caribou Herd will have less resources for insect relief. Lesser Snow Geese are not only an issue in Alaska's North Slope, but also in the Northwest Territories. The increased nesting colonies of Lesser Snow Geese in the Northwest Territories altered microtopography, near-surface ground temperatures, and water retention (Campbell, Lantz, and Fraser 2018). To see if snow geese impacts other migratory animals in the Arctic, further studies could be focused on the nesting distribution and density.

Conclusion

It is critical to understand how Arctic animals interact and respond with their habitats in the changing climate. The Lesser Snow Geese are a threat to ecosystems because of the cumulative effects of vegetation loss and water resilience to climate change. The potential caribou habitat alterations caused by Lesser Snow Geese and climate change could disrupt regular caribou distributions and make the caribou become ill. Changes in caribou distribution will make subsistence hunting challenging because the caribou will not be easily accessible to hunters. Therefore, subsistence hunters, community members, and waterfowl hunters in the Lower 48 should create and enforce regulations on Lesser Snow Goose harvest in order to reduce vegetation loss and stabilize water availability in the Arctic and the Lower 48. The Arctic's sensitive ecosystem needs to be protected and preserved. Mitigating Lesser Snow Goose populations is a step we can take in order to save nature, Inuit cultures, and other species and habitats from any further destruction and loss.

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