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Monitoring the Health of Wildlife and their Ecosystems in the Arctic: Hg Toxicology and Stable Isotopes

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Review Article

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Abstract

A major survival issue affecting wildlife ecosystems globally is climate change. Climate change fluctuations impact not only atmospheric weather, but also river watersheds and oceans, the health of animal populations, and the health of ecosystems as a whole. Arctic wildlife sentinels can be used as a proxy to monitor both ecosystem health and the health of Arctic subsistence users. In addition to a changing climate, the Arctic is a region of increased activity by the international mining industry. This One Health based literature approach integrates principles of environmental science, forensics, anthropology, physiology and geology, which will focus on toxicology (Hg) and feeding ecology (stable isotopes of $\delta^{13}C$ and $\delta^{15}N$) of key terrestrial and marine mammal sentinel species. In the context of climate change, a forensic approach suggests a paleohealth (mercury) and paleodietary (isotopes) indicators in various animal tissues from museum samples as a baseline for future assessments of the impact of metals in food webs.

Keywords: Toxicology; Mercury; Stable Isotopes; Arctic; Climate Change

Introduction

One Health

In the far North, ecosystems and indigenous peoples are impacted by climate change. These impacts include, but are not limited to, significant health problems from the persistent organic pollutants, heavy metal accumulation and significant social and cultural changes related to survival [1].

Understanding this mosaic of processes both globally and locally requires an understanding of the array of toxicological processes for both terrestrial and marine ecosystems as well as the people living in this changing environment [2]. The extraordinary closeness of rural people to their land, which is absent in metropolitan communities, necessitates the interdisciplinary perspective of One Health in which contaminates impact the evolutionary healthy processes between animals, plants and the human social system [2,3]. This One Health approach focuses on climate change, toxicants, and stable isotope studies for both terrestrial and marine mammals living in the Arctic regions.

As a One Health interdisciplinary approach develops diverse data sets, interpretation becomes essential about the key health interactions between animals, environments and humans. One Health collaborations among experts can improve research design and implement international policies and programs to help insure an optimal future for animals, ecosystems and humans [4-9].

Climate Change

One of the major global issues affecting ecosystems is climate change. Global warming not only impacts terrestrial and marine populations, but also the physical environment which impacts ecosystem services [1,10]. One high risk area that is being impacted is the Arctic where ecosystems are experiencing quicker and greater warming occurrences [11-18]. The Alaskan Arctic and subarctic ecosystems, with their changing weather patterns due to climate changes as well as the increase of industrialization and mining activities release contaminants into the environment. The concentration of mercury (Hg) in animal's food sources [4,7,19-22] is increasing. These types of changes will have an impact on the health of specific species [23]. For example, mercury bioaccumulation in pristine tundra vegetation would have a significant negative effect on the health of Arctic biota [20]. Whereas, if temporal changes and sudden shifts are observed in stable isotope ($\delta^{13}C$ and $\delta^{15}N$) values, this would signify that adaptation behavior is required, such as new locations for foraging or trophic changes [24,25].

In addition to Alaska, another Arctic region is the Svalbard Archipelago in Norway. This area has become a noteworthy location for contaminants emitted in the Northern Hemisphere [10]. These contaminants arrive in the form of volcanic activities, soil dusts, sea salt aerosols and transport of anthropogenic emissions from lower latitude power plants. The anthropogenic emissions of contaminants seems to account for the greatest amount of pollutants [26,27]. This is a global problem that threatens the Arctic ecosystems due to long range transportation and accumulation of contaminants [27,28]. The tundra stores the atmospheric Hg disposition in permafrost and over time it migrates to the Arctic Ocean [29]. It has been found that about 70% of atmospheric Hg disposition occurs through gaseous elemental mercury that is initially taken up by the soil and vegetation [20,29,30].

A study conducted on Hg at the Toolik Field Station in Alaska was performed by measuring Hg in the atmosphere, soil pore air, and interstitial snow air, then characterizing the flux of Hg in the tundra ecosystems [29,31,32]. This study indicated that the uptake of Hg by ground vegetation of the tundra played the commanding role in the Hg cycling. For example, it was observed that lichen and moss accounts for half of tundra biomass and had high concentrations of Hg [20]. This absorption of Arctic tundra Hg will be continuing due to the ongoing greening trend and the warming associated with climate change [21,29]. With the soil temperatures rising, leading to permafrost thawing, the Alaskan Arctic has an increased risk of remobilizing higher amounts of stored Hg [33,34].

MacDonald and colleagues [35] reviewed the ecological effects of global climate change using Hg and persistent organic pollutants (POPs) pathways and their exposure in Arctic marine ecosystems. The exposure pathways of transported chemicals is detrimental to the overall health of terrestrial and marine wildlife in the Arctic. A transportation of this kind can present toxins to an otherwise healthy wildlife and rural human populations [1,7,23,36-39] as the climate changes, exposure is predicted to increase.

A prediction associated with a warming climate proposes that an increased precipitation at high latitudes will cause sea level rise and seasonal flooding [1,40]. This fresh water discharge has the potential for the introduction of river-borne pollutants into Arctic marine ecosystems [41].

The appearance of infectious diseases in the polar regions has also been a factor related to climate change [36,42], indicated by changes in Arctic species composition and the transportation of pathogens [43]. The survival rate of infected animals during warmer temperature winters will increase the risk from pathogens and metals like mercury to marine mammals, with eventual transmission to humans [44-47].

Sea ice has also been decreasing for several decades (i.e. 1993 to now) in the Arctic Ocean due to climate warming [18,36,48-55]. Because of the receding sea ice, there are direct and indirect impacts on the seasonal distributions of food, the patterns of migration over geographic ranges and the nutritional stress on marine mammals [16,18,36,56,57]. Climate warming trends also affect the Arctic by decreasing sea ice thickness [53,54,58]. This change in sea ice thickness affects species that rely on the presence of sea ice for pupping and molting [59,60].

River watersheds play a key role in ecosystems as well as providing benefits in human civilizations. These river sheds are intrinsic to physical and biogeochemical cycles of aquatic biota as well as transportation waterways [1]. With the predicted change in climate, riversheds have the potential to change. For example, Hg is distributed across landscapes before it enters the ocean by a rise in river water levels [1,18,61]. Understanding the functions of less structured watersheds can be used as a barometer of the health of ecosystems and need an interdisciplinary research approach [1]. One way to monitor the health of watersheds is using wildlife to achieve insights into shifting stresses caused by Hg as well as industrial development [62-64]. Similarly, in marine ecosystems, the baseline $\delta^{13}C$ and $\delta^{15}N$ values will vary from offshore to inshore gradients as well as latitudinally [25]. Distinct spatial values will be identified (i.e. isoscape). These isoscapes can then be used to track movements and trophic interactions of species [65-68].

The complex Hg cycle in the Arctic, e.g. remobilization of Hg stored in tundra, which is impacted by climate change, is a model that should be expanded to other toxic metals, including the rare earth elements. An urgency to monitor metal concentrations in precipitation, air, bodies of water, soils and $\delta^{13}C$ and $\delta^{15}N$ levels in food webs will increase the knowledge of the impact of global industrial activity, such as the production of raw materials. Monitoring will improve studies to determine if the patterns observed in different regions throughout the world, including the Arctic, will be similar across all species as the warming climate continues.

Mercury as a Tracer for Change in Metal Distribution

Some elements are seen as more toxic than other pollutants [69]. This viewpoint brings together diverse and multiple approaches to interpreting how chemicals shape humanity's future [70]. Such viewpoints include, but are not limited to, the distribution and movement of chemicals related to people, wildlife, and nature, in order to learn and understand our ever changing environment.

One element that is of major concern worldwide is mercury. It is found in the environment in three forms: elemental (metallic), organic (methylmercury (MeHg)) and inorganic (mercury salts), where all three forms are toxic [71-73]. Globally, mercury is a pollutant that affects both ecosystem and human health [21,72,74-76] and is released into the environment by both anthropogenic and natural sources. The aim of the Minamata Convention on Mercury in August 2017, was for the reduction of global emissions to protect the environment and human health; as a result, it was approved by 91 countries [73]. Because of this convention, Hg needs to be continually monitored in the environment to determine if new measurements set by this treaty will reduce the impact of Hg on marine food webs in the future.

The atmosphere is the most important pathway of mercury deposition for redistribution to both the terrestrial and marine ecosystems [37,74]. As anthropogenic elemental mercury vapor is transported via air currents from industrial activities, such as gold mining or coal-fired power stations, it accumulates in the animal's respiratory system and/or on the food they ingest [77,78]. Whereas natural occurring mercury dwells in the atmosphere for about one year and then is deposited on the Earth's surface [72,74,76,79]. For example, when permafrost and glaciers thaw in the Arctic, Hg is released into the environment [34,80,81]. How Hg is released into the Arctic environment is by a phenomenon called a polar sunrise during the springtime [82]. During this polar sunrise is when Hg in the atmosphere mixes with the lower ozone layer causing the Hg to be deposited onto snow packs at an accelerated rate [82,83]. Then in the summer, when the snow melts, the Hg is released and found on soil and foliage, which can impact the health of wildlife through trophic level accumulation [1,71,82]. In addition, the terrestrial and marine ecosystems often show a higher accumulation of different compounds such as $HgCl_2$, CH_3Hg in their food webs [22,84]. It is these forms of Hg that are a key benchmark for research. By understanding the mechanisms of mercury distribution, we can then address the metals effecting the diets of Arctic wildlife and the local environment in order to keep a healthy Arctic ecosystem [21].

Another effect of global warming is the quick hardening of small snow layers during the winter. This hardening of snow layers, called snow-pack, produces changes in ice properties. This change called ground icing, in turn, effects the vegetation caught under this hard ice layer [85,86]. These changes in weather can create long term affects that impact the condition of vegetation, which in turn affects wildlife foraging profile and nutritional status [10]. For example, the ungulates in Norway are restricted in their food availability during ground icing which is caused by overgrazing [87]. This overgrazing causes the ungulates to increase their foraging areas, which causes an increase in environmental imprints. By increasing foraging areas, the ungulates ingest more undesirable food sources, e.g. goose droppings or algae from marine sources [88,89].

In aquatic ecosystems, mercury is directly deposited via snow, rain and by soil runoffs into aquatic ecosystems [72,73]. It is in these aquatic ecosystems where mercury, Hg, transforms into methylmercury, CH_3Hg, biomagnifying through food webs. The marine fish and mammal's health is impacted by the consumption of CH_3Hg contaminated foods, which increases the trophic level transfers [5,21,39,74]. This, in turn, affects the Indigenous Arctic populations, especially those who rely on seafood as a major part of their diet, where they are exposed to CH_3Hg impacting their health [1,22,52,74,90]. These Hg cycles of deposition continues to increase the toxic load on a regional scale.

Hg as a trace element can bioaccumulate and biomagnify along food chains [73,76,91,92]. The mercury methylation is by a natural bacterial process taking place in aquatic sediments [93]. The Arctic fish and marine mammals, specifically those at the top of the food web, will have high Hg burdens [92]. Lamborg and colleagues [94] estimated that the Hg burden in marine environments have tripled since the pre-industrial period. In addition, Dietz and colleagues [95] have estimated a 14-fold increase in Hg concentration in polar bear hair from Greenland between 1300 years ago and present.

Lavoie and colleagues [96] found bio-magnification rates to be approximately 6.0 ± 3.7 times for each trophic level in

Arctic marine food webs. The tropical marine food webs were increased only 5.4 times at each trophic level [97]. The MeHg is transferred through the food web chain in fish more than other forms of Hg, similar to the way it is absorbed into fatty tissues [91,73,76]. In some tissues, it slowly metabolizes to inorganic Hg ($HgCI_2$) [98]. The MeHg moves to the kidney, liver, spleen and eventually travels to the brain and muscles [99]. However, in the vertebrate gastrointestinal tract, inorganic Hg is weakly absorbed and leaves the body rapidly in urine and feces [100]. Evans and colleagues [101] also reported that MeHg is slowly eliminated from the body with a half-life of 10 to 15 days depending on the organ affected.

Research has shown that the patterns of Alaskan Native diets have shifted from a complete subsistence diet in pre-contact circumpolar populations to it's current condition that includes more "Western" foods for these indigenous circumpolar populations [102-105]. Concurrently, terrestrial and marine ecosystems have been measuring the impact of terrestrial ecosystems Hg cycling by toxicants over the last century, which led to the Minamata Convention. This global cycling of Hg affects not only the health of terrestrial and marine biota, but has a negative affect on human health. Monitoring is not only important because of the atmospheric Hg sink strength and it's impact on Polar ecosystems, but also how quickly Hg is transferred from these ecosystems to Hg found in foods for human consumption. This has been shown in the Polar environment and how it has been impacted by both climate shifts and Asian industrial development [106].

When Hg is recirculated back into the atmosphere [21] via air and ocean currents, it causes the toxins to migrate to the poles. However, most of the remediation focus is on the more populated areas at lower latitudes. Whereas, the toxic effects from Hg circulating in the Arctic environment needs increased monitoring in order to assess the current and future health impacts (e.g. infectious and zoonotic diseases) on terrestrial and marine ecosystem.

Stable Isotopes

In order to properly assess the effect of global climate changes on diet and movements of terrestrial animals and marine mammals, the ratio of the stable isotopes of carbon and nitrogen values are applied [18,25,107-113]. The stable nitrogen isotope ($^{15}N/^{14}N$) has been used to identify food web trophic structures, i.e. the relationship of diet type to the ecosystem in which organisms live [1,52,112,114-118]. Nitrogen isotope values are used to compare trophic levels [107,112,119-124]. These trophic levels are described by Trites [125] as level 1-Algae and phytoplankton, level 2-herbivores and detritivores and levels 3-5 carnivores and omnivores including marine mammals; where each level is determined by what the animal consumes. In a paper by Hoondert and colleagues [113], they state the trophic level characterization of ecological communities should include one of three objectives: 1, to define the trophic patterns associations within an ecosystem's community, 2, what components are affecting the grouping of these ecosystems, and 3, what are the pathways of nutrients, energy, and contaminants these animals are exposed to in specific ecosystems [126].

Stable isotope studies traditionally trace pathways of organic matter using $\delta^{13}C$ and $\delta^{15}N$ [127]. Different stable isotope ratios, (i.e.$^{13}C/^{12}C$), also arise in the photosynthetic pathways of C_3 and C_4 plants [128-130]. In Western and Arctic Alaska, the native vegetation is exclusively composed of C_3 plants [131,132]. There are some native C_4 plants that are rare in Alaska, which include a few wetland rushes (*Juncus*), spikerushes (*Eleocharis*), and beaked sedge (*Rhyncospora*) as well as some coastal grasses such as saltgrass (*Distichlis*) [133].

These stable carbon isotopes are reflective of naturally occurring isotope values in animals' diets and reflective of animals' movement patterns [134-136]. This has been established in various studies of stable isotope ratios reflecting dietary sources from coastal, terrestrial, benthic and pelagic environments [137-140]. For example, with the sea ice shifting due to climate warming, the biodiversity and distribution of marine mammals may shift toward the poles [141]. Also, coastal terrestrial animals that feed on fish can leave a ^{15}N signal in coastal plants [142]. In regard to human movement patterns, distinguishing Arctic wild foods from processed store-bought foods can be established because of the difference in carbon isotopes [112,122,136,143,144].

In Arctic marine systems a high spatiotemporal intra-species variability in trophic level is exhibited, e.g. a system driven by seasonal fluctuations in light and temperature [145]. Changing peaks in abundance of primary producers and declining prey availability due to loss of sea ice in summer, lead to these changing trophic interactions among species in high-latitude marine environments; thus, affecting the trophic position and contaminant level of species [146,147]. One such marine mammal that has been used to monitor changes in trophic positions from migration patterns is that of whales [148].

Stable isotopes of $\delta^{13}C$ and $\delta^{15}N$ can also be connected to toxins such as Hg during climate changes on ecosystems. As this increased warming phenomena continues in the Arctic, the weather will continue to stress the Arctic ecosystems and lead to both vegetation damage and the decline of wildlife health [39,149]. During climate changes, precipitation moves Hg from the atmosphere cycling it back into the oceans and rivers and to the soils exposing more Arctic organisms to Hg loads. Then as the climate warms, the sea ice cover decreases, which in turn increases the Hg levels in the atmosphere [39,150,151]. This melting of ice and snow releases an increased amount of Hg into the river watersheds which then leads to an uptake in Hg in food webs.

It is these applications of stable isotope values which provide information regarding the impact climate change has in informing or the distribution of species [1,107,111,113,152]. Additionally, stable isotopes not only informs about animals, but all historical indigenous human movement patterns in search for sustainable food supply [112,153,154].

Two Important Tissues Needed In Wildlife Monitoring Studies

As a consequence of climate change over the last three decades in northern latitudes, Alaskan wildlife and their ecosystems are experiencing the impact of global warming [155]. The larger animals in a region, such as moose, muskoxen and caribou, are experiencing conflicts with timing of resource availability and migration patterns, Funck and colleagues [19,24,156-158] have noted changes in caribou migration patterns due to warmer summers and winters. Additionally, elevated amounts of Hg have been observed in Arctic marine mammals such as the polar bear, seals, and whales, where Hg has threatened the health of these ecosystems [22,91,159]. Because these factors effect the lifestyle of both terrestrial and marine wildlife, innovative approaches in research need to be used. Specifically, there are two tissues that stand out amongst many others and are lacking in the literature, that is, bone and renal cortex and medulla. The more innovative approaches are used on tissues, the more essential information can be derived. In turn, this information can be beneficial in acquiring a more in-depth knowledge about the health of terrestrial and marine wildlife.

Role of Bone

Bone has not been widely used in research, mainly archival bones, yet provides valuable information [160]. Bone can be easily sampled and cataloged, thus providing a unique way to monitor the pathway of pollutants and diets from museum samples for past historical patterns. In this regard, bone can help to understand changes in the behavioral and health patterns in wildlife due to warming climate changes around the world, specifically the Arctic.

The main components which make up bone are hydroxyapatite (mineral) and collagen (organic) [161]. Bone is unique in the way it remodels itself throughout life [162,163]. However, the remodeling rate is dependent upon an animal's physiological factors and their age [164]. The bone collagen is used in stable isotope studies to infer the diet intake during recent years of life [112,165]. Bone collagen and keratinized tissues are useful tools in understanding migration patterns during periods of rapid climate changes, in both terrestrial and marine wildlife as each species will consume more than one kind of prey, with each prey uptake energy and nutrients from different sources in their particular ecosystem [52,148,166].

Diagenesis is the breakdown of bone and its interaction with the local physical, chemical and biological environment over time [167]. These processes modify the bone's original structural and chemical properties and can either preserve or destroy the bone. It is the physical factors such as soil and climate, and chemical factors such as deterioration of the organic and mineral phases, as well as biological factors such as alterations that take place on the bone itself (when exposed to elements or in a burial context), that play a important factor in the diagenesis process [168]. Because bones are not in equilibrium with the soil solution of a particular environment, they undergo various chemical deteriorations [167,169]. When bone is exposed to moist environmental conditions, a key agent of change is diagenesis. It's altered states are in the proportions of the inorganic components (e.g. calcium, hydroxyapatite, magnesium) with the organic component (e.g. collagen). Other changes in bone take place and need to be considered. This is because various types of soil components are absorbed onto the bone surface and cause the components of the bone to leach out [168,170].

It has been shown in various studies that bone can also be used to predict toxicant levels in soft tissue from Arctic animals [64,171-173]. Also, in bone mineral, toxicants are actively absorbed and then released during bone remodeling [174]. Toxicants, such as Hg has a direct effect on the bone itself as well as an underlying effect on other organ systems when it is released. Bone collagen has a slow turnover rate [175], and was used in stable isotope research to infer the lifetime of a red fox's diet [64]. We are fortunate to have some studies describing techniques for the preservation of bone, classification of soil environment, and detection of the factors in the environment which affect the preservation of bone [169,176].

Role of Renal Cortex and Medulla

The kidney is widely used to monitor contaminant levels in Arctic animals. In the bulk of the literature, the kidney is digested whole (both cortex and medulla together) [177-181]. However, one study used an innovation approach of separating the renal cortex from the kidney medulla and analyzing each component of the kidney individually [182]. It is important to note, and to consider in future studies, that different structures in the kidney perform different functions. Therefore, these different structures can accumulate toxicants at different rates and amounts [183,184].

Terrestrial Wildlife Studies

An important process for the animal community structure and their ecological relationships in an ecosystem is that of competition [10,185]. Researchers have used the feeding ecology knowledge of Hg concentrations to indicate what small mammals, birds and/or fish as omnivores to know what they are consuming. This diet knowledge leads to an understanding of the overall health of these animal populations [64,91]. In addition, studies have shown how monitoring the diet differences between trophic levels in wildlife, using $\delta^{13}C$ and $\delta^{15}N$ diet, can be used as biomarkers for regional availability of foods during climate change fluctuations.

Mercury

In the Arctic, foxes are similar to dogs and coyotes as they are also omnivores [71]. Therefore, red foxes (*Vulpes vulpes*) were used as a sentinel species to provide information about Hg concentrations and changes in exposure [64,71]. Working together with local trappers in western Alaska, Dainowski and colleagues [64] evaluated 65 red fox tissues to see if total mercury (THg) concentrations of keratinized tissue, hair, and bone could predict total mercury (THg) concentrations in skeletal muscle, renal medulla, renal cortex, and liver. They reported the keratinized tissue of hair THg concentration had a compelling positive correlation with liver, renal medulla, renal cortex, and muscle. The THg concentration for males and females was reasonably predictive of THg concentration in the renal cortex and liver based on R^2 values (R^2 = 0.61 and 0.63, respectively). This study also used an innovative approach of separating the renal cortex from the medulla in the kidney, and analyzing the components individually. Their data indicated the cortex had consistently higher THg concentration than the medulla (~3:1). The separation of this tissue is an important consideration for future research. By monitoring the concentration levels in each kidney component, a more precise picture of the potential adverse effects from Hg can be obtained.

In another study of trapped foxes, Hallanger and colleagues [39] from Svalbard, Norway explored temporal trends of Hg in 109 Arctic foxes, over 11 trapping seasons between 1997-2014. The Arctic fox (*Vulpes lagopus*) from Svalbard, Norway has been shown to have among the highest THg concentration levels of any other apex animal [186]. This is because the Arctic foxes mainly feed from marine carcasses (e.g. seals (*Phocidae spp.*) in addition to their terrestrial animals (e.g. Svalbard reindeer carcasses (*Rangifer tarandus platyrhynchus* [187]. When Hallanger and colleagues [39] adjusted their study for sea ice cover, consumption of reindeer carcasses, and differences of $\delta^{13}C$, they found the THg concentration levels in the liver of the Arctic foxes increased by 7.2%. But, Hallanger and colleagues [39] found the THg concentration level increased in the 'raw annual trend' by only 3.5%. They also reported the THg levels had up to five-fold variation between trapping seasons. This study suggested how sea ice cover and food webs affect mercury concentration levels in an important organ, the liver.

Caribou (*Rangifer tarandus*) are also considered one of the main components of the tundra biome [188] in northern latitudes, including, Alaska [189]. Caribou and reindeer (semidomesticated caribou) diets consist of mainly vegetation, which includes lichens, that can accumulate contaminants from the atmosphere. Therefore, when caribou consume these lichens, they accumulate high concentrations of mercury [189]. Duffy and colleagues [189] research investigated the total mercury (THg) in the hair of both caribou and reindeer from the Seward Peninsula, Alaska. The Seward Peninsula is where total mercury (THg) has been defined as the aggregate of different forms of mercury that is found in tissues of terrestrial animals. They compared differences between a free-range diet and a pollock-based fishmeal diet. The freeranging reindeer's average THg concentrations were 55.3ng/g; whereas, the fishmeal fed reindeer was 19ng/g. This research was able to show that the free-ranging reindeer and caribou feed on a diet of lichen, indicating a greater exposure to Hg. On the other hand, Pacyna and colleagues [10] used hair samples from the Svalbard reindeer (*Rangifer tarandus platyrhynchus*) to determine Hg concentration levels. Their research found very low levels which agreed with other published literature of lichen and moss in Svalbard. These two studies have clearly shown that different ecosystems in the northern latitude tundra biome's are affected differently by climate changes.

Research conducted by Kalisinska and colleagues [76] used three mesocarniore species (piscivorous Eurasian otter, feral American mink and the invertebrativorous European badger of NW Poland) in their respective northern ecosystems to determine the THg levels for mercury contamination. Their investigation revealed that all three mesocarniore species were not significantly different in their livers and kidneys for THg. The Hg levels in the liver were non-significant between the American mink and Eurasian otter. However, THg concentrations were significantly higher for roadkill animals than the trapped American minks. Their study also indicated that the European badger, who lives in the floodplains, bioaccumulated Hg at higher concentration levels. Since this badger was from floodplains, Kalisinska and colleagues [76] could use this species as a bioindicator of mercury soil contamination. Therefore, further studies are needed in order to understand how to optimize not only the health of these wildlife animals, but also their specific ecosystem.

Stable Isotopes

Stable isotopes are used to provide trophic levels as well as the feeding ecology of each species. Nitrogen stable isotope ($\delta^{15}N$) analysis is often used for determining relative trophic position using a 3-5% increase in $\delta^{15}N$ values with each trophic step [109,114,190,191]. These increases in $\delta^{15}N$ values may develop from various diet resources. The increases in $\delta^{15}N$ will also depend on the tissue turnover rates [112,192]. For example, in the liver and plasma of blood, the turnover rate is usually in the range of days, whereas, in muscle and red blood cells the turnover rate is usually several weeks to months [193]. If stomach and scat analysis is used for trophic positions, then the prey that was consumed, as well as the rate at which digestion takes place, should be known [194]. Additionally, the diversity among species, the condition of the ecosystem, and the baseline species [113] needs to be considered when applying tropic positions. The carbon stable isotope analysis ($\delta^{13}C$) is used to determine the source of carbon in a food chain, i.e. the feeding habits of animals [109]. For example, $\delta^{13}C$ is used to reconstruct the diets, whether that is animal or plants, of a wildlife species. Something worthy to note, and has been demonstrated by Trites [125], supporting the strength of stable isotope studies is the use of biopsy samples, instead of the stipulation to kill an animal.

In the Arctic of western Alaska, research of stable isotope ratios of $\delta^{15}N$ were used to assess trophic levels and $\delta^{13}C$ ratios as indicators of regional variability of marine vs. terrestrial prey of free-ranging red foxes (*Vulpes vulpes*) [112]. Five tissues (hair, bone, muscle, renal cortex, renal medulla, liver) were used for this stable isotope study. This study found that hair, bone, muscle, liver, renal cortex and medulla tissues of the red fox were isotopically different [112]. In addition, Dainowski and colleagues [112] observed a correlation between $\delta^{15}N$ values and THg concentrations of hair. The hair $\delta^{15}N$ values varied between 5.00 and 7.00‰, as the THg concentrations varied between 1.00 and 3.00 ppm. This revealed a link between $\delta^{15}N$ and THg, by showing when $\delta^{15}N$ increases, THg concentrations also increase. Further studies in the correlation between $\delta^{15}N$ and THg needs to be addressed during climate warming in order to assess if any health changes of wildlife are taking place in this Arctic region.

In the Arctic of Svalbard, Norway, the soil nitrogen pools and differences in vegetation have been impacted by climate changes and soil moisture during the growing seasons [10]. Pacyna and colleagues [10] investigated if diet variations could be seen in the hairs of the Svalbard reindeer (*Rangifer tarandus platyrhynchus*), a key species in their region. Their research pointed out a high variability of $\delta^{15}N$, which suggests the reindeers were consuming vegetation with various $\delta^{15}N$ values. Because the $\delta^{15}N$ values indicated high variations in the isotope signatures, this indicates that the High Arctic tundra does retain the nitrogen signature that has been transported during weather events [195].

Hallanger and colleagues [39], used innovative research with their Hg study, by using $\delta^{13}C$ as a substitute for both terrestrial and marine feeding ecology. They found that the $\delta^{13}C$ ratios in muscle tissues of Arctic foxes from Svalbard Norway mirrored the fall and winter feeding habits and were produced by a diet of 1-2 months before death [116]. They also found that the $\delta^{13}C$ values did explain the increase in THg levels and thus can be used a predictor in feeding habits of sea ice cover and reindeer carcasses in Arctic fox livers. This study also revealed that the Arctic foxes food consumption of a marine diet exposed them to higher levels of THg than those foxes feeding on a terrestrial diet, and was in line with other studies [142,196,197].

Marine Mammal Studies

Environmental pollutants, such as Hg, along with a warming climate, threaten marine mammals more so than any other mammals in the world [91,92]. Because of these impacts on the environment, questions need to be addressed, such as: what impact will climate warming have on marine mammals in the Arctic, and, what impact will the increase in activity of Hg in Arctic waters, where sea ice levels fluctuate, have on the health of these marine populations. Research needs to continue to monitor, heavy metal (Hg) changes, and migration patterns ($\delta^{13}C$ and $\delta^{15}N$), in order 1) to observe and maintain terrestrial mammals at a nutritive equalibrium for optimal health and 2) in order to protect the decline of marine populations.

Mercury

A serious issue which impacts both the health of Arctic indigenious populations as well as Arctic ecosystems, on a global scale, is that of mercury contamination. Once mercury leaves the atmosphere and enters a water system it converts to methylmercury by the way of bacterial processes. Once in the waters, methylmercury is one of the most toxiferous admixture that bioaccumulates and biomagnifies at a very high rate along the food chain in marine mammal ecosystems [91,92]. Therefore, any wildlife animals, fish or birds that consume a marine or sea ice based diet may be at risk from the toxic MeHg levels, as MeHg is known to cause neurochemical, reproductive, and even behavioral changes in fauna [198].

Tilson, Das and colleagues and Roos and colleagues [199-201] have defined neurotoxicity as "an adverse change in the structure or function of the central and/or peripheral nervous system, following the exposure to a chemical, physical or biological agent". It is the loss of neurons and gliosis, a variation in the cerebellum, along with, motor and sensory defects, which causes behavior changes from high amounts of MeHg intake [73]. The neurotoxicity caused from MeHg, depends on many factors, such as: 1, the nutritional health of the marine mammal populations; 2, the degree of exposure; and 3, how each mammal metabolizes and excretes the toxin [92].

Another general concern among scientists is that of the transfer of MeHg crossing the placenta [202], and the resulting Hg concentrations in fetal brains [203]. In a systematic study by López-Berenguer [92] MeHg can cross the placental barrier of pregnant marine mammals and accumulate in the fetal bloodstream; in turn, crossing the blood-brain barrier. Their study agreed with Evans and colleagues [101] confirming that inorganic Hg and MeHg can cross the blood-brain barrier, thus resulting in neurotoxic effects in marine mammals. These developmental risks of neurotoxicity can affect the future health of generations of marine mammals and therefore a high priority is needed to study, research and publish on the effects of MeHg in marine mammals and in their ecosystem.

The bioaccumulation of MeHg has also been shown to increase in Northern latitudes as a result of climate change [5,91]. With climate warming, the lower sea ice levels facilitate dietary changes associated with higher Hg levels in some populations of marine mammals, such as polar bears and ringed seals [35].

The adipose tissue and blood from key marine mammal species such as polar bears and ringed seals have also been analyzed for the purpose of studying spatial and temporal trends and human exposures to contaminants in the Arctic areas of Greenland, Alaska, and Canada [7]. These studies of free-ranging animals suggest high Hg loads in the Arctic, which, in turn, creates an immune suppression in which the body does not have the ability to respond to infectious pathogens [80].

As part of the human exposure of Hg, sea otters (*Enhydra lutris*) are part of the Native Alaskan hunt for subsistence foods [204]. As scientists, by working in conjunction with these Alaskan hunters, we can use the sea otter to serve as a keystone species for the health of their community structures, as well as, marine ecosystems [205-208]. Sea otters are a good species to study as they live in small home areas and their prey, for example, clams (*Bivalvia sp.*), crabs (*Dungeness*) and sea cucumbers (*Holothuroides sp.*), is sedentary which mirrors the contamination of their local environment [204,207,209-212]. A group of researchers [204], in Icy Strait, Alaska, worked with the local Alaskan Native subsistence hunters and collected four females and 10 male sea otters. Brown and colleagues [204] analyzed the sea otters liver, gonad, brain and kidney tissues to determine the THg concentration levels. The THg concentration levels in the kidneys and livers were the highest. The average concentration of THg in the kidneys of these sea otters were 30 times greater in comparison to the kidneys of sea otters from South-central Alaska [204,210].

Stable Isotopes

Hoondert and colleagues [113] studied the trophic levels of Arctic species using pelagic and benthic food webs in four areas of the Arctic, including Alaska. They determined intra-sample, intra-studies, and inter-region variations of trophic levels. A statistically significant difference ($P < 0.05$) in species trophic levels between these areas was reported. Their findings supported the nitrogen isotopic baselines as established by Carscallen and colleagues [213], where the corrected trophic level is 3.17 ± 0.88 and trophic level estimates are 3.32 ± 0.79 for Arctic areas. However, they did find the variability in trophic levels was higher between region verses within one region for both benthic and pelagic food webs. Since a single region is not suitable as a baseline for the Arctic as a whole, this inter- and intra-study provides valuable information showing how one vast area called the Arctic, actually constitutes different ecosystems with different trophic levels depending on spatial, seasonal and temporal influences [113].

Using trophic levels of stable isotope analysis, feeding relationships can be established; where one species competes for food more than the other species [125]. Trites [125] found that pollock and baleen whales overlap in their diets by 73-86%. Whereas toothed whales compete for food with beaked whales and seals, and sea lions compete with large flatfish, toothed whales and seals. He found that fish are the largest part of competition among these marine mammals. In his study of trophic levels, Trites [125] found marine mammals to be in the following trophic levels: manatee, level 2, baleen whales, level 3.35, sea otters, level 3.45, seals, level 3.95, sea lions and fur seals, level 4.03, toothed whales, levels 4.23 and at the top of the food chain - polar bears, at level 4.80. His study was useful in understanding how many species, like fish, can occupy the same, or higher, trophic levels of marine mammals, and thus both species are competing with each other for the same foodweb.

Stable isotope ratios are also used as biomarkers to determine the diet differences among ringed (*Phoca hispida*), bearded (*Erignathus barbatus*), and harbour (*P.*

vitulina) seals in the Hudson Bay subarctic marine ecosystem [107]. Their study revealed that adult bearded seals had significantly lower $\delta^{15}N$ values in muscle than the pups. Conversely, ringed seals pups had lower $\delta^{15}N$ values than the adults suggesting foraging differences in trophic food positions for both species was age specific. On the other hand, $\delta^{15}N$ values were not significantly different. The $\delta^{13}C$ values were significantly different for different ages of harbor seals. Muscle $\delta^{13}C$ values supported the conclusion that bearded seals are benthic feeders and are feeding in a separate food web from harbor and rings seals. For $\delta^{15}N$, harbor seals had the highest levels. This high level indicated their prey came from a higher trophic level relative to ringed and bearded seals. Young and colleagues [107] concluded that the $\delta^{13}C$ and $\delta^{15}N$ values exhibit the partitioning of resources among, and indicated evidence of separation of life stages within, these three seal species.

Keratinized tissues are widely used in isotope studies due to the non-invasive method in obtaining a sample. Crain and colleagues [55] used the keratinized tissue of claws from bearded (*Erignathus barbatus*) and ringed (*Pusa hispida*) seals because their claws can store up to 14 years of sequential data. These claws are two tone in color, where these colors indicate seasonal diets; for example, the light bands are produced in the last spring to last summer and dark bands are from early fall to early spring [214,215] . In addition, the closer to the tip of the claw represents the age of the seal when they were younger [55]. Stable isotopes in claws can also reflect the stomach content of bearded and ringed seals; and therefore, helpful to evaluate diet and reproduction [55]. Connecting these life history parameters through time adds to an understanding of the overall biology of these marine mammals [55].

Other keratinized tissues used in analyzing nitrogen levels, is that of whiskers and baleen. Whiskers and baleen can provide an insight into the timing of diet shifts in marine mammals, a look into their life history of dietary information [125]. By measuring the carbon ratio's of baleen from the bowhead whale, Trites and colleagues [125] were able to show that the ocean productivity, and overall carrying capacity, was lower and may have had an affect on the decrease of northern fur seals, harbor seals, and steller sea lions from the Bering Sea in the northern part of the Pacific ocean during the 1970's through 1990's. This study was useful in detecting this rearrangement of the ocean's capacity as well as the diets of marine mammals.

In addition to baleen and whiskers, the whale's earplugs, a plug of waxy material that forms in the ear canal by the accumulation of cerumen [25], can also give a comparison to the timing of diet from stable isotope analysis. These dark and light growth layers (bands of laminae laid down yearly) are used to age the baleen whales. Mansouri and colleagues [25] reconstructed $\delta^{13}C$ and $\delta^{15}N$ in earplugs over the lifetime of three species of baleen whales: fin (two *Balaenoptera physalus*), blue (two *Balaenoptera musculus*), and humpback (two *Megaptera novaeangliae*). They reported that the earplugs revealed inter and intraspecies differences. These differences showed that the mean lifetime $\delta^{13}C$ values from blues whales was more depleted than fin whales. This dataset did provide a lifetime history of changes in foraging locations or trophic positions as well as ecosystem changes associated with the Suess effect [25]. As the nitrogen levels change in the whiskers, baleen and earplug tissues, it can also provide both an association with climate change and oceanographic occurrences [25,166]. Furthermore, comparison of time series stable isotope profiles from baleen whale earplugs, with regional and global external datasets such as sea surface temperature and chlorophyll concentration, could provide a proxy for change in marine productivity in association with climate change and oceanographic events [25,166].

Forensic Studies

Investigating forensic wildlife toxicology plays an important role in providing information about the biological effects of contaminants in the environment worldwide. Contaminants may bioaccumulate and biomagnify, entering into food webs, thus having adverse effects on both wildlife and in many cases, humans. Understanding how contaminants move through food webs is imperative for the health of the ecosystem, wildlife health, and as a variety of terrestrial and marine wildlife serve as subsistence food for indigenous populations in the Arctic.

Forensic science uses analytical techniques and observations to measure data from wildlife remains. The commonly used techniques include toxicology and stable isotope analysis of animal bone [216,217]. As the impact of mercury (THg) to the environment is continuing, due to climate warming, Hg has the ability to build up in organisms and food webs, causing a significant negative influence on the health of animals. Understanding THg contamination in the environment can help prevent it's ecological effects on biological diversity which lead to the damage of ecosystems in Arctic regions [1].

Through the study of $\delta^{13}C$ and $\delta^{15}N$ analysis, time-series datasets from a variety of animal tissues can provide opportunities in reconstructing past ecosystems [218,219]. The stable isotopic ($\delta^{13}C$ and $\delta^{15}N$) composition of animal tissues establish a relationship between diet, geographic location and trophic levels in archaeological and palaeodietary studies [216,217]. Historical diets and trophic status of animals, relative to their prey, can be seen through current climate changes [67,220,221]. For example, how animals, at both the individual and population levels, respond to environmental changes through time [134,222-226].

When studying climate change, Polyak and colleagues [227] stated there is a lack of understanding in how Arctic ecosystems respond to long periods of climate change. In response to this, Szpak and colleagues [16] stated that we need to rely on a variety of proxies living in past ecosystems to see how wildlife has responded to those changes. It is the archaeological record that gives the researcher an opportunity to investigate biotic responses, predict a historical baseline for current ecosystem changes, and to develop education and adaptation strategies [16].

Paleo-Health (Mercury)

One forensic approach for assessing THg concentrations over time (millennia) based on museum samples to use this information as a foundation for future assessments of THg in food webs [52,173], is a study by Dainowski and Duffy [173]. They examined two Arctic foxes and three red foxes of unknown age and origin, and found the Yukon Territory Arctic foxes bone THg concentrations were 0.017 and 0.025 mg/kg; and the red foxes bone THg concentrations were 0.010, 0.036 and 0.073 mg/kg. They concluded that total mercury (THg) concentrations of bone-based tissues will be able to predict the possible THg concentrations in skeletal muscle, renal medulla, renal cortex, and liver of that animal over different time epochs from a previous study with red foxes [64].

Gerlach and colleagues [19] examined THg in caribou hair from two houses in a Western Thule archaeological settlement in Alaska. The settlement was the Alaskan Native community of Derring, which was dated ca. AD 1150 [19]. They found it yielded information about the temporal trends of human subsistence users exposure to mercury through caribou harvest times [19]. The caribou hair THg average value was 86ng/g, the same range as indicted in modern caribou and reindeer (*Rangifer sp.*) [19]. The caribou hair found in the first home had a THg level of 99.6 ng/g; whereas, the caribou hair from the second home had THg levels of 64.2ng/g. Since lichen is a normal diet for caribou; Gerlach and colleagues [19] suggests that the compositional changes in the lichen, THg, could account for the variations found in the hair mercury values. This type of data gives a good overall picture of a historical ecosystem [19].

Bones from marine mammals can be used in stable isotope studies to reconstruct ancient food webs by identifying the prey in a study of the sea otter's diet [1,228]. Since the habitat of sea otters (*Enhydra Lutris*) in the Arctic waters of Alaska encompasses a long stretch of the Gulf of Alaska, Duffy and colleagues [228] compared modern sea otter bones for mercury concentrations to that of sea otter bones from the early Holocene period. By using both mercury and stable isotope studies, they found the diet of these mid-trophic level modern sea otter bones comprised mainly of a benthic diet. However, the ancient bones had higher levels of mercury and $\delta^{15}N$ values indicating a rising sea level, followed by a period in which ice sheets covered large parts of the earth [228]. Brinkmann and Rasmussen [229] suggested that these sizable increases may be associated with the sea levels rising. This rising sea level shifted the mid- trophic level sea otter to one of an upper-trophic level during the Holocene epoch. Studies like this can then be applied to present day climate change concerns in order to maximize the potential for a healthy ecosystem and wildlife community.

Paleodiet (Isotopes)

Stable carbon and nitrogen isotope ratios of bone collagen are used to establish foraging and movements of wildlife and human populations [64,111,112,173,230,231]. Assessment of parameters such as collagen yield and composition is important to assure the quality of stable isotopic data [232]. Measurement of these parameters is particularly important for analyses of specimens from zooarchaeological assemblages, as poor preservation and diagenesis may degrade collagen and impact stable isotope ratios [232,233]. Additionally, C/N ratios provide information about whether lipids were effectively removed from a sample during collagen extraction. Failure to remove lipids from bone will result in more negative $\delta^{13}C$ values and may cause an underestimation of the dietary contributions of C_4 plants or marine foods [232]. Understanding these differences is important as this information might allow researchers to exclude any bones from analysis that are unlikely to be representative of the whole skeleton.

It is important to note that the skeleton of animals who have lived a long life, will only reflect differences in stable isotope ratios if their feeding location or diet changes considerably [111,114]. Whereas animals having a repetitive diet, their stable isotope ratios will stay the same, regardless of the turnover rates in bone [115]. The faster or slower turnover rates in bone only show differences in stable isotopic ratios of the bone collagen if the food consumed by the animal changed during their lifetime; either by movement, geography or diet [222].

Funck and colleagues [158] examined a steppe bison (*Bison priscus*) skeleton that was excavated in Alaska's Northern Arctic region. Using radiocarbon dating on the keratin tissue of the horn, the age was determined to be ~46,000 ± 1000 cal yr BP. They also employed $\delta^{13}C$ and $\delta^{15}N$ analyses of the same horn keratin to establish a seasonal cycle, and found these values: $\delta^{13}C$ - 20.0‰ (±0.6) and $\delta^{15}N$ - 4.2‰ (±0.1). They concluded that the high $\delta^{15}N$ values were consistent with that of modern day bison, however, as the ecosystem changed, the bison began dispersal and faced significant nutritional stress. Whereas, the $\delta^{13}C$ value was consistent with the bison continuing a diet of C_3 plants. Funck and colleagues [158] came to the conclusion that the past bison might have lived in an interstadial period and possibly under stress in harsher winters than what is seen today in Northern Alaska's Arctic. Since this study is signifies that climate changes have taken place in the Arctic landscape overtime, more forensic studies need to be conducted in order to monitor the impact climate change is having on current wildlife and food sources for Native Alaskan communities.

Goude and Fontugne [24] studied $\delta^{13}C$ and $\delta^{15}N$ levels in bone collagen of carnivores, omnivores and wild herbivores from Liguria in NW Italy and France during the Neolithic period. They found significant correlations between latitude and $\delta^{13}C$ for all groups and latitude and $\delta^{15}N$ for wild herbivores. The wild herbivores in northern France had lower $\delta^{13}C$ values and higher $\delta^{15}N$; whereas, the omnivores had just the lower $\delta^{13}C$ values. Their study added new data for the Mediterranean and Western Europe, and the prospect of nitrogen to be used in environmental studies during the Neolithic period.

Another forensic research approach looked at the paleo-dietary (isotopes) indicators in preserved museum bone collagen of the red (*Vulpes vulpes*) and Arctic fox (*Vulpes lagopus*), from a Yukon watershed [173]. This study was designed to 1, establish information on reconstructing a diet using carbon stable isotopes and 2, establish a trophic level using nitrogen stable isotopes, for these sentinel species [64,112]. Because of the small sample sizes, two red fox bones, and three Arctic fox bones, as well as different bones (i.e. femur, tibia, mandible) being analyzed, and no indication of the sex of the foxes, it had no statistical analysis value. Stable isotopes means and standard deviations only gave a visual perspective on what a diet might look like. The $\delta^{13}C$ levels were -21.13 and -21.36‰ for Arctic foxes and -20.05, -20.08, and -23.12‰ for red foxes. Their $\delta^{15}N$ levels were 5.59 and 7.22‰ for the Arctic foxes and 6.10, 6.57 and 6.66‰ for red foxes. The diet of the two Arctic foxes and two of the red foxes from the Yukon Territory Fossil Collection tend toward a salmon diet, while the third red fox showed a terrestrial mammal diet [173]. The trophic levels indicate these red and Arctic foxes from the Yukon Territory are similar to other red foxes in the watershed, tending toward a slight salmon diet [173].

The NW Coast of Canada was an important area of glacials in Late Pleistocene times [118]. Refugia locations identified for the survival of species were on the outside limits of the Cordilleran Ice Sheet during the Wisconsin glaciation period MIS 4-2. The refugee is now NW Canada and SE Alaska [234]. Kubiak and colleagues [118] reported on collagen samples from an antler fragment dating to the Fraser Glaciation (MIS 3). The collagen isotope values revealed Rangier were consuming a large amount of seaweed, indicating little foraging opportunities during the time period of antler growth [118]. The findings of seaweed consumption further indicated that Caribou herds were unable to break through ice or deep snow drifts to access the resources, especially terrestrial resources, needed for their diets [235]. Events taking place, like MIS 3, indicate climatic change impacts such as hard snow packs due to extreme winds which would delay springtime growth [236,237].

Clark, et al. [111] studied the variability of $\delta^{13}C$ and $\delta^{15}N$ in skeletons of Alaska marine mammals to regulate if there were any methodical differences in stable isotope ratios among the skeletal elements. They used the crania and mandibles from 11 Pacific walruses (*Odobenus rosmarus* divergent), 10 adult ringed seals (*Pusa hispida*), 9 juvenile seals (*Phoca*), and 8 adult sea otters (*Enhydra lutris*). They found no significant differences among the walrus cranium/mandible pairs. They did find a greater variability, exceeding 1.0‰, across seal and sea otter skeletons. Clark and colleagues [111] did remove distal appendicular bones (calaneus, metatarsal, and phalanx) as well as the scapula and vertebra from the rest of the bones in the sea otter. They found by removing these, 'extra' sea otter bones from their analysis, the overall variability was greatly reduced in all three animals. This indicates that individual skeletal bones from individual animals can result in different $\delta^{13}C$ and $\delta^{15}N$ levels, which could be based upon bone turnover rates [112] and thus should be reported separately. This innovative study confirms the study conducted by Newsome and colleagues [222] in that turnover rates in bone will reveal different stable isotopic ratios in bone collagen as the animal changes environments and consuming a different diet during their lifetime. This change in diet could confer a change in climate during this time causing the marine mammals to change their movement patterns.

Szpak and colleagues [16] reported $\delta^{13}C$ and $\delta^{15}N$ values for bone collagen from marine mammals at different archaeological sites on Kotzebue Sound, Alaska, dating around A.D. 1170-1813. They compared modern mammal bone collagen samples from the same areas to determine trends over time for sea ice productivity and foraging ecology [16]. Between the 19th and 21st centuries, they observed significant changes in $\delta^{13}C$ and $\delta^{15}N$ values of ringed seals. The large decline in $\delta^{13}C$ suggests a reduction of ice algae and organic matter to the benthos in the recent warming trend in the Arctic. These events influence the foraging ecology of these marine mammals [16], and in other areas, such as the Bering Sea to the south, and where climate changes are moving more towards subarctic conditions [16].

Ecosystems

With climate changes currently affecting ecosystems in the Arctic, it is important to establish a baseline for toxicants and stable isotopes in order to identify any future changes that may affect not only wildlife health but that of the indigenous populations. A focused forensic science approach which uses observations and analytical techniques provide data for One Health programs. The One Health techniques should include both toxicology and stable isotope analysis of wildlife tissues and the environment. Since the impact of metals on the environment is increasing, a significant influence on the health of organisms can be expected. Understanding THg and other metal contamination in the environment can help reduce ecological effects on biological diversity in Arctic ecosystems. Stable isotopic studies have shown that the $\delta^{13}C$ and $\delta^{15}N$ composition in animal tissues establishes the relationship between diet, geographic location and trophic levels in archaeological and palaeodietary studies.

In a study of the Hudson Bay area, a subarctic ecosystem that has seen changes in the environment due to the warming climate, Young and colleagues [107] noted that some species of marine mammals may consume different foods, or compete for the same foods, or change their feeding areas completely [36]. Their study noted that Hudson Bay ice cover is receding. They suggested that the ringed (*Phoca hispida*) and beard seals (*Erignathus barbatus*), who have adapted to the presence of ice cover, may decline in numbers. In contrast, the harp (*P. groenlandica*) and harbour seal (*P. vitulina*) populations would increase [238].

Murray and colleagues [52] conducted a study of THg concentrations in marine fish off the Gulf of Alaska that spanned the Holocene period. This study related the increasing sea level and associated this increase with coastal flooding and with Hg bioaccumulation in the marine food webs. This suggested the early human coastal populations would have been exposed to higher levels of mercury in their subsistence food during the Holocene when mercury was not linked to industrial mining activities. This increase in mercury mobilization was caused by a rise in sea levels due to glacial melting which eventually submerged Beringia [52].

Mercury has also been observed in high apex marine mammals of the Arctic, the polar bear (*Ursus maritimus*). The potential for long-term accumulation of contaminates can be found in their lipids, in the subcutaneous layer (known as blubber layer) [91,239,240]. Other marine mammals affected are the beluga whales (*Delphinapterus leucas*), hooded seals (*Cystophora cristata*), pilot whales (*Globicephala melas*), and the toothed whale [91], where they also accumulate contaminants like Hg. However, the baleen whales (*Mysticeti*), like the bowhead whale (*B. mysticetus*) which feed at lower trophic levels, do not show the same degree of a high climatic imprint [104,148].

Conclusion

Changes continue to occur in the Arctic and is a reality, as it has been witnessed by many studies on the wildlife populations. The Arctic is changing more rapidly than other parts of the world. The warming of the Arctic will have consequences worldwide, through precipitation patterns causing low changes in sea levels. We expect changes in movement patterns and/or loss of wildlife and marine mammals. These changes of migration patterns and movements, or loss of animals entirely will impact the Alaskan Natives who rely on these animals for survival. We strongly support that wildlife and marine mammals can be used as models to understand the effect of diet changes over time. The association between diet ($\delta^{13}C$ and $\delta^{15}N$) and contaminants (THg) to monitor climate change (temporal and regional) can inform on the health of wildlife and marine mammals and their ecosystems. Since bone usually survives in archaeological and paleontological sites world wide, bone has an important role as another valuable tool for monitoring metals, while stable isotope applications can reconstruct health patterns over time. A One Health approach allows scientists, veterinarians, medical professionals, or local hunters and fishermen to collaborate together in order to develop common goals that will benefit our world. Wildlife managers can then move this beyond "monitoring" to data based adaptive system management.

Data Availability

Data is available. The authors used published, peer-reviewed articles for this review.

Conflicts of Interest

The authors declare the absence of any competing personal relationships or financial interests that could be construed as potential conflicts of interest in this paper.

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References

1. Duffy LK, Dainowski B, Dunlap K, Hirons A (2017) Climate Change, One Health and Mercury. Adv Clin Toxicol 2(1): 1-6.
2. Phillip RB (2013) Ecosystems and Human Health: Toxicology and Environmental Hazards. Boca Raton CRC Press.
3. Duffy LK (2011) Exposure Assessment. Green Series: Green Business, In: Cohen N (Eds.), SAGE Press, Thousand Oaks, CA, pp: 250-253.
4. Loring PA, Duffy LK (2011) Managing environmental risks: the benefits of a place-based approach. Rural Remote Health 11(3): 1800.
5. Burger J, Gochfield M, Powers CW, Niles L, Zappalorti R, et al. (2013) Habitat protection for sensitive species: Balancing species requirements and human constraints using bioindicators as examples. Natural Science 5(5): 50-62.
6. Nyatanyi T, Wilkes M, McDermott H, Nzietchueng S, Gafarasi I, et al. (2017) Implementing One Health as an integrated approach to health in Rwanda. BMJ Global Health 2(1).
7. Sonne C, Letzter RJ, Jenssen BM, Desforges JP, Eulaers I, et al. (2017) A veterinary perspective on One Health in the Arctic. Acta Vet Stand 59(1): 84.
8. CDC (2021) One Health.
9. FDA (2021) One Health: It's for All of Us.
10. Pacyna AD, Koziorowska K, Chmiel S, Mazeroski J, Polkowska Z (2018) Svalbard reindeer as an indicator of ecosystem changes in the Arctic terrestrial ecosystem. Chemosphere 203: 209-218.
11. Overpeck J, Hughen K, Hardy D, Bradley R, Case R, et al. (1997) Arctic Environmental Change of the Last Four Centuries. Science 278(5341): 1251-1256.
12. Hoegh Guldberg O, Bruno JF (2010) The impact of climate change on the world's marine ecosystems. Science 328(5985): 1523-1528.
13. Stern G, MacDonald RW, Outridge PM, Wilson S, Chételat J, et al. (2012) How does climate change influence Arctic mercury? Sci Total Environ 414: 22-42.
14. IPCC (2013) Climate change 2013: The physical science basis. In: TF Stocker, et al. (Eds.), Contribution of working group I to the fifth assessment report of the Intergovernmental Panel on Climate Change Cambridge, UK: Cambridge University Press, pp: 255-316.
15. Carmack E, Polyakov I, Padman L, Fer I, Hunke E, et al. (2015) Toward quantifying the increasing role of oceanic heat in sea ice loss in the New Arctic. Bull Amer Meteor 96(12): 2079-2105.
16. Szpak P, Buckley M, Darwent CM, Richards MP (2017) Long-term ecological changes in marine mammals driven by recent warming in northwestern Alaska. Glob Change Biol 24(1): 490-503.
17. Post E, Alley RB, Christensen TR, Macias-Fauria M, Forbes BC, et al. (2019) The polar regions in a 2˚C warmer world. Sci Adv 5(12): eaaw9883.
18. de la Vega C, Jeffreys RM, Tureen R, Ganeshram R (2019) Temporal and spatial trends in marine carbone isotopes in the Arctic Ocean and implications for food web studies. Glob Change Biol 25(12): 4116-4130.
19. Gerlach SC, Duffy LK, Murray MS, Bowers PM, Adams R, et al. (2006) An exploratory study of total mercury levels in archaeological caribou hair from northwest Alaska. Chemosphere 65(11): 1909-1914.
20. Olson CL Jiskra M, Sonke JE, Obrist D (2019) Mercury in tundra vegetation of Alaska: Spatial and temporal dynamics and stable isotope patterns. Sci Total Environ 660: 1502-1512.
21. Bishop K, Shanley JB, Riscassi A, deWit HA, Eklof K, et al. (2020) Recent advances in understanding and measurement of mercury in the environment: Terrestrial Hg cycling. Sci Total Environ 721: 137647.
22. Zheng W, Chandan P, Steffen A, Stupre G, DeVera J, et al. (2021) Mercury stable isotopes reveal the sources and transformations of atmospheric Hg in the high Arctic. J App Geochem 131: 105002.
23. Reuther J, Shirar S, Mason O, Anderson S, Coltrain J, et al. (2021) Marine reservoir effects in seal (phocidae) bones in the northern Bering and Chukchi seas, northwestern Alaska. Radiocarbon 63(1): 301-319.
24. Goude G, Fontugne M (2016) Carbon and nitrogen isotopic variability in bone collagen during the Neolithic period: InWluence of environmental factors and diet. J Archaeol Sci 70: 117-131.

25. Mansouri F, Winfield Z, Crain D, Morris B, Charapata P, et al. (2021) Evidence of multi-decadal behavior and ecosystem-level changes revealed by reconstructed lifetime stable isotope profiles of baleen whale earplugs. Sci Total Environ 757: 143985.

26. AMAP (2005) AMAP assessment 2002: heavy metals in the arctic. In: Arctic Monitoring and Assessment Programme.

27. Halbach K, Mikkelsen O, Berg T, Steinnes E (2017) The presence of mercury and other trace metals in surface soils in the Norwegian Arctic. Chemosphere 188: 567-574.

28. Davis N (1996) The Arctic wasteland: a perspective on Arctic pollution. Polar Rec 32(182): 237-248.

29. Jiskra M, Sonke J, Agnan Y, Helmig D, Obrist D (2019) Insights from mercury stable isotopes on terrestrial-atmosphere exchange of Hg(0) in the Arctic tundra. Biogeosciences 16(20): 4051-4064.

30. Box JE, Colgan WT, Christensen TR, Schmidt NM, Lund M, et al. (2019) Key indicators of Arctic climate change: 1971-2017. Environ Res Lett 14: 045010.

31. Skov H, Christensen JH, Goodsite ME, Heidam NZ, Jensen B, et al. (2004) Fate of elemental mercury in the arctic during atmospheric mercury depletion episodes and the load of atmospheric mercury to the arctic. Environ Sci Technol 38(8): 2373-2382.

32. Dastoor AP, Durnford DA (2014) Arctic Ocean: is it a sink or a source of atmospheric mercury? Environ Sci Technol 48(3): 1707-1717.

33. Olson C, Jiskra M, Biester H, Chow J, Obrist D (2018) Mercury in Active-Layer Tundra Soils of Alaska: Concentrations, Pools, Origins, and Spatial Distribution, Global Biogeochem Cycles 32(7): 1058-1073.

34. Schuster PF, Schaefer KM, Aiken GR, Antweiler RC, Dewild JF, et al. (2018) Permafrost stores a globally significant amount of mercury. Geophys Res Lett 45(3): 1463-1471.

35. Macdonald RW, Harner T, Fyfe J (2005) Recent climate change in the Arctic and its impact on contaminant pathways and interpretation of temporal trend data. Sci Total Environ 342(1-3): 5-86.

36. Tynan CT, DeMaster DP (1997) Observations and Predictions of Arctic Climatic Change: Potential Effects on Marine Mammals. Arctic 50(4): 308-322.

37. Douglas TA, Loseto LL, MacDonald RW, Outridge PM, Dommerque A, et al. (2012) The fate of Hg in Arctic terrestrial and aquatic ecosystems, a review. J Environ Chem 9(4): 321-355.

38. De Palmer MT, Trahan LH, Eliza JM, Wagner AE (2015) The relationship between Diabetes self efficacy and self-care in American Indians and Alaska Natives. Am Indian Also Native Ment Health Res 22(2): 1-22.

39. Hallanger IG, Fuglei E, Yoccoz NG, Pedersen AO Konig M, et al. (2019) Temporal trend of mercury in relation to feeding habits and food availability in arctic foxes (Vulpes lagopus) from Svalbard, Norway. Sci Total Environ 670: 1125-1132.

40. Marzeion B, Levermann A (2014) Loss of cultural world heritage and currently inhabited places to sea-level rise. Environ Res Lett 9: 7.

41. Fisher JA, Jacob DJ, Sorensen AL, Amos HM, Steffen A, et al. (2012) Riverine source of Arctic Ocean mercury inferred from atmospheric observations. Nat Geosci 5: 499-504.

42. Institute of Medicine (2008) Global climate change and extreme weather events: understanding the contributions to infectious disease emergency. Washington, DC: The National Academic Press, Institute of Medicine, pp: 280.

43. Parkinson AJ, Butler JC (2005) Potential impacts of climate change on infectious diseases in the Arctic. Int J Circumpolar Health 64(5): 478-486.

44. Greer A, Ng V, Fisman D (2008) Climate change and infectious diseases in North America: the road ahead. CMAJ 178(6): 715-722.

45. Jenkins EJ, Castrodale LJ, de Rosemond SJ, Dixon BR, Elmore SA, et al. (2013) Tradition and transition: parasitic zoonoses of people and animals in Alas- ka, northern Canada, and Greenland. Adv Parasitol 82: 33-204.

46. Tryland M, Nesbakken T, Robertson L, Grahek Ogden D, Lunestad BT (2013) Human pathogens in marine mammal meat-a northern perspective. Zoonoses Public Health 61(6): 377-394.

47. Desforges JPW, Sonne C, Levin M, Siebert U, De Guise S, et al. (2016) Immunotoxic effects of environmental pollutants in marine mammals. Environ Int 86: 126-139.

48. Chapman WL, Walsh JE (1993) Recent variations of sea ice and air temperature in high latitudes. Bull Amer Meteor 74(1): 33-48.

49. Maslanik JA, Serene MC, Barry RG (1996) Recent

decreases in Arctic summer ice cover and linkages to atmospheric circulation anomalies Geophys 23(13): 1677-1680.

50. Screen JA, Simmonds I (2010) The central role of diminishing sea ice in recent Arctic temperature amplification. Nature 464: 1334-1337.

51. Cohen J, Screen JA, Furtado JC, Barlow M, Whittleston D, et al. (2014) Recent Arctic amplification and extreme midlatitude weather. Nat Geosci 7(9): 627-637.

52. Murray MS, McRoy CP, Duffy LK, Hirons AC, Schaaf JM, et al. (2015) Biogeochemical analysis of ancient PaciWic cod bone suggest Hg bioaccumulation was linked to paleo sea level rise and climate change. Front Environ Sci 3(8): 1-8.

53. Kwok R (2018) Arctic sea ice thickness, volume, and multi- year ice coverage: Losses and coupled variability (1958-2018). Environ Res Lett 13(10): 105005.

54. Shaftel H, Jackson R, Tenebaum L (2020) Arctic sea ice minimum NASA global climate change, earth science communications team at NASA's jet propulsion laboratory, climate change: vital signs of the Planet.

55. Crain DD, Karpovich SA, Quakenbush L Polasek L (2021) Using claws to compare reproduction, stress and diet of female bearded and ringed seals in the Bering and Chukchi seas, Alaska, between 1953-1968 and 1998-2014. Conserv Physiol 9(1).

56. Steele M, Ermold W, Zhang J (2008) Arctic Ocean surface warming trends over the past 100 years. Geophys Res Lett 35(2): L02614.

57. Faust JC, Marz C Henley SF (2019) The Carbon Story of a Melting Arctic. The Earth and its Resources.

58. Stroeve J, Holland MM, Meier W, Scambos T, Serreze M (2007) Arctic Sea ice decline: faster than forecast. Geophys Res Lett 34(9).

59. Cameron MF, Bengtson JL, Boveng PL, Jansen JK, Kelly BP, et al. (2010) Status review of the bearded seal (Erignathus barbatus). NOAA Technical Memorandum NMFS- AFSC-211. Alaska Fisheries Science Center, pp: 1-263.

60. Kovacs KM, Lydersen C, Overland JE, Moore SE (2011) Impacts of changing sea-ice conditions on Arctic marine mammals. Mar Biodivers 41: 181-194.

61. Tamabayeva D, Duffy LK, Loring PA, Barnes D (2013) Mitigation history of the industrial Hg contamination in the Nura River watershed of the Republic of Kazakhstan: Evolution of an Adaptive Management Approach. EMSD 2: 187-194.

62. Stokes PM, Wren CD (1987) Bioaccumulation of Hg by aquatic biota in hydroelectric reservoirs: a review and consideration of mechanisms. Lead, Mercury, Cadmium and Arsenic in the Environment, pp: 255-257.

63. Sleeman JM (2013) Has the time come for big science in wildlife health? EcoHealth 10: 335-338.

64. Dainowski BH, Duffy LK, McIntyre J, Jones P (2015) Hair and bone as predictors of tissular mercury concentration in the Western Alaska Red Fox, Vulpes vulpes. Sci Total Environ 518-519: 526-553.

65. Graham BS, Koch PL, Newsome SD, McMahon KW, Aurioles D (2010) Using isoscapes to trace the movements and foraging behavior of top predators in oceanic ecosystems. In JB West, GJ Bowen, TE Dawson, KP Tu (Eds.), Isoscapes. Dordrecht, the Netherlands: Springer, pp: 299-318.

66. MacKenzie KM, Palmer MR, Moore A, Ibbotson AT, Beaumont WRC, et al. (2011) Locations of marine animals revealed by carbon isotopes. Scientific Reports 1: 21.

67. McMahon KW, Hamady LL, Thorrold SR (2013) A review of ecogeochemistry approaches to estimating movements of marine animals. Limnology and Oceanography 58(2): 697-714.

68. Magozzi S, Yool A, Zanden VH, Wunder M, Trueman C (2017) Using ocean models to predict spatial and temporal variation in marine carbon isotopes. Ecosphere 8(5): e01763.

69. Romero AM, Guthman J, Galt RE, Huber M, MansWield B, et al. (2017) Chemical geographies. GeoHumani- ties 3(1): 158-177.

70. Stine C (1942) Molders of a better destiny. Science 96(2492): 305-311.

71. Duffy LK, Dunlap KL, Reynolds A, Gerlach SC (2013) Sled dogs as indicators of climate change and resultant contaminant fate and transport along the Yukon River. Int J Circumpolar Health Suppl 1: 508-510.

72. Siddiqi ZM (2018) Transport and Fate of Mercury (Hg) in the Environment: Need for Continuous Monitoring. In: Hussain C (Ed.), Handbook of Environmental Materials Management. Cham: Springer International Publishing, pp: 1-20.

73. Kershaw J, Hall A (2019) Mercury in Cetaceans: Exposure,

Bioaccumulation and Toxicity. Sci Total Environ 694: 133683.

74. Driscoll CT, Mason RP, Chan HM, Jacob DJ, Pirroke N (2013) Mercury as a Global Pollutant: Sources, Pathways, and Effects. Environ Sci Technol 47(10): 4967-4983.

75. Kim K, Kabir E, Jahan SA (2016) A review on the distribution of Hg in the environment and its human health impacts. J Hazard Mater 306: 376-385.

76. Kalisinska E, Lanocha-Arendarczyk N, Podlasinska J (2021) Current and historical nephrite and hepatic mercury concentrations in terrestrial mammals in Poland and other European countries. Sci Total Environ 775: 145808.

77. Rodgers DW (1994) You are what you eat and a little bit more: bioenergetics-based models of methylmercury accumulation in Fish revisited. In: Watras CJ, et al. (Eds.), Mercury Pollution: Integration and Synthesis. Lewis Publishers, WS/Palo Alto, California.

78. Duffy LK, Kaiser C, Ackley C, Richter KS (2001) Mercury in hair of large Alaskan herbivores: routes of exposure. Alces 37: 293-301.

79. Schroeder WH, Munthe J (1998) Atmospheric mercury-an overview. Atmos Environ 32(5): 809-822.

80. AMAP (2015) Arctic Monitoring and Assessment Programme: human health in the Arctic.

81. Schaefer K, Elshorbany Y, Jafarov E, Schuster PF, Striegl RG, et al. (2020) Potential impacts of mercury released from thawing permafrost. Nat Commun 11: 4650.

82. Lindberg SE, Brooks S, Lin CJ, Scott KJ, Landis MS, et al. (2002) Dynamic oxidation of gaseous mercury in the Arctic troposphere at Polar Sunrise. Environ Sci Technol 36(6):1245-1256.

83. Berg T, Aspmo K, Steinnes E (2008) Transport of Hg from atmospheric mercury depletion events to the mainland of Norway and its possible influence on Hg deposition. Geophys Res Lett 35(9).

84. Steffen A, Bottenheim J, Cole A, Ebinghaus R, Lawson G, et al. (2014) Atmospheric mercury speciation and mercury in snow over time at Alert, Canada. Atmospheric Chem Phys 14(5): 2219-2231.

85. Hansen BB, Aanes R, HerWindal I, Kohler J, Sæther BE (2011) Climate, icing, and wild arctic reindeer: past relationships and future prospects. Ecology 92(10): 1917-1923.

86. Loe LE, Hansen BB, Stien A, Albon SD, Bischof R, et al.2016) Behavioral buffering of extreme weather events in a high-Arctic herbivore. Ecosphere 7(6): 1-13.

87. Wegrzyn M, Wietrzyk P, Lisowska M, Klimek B, Nicia P (2016) What influences heavy metals accumulation in arctic lichen Cetrariella delisei in Svalbard? Political Sci 10: 532-540.

88. Van der Wal R, Loonen MJJE (1998) Goose droppings as food for reindeer. Can J Zool 76: 1117-1122.

89. Hansen BB, Aanes R (2012) Kelp and seaweed feeding by High-Arctic wild reindeer under extreme winter conditions. Polar Res 31: 17258.

90. Burger J, Gochfeld M (2007) Risk to consumers from mercury in PaciWic cod (Gadus microcephalus) from the Aleutians: Fish age and size effects. Environ 105(2): 276-284.

91. Dietz R, Sonne C, Basu N, Braune B, O'Hara T, et al. (2013) What are the toxicological effects of mercury in Arctic biota? Sci Total Environ 443: 775-790.

92. López-Berenguer G, Peñalver J, Martínez-López E (2020) A critical review about neurotoxic effects in marine mammals of mercury and other trace elements. Chemosphere 246: 125688.

93. Tang WL, Liu YR, Guan WY, Zhong H, Qu XM, et al. (2020) Understanding mercury methylation in the changing environment: recent advances in assessing microbial methylators and mercury bioavailability. Sci Total Environ 714: 136827.

94. Lamborg CH, Hammerschmidt CR, Bowman KL, Swarr GJ, Munson KM, et al. (2014) A global ocean inventory of anthropogenic mercury based on water column measurements. Nature 512(7512): 65-68.

95. Dietz R, Riget F, Born EW, Sonne C, Grandjean P, et al. (2006) Trends in mercury in hair of Greenlandic polar bears (Ursus maritimus) during 1892-2001. Environ Sci Technol 40(4): 1120-1125.

96. Lavoie RA, Jardine TD, Chumchal MM, Kidd KA, Campbell LM (2013) BiomagniWication of mercury in aquatic food webs: a worldwide meta-analysis. Environ Sci Technol 47(23): 13385-13394.

97. Kehrig HA, Seixas TG, Malm O, Di Beneditto APM, Rezende CE (2013) Mercury and selenium biomagnification in a Brazilian coastal food web using nitrogen stable isotope analysis: a case study in an area under the influence of the Paraiba do Sul River plume. Mar Pollut Bull 75: 283-290.

98. Bridges CC, Zalups RK (2010) Transport of inorganic mercury and methylmercury in target tissues and organs. J Toxicol Environ Health, Part B 13(5): 385-410.

99. Ribeiro O, Rouleau CA, Pelletier É, Audet C, Tjälve H (1999) Distribution kinetics of dietary methylmercury in the Arctic Charr (Salvelinus alpinus). Environ Sci Technol 33(6): 902-907.

100. Clarkson TW (1997) The toxicology of mercury. Crit Rev Clin Lab Sci 34: 369-403.

101. Evans RD, Hickie B, Rouvinen-Watt K, Wang W (2016) Partitioning and kinetics of methylmercury among organs in captive mink (Neovison vison): a stable isotope tracer study. Environ Toxicol Pharmacol 42: 163-169.

102. Loring PA, Gerlach SC (2009) Food, culture, and human health in Alaska: an integrative health approach to food security. Environ Sci Policy 12(4): 466-478.

103. Fogel ML, Tuross N, Johnson BJ, Miller GH (1997) Biogeochemical record of ancient humans. Org Geochem 27(5-6): 275-287.

104. Coltrain JB, Hayes MG, O'Rourke DH (2004) Sealing, whaling and caribou: the skeletal isotope chemistry of Eastern Arctic foragers. J Archaeol Sci 31: 39-57.

105. Richards MP, Schulting RJ, Hedges REM (2003) Sharp shift in diet at onset of Neolithic. Nature 425: 366.

106. Werth AJ (2019) Evaluating Environmental Threats to the Trophic Ecology of Arctic Marine Mammals. JMBAC 2(1): 17-24.

107. Young BG, Loseto LL, Ferguson SH (2010) Diet differences among age classes of Arctic seals: evidence from stable isotope and mercury biomarkers. Polar Biol 33(2): 153-162.

108. Hobson KA (1999) Tracing origins and migration of wildlife using stable isotopes: a review. Oecologia 120: 314-326.

109. Kelly JF (2000) Stable isotopes of carbon and nitrogen in the study of avian and mammalian trophic ecology. Can J Zool 78(1): 1-27.

110. Amesbury MJ, Charman DJ, Newnham RM, Loader NJ, Goodrich JP, et al. (2015) Carbon stable isotopes as a palaeoclimate proxy in vascular plant dominated peatlands. Geochim Cosmochim Acta 164: 161-174.

111. Clark CT, Horstmann L, Misarti N (2017) Quantifying variability in stable carbon and nitrogen isotope ratios within the skeletons of marine mammals of the suborder Canifornia. J Archeaol Sci: Reports 15: 393-400.

112. Dainowski BH, Duffy LK, McIntyre J, Jones P (2020) Stable Carbon and Nitrogen Isotopes of A Sentinel Species, the Western Alaska Red Fox (Vulpes vulpes). Adv Clin Toxicol 5(1): 1-10.

113. Hoondert RP, van den Brink N, van den Heuvel-Greve M, Ragas AD, Hendriks A (2021) Variability in nitrogen-driven trophic levels of Arctic marine biota. Polar Biol 44: 119-131.

114. Minagawa M, Wada E (1984) Stepwise enrichment of ^{15}N along food chains: further evidence and the relation between δ^{15}N and animal age. Geochim Cosmochim Acta 48: 1135-1140.

115. DeNiro MJ, Schoeninger MJ (1983) Stable carbon and nitrogen isotope ratios of bone collagen: variations within individuals, between sexes, and within populations raised on monotonous diets. J Archaeol Sci 10(3): 199-203.

116. Roth JD, Hobson KA (2000) Stable carbon and nitrogen isotopic fractionation between diet and tissue of captive red fox: implications for dietary reconstruction. Can J Zool 78(5): 848-852.

117. Bocherens H (2003) Isotopic biogeochemistry and the paleoecology of the mammoth steppe fauna. In: Reumer J (Ed.), Advances in Mammoth Research, Proceedings of the 2nd International Mammoth Conference, Deinsea, Rotterdam, pp: 57-76.

118. Kubiak C, Mathewes R, Grimes V, van Biesen G, Richards MP (2021) Evidence of a significant marine plant diet in the Pleistocene caribou from Haida Gwaii, British Columbia, through compound-specific stable isotope analysis. Palaeogeogr Paleoclimatol Paleoecol 564: 110180.

119. DeNiro MJ, Epstein S (1981) Influence of diet on the distribution of nitrogen isotopes in animals. Geochim Cosmochim Acta 45(3): 341-351.

120. Post DM (2002) Using stable isotopes to estimate trophic position: models, methods and assumptions. Ecology 83(3): 703-718.

121. Dehn LA, Follmann EH, Thomas DL, Sheffield GG, Rosa C, et al. (2006) Trophic relationships in an Arctic food web and implications for trace metal transfer. Sci Total Environ 362(1-3): 103-123.

122. Fry B (2006) Stable Isotope Ecology. Springer: New York, NY.

123. Misarti N, Finney B, Maschner H, Wooller MJ (2009) Changes in northeast Pacific marine ecosystems over the last 4500 years: evidence from stable isotope analysis of bone collagen from archeological middens. The Holocene 19: 1139-1151.

124. Bocherens H, Drucker DG, Germonpré M, Laznickova-Galetova M, Naito YI, et al. (2015) Reconstruction of the Gravettian food-web at Předmostí I using multi-isotopic tracking (^{13}C, ^{15}N, 34S) of bone collagen. Quat Int 359-360: 211-228.

125. Trites AW (2019) Marine Mammal Trophic Levels and trophic interactions. Encyclopedia of Ocean Sciences, 3rd (Edn.), Steele JH, (Ed.), Academic Press, pp: 589-593.

126. Vander Zanden MJ, Rasmussen JB (1996) A trophic position model of pelagic food webs: impact on contaminant bioaccumulation in lake trout. Ecol Monogr 66(4): 451-477.

127. McCutchan JH, Lewis WM, Kendall C, McGrath CC (2003) Variation in trophic shift for stable isotope ratios of carbon, nitrogen, and sulfur. OIKOS 102(2): 378-390.

128. Farquhar GD, Ehleringer JR, Hubick KT (1989) Carbon isotope discrimination and phytosynthesis. Annu Rev Plant Physiol Plant Mol Biol 40: 503-537.

129. Smith BN, Epstein S (1971) Two categories of $^{13}C/^{12}C$ ratios for higher plants. Plant Physiol 47(3): 380-384.

130. Vogel JC, Van Der Merwe NJ (1977) Isotopic evidence for early maize cultivation in New York State. Am Antiq 42(2): 238-242.

131. Sage RF, Wedin DA, Li M (1999) The biogeography of C4 photosynthesis: patterns and controlling factors. In: Sage RF (Ed.), C4 plant biology. Academic Press, San Diego, pp: 596.

132. Wooller MJ, Zazula GD, Edwards M, Froese DG, Boone RD, et al. (2007) Stable carbon isotope compositions of Eastern Beringian grasses and sedges: investigating their potential as paleoenvironmental indicators. Arct Antarct Alp Res 39(2): 318-331.

133. Bella L (2013) Wildlife and Habitat, Refuge Notebook 3-22-2013 article. US Fish & Wildlife. Kenai. National Wildlife Refuge/Alaska.

134. Peterson BJ, Fry B (1987) Stable isotopes in ecosystem studies. Anna Rev Ecol Syst 18: 293-320.

135. Dalerum F, Angerbjorn A (2005) Resolving temporal variation in vertebrate diets using natural occurring stable isotopes. Oecologia 144(4): 647-658.

136. Lehner N (2012) Arctic Fox Winter Movement and Diet in Relation to Industrial Development on Alaska's North Slope (MS Thesis). University of Alaska Fairbanks, Fairbanks, AK.

137. Rounick JS, Winterbourn MJ (1986) Stable carbon isotopes and carbon flow in Ecosystems. Bioscience 36(3): 171-177.

138. Rau GH, Ainley DG, Bengston JL, Torres JJ, Hopkins TL (1992) $^{15}N/^{14}N$ and $^{13}C/^{12}C$ in Weddell Sea birds, seals, and Fish: implications for diet and trophic structure. Mar Ecol Prog Ser 84(1-8): 1-8.

139. France RL (1995) Carbon-13 enrichment in benthic compared to planktonic algae: foodweb implications. Mar Ecol Prog Ser 124: 307-312.

140. Hobson KA, Fisk AT, Karnovsky N, Holst M, Gagnon JM, (2002) A stable isotope ($\delta^{13}C$, $\delta^{15}N$) model for the North Water foodweb: implications for evaluating trophodynamics and the flow of energy and contaminants. Deep-Sea Res Part II: Topical studies in Oceanography 49(22-23): 5131-5150.

141. Whitehead H, McGill B, Worm B (2008) Diversity of deep-water cetaceans in relation to temperature: implications for ocean warming. Ecol Lett 11(11): 1198-1207.

142. Ben-David M, Flaherty E (2012) Stable isotopes in mammalian research: a beginner's guide. J Mammal 93(2): 312-328.

143. Jahren AH, Saudek C, Yeung EH, Kao WHL, Kraft RA, et al. (2006) An isotopic method for quantifying sweeteners derived from corn and sugar cane. AJCN 84(6): 1380-1384.

144. Jahren AH, Kraft RA (2008) Carbon and nitrogen stable isotopes in fast food: signatures of corn and confinement. PNAS 105(46): 17855-17860.

145. de Laender F, van Oevelen D, Frantzen S, Middelburg JJ, Soetaert K (2009) Seasonal PCB bioaccumulation in an Arctic marine ecosystem: a model analysis incorporating lipid dynamics, food-web productivity and migration. Environ Sci Technol 44: 356-361.

146. Murphy EJ, Cavanagh RD, Drinkwater KF, Grant SM, Heymans J, et al. (2016) Understanding the structure and functioning of polar pelagic ecosystems to predict the impacts of change. Proc Royal Soc B-Biol Sci 283(1844): 20161646.

147. Durant JM, Molinero JC, Ottersen G, Reygondeau G, Stige LC, et al. (2019) Contrasting effects of rising

temperatures on trophic interactions in marine ecosystems. Sci Rep 9(1): 1-9.

148. Shore SL, Giarikos DG, Duffy LK, Edwards MR, Hirons AC (2021) Temporal Baseline of Essential and Non-essential Elements Recorded in Baleen of Western Arctic Bowhead Whale (Balaena mysticetus). Bull Environ Contam Toxic. https://doi.org/10.1007/s00128-021-03394-2.

149. Peeters B, Pedersen AO, Loe LE, Isaksen K, Veiberg V, et al. (2019) Spatiotemporal patterns of rain-on snow and basal ice in high Arctic Svalbard: detection of a climate-cryosphere regime shift. Environ Res Lett 14(1): 015002.

150. Outridge PM, Macdonald RW, Wang F, Stern GA, Dastoor AP (2008) A mass balance inventory of mercury in the Arctic Ocean. Environ Chem 5: 89-111.

151. Obrist D, Kirk JL, Zhang L, Sunderland EM, Jiskra M, et al. (2018) A review of global environmental mercury processes in response to human and natural perturbations: changes of emissions, climate and land use. Ambio 47: 116-140.

152. Ambrose SH, DeNiro MJ (1989) Climate and habitat reconstruction using stable carbon and nitrogen isotope ratios of collagen in prehistoric herbivore teeth from Kenya. Quat Res 31(3): 407-422.

153. Barberena R, Zangrando AF, Gil AF, Martínez GA, Politis GG, et al. (2009) Guanaco (Lama guanicoe) isotopic ecology in southern South America: spatial and temporal tendencies, and archaeological implications. J Archaeol Sci 36(12): 2666-2675.

154. Lamb AL, Evans JE, Buckley R, Appleby J (2014) Multi-isotope analysis demonstrates significant lifestyle changes in King Richard III. J Archaeol Sci 50: 559-565.

155. Moon TA, Overeem I, Druckenmiller M, Holland M, Huntington H, et al. (2019) The expanding footprint of rapid arctic change. Earth's Future 7(3): 212-218.

156. Post E, Forchhammer MC (2008) Climate change reduces reproductive success of an Arctic herbivore through trophic mismatch. Philos Trans R Soc B-Biol Sci 363(1501): 2369-2375.

157. Sharma S, Couturier S, Coté SD (2009) Impacts of climate change on the seasonal distribution of migratory caribou. Glob Change Biol 15(10): 2549-2562.

158. Funck J, Heintzman Pd, Murray GR, Shapiro B, McKinney H, et al. (2020) A detailed life history of a pleistocene steppe bison (Bison priscus) skeleton unearthed in Arctic Alaska. Quat Sci Rev 249: 106578.

159. Kirk JL, Lehnherr I, Andersson M, Braune BM, Chan L, et al. (2012) Mercury in Arctic marine ecosystems: sources, pathways and exposure. Environ 119: 64-87.

160. Doyle JJ (1979) Toxic and Essential Elements in Bone - A Review. JAS 49(2): 482-497.

161. Feng X (2009) Chemical and Biochemical Basis of Cell-Bone Matrix Interaction in Health and Disease. Curr Chem Biol 3(2): 189-196.

162. Ambrose SH (1993) Isotopic analysis of paleodiets: methodological and interpretative considerations. In: Sandford MK, (Ed.), Investigations of Ancient Human Tissue Chemical Analyses in Anthropology. Gordon and Breach Science Publishers, Langhorne, pp: 59-130.

163. Hedges R, Clement JG, David C, Thomas L, O'Connell TC (2007) Collagen turnover in the adult femoral mid-shaft: modeled from anthropogenic radiocarbon tracer measurements. Am J PhysAnthropol 133(2): 808-816.

164. Han ZH, Palnitkar S, Rao DS, Nelson D, Parfitt AM (1997) Effects of ethnicity and age or menopause on the remodeling and turnover of iliac bone: implications for mechanisms of bone loss. JBMR12(4): 498-508.

165. Ambrose SH, Norr L (1993) Experimental evidence for the relationship of the carbon isotope ratios of whole diet and dietary protein to those of bone collagen and carbonate. In: Lambert JB, et al. (Eds.), Prehistoric Human Bone Archaeology at the Molecular Level. Springer-Verlag, Berlin, pp: 1-37.

166. Noël M, Brown TM (2021) Contaminants as a Conservation Threat to Marine Mammals. In: Underkoffler SC, et al. (Eds.), Wildlife Biodiversity Conservation. Springer, Cham, pp: 401-420.

167. Collins MJ, Nielsen-Marsh CM, Hiller J, Smith CI, Roberts JP, et al. (2002) The survival of organic matter in bone: a review. Archaeometry 44(3): 383-394.

168. Hedges REM (2002) Bone Diagenesis: An Overview of Processes. Archaeometry 44(3): 319-328.

169. Dietz R, Outridge PM, Hobson KA (2009) Anthropogenic contributions to mercury levels in present-day Arctic animals-a review. Sci Total Environ 407(24): 6120-6131.

170. Vast AA (2001) Beyond the grave: understanding human decomposition. Microbiol Today 28: 190-192.

171. Lobedell JE, Dekin AA (1984) The Frozen Family

from the Utqiagvik Site, Barrow, Alaska - Papers from a Symposium-Introduction. Arct Anthropol 21(1): 1-4.

172. Keenleyside A (1998) Skeletal Evidence of Health and Disease in Pre-Contact Alaskan Eskimos and Aleuts. Am J Phys Anthropol 107(1): 51-70.

173. Dainowski BH, Duffy LK (2021) A Forensic Evaluation: the use of Mercury and Stable Isotope analysis of Museum Bone Samples to Monitor if Environmental Changes are affecting the Eating Patterns of Red and Arctic Foxes. Adv Clin Toxicol 6(3): 1-9.

174. McGowan JA (1996) Bone: Target and source of environmental pollutant exposure. J Otolaryngol Head N 114(2): 220-223.

175. Tieszen LL, Boutton TW, Tesdahl KG, Slade NA (1983) Fractionation and turnover for δ13C analysis of diet in animal tissues: Implications for $\delta^{13}C$ analysis of diet. Ecology 57: 32-37.

176. Jans MME, Kars H, Nielsen-Marsh CM, Smith CI, Nord AG, et al. (2002) In situ preservation of archaeological bone: a histological study within a multidisciplinary approach. Archaeometry 44(3): 343-352.

177. Gutieb AC, Kranz A, Nechay G, Toman A (1998) Heavy Metal Concentrations in Livers and Kidneys of the Otter (Lutra lutra) from Central Europe. Bull Environ Contam Toxicol 60(2): 273-279.

178. Dietz R, Riget F, Born EW (2000) Geographical differences of zinc, cadmium, mercury and selenium in polar bears (Ursus maritimus) from Greenland. Sci Total Environ 245(1-3): 25-47.

179. Dip R, Stieger C, Deplazes P, Hegglin D, Muller U, et al. (2001) Comparison of Heavy Metal Concentrations in Tissues of Red Foxes from Adjacent Urban, Suburban, and Rural Areas. Arch Environ Contam 40(4): 551-556.

180. Cybulski W, Chalabis-Mazurek A, Jakubczak A, Jarosz L, Kostro K, et al. (2009) Content of lead, cadmium, and mercury in the liver and kidneys of silver foxes (Vulpes vulpes) in relation to age and reproduction disorders. Bull Vet Inst Pulawy 53(1): 65-69.

181. Bilandzic N, Dezdek D, Sedak M, Dokic M, Solomun B, et al. (2010) Concentrations of Trace Elements in Tissues of Red Fox (Vulpes vulpes) and Stone Marten (Martes foina) from Suburban and Rural Areas in Croatia. Bull Environ Contam Toxicol 85(5): 486-491.

182. Dainowski BH (2017) An innovative stable isotope in internal tissues of wildlife in a changing western Alaska Environment. PhD thesis, University of Alaska Fairbanks.

183. Aukland K (1989) Myogenic mechanisms in the kidney. J Hypertens Supplement 7(4): S71-76.

184. Reidy KJ, Rosenblum ND (2009) Cell and Molecular Biology of Kidney Development. Semin Nephrol 29(4): 321-337.

185. Morin PJ (1999) Community Ecology. 2nd (Ed.), Blackwell Science, Malden, pp: 1-424.

186. Pedersen KE, Styrishave B, Sonne C, Dietz R, Jenssen BM (2015) Accumulation and potential health effects of organohalogenated compounds in the arctic fox (Vulpes lagopus)-a review. Sci Total Environ 502: 510-516.

187. Ehrich D, Ims RA, Yoccoz NG, Lecomte N, Killengreen ST, et al. (2015) What can stable isotope analysis of top predator tissues contribute to monitoring of tundra ecosystems? Ecosystems 18(3): 404-416.

188. Braune B, Muir D, Demarch B, Gamberg M, Poole K, et al. (1999) Spatial and temporal trends of contaminants in Canadian Arctic freshwater and terrestrial ecosystems: a review. Sci Total Environ 230(1-3): 145-208.

189. Duffy LK, Duffy RS, Finstad G, Gerlach C (2005) A note on mercury levels in the hair of Alaskan Reindeer. Sci Total Environ 339(1-3): 273-276.

190. Fry B, Anderson RK, Entzeroth L, Bird JL, Parker PL (1984) 13C enrichment and oceanic food web structure in the northwestern Gulf of Mexico. Contrib Mar Sci 27: 49-63.

191. Hobson KA, Piatt JF, Pitochelli J (1994) Using stable isotopes to determine seabird trophic relationships. J Anim Ecol 63(4): 786-798.

192. Clark CT, Horstmann L, Misarti N (2019) Lipid normalization and stable isotope discrimination in Pacific walrus tissues. Sci Rep 9(1): 5843.

193. Zhao L, Schell DM (2004) Stable isotope ratios in harbour seal Phoca vitulina vibrissae: effects of growth patterns on ecological records. Mar Ecol Prog Ser 281: 267-273.

194. Kurle CM, Worthy GAJ (2001) Stable isotope assessment of temporal and geographic differences in feeding ecology of northern fur seals (Callorhinus ursinus) and their prey. Oecologia 126: 254-265.

195. Choudhary S, Blaud A, Osborn AM, Press MC, Phoenix GK (2016) Nitrogen accumulation and partitioning in a High Arctic tundra ecosystem from extreme atmospheric

N deposition events. Sci Total Environ 554-555: 303-310.

196. Overjordet IB, Gabrielsen GW, Berg T, Ruus A, Evenset A, et al. (2015) Effect of diet, location and sampling year on bioaccumulation of mercury, selenium and cadmium in pelagic feeding seabirds in Svalbard. Chemosphere 122: 14-22.

197. Riget F, Dietz R, Vorkamp K, Johansen P, Muir D (2004) Levels and spatial and temporal trends of contaminants in Greenland biota: an updated review. Sci Total Environ 331(1-3): 29-52.

198. Scheuhammer AM, Meyer MW, Sandheinrich MB, Murray MW (2007) Effects of environmental methyl mercury on the health of wild birds, mammals, and Fish. Ambio 36(1): 12-28.

199. Tilson HA (1990) Neurotoxicology in the 1990s. Neurotoxicol Teratol 12(4): 293-300.

200. Das K, Debacker V, Pillet S, Bouquegneau JM (2003) Heavy metals in marine mammals. In: Vos JG, et al. (Eds.), Toxicology of Marine Mammals. New Perspectives: Toxicology and the Environment. Taylor & Francis, London, pp: 135-167.

201. Roos DH, Puntel RL, Lugokenski TH, Ineu RP, Bohrer D, et al. (2010) Complex methylmercury-cysteine alters mercury accumulation in different tissues of mice. Basic Clin Pharmacol Toxicol 107(4): 789-792.

202. Wagemann R, Trebacz E, Boila G, Lockhart WL (1998) Methylmercury and total mercury in tissues of arctic marine mammals. Sci Total Environ 218(1): 19-31.

203. Wolfe MF, Schwarzbach S, Sulaiman RA (1998) Effects of mercury on wildlife: a comprehensive review. Environ Toxicol and Chem 17(2): 146-160.

204. Brown KL, Atkinson S, Furin CG, Mueter FJ, Gerlach R (2021) Metals in the stomach contents and brain, gonad, kidney, and liver tissues of subsistence-harvested northern sea otters (Tnhydra ultras kenyoni) from Icy Strait, Alaska. Mar Pollut Bull 166: 112183.

205. Estes JA, Palmisano JF (1974) Sea otters: their role in structuring nearshore communities. Science 185(4156): 1058-1060.

206. Garshelis DL, Garshelis JA, Kimker AT (1986) Sea otter time budgets and prey relationships in Alaska. J Wildl Manag 50(4): 637-647.

207. Jessup D, Miller M, Ames J, Harris M, Kreuder C, et al. (2004) Southern sea otter as a sentinel of marine ecosystem health. EcoHealth 1: 239-245.

208. Estes JA (1990) Growth and equilibrium in sea otter populations. J Anim Ecol 59(2): 385-401.

209. Bacon CE, Jarman WM, Estes JA, Simon M, Norstrom RJ (1999) Comparison of organochlorine contaminants among sea otter (Enhydra lutris) populations in California and Alaska. Environ Toxicol Chem 18(3): 452-458.

210. Comerci LR, Gorbics CS, Matz AC, Trust KA (2001) Tissue Concentrations of Elemental and Organochlorine Compounds in Sea Otters in Alaska. U.S. Fish and Wildlife Service Technical Report, pp: 103.

211. Brancato MS, Milonas L, Bowlby CE, Jameson R, Davis JW (2009) Chemical contaminants, pathogen exposure and general health status of live and beach-cast Washington sea otters (Enhydra lutris kenyoni). Marine Sanctuaries Conservation Series ONMS-09-01 U.S. Department of Commerce National Oceanic and Atmospheric Administration, OfWice of National Marine Sancturaries, Silver Spring, MD, pp: 181.

212. Kennan K, Moon HB, Yun SH, Agusa T, Thomas NJ, et al. (2008) Chlorinated, brominated, and per uorinated compounds, polycylcic aromatic hydrocarbons and trace elements in liver of sea otters from California, Washington, and Alaska (USA) and Kamchatka (Russia). J Environ Monit 10: 552-558.

213. Carscallen WMA, Vandenberg K, Lawson JM, Martinez ND, Romanuk TN (2012) Estimating trophic position in marine and estuarine food webs. Ecosphere 3(3): 1-20.

214. McLaren IA (1958) Some aspects of growth and reproduction of the bearded seal, Erignathus barbatus (Erxleben). J Fish Res Board 15(2): 219-227.

215. Karpovich SA, Horstmann LA, Polasek LK (2020) Validation of a novel method to create temporal records of hormone concentrations from the claws of ringed and bearded seals. Conserv Physiol 8(1).

216. Meier-Augenstein W, Fraser I (2008) Forensic Isotope analysis leads to identification of a mutilated murder victim. Sci Justice 48(3): 153-159.

217. NRC (2009) Publications Available in the Agency wide Documents Access and Management System (ADAMS).

218. Chen YW, Huang CF, Tsai KS, Yang RS, Yen CC, et al. (2006) Methylmercury induces pancreatic Beta-cell Apoptosis. Chem Res Toxicol 19(8): 1080-1085.

219. Zangrando AF, Panarello H, Piana EL (2014) Zooarchaeological and Stable Isotopic Assessments on Pinniped-Human Relations in the Beagle Channel (Tierra del Fuego, Southern South America). Int J Osteoarchaeol 24: 231-244.

220. DeNiro MJ, Epstein S (1978) Influence of diet on the distribution of carbon isotopes in animals. Geochim Cosmochim Acta 42: 495-506.

221. Drucker DG, Bridault A, Hobson KA, Szuma E, Bocherens H (2008) Can carbon-13 in large herbivores reflect the canopy effect in temperate and boreal ecosystems? Evidence from modern and ancient ungulates. Palaeogeogr Paleoclimatol Paleoecol 266(1-2): 69-82.

222. Newsome SD, Clementz MT, Koch PL (2010) Using stable isotope biogeochemistry to study marine mammal ecology. Mar Mamm Sci 26(3): 509-572.

223. Hobson KA, Wassenaar LI (1999) Stable isotope ecology: an introduction. Oecologia 120(3): 312-313.

224. Schwarcz HP, White CD, Longstaffe FJ (2010) Stable and radiogenis isotopes in biological archaeology: some applications. In: West JB, et al. (Eds.), Isoscapes Understanding Movement, Pattern and Process on Earth through Isotope Mapping. Springer, New York, pp: 335-356.

225. Fleming AH, Clark CT, Calambokidis J, Barlow J (2016) Humpback whale diets respond to variance in ocean climate and ecosystem conditions in the California Current. Glob Change Biol 22(3): 1214-1224.

226. Fleming AH, Kellar NM, Allen CD, Kurle CM (2018) The utility of combining stable isotope and hormone analy- ses for marine megafauna research. Front Mar Sci 5: 338.

227. Polyak L, Belt ST, Cabedo-Sanz P, Yamamoto M, Park YH (2016) Holocene sea-ice conditions and circulation at the Chukchi-Alaskan margin, Arctic Ocean, inferred from biomarker proxies. The Holocene 26(11): 1810-1821.

228. Duffy LK, Hirons AC, Schaaf JM, McRoy CP, Murray MS, et al. (2022) Sea Otters, Mercury, and Monitoring Climate Change. Adv Clin Toxicol 7(1): 1-7.

229. Brinkmann L, Rasmussen JB (2010) High levels of Hg in biota of a new prairie irrigation reservoir with a simplified food web in southern Alberta, Canada. Hyrobiologia 641(1): 11-21.

230. Drucker D, Gambier D, Bocherens H, Mariotti A (2000) Approche isotopique des reconstitutions paléoécologiques : application aux humains du Paléolithique supérieur du sud-ouest de le France. In: Bulletin de la Société Préhistorique Française, 25ème Congres préhistorique de France “Approches fonctionnelles en Préhistoire”. SPF, Paris, pp. 80-81.

231. Hedges REM, Rhiannon ES, Richards MP (2004) Bone as a stable isotope archive for local climatic information. Quat Sci Rev 23(7-8): 959-965.

232. Ambrose SH (1990) Preparation and characterization of bone and tooth collagen for isotopic analysis. J Archaeol Sci 17(4): 431-451.

233. van Klinken GJ (1999) Bone collagen quality indicators for palaeodietary and radio-carbon measurements. J Archaeol Sci 26(6): 687-695.

234. Shafer ABA, Cullingham CI, Coté SD, Coltman DW (2010) Of glaciers and refugia: a decade of study sheds new light on the phylogeography of northwestern North America. Mol Ecol 19(21): 4589-4621.

235. Hall BK, Hall B (2005) Bones and Cartilage: Developmental and Evolutionary Skeletal Biology. Elsevier 1st (Edn.), Science & Technology.

236. Miller FL, Gunn A (2003) Catastrophic Die-off of Peary Caribou on the Western Queen Elizabeth Islands, Canadian High Arctic. ARCTIC 56(4): 381-390.

237. Lorentzen JR (2015) Marine Biomass Consumption by Wild Svalbard Reindeer: Fecal Stable Isotope Analysis as a Tool to Detect Climate Change Effects. MSC thesis. Norwegian University of Science and Technology, Trondheim.

238. Derocher AE, Lunn NJ, Stirling I (2004) Polar bears in a warming climate. Integr Comp Biol 44(2): 163-176.

239. Alexander V (1995) The influence of the structure and function of the marine food web on the dynamics of contaminants in Arctic Ocean ecosystems. Sci Total Environ 160-161: 593-603.

240. Attwell L, Hobson KA, Welch HE (1998) Biomagnification and bioaccumulation of mercury in an Arctic marine food web: insights from stable nitrogen isotope analysis. Can J Fish Aquat Sci 55: 1114-1121.