# Understanding Extent of Pathogen Risk Associated with Walrus (*Odobenus Rosmarus*) Haul-Out Behavior

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## Background and Context:

When looking at the rhetoric of why societies need to combat climate change, it is typically the dramatic, direct effects of our warming planet that dominate public discussion. Public discourse is bombarded with looming threats of sea level rise and altered weather patterns, and messaging about polar regions hones its focus to the consequences of ice and habitat loss for charismatic Arctic species (Manzo 2010). However, there is a substantial case to be made for emphasizing the myriad indirect effects of climate change alongside the direct. One indirect effect of great importance is the potential for new disease dynamics that rise as a consequence of complex ecological responses to climate change (Leal Filho et al. 2022; Carlson et al. 2022). Although it is many steps removed from an easy “A to B” result of climate change, the importance of mitigating disease cannot be understated. Scientific consensus of the COVID-19 pandemic being zoonotic in origin should be the canary in the coal mine when it comes to underscoring the pressing need to incorporate wildlife disease monitoring into humanity’s response to climate change (Boni et al. 2020).

This paper will focus on walruses (*Odobenus rosmarus*) and the trend of mass haul-outs as a case study relevant to that topic. Walruses are social and gregarious animals that will preferentially haul out on patches of ice to rest and molt when conditions are windless and warm (Fischbach et al. 2016; Jay et al. 2017). While hauled out, they lay close to one another and occasionally make foraging trips in groups (Lyderson 2018). Loss of ice-associated habitat has led these animals to cluster into sparse patches of land, with some colonies accumulating thousands of tightly packed individuals (Fischbach et al. 2016; Jay et al. 2017). The constant close proximity of walruses in these haul-out zones could create the ideal conditions for a disease to spread rapidly throughout a population, which would be exacerbated by the weakened immune response imposed from stresses related to competition for space and resources (Udevitz et al. 2017). A particularly large outbreak could have implications both for the conservation status of walruses as well as the public health of nearby communities. For this project, I aim to assess the pathological risks and possibilities associated with walrus hauling-out behavior and evaluate the need to monitor the health of hauled-out walrus populations.

## Pinnipeds, Walruses, and Currently Known Pathologies

Because data about the pathology of pinnipeds (the clade to which walruses belong) is biased towards organisms that are frequently found stranded by humans or housed in captivity, this section takes a broad look at pinnipeds before diving into walruses specifically (Colegrove et al. 2018). Although there is likely a considerable amount of variability that can be accounted for by species difference, many pinnipeds show enough proximity in phylogeny and biological characteristics to merit this decision (Van Bonn 2015).

Pinnipeds have a plethora of associated diseases that are well documented in the scientific literature (Tryland 2000; Waltzek et al. 2012; Colegrove et al. 2018). This scientific interest is fueled by concerns related to both conservation and public health such as: monitoring marine mass mortality events (MMEs), vigilance towards zoonotic diseases, and suiting needs of veterinarians and wildlife biologists who interact closely with them on a frequent basis (Waltzek et al. 2012). Scrutiny towards pinniped pathology is comparatively greater than other marine mammals because of their ecological position at the terrestrial-aquatic interface (Sanderson and Alexander 2020, Colegrove et al. 2018). Time spent on land and in the water both constitute a significant proportion of a pinniped's day-to-day life, allowing them to be vectors to both receive and spread pathogens from one type of environment to another (Sanderson and Alexander 2020). This terrestriality can be a double edged sword. A pinniped laying on the beach may be much easier to sample and monitor than a cetacean in deep water, but that they occupy that space makes human-animal interactions with pathogen transmission potential more likely.

The diseases that have been sampled and known to science encompass a wide variety of pathogens, including bacteria, viruses, fungi, protozoans, and parasitic worms (Tryland 2000; Waltzek et al. 2012; Colegrove et al. 2018). Among these, viruses are extremely well documented and are responsible for several prevalent diseases that either broadly target vertebrates or are pinniped specific, such as influenza A and phocine distemper virus (Colegrove et al. 2018; Shin et al. 2019; Puryear et al. 2021). Viruses also comprise the vast majority of pathologies found in cases of mass mortality, nearly triple that of bacteria and many times greater than any other type of pathogen (Sanderson and Alexander 2020). Many of the viruses and bacterial infections associated with pinnipeds are also zoonotic in nature, and well known contagions like “seal finger” (from the bacterium *Mycoplasma phocacerebrale*) are significant occupational risk for seal hunters, seal meat handlers, or people who work with seals in a veterinary capacity (White and Jewer 2009). Notably, both influenza A and morbilliviruses are zoonotic, have been implicated in some of the largest MMEs to date, and are related to diseases that have historically been problematic for humankind (Geraci et al. 1982; Visser et al. 1993; Kennedy et al. 2000; Rima and Duprex 2006; Waltzek et al. 2012; Fereidouni et al. 2016).

When it comes to Walrus pathology, it is comparatively difficult to survey this species because its range is constricted to the Arctic, a region that is challenging and expensive to study (Lydersen 2018). Such challenges deprive walrus populations of the same level of attention from infectious disease studies that is given to populations of other pinnipeds (Tryland 2000). One of the more recent serological studies of a Pacific Walrus population emphasized this fact, noting that at the time of its writing, other surveys were much narrower and were twenty or thirty years out of date (Calle et. al 2002). Nonetheless, there are still multiple examples of diseases specific to walruses, many of which were zoonotic, as well as evidence that walruses were exposed to some of the diseases behind other pinniped MMEs (Tryland 2000).

Like other pinnipeds, walrus diseases stem from a variety of distinct sources but see frequent examples of bacteria and viruses, such as brucella, mycoplasma, calicivirus, phocid herpesvirus-1 and -2, influenza A and other agents associated with pneumonia (Barlough et al. 1986; Nielsen et al. 1996; Tryland 2000; Westley et al. 2016). Distinct walrus populations all have unique histories of exposure or isolation from strains of many of these diseases that will likely be influential in determining resistance to future outbreaks (Calle et al. 2002). Although several of these diseases have been the source of MMEs in other pinnipeds, the literature contains a noticeable lack of examples of recorded walrus MMEs caused by diseases.

In addition to being associated with MMEs, many of the pathogens listed above are highly zoonotic in nature (Tryland 2000). Historically, most of the cases of walrus diseases making their way to humans have been from incidents that involve the consumption of walrus meat, such as seal finger and trichinellosis (Springer 2017).

Walruses are not unique among pinnipeds in many of the facts of their immunology. They see a similar variety of pathogen types, have many of the same diseases associated with them, and share the capacity to link pathogens between aquatic and terrestrial environments. Future zoonoses would not be without precedent, and as I will demonstrate in the next section, changing ecological conditions may set the stage for outbreak events with profound implications for the species' conservation status and human public health.

## Assessing Ecological Risks of an Outbreak

In walruses, in pinnipeds, and in most biological organisms, disease is a natural and not uncommon force of top-down or bottom-up control that has long shaped the evolution of individual organisms and their ecosystems (Lenting et al. 2019; Ashley et al. 2020). On the other side of the coin, disease also poses an existential threat to species and ecosystems that are already buckling under the weight of other environmental pressures (McCallum 2012). Recent blights of eelgrass and sea star wasting disease illustrate how the consequences of mass contagion can reach far beyond a host population infected. Both have drastically removed organisms that structure habitat, provide a nursery for plenty of other organisms[1], and have a role in carbon sequestration (Hewson et al. 2014; Aoki et al. 2022; Galloway et al. 2023). As both predator and prey, walruses play a large enough role in Arctic ecology that their removal would significantly influence the ecological structure of their habitats. They can consume dozens of kilograms of benthic molluscs in a single day, and in the process of hunting carve long furrows into the seafloor that disturbs large amounts of sediment and alters the dynamics of benthic invertebrate communities (Acquarone 2004). The process of digging scatters invertebrates that were not even the target of feeding, and the discarded shells provide scraps to scavengers and ecosystem structure to other small organisms (Oliver 1983; Oliver et al. 1985). Walruses are also an important potential source of food for polar bears (*Ursus maritimus*), since their large size and high amount of blubber allows just a single one to provide a bear with a significant nutritional boon (Rode et al. 2014).

A considerable body of evidence is building that climate change will increase the frequency of outbreaks, whether through the direct effect of warmer water expediting the processes of pathogens or indirect effects of habitat contamination, disrupted ecological processes, and altered species boundaries (Sanderson and Alexander 2020; Carlson et al. 2022). The Arctic region will likely be exceptionally labile to these new disease dynamics because it is

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[1] In the case of sea star wasting disease, this comes from the indirect effect of the loss of kelp forests from uncontrolled sea urchin grazing.

warming faster than anywhere else on the globe and is seeing rapid changes to its landscape from sea ice loss (Rantanen et al. 2022). Walruses have historically lived in the Arctic through multiple glacial periods and demonstrate a historical resilience to its dramatic changes in climate (Harington 2008). However, this historical resilience cannot guarantee any prophecy of future survival. Climate shifts of this speed and anthropogenic influences of this magnitude are unprecedented in the last few million years that walruses have lived in the Arctic, and thus there are still risks that the large numbers of walruses may be unarmed to adapt to an epidemic outbreak (Diffenbaugh and Field 2013; Osman et al. 2021). The recent mass haul-out events associated with rapid climate change may set the stage for contagion to spread rapidly throughout the species, emphasizing the importance of proactive measures to survey pathogens.

As melting of sea ice utilized for haul-outs grows scarce, large numbers of walrus are forced to settle for haul out spots that are less than ideal (Laidre et al. 2015). Finding shallow-water shellfish beds for food may require longer and more energetically costly voyages, and space may be in short supply, prompting discomfort and aggression as well as increasing exposure to the excretion and carrion of other walruses and seabirds (Miller 1982; Jay et al. 2017; Puryear et al. 2021). Factor in the increased competition with the fact that walruses will more frequently have to share these haul-out sites with predatory polar bears makes it evident that walruses forced onto land will be under a significant amount of stress- a stress that could inhibit the effectiveness of immune system response (Dohms and Metz 1991; Laidre et al. 2008). Food scarcity may also lead walruses to consume seals and seabirds, an unusual and uncommon but not unprecedented behavior that could potentially open up new pathways of disease (Gjertz 1990; Rausch et al. 2007; Giljov et al. 2017). This issue may also be further compounded by even more routes of transmission opening up from shifts of several subpolar species distributions into the Arctic (Huntington et al. 2020; Carlson et al. 2022). The confluence of high levels of stress, constant proximity of conspecifics, and exposure to novel vectors of disease each contribute to a perfect storm of risk factors for a disease to spread quickly within a haul-out. Furthermore, longer seasons of low ice could allow for more time for a potential pathogen exposure to happen or for the prognosis of a disease to play out (Jay et al. 2017). Should an outbreak erupt amongst a group of walruses, the question of whether the disease would leave the haul-out site and what trajectory it would take is complicated by environmental and biological factors.

Not all populations or herds of walrus are equal in their vulnerability to disease or their ability to spread a contagion. Patterns of ice loss that contribute to the risk factors discussed above are also not uniformly distributed across the Arctic, but instead based around a host of atmospheric, geographical, and seasonal factors (Liu et al. 2021). The division of walruses into Atlantic (*Odobenus rosmarus rosmarus*) and Pacific (*Odobenus rosmarus divergens*) subspecies with a proposed third (*Odobenus rosmarus laptevi*) reflects the role of regional conditions in shaping walrus genetics, ecology, and behavior (Laidre et al. 2008). Between Pacific and Atlantic walruses, the former is vastly greater in terms of sheer population size and more consistently distributed across the northern Pacific Ocean, while the latter numbers far fewer but has a greater number of populations due to the disjointed nature of its distribution (Laidre et al. 2015; Lydersen 2018). For the Atlantic walrus, both of these factors limit the opportunity of a disease to spread far beyond the reach of a haul-out site. Walruses also prefer to not travel great distances to get to foraging sites, so individuals or groups that were already regularly using land will likely not have as much additional stress or changes to their lifestyle as those that were displaced from loss of sea ice (Lyderson 2018). This could be a key factor in the difference towards how Pacific and Atlantic walruses respond to increased ice loss. In the Pacific, the continental shelf provides shallow feeding grounds for walruses even when their ice is hauled out over open waters, whereas in the Atlantic land-based haul-outs are more common since most of the open ocean is far too deep to be convenient for feeding (Laidre et al. 2008). Furthermore, regional factors will also influence any genetic mechanisms that shape disease resistance, such as gene flow between populations and bottleneck effects from histories of overharvesting (Andersen et al. 2009; Shitova et al. 2017). Quantifying the exact risk that the species faces necessitates future studies that can analyze biological and environmental factors on a population scale while taking into account the amount of interconnectedness between populations. While there are signs pointing towards a higher degree of resilience in the Atlantic subspecies, too much uncertainty exists to make any call beyond saying that patterns of vulnerability will be unevenly distributed.

Social structures of age and sex at haul-out sites may also have epidemiological implications. Walruses gather into large congregations of the same sex, and upon weaning, female calves join their mother's herd while male calves splinter off into separate groups. Seasonality of haul-out behavior varies between male and female groups, with male walruses hauling out onto ice in the winter and spring and female walruses hauling out in every season

(Fay 1982). If a pathogen's effects vary based on age and sex characteristics, this composition may either shield or heighten the risk upon the population. For most diseases, the groups of males could possibly have stronger defenses against pathogens because the composition of the herd has an older age and less genetic links to one another than a female herd (Lyderson 2018).

Regardless of location or scope, future disease outbreaks and MMEs are of great concern to the conservation status of walruses (MacCracken 2012). The history of commercial overharvest and present day threats from climate change has prompted a Near Threatened listing on the IUCN Red List (Kovac 2016). A few populations of Atlantic walruses have been shown to have increasing or stable population trends, but the status of most populations is currently unknown (Laidre et al. 2015). If, in the future, climate change were to make a particular group or population more vulnerable to collapse, a disease outbreak could either exacerbate the problem or be a potential tipping point (McCallum 2012). Additionally, zoonosis could potentially cascade the contagion's effects into the broader Arctic community, further endangering other species already facing pressure from global warming (Tryland 2000). As climate change continues into the future, careful surveillance of walrus population health and further scientific investigation on a regional scale will be an effective step in protecting the health of the Arctic ecosystem.

## Assessing Anthropological Risks

Modern walruses predate humans in the Arctic by hundreds of millennia, but the two species have been inextricably linked ever since the earliest humans migrated to the Arctic (Harington 2008; Hill 2017). Virtually every society in history that maintained a connection to Arctic resources was connected to the walrus for sustenance or trade, from Indigenous peoples to Norse settlers to Industrial-era European hunters (Keighley et al. 2022). At the height of European hunting, as many as 140,000 were slain in the period from 1848-1914, reaching a pinnacle of tens of thousands a year (Bockstoce and Botkin 1982). This unsustainable rate of exploitation subsequently crashed populations of Pacific walruses and imperiled Native communities (Mudar and Speaker 2003). Bans on commercial hunting and quotas on subsistence harvest eventually reeled in the scale of exploitation, but many Indigenous communities maintain deep connections with walruses and the resources they provide (Keighley et al. 2022). Such connections are the most consistent links between human activity and walruses in the present day, which necessitates the placement of Indigenous peoples at the center of assessments of risks of zoonosis.

Significant and long-lasting cultural connections to the walrus remain in several aspects of the variety of Indigenous cultures that interact with the animal in some way. This is best exemplified in the rich vocabulary of terms related to the animal in many languages of the north, all of which can reach a degree of specificity that reaches far beyond the limits of the scientific lexicon (Krupnik and Ray 2007). For virtually every part of the walrus there can be found some type of traditional use: hides in the construction of homes and boats, ivory tusks in tools and artisanal goods, and meat as a valuable source of nutrition (Fair 2005; Krupnik and Ray 2007; Prins and McBride 2012). The meat is consumed around the globe and is eaten in forms either raw, frozen, or on special occasions fermented as part of a dish known as igunaq (Larrat et al. 2012). The consumption of raw meat is among the most consistent uses of walrus and likely poses the highest danger in terms of disease exposure (Springer 2017). Several small outbreaks have already occurred in recent history. Botulism and a series of trichinellosis infections dating back to the 1970s prompted a series of governmental disease monitoring and education campaigns in the US and Canada (Larrat et al. 2012; Parkinson et al. 2014). Encouraging the safest meat preparation practices is somewhat complicated because an unmindful approach runs the risk of dishonoring traditional hunting practices. In one of the most recent trichinellosis outbreaks, the CDC's strategy to balance the need for cultural sensitivity with public health objectives was to educate affected communities about risks and alternatives associated with eating raw meat and giving them room to make future decisions under their own judgment (Springer 2017). This approach provides a commendable amount of cultural autonomy but leaves the future health status somewhat uncertain. Future surveys about what changes to food preparation practices, if any, community members made after the educational program could provide valuable information as to whether the program reduced the risk of pathogen exposure.

A pathogen particularly viral among walruses would have dramatic effects on resource availability for the variety of Arctic communities that rely on this pinniped over other forms of sustenance. One that is particularly viral when it jumps to humans could pose a significant threat. The Arctic's remoteness does provide a tangible benefit in limiting a disease's spread when there is ample time for communities and public health infrastructure to coordinate a response, but there are still a host of factors that leave many of them vulnerable (Petrov et al. 2021). Crowded housing conditions, inaccessible healthcare, food insecurity, and overuse of antibiotics all create cracks in the foundation of pathogen resistance that have proved challenging and costly to patch up (Parkinson et al. 2014). The outbreak of Spanish flu of 1918 stands as a case study of almost apocalyptic proportions. Across North America, entire villages were wiped out and many were left with only young children as the survivors. 80% of the deaths in Alaska were Native, and Labrador lost an entire third of its population (Barry 2004; Mamelund et al. 2013). Aiming not to repeat a tragedy of that scope, the United States and Canada took swift and rigorous action to limit the spread of COVID-19 as it crawled towards the far north (Parkinson et al. 2014). Although it would be unlikely for any presently walrus-associated disease to spread among humans with such tenacity, this history should make an especially strong case for the monitoring of pinniped-associated avian influenza that could be directly or indirectly transmitted to Indigenous communities in light of recent discoveries of avian genetic samples within the deadly flu virus (Worobey et al. 2014). The nature of interactions between walruses, other seals, and birds are rapidly changing as walruses shift their diets and the latter two species shift their distributions (Gjertz 1990; Rausch et al. 2007; Carlson et al. 2022). As the Arctic warms, understanding the changing ecological dynamics that walruses and their haul-outs play a part in could play a significant role in protecting remote communities from future scourges of disease.

The role that Arctic tourism will have in shaping ecological interactions has also recently become a topic of growing interest (Stewart et al. 2007; Maher et al. 2014). As it stands, it seems that tourism will have little direct impact on the extent to which walruses and humans come into contact. Most cruises or marine safaris follow strict guidelines on maintaining a safe distance away from the animals to avoid disturbance, and a study showed that the presence of tour vessels had little impact on the behavior of walruses within their vicinity (Øren et al. 2018). However, the influence that tourism plays in the local economy may have indirect influence on human walrus-interactions. Local communities that shift from subsistence to tourism-focused economies may see the nature of walrus interactions change, and with it the number of opportunities where an interaction may lead to infection (Stewart et al. 2007).

## Discussion

There is an abundance of evidence to support the conclusion that as the Arctic warms, the dynamics of walrus pathology will be fundamentally different from the conditions of the past.

Warmer waters and the arrival of new species will bring a host of new pathogens to the species' domain, and increased haul-out behavior will increase the number of opportunities for infection as well as the ease in which a disease can spread (Diffenbaugh and Field 2013; Jay et al. 2017; Sanderson and Alexander 2020; Huntington et al. 2020; Carlson et al. 2022). What is not as clear are the questions of what, when, and where future outbreaks will occur, as well as their level of impact. None of these queries will have an answer that encompasses the whole species because of the myriad ways in which geography will influence factors like which walrus populations will be less adapted to large-scale land haul-outs and how often do humans interact with walruses. Some speculation can be made on a subspecies or stock level basis, but there is too much unknown information to make quantitative predictions of likelihood.

As management organizations create and adjust strategies to adapt to a new era of climate change, there is considerable merit to incorporating the monitoring of wildlife diseases into their calculus (Mörner et al. 2002; Carlson et al. 2022). In the Arctic, this holds true for the surveillance of walrus population health. An enormous outbreak like the 1988 phocine distemper virus could spell disaster for the species' status, but even smaller outbreaks like the morbillivirus that halved the Mediterranean monk seal (*Monachus monachus*) population in 1998 could seriously impede conservation efforts (Heide-Jørgensen et al. 1992; Osterhaus et al. 1998). Furthermore, Indigenous communities would benefit from early knowledge of disease outbreaks because it would prepare them to make changes in harvesting practices or coordinate public health responses. Robust initiatives to monitor the presence of diseases as they occur could be incredibly useful for conservationists and people who rely on harvesting walrus to proactively respond to outbreaks, but there are already significant obstacles to putting one in place.

As it stands, most assays of walrus health are performed infrequently and inconsistently and efforts to curb outbreaks are typically applied retroactively rather than proactively (Calle et al. 2002). The assessment of walrus stocks falls under the purview of five different countries with different approaches and levels of collaboration: The United States, Russia, Canada, Greenland, and Norway (Wiig et al. 2014; Elizaveta 2017). Among these, perhaps the proactive initiative is the Trichinellosis Monitoring Program done by the Makivik Corporation in Canada, which regularly screens samples of walrus meat for trichinella (Larrat et al. 2012). In the US, NOAA, the USGS and the USFWS work together to monitor the status of walrus stocks and investigate the sources of MMEs (Litz et al. 2014; Fischbach et al. 2016). The only consistent and up-close health screening program of walruses conducted by these organizations was in direct response to a 2011 outbreak of skin lesions among ice seals and was closed in 2014 (Speegle and Medeiros 2014). Collaboration with Russian government agencies and scientists was an integral part of the US' approach until the invasion of Ukraine caused it to sever ties with Russian government-affiliated institutions (Gallo-Cajiao et al. 2023). Scientific and managerial organizations within NAMMCO (A commission involving Greenland and Norway) and Canada also consistently track and report on the health status of Atlantic populations, but this work is typically done by aerial stock surveys (COSWEIC 2017; NAMMCO 2018).

Despite the growing importance of wildlife disease monitoring, it is an incredibly costly and obstacle-ridden affair in terms of funding, labor, and infrastructure (Stallknecht 2007). In an environment as remote and forbidding as the Arctic, these challenges are heightened to even greater extremes. Incorporating surveillance of serological health that is forward-acting into climate change adaptation strategy will require insight that helps managers determine which populations they should prioritize allocating the necessary resources to. Further studies can work towards this goal by identifying which groups are in abnormally larger, longer, and more energetically demanding haul-outs due to climate change and thus potentially most at risk of disease outbreaks. In addition, since the last serological study of walruses that looked at a broad array of pathogens was over twenty years ago, it is high time for new investigations of antibodies and disease naivety among walrus populations. Building a means to quickly spot and deal with dangerous pathogens will require a great deal of investment and international collaboration. However, if significant outbreaks do occur in the future then it will have been well worth the endeavor to be prepared for action rather than scrambling for a solution.

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