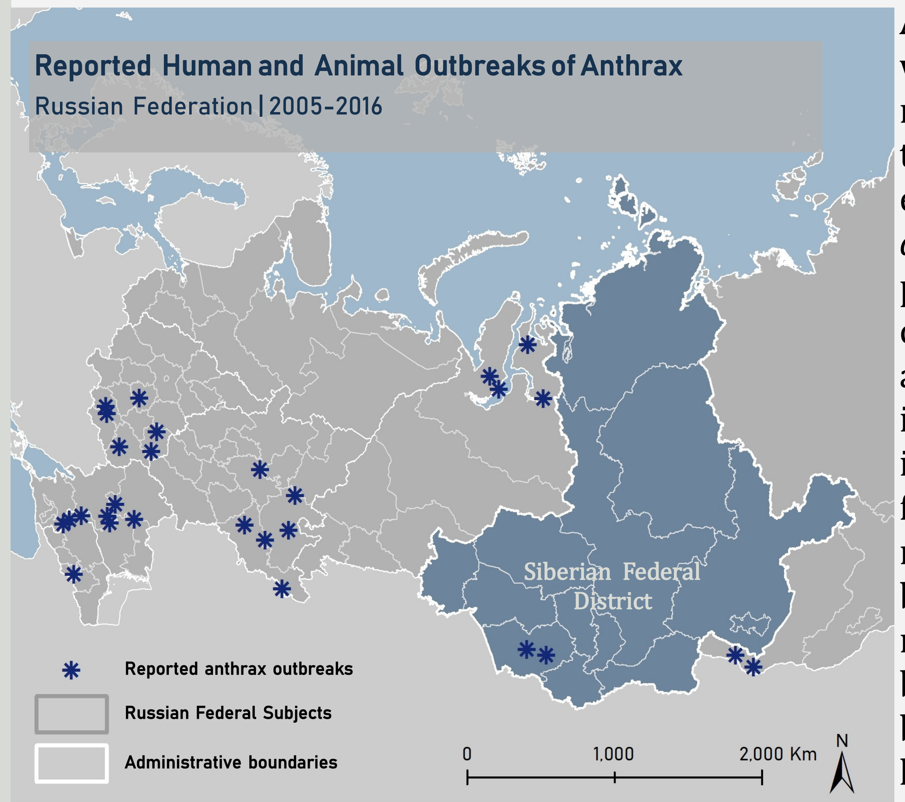
Disease From the Deep Freeze: A Multifactorial Risk Analysis of Anthrax Outbreaks From Thawing Permafrost in the Siberian Federal District of Russia

Tufts University | Cummings School of Veterinary Medicine

When Anthrax Attacks



Anthrax infects a wide variety of domestic and wild animals with extremely high mortality rates and is often associated with spillover into humans, making it a globally significant disease . The infectious agent of anthrax, *Bacillus anthracis*, is a sporulating bacteria, making it particularly persistent in the environment. It can remain dormant in harsh conditions, such as permafrost, before it is uncovered by a grazing animal or other potential host. Mass thawing events, however, can release endospores from permafrost in large numbers, contaminating the environment and causing an outbreak among nearby human or animal hosts. If recognized quickly, instances of these outbreaks in humans and domestic animals can be contained, but when outbreaks infect wildlife, it often leads to mass population die-offs. This large-scale mortality can be devastating to the diversity and natural order of a biological community, especially for species of conservation concern. As global warming becomes an increasingly forthcoming problem, permafrost that was once thought to be permanent is now at risk of thawing and releasing centuries old *Bacillus anthracis*. We have already seen instances of these outbreaks in Siberia where a heat wave in the summer of 2016 caused the death of over 2,300 reindeer. Although it is becoming increasingly more relevant, melting permafrost is not the only trigger for anthrax outbreaks. This analysis seeks to map multiple factors that make animal populations more vulnerable to the spread of anthrax that may inform a proactive, rather than reactive, disease management plan.

Risk Factors and Methods

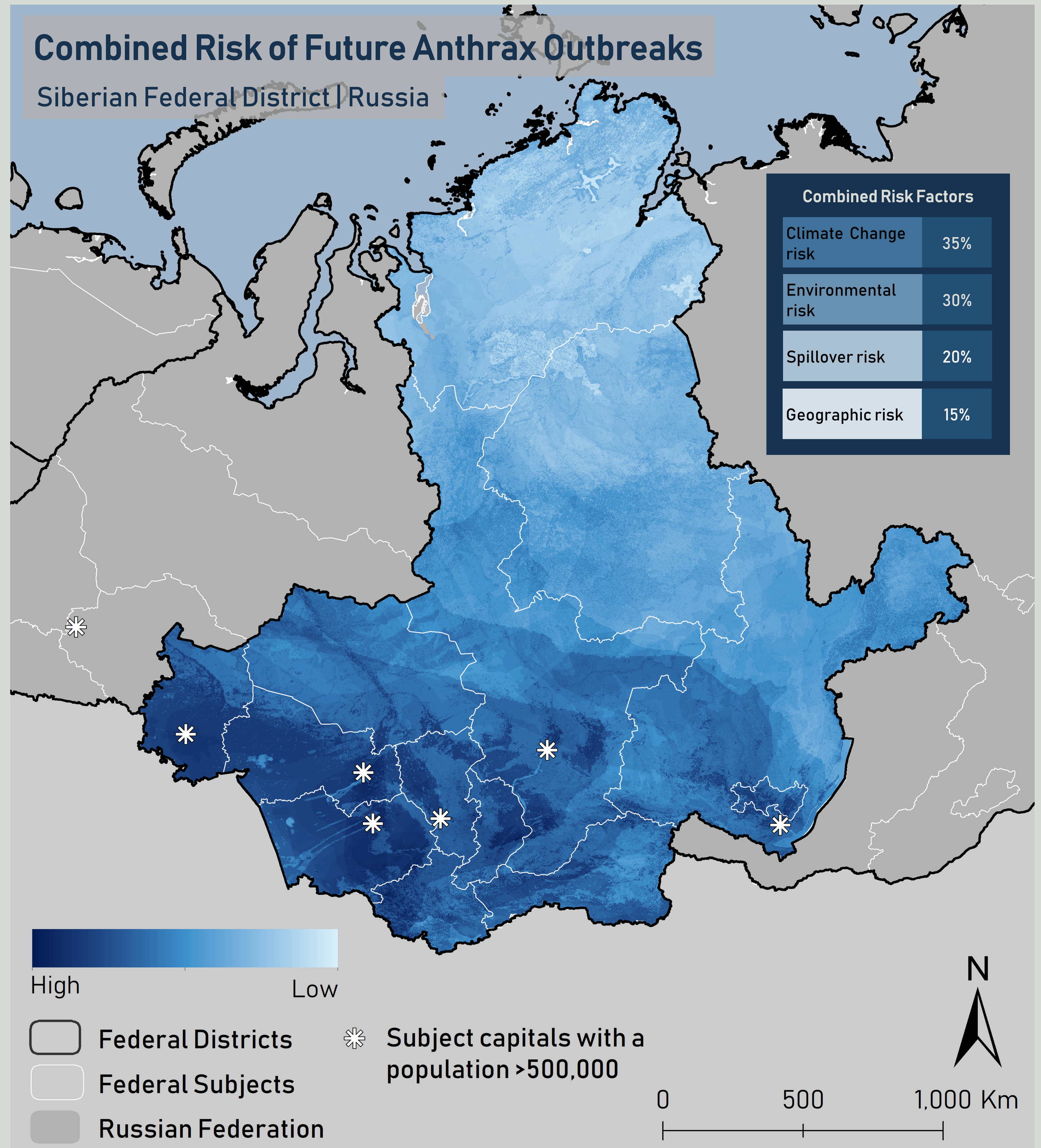
Many of the triggers for anthrax outbreaks in the Russian Arctic are not easily analyzed together. For this reason, factors that influence outbreak risk were analyzed using a multistep step method. Factors were initially divided into four groups and weighted based on the extent of their influence on an outbreak. The risk contributed by each category was then re-weighted and combined using a raster calculator to create a final outbreak risk analysis across the Siberian Federal District.

Geographic Risk

The geographic risk factors focused on areas with the most potential for runoff and water pooling that could transport bacterial particles. Factors included elevation, slope, average annual precipitation, and proximity to major rivers. Low elevation, high slope, more precipitation, and closer proximity to rivers were all considered higher risk. First, a slope tool was used on an elevation dataset to extract necessary slope information. Next, the Euclidian distance tool was used on data of major rivers. All factors were then reclassified, weighted, and added using the raster calculator.

Climate Change Risk

The risk associated with factors related to climate change focused on melting permafrost and its potential to release anthrax particles. This included looking at an average of projected annual climate change data, average annual precipitation, and permafrost extent. Permafrost can melt between 0 and -2.5 °C and is more likely to melt when it is less dense, so these conditions were considered high risk. Projected annual temperatures for every fifth year through 2050 were averaged to achieve a projected change. All factors were then reclassified, weighted, and added using the raster calculator.

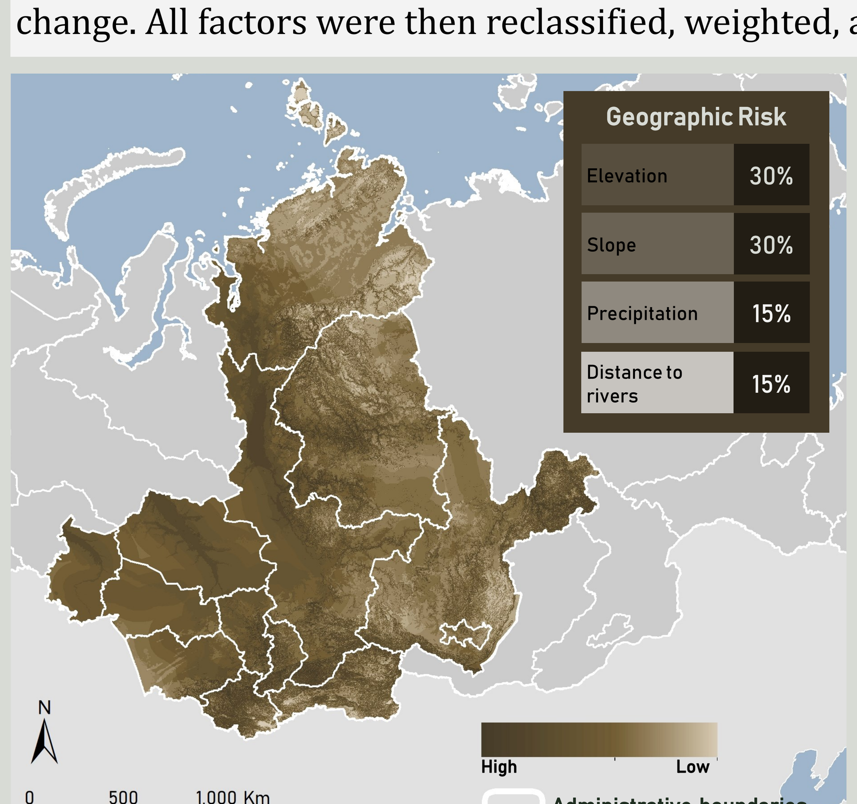


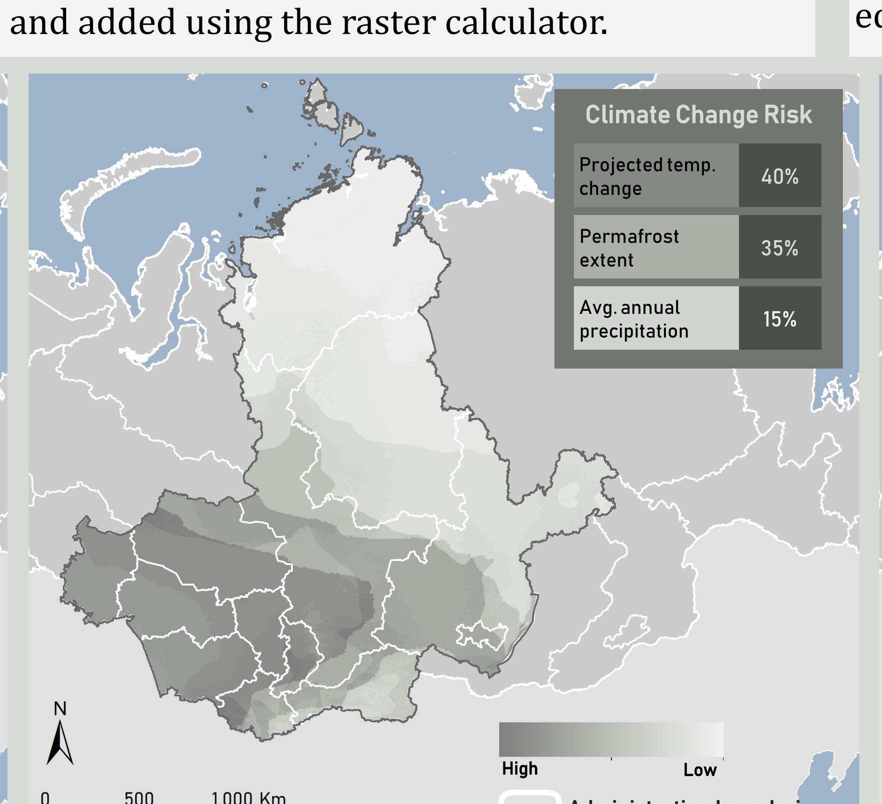
Environmental Risk

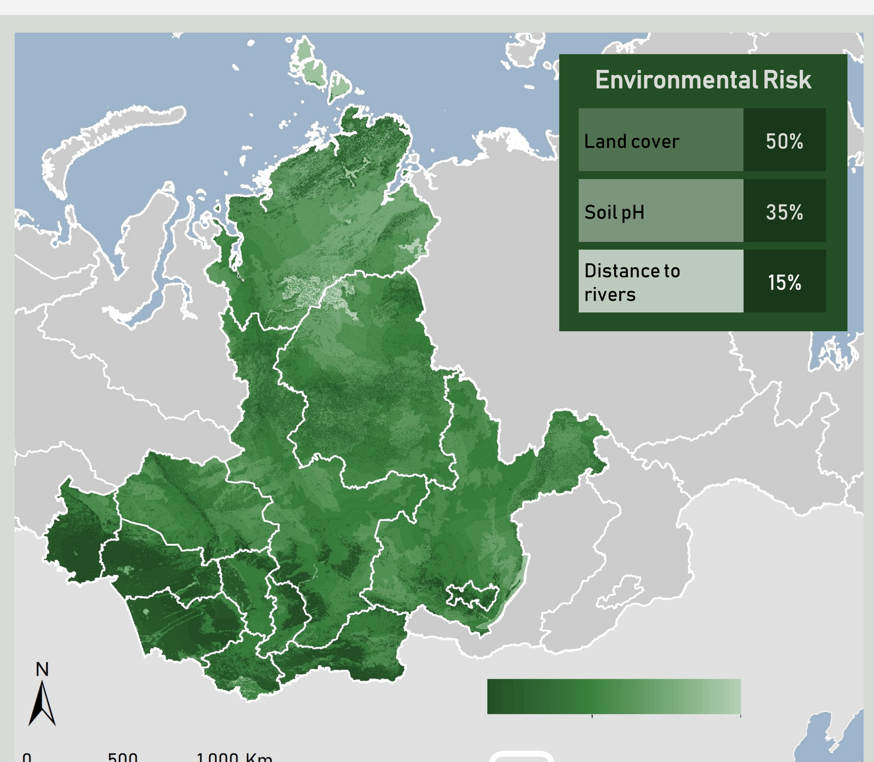
The risk from environmental factors focused on the likelihood that anthrax is in a given area based on favorable environmental conditions. This included land cover, soil pH, and proximity to rivers. Grasslands and croplands as well as a soil pH between 5 and 9 are most favorable for *Bacillus anthracis* and were all considered high risk. Using the distance to rivers layer from the geographic analysis as a measure of potential water contamination, all factors were immediately reclassified, weighted, and added using the raster calculator.

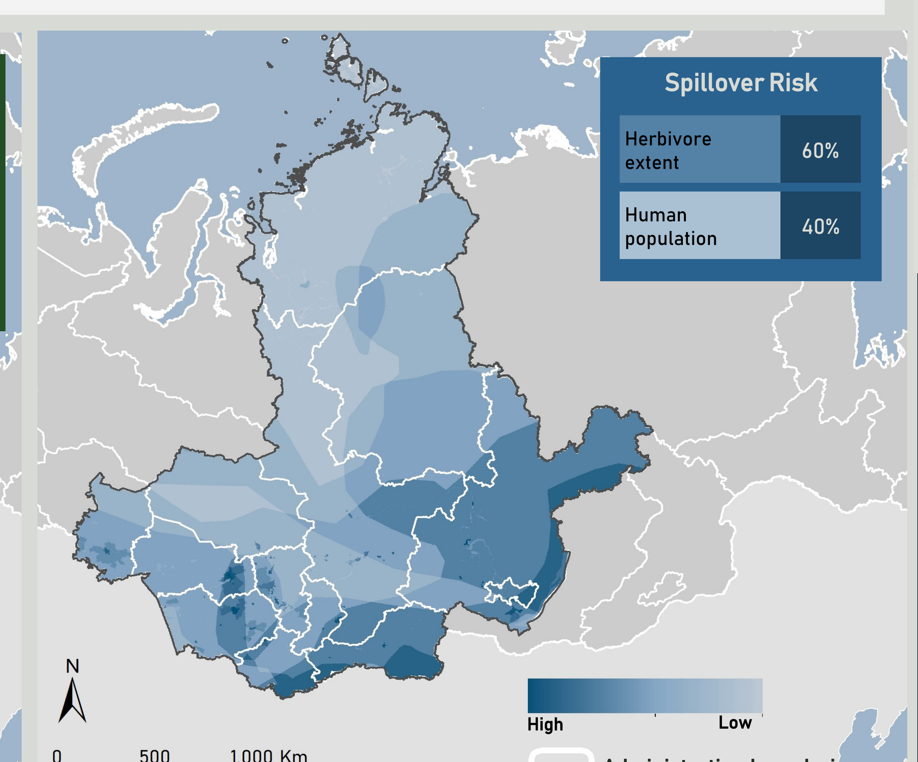
Spillover Risk

Factors associated with the risk of spillover between humans and other animals focused on how likely it was for anthrax to spread if an outbreak were to occur. This was analyzed by looking at human population density as well as herbivore population extent as herbivores are most likely to contract environmental anthrax because of their grazing and grooming behaviors. Large populations also increase contact between herbivore species as well as humans and promote the spread of disease. The herbivore habitat extents were converted to rasters using a polygon to raster tool and then all factors were reclassified, weighted, and added using the raster calculator.

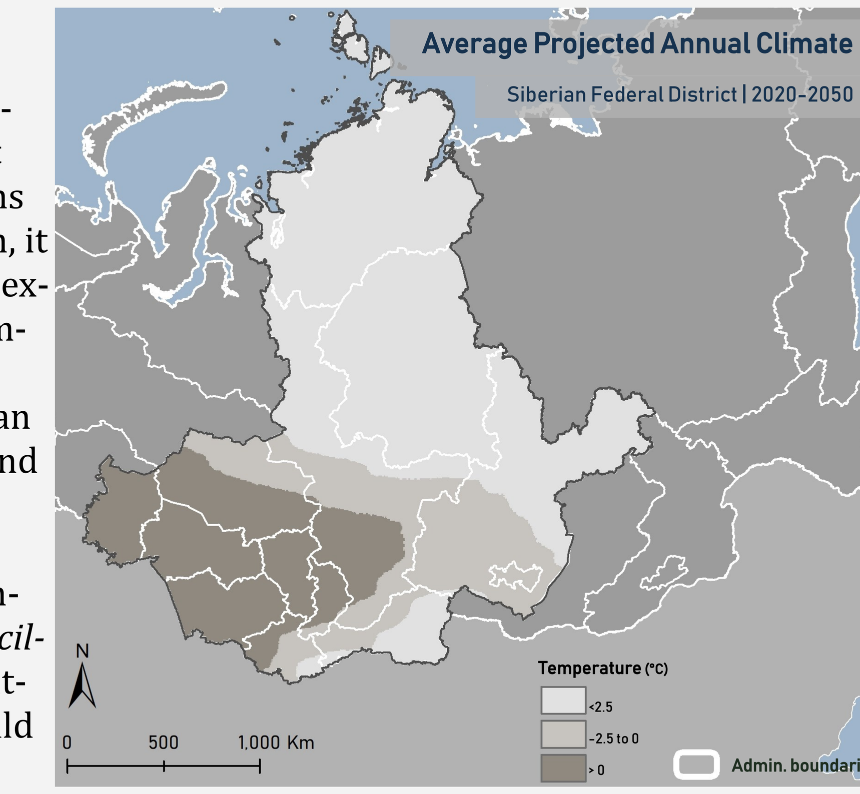




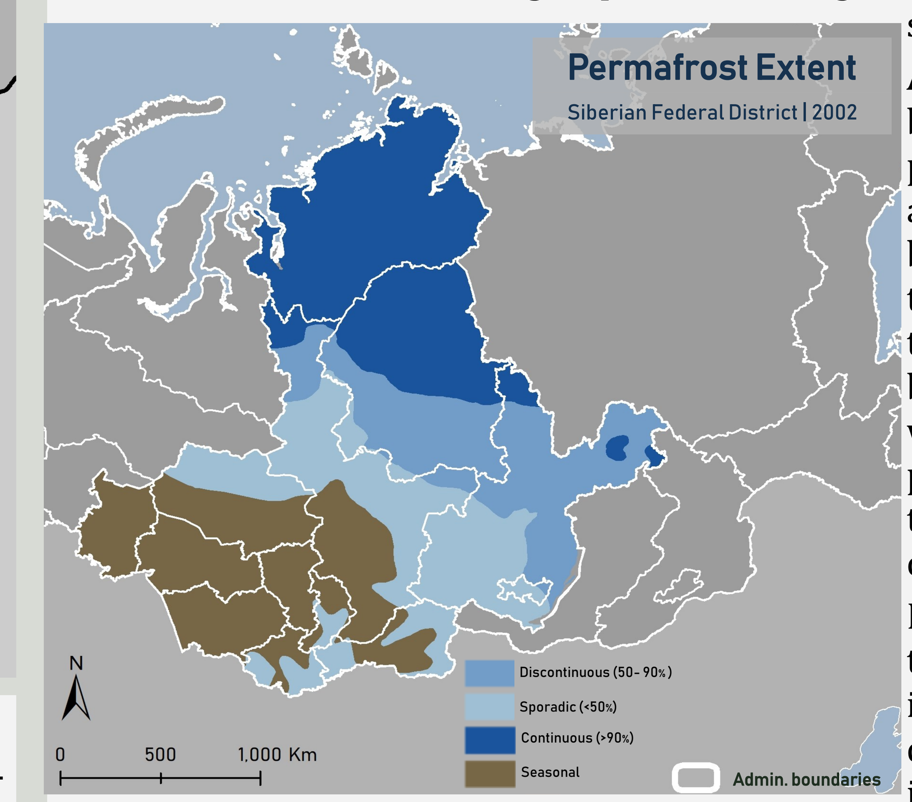




Results and Discussion



Based on the final combined factor map, it is clear that the southwest region of the Siberian Federal District is at highest risk of a future anthrax outbreak by 2050. This poses the largest threat to herbivores but is also a risk to humans as well as other animal species. For this reason, it is critical not to ignore the potential risks that exist in other parts of Siberia and Russia. Most importantly, the final risk map is consistent with two of the most recent outbreaks in the Siberian Federal District, but the analysis does not extend to areas where other outbreaks have occurred throughout the country (depicted in the "Reported Human and Animal Outbreaks of Anthrax" map). Another consideration is that *Bacillus anthracis* is a very versatile bacteria and, although it has environmental preferences, it could be released from any region of thawed permafrost. That being said, it appears that the majority of permafrost thawing will occur in the middle region of the country by 2050. This is still in agreement with the region of highest risk for future outbreak but may change climate projections. The other categories of risk show there are also pockets of high-risk in regions that are specific to certain factors. For example, it appears the highest geographic risk is in the northwest part of Siberia, contradicting the final map. For this reason, deciding to consider the four risk factor groups together or in isolation may be situationally dependent on environmental extremes. Attempting to incorporate both the combined and isolated factor groups into a management plan, however, could create a better understanding of the full extent of risk.

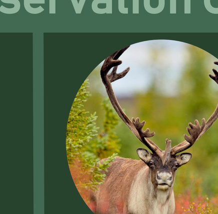


As a result of the complexity of anthrax outbreaks, there are several limitations to the applied analysis. First, *Bacillus anthracis* can be aerosolized, but this was not a factor that could be readily and geographically analyzed. In addition, only herbivores were considered here as they are at highest risk for contracting anthrax, but there are risks to other hosts whose ranges were not included in this analysis. Most importantly, however, future analyses should be extended to the western districts where many past outbreaks have occurred.

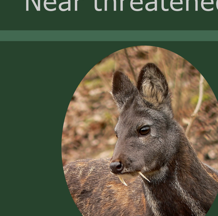
Based on these combined observations it is hard to pinpoint a single region of concern, emphasizing the need for a proactive approach to anthrax disease surveillance in Siberia. This should be implemented through surveillance of high-risk areas as well as changes and extremes in individual factors that trigger outbreaks. Proactive intervention could include testing soil samples in multiple areas as well as vaccinating high-risk domestic and wild animals to create barriers to spillover and outbreak. The findings of this analysis are critical to conservation as many of the high-risk areas are near human populations as well as several species of conservation concern. Considering the way climate change is altering the environment has major implications for the health of humans and animals in this arctic region of Russia.

Species of Conservation Concern

Ovis ammon
Common name: Mountain sheep
IUCN status: Near threatened



Rangifer tarandus
Common name: Reindeer (caribou)
IUCN status: Near threatened



Moschus moschiferus
Common name: Siberian musk deer
IUCN status: Near threatened

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Projection: North Pole Lambert Azimuthal Equal Area Russia

Data Sources: IUCN Red List of Threatened Species, the Database of Global Administrative Areas, ArcGIS Online, Land Resources of Russia, viewfinderpanoramas.org (global DEM data), CIESEN Gridded Pop. of the World, Global Land Cover, ESRI Data Maps 2018 Hydrolines, World Clim.

Works cited:

Goudarzi, Sara. "As Earth Warms, the Diseases That May Lie within Permafrost Become a Bigger Worry." *Scientific American*, November 2016.
Walsh, Michael G., et al. "Climatic Influence on Anthrax Suitability in Warming Northern Latitudes." *Scientific Reports*, vol. 8, no. 1, June 2018, pp. 1–9.