INTERNATIONAL JOURNAL OF CIRCUMPOLAR HEALTH
2021, VOL. 80, 1925446
https://doi.org/10.1080/22423982.2021.1925446

Taylor & Francis
Taylor & Francis Group

OPEN ACCESS Check for updates

The "second wave" of the COVID-19 pandemic in the Arctic: regional and temporal dynamics

Andrey N. Petrov [a,b], Mark Welford[b], Nikolay Golosov[a,b], John DeGroote[b], Michele Devlin[c], Tatiana Degai [a,b] and Alexander Savelyev [d]

[a]ARCTICenter, University of Northern Iowa, Cedar Falls, IA, USA; [b]Department of Geography, University of Northern Iowa, Cedar Falls, IA, USA; [c]Department of Health, Recreation, and Community Services, University of Northern Iowa, Cedar Falls, IA, USA; [d]Department of Geography, Texas State University, Round Rock, TX, USA

ABSTRACT
This article focuses on the "second wave" of the COVID-19 pandemic in the Arctic and examines spatiotemporal patterns between July 2020 and January 2021. We analyse available COVID-19 data at the regional (subnational) level to elucidate patterns and typology of Arctic regions with respect to the COVID-19 pandemic. This article builds upon our previous research that examined the early phase of the COVID-19 pandemic between February and July 2020. The pandemic's "second wave" observed in the Arctic between September 2020 and January 2021 was severe in terms of COVID-19 infections and fatalities, having particularly strong impacts in Alaska, Northern Russia and Northern Sweden. Based on the spatiotemporal patterns of the "second wave" dynamics, we identified 5 types of the pandemic across regions: Shockwaves (Iceland, Faroe Islands, Northern Norway, and Northern Finland), Protracted Waves (Northern Sweden), Tidal Waves (Northern Russia), Tsunami Waves (Alaska), and Isolated Splashes (Northern Canada and Greenland). Although data limitations and gaps persist, monitoring of COVID-19 is critical for developing a proper understanding of the pandemic in order to develop informed and effective responses to the current crisis and possible future pandemics in the Arctic. Data used in this paper are available at https://arctic.uni.edu/arctic-covid-19.

ARTICLE HISTORY
Received 26 March 2021
Revised 29 April 2021
Accepted 29 April 2021

KEYWORDS
COVID-19; Arctic; regions; pandemic; trends; mortality; waves

Introduction

The COVID-19 pandemic has spread across the globe while exhibiting considerable spatial and temporal variability. COVID-19 propagated rapidly in early 2020 as "superspreaders" moved freely around the world before the global emergency was recognised. First, COVID-19 spread rapidly across China [1] and escaped beyond borders through airline travel [2,3]. Thereafter, local commuting for work [4] and K-college students seeded more local disease propagation [5], while systemic power, economic, political and social inequalities facilitated more COVID-19 infections, greater COVID-19 disease severity and higher COVID-19 mortalities among socially disadvantaged groups [6]. Remote regions tended to have the later occurrence of COVID-19 with rotating workers or other travellers eventually seeding clusters of COVID-19 [7].

The Arctic is of special interest with respect to the COVID-19 pandemic. As of 1 February 2021 there were 412,154 confirmed cases of COVID-19 and 6,751 deaths. Among 7.5 million Arctic residents [8] who live in 8 countries, there is considerable diversity in terms of demography, living conditions, ethnicity, access to culturally appropriate public health programming and the availability of quality medical care. Although populations are mostly concentrated in cities [9], rural and remote communities have a large number of people characterised by high vulnerability to COVID-19. Native populations in the Arctic, as in many Indigenous communities around the world, can experience disproportionately higher rates of morbidity and mortality from COVD-19 due to a number of factors. These can include, for instance, geographic barriers to health services, political marginalisation and disenfranchisement, multigenerational and densely packed housing, poor sanitation and water systems, higher rates of pre-existing health issues like diabetes, obesity, and respiratory infections, and other factors [10,11]. In the USA, Native Americans and Alaska Natives were 1.8 times more likely to die than White residents [12]. Additionally, because mortality rates for COVID-19 are highest among older populations, Indigenous communities are

CONTACT Andrey N. Petrov andrey.petrov@uni.edu 1227 W 27th Street Cedar Falls, IA 50614, USA

particularly at risk for losing their elders [11–13]. This is especially tragic given the key leadership roles of elders in Indigenous societies with respect to Indigenous languages, traditional healing and medicinal practices, and sustainable living.

At the same time, Indigenous communities possess a unique potential for resilience. Arctic Indigenous Peoples have survived multiple-health disasters over many decades [14] and developed ways to cope with infectious diseases [15]. The high level of vigilance and preparedness to deal with a health catastrophe was instrumental in preventing the spread of COVID-19 in many predominantly Indigenous regions (e.g. Nunavut and Greenland) or helped curtail pandemic through rapid vaccination (e.g. rural Alaska). For example, First Nations, Meti and Inuit in Canada, managed to keep infection rates below the national average [16]. These experiences are instrumental in understanding what actions could be effective in managing future epidemics in remote and rural areas [17,18].

The COVID-19 pandemic in the Arctic captured considerable attention from policymakers and researchers, although there are still very few academic papers that provide a thorough analysis of COVID-19 data at the regional level. The Arctic Council published an early report [19] that highlighted multifaceted impacts of the COVID-19 pandemic on health, economy, culture and society in Arctic regions. It also pointed to additional vulnerabilities to the pandemic observed in Arctic communities. At the same time, this and other sources also described the ways in which Indigenous knowledge and traditions could be helpful in fighting COVID-19 and similar health emergencies [19,20]. A considerable amount of reporting has focused on the Indigenous Peoples' sufferings, in particular, due to limited access to medical facilities, low quality of care, impacts on elderly and cultural implications [21; 22]. Indigenous food systems in the Arctic were also severely affected both with respect to the ability to secure food [23] and to sell food products, such as reindeer meat [24].

A few systematic studies were conducted at the circumpolar level. Petrov et al. [7] examined spatiotemporal dynamics in the early stages of the COVID-19 pandemic, between February and July. The paper illustrates distinct typologies across Arctic regions while predicting the worst of the pandemic will be observed later in 2020. A small number of available studies focused on one region [e.g. 25–27]

The goal of this paper is to undertake a preliminary analysis of the spatiotemporal dynamics of the COVID-19 pandemic in the Arctic with particular focus on the "second wave" (SW) that took place in the Arctic between September 2020 and January 2021. We build upon an earlier publication [7] and extend our analysis in time to cover the 12 months, February 2020 to January 2021, since COVID-19 was detected in the Arctic. The paper's objectives are to (1) examine the spatiotemporal dynamics of COVID-19 from February 2020 to January 202 and in particular, the pandemic's SW in September 2020 to January 2021; and (2) develop a typology of Arctic regions based on the spatiotemporal patterns of the pandemic.

Methods

Spatial coverage and data

COVID-19-related spatial and temporal data have been collected at the subnational (regional, county) level for 52 regions in 8 countries (Figure 1): Canada, Kingdom of Denmark (Greenland and Faroe Islands), Finland, Iceland, Norway, Sweden, Russia and the USA. We generally used the Arctic boundaries established by the Arctic Human Development Report [28] and extended by Jungsberg et al. [8].

Data

Data on COVID-19 cases and deaths were harvested daily at 17:00 GMT from the Johns Hopkins University Systems Science and Engineering for Canada, Greenland, Faroe Islands, Iceland, and the USA (https://coronavirus.jhu.edu/map.html), the Public Health Agency of Sweden (https://www.folkhalsomyndigheten.se/), the National Institute for Health and Welfare of Finland (https://thl.fi), the Government of the Russian Federation (https://стопкоронавирус.рф), and Verdens Gang (Norway) – https://vg.no. We gathered and analysed data between 21 February 2020 (the first documented case in the Arctic) and 31 January 2021. Automated collection processes were used for the data retrieval. The data were published daily on the Arctic COVID-19 dashboard (https://arctic.uni.edu/arctic-covid-19).

Variables and definitions

We examined the variables most frequently used to describe epidemics [29]. *Confirmed cases* are the number of medically confirmed cases (based on jurisdiction-specific standards) of COVID-19. *Daily increase* is the number of additional cases confirmed within 24 hours after the previous reporting. *Incidence rate* represents a cumulative number of confirmed cases per 100,000 residents in a given period of time. *Confirmed deaths* are the number of medically confirmed deaths attributable to the COVID-19 infection (based on the jurisdiction-specific standards). *Mortality rate* is the number of confirmed deaths

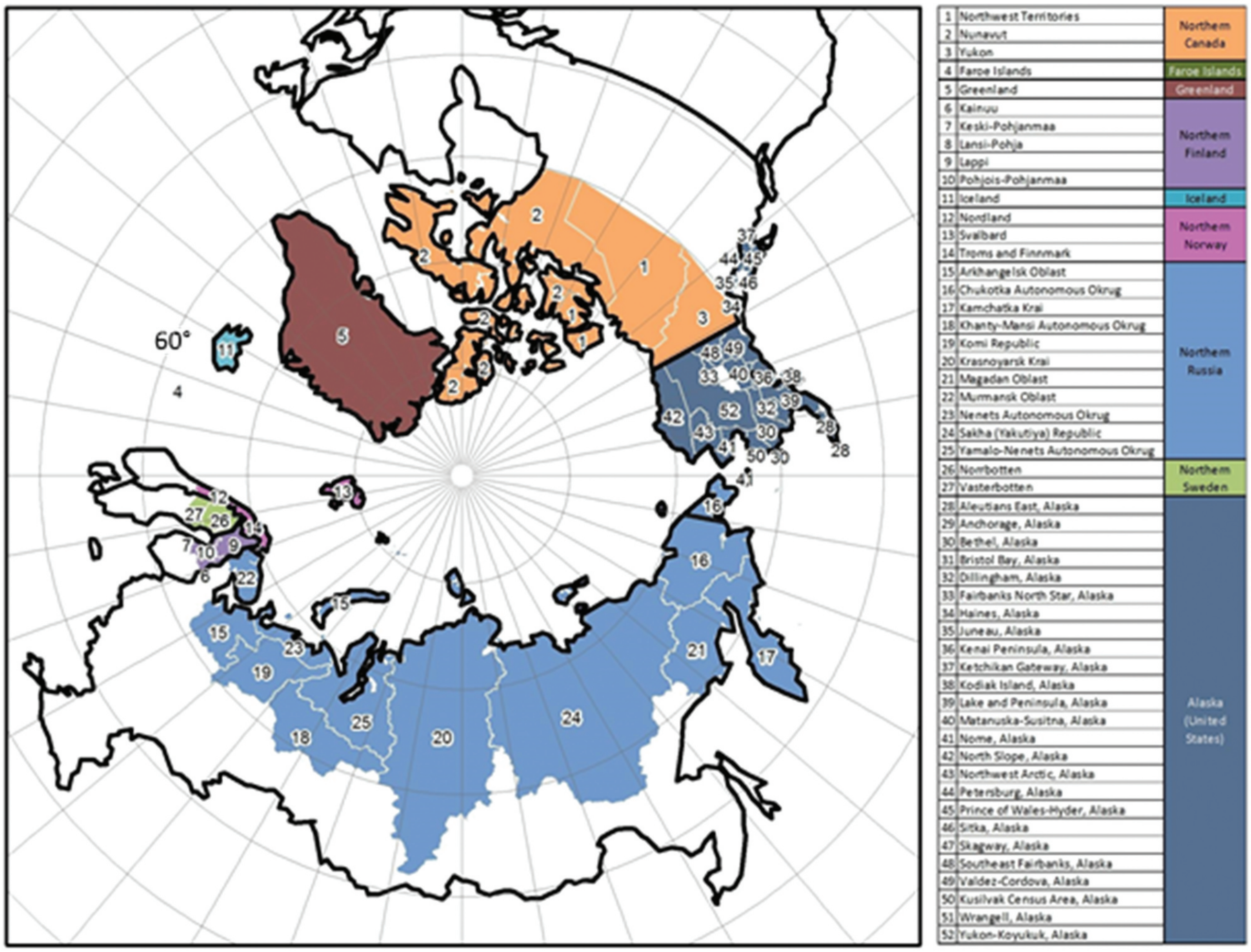

Figure 1. Study area.

attributable to COVID-19 infection per 100,000 residents in a given period of time. *Case Fatality Ratio*, or CFR, is the total number of deaths divided by the total number of confirmed cases at a given point in time. We also examined Google mobility data [30] to explore the connectivities between workplace and other mobilities and COVID-19 proliferation. Although mass vaccinations started only in late December 2020 and are not separately analysed in this paper, we used the ArcticVAX tracker [31] to obtain background information on vaccination trends.

Results

Overall dynamics: cases, deaths and CFR – the "first wave"

Petrov et al. [7] reported that COVID-19 arrived in the Arctic in February 2020, and infections rapidly spread in spring and summer, when many Arctic regions, in particular, the Russian Arctic, became COVID-19 hotspots. COVID-19 literature often uses an analogy of "waves" to describe the pandemic's temporal pattern [32,33]. A "wave" in epidemiological terms could be described as a dynamic characterised by distinct upward and/or downward periods that are sustained over a period of time (vs. temporary spikes, upticks, daily variability, etc.) [34]. It is important to point out that the start and end periods, magnitude and sequence of the "waves" can vary considerably among regions and localities.

In the Arctic, as seen in Figure 2, the growth in confirmed cases was initially relatively steady, but increased in the late spring and early summer forming the "first wave" of pandemic in May–July. By 1 July 2020 53,057 Arctic residents had been diagnosed with COVID-19, and 560 died of the disease. The "wave" began to recede in July and August, flattening the rate of COVID-19 cases growth through September. The "first wave" pattern was evident for all Arctic regions with significant proliferation of the pandemic (only Northern Canada and Greenland had

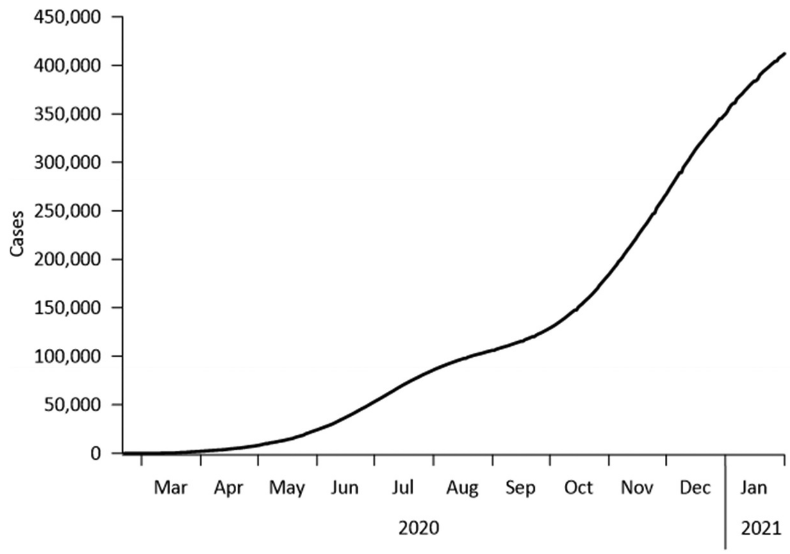

Figure 2. Cumulative confirmed COVID-19 cases in the Arctic.

very few cases). Figure 3 demonstrates that, while different parts of the Arctic started experiencing the pandemic at slightly different times (first in Iceland and Norway, and later in Russia), the cumulative number of cases per 100,000 increased and then levelled off. Northern Russia was the only jurisdiction with less pronounced flattening in late summer and early fall.

A summer decrease in daily cases was observed in many areas of the world, including the Arctic counties [35]. Its origins are not entirely understood, but they were likely related to seasonal weather and activity dynamics, availability of outdoor spaces and preventive measures, such as lockdowns, closures, quarantines and telecommuting [36,37].

The pattern of COVID-19-related deaths closely followed the infections (Figure 3), with the "first wave" taking shape in late spring and summer and generally ending by late August. Notably, countries with swift and strict restrictive measures, such as Iceland, cut the first wave in April and generally experienced a COVID-19 deaths free summer. In contrast, deaths continued to grow in Northern Russia and Alaska.

The "second wave"

The signs of the "second wave" appeared in the Arctic in mid-September 2020, with a major increase between October and December. The wave generally subsided by February 2021 (Figure 4). This second wave has been observed around the world but with different timing: for example, it started in late July in Europe [38]. The Arctic's "second wave" was far more severe than the first one. In all regions, the daily number of confirmed cases and deaths exceeded spring volumes. At the height of the "first wave" the Arctic as a whole reached a daily increase of 10 cases per 100,000 (July) while in mid-December 2020 it topped 25. Similarly, the daily death rate climbed to 0.5 per 100,000 in December from an early peak of 0.2 in July. It is important to recognise that in the early stages of the pandemic, testing was less available thus fewer cases might have been detected. Still, there is enough evidence to suggest that the "second wave" was more pronounced and deadly.

COVID-19-related deaths during the "second wave" grew rapidly beginning in October and spiking in December and early January, with an average lag of 2 weeks from the corresponding highs in recorded infections (Figures 3 and 4). COVID-19 mortality steadily declined in January. Daily death rates were generally higher in the second wave, particularly in Alaska, where they have risen to nearly 0.7 per 100,000.

It is notable that the CFR exhibited a different pattern during the "second wave" as compared to the first (Figure 5). In general, after the "first wave" spike, CFR was steady, probably as a function of more prevalent testing and improved medical care. The most remarkable drop was in Northern Sweden, which had very high CFR in the first and into the second wave but eventually settled more in line with other regions.

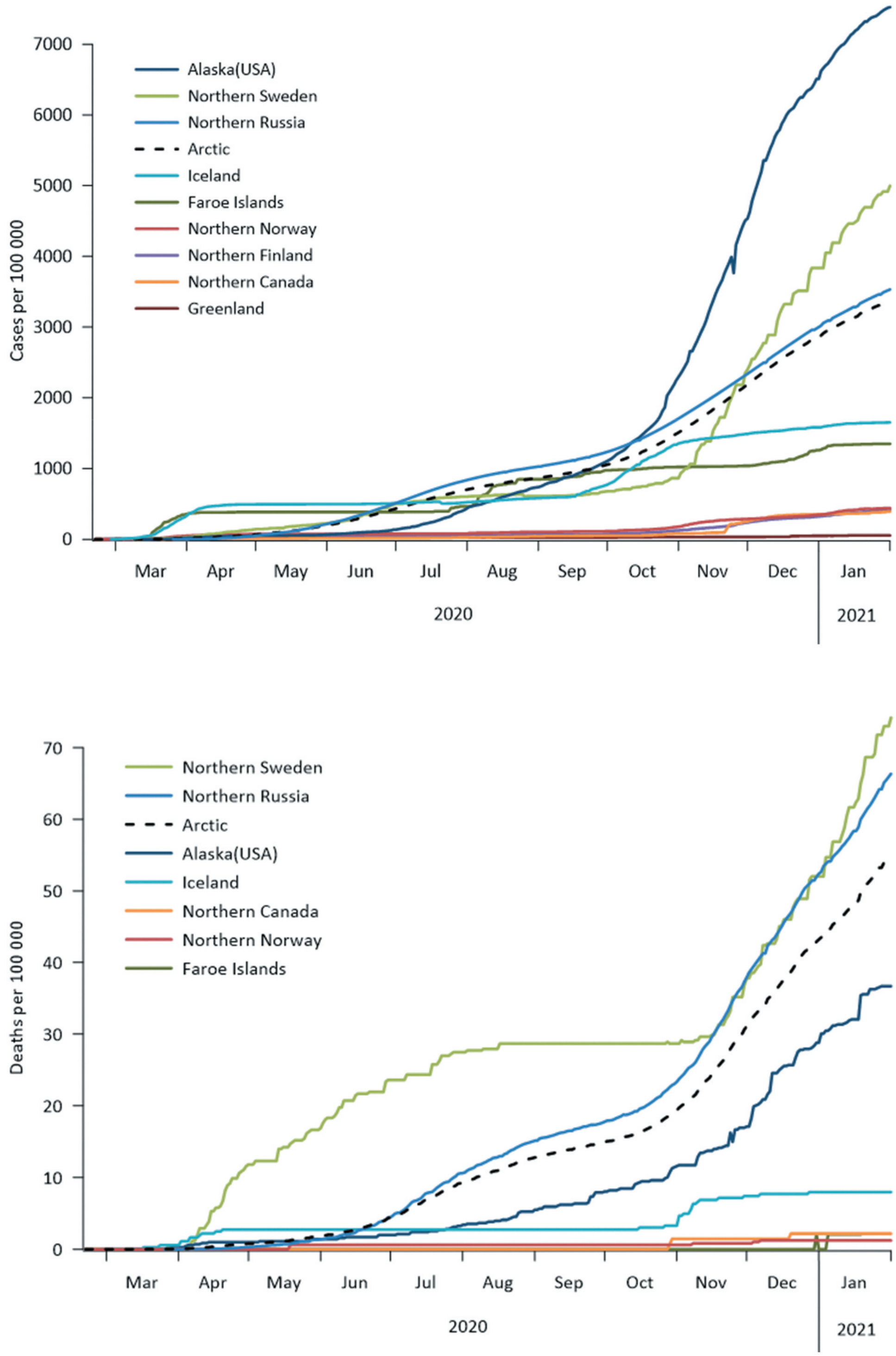

Figure 3. Cumulative cases per 100,000 (top); Cumulative deaths per 100,000 (bottom).

Sweden had enforced rather soft anti-pandemic policies throughout the year. Still, CFR in the Arctic neared 1.5 in December, although CFR in northern regions was consistently smaller than in the southern parts of the Arctic states, with the exception of Northern Russia.

Petrov et al. [7] indicated that in the early stages of the pandemic the proliferation of the COVID-19 in

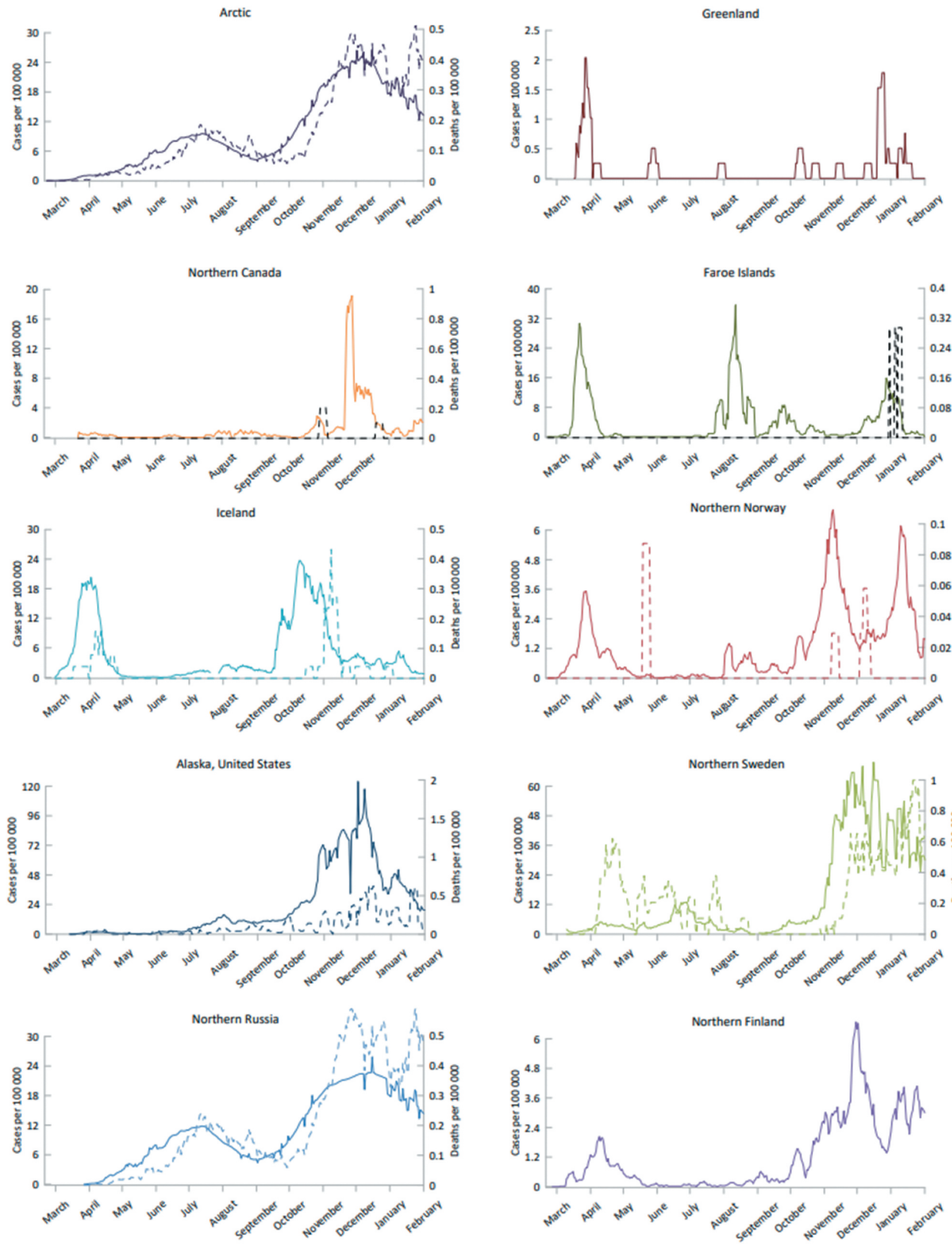

Figure 4. Daily increase in confirmed COVID-19 cases and deaths (7-day moving average).

Note: Finland aggregates fatalities by hospital districts, which differ from regions used for aggregating cases. Death rates for Finland are not reported.

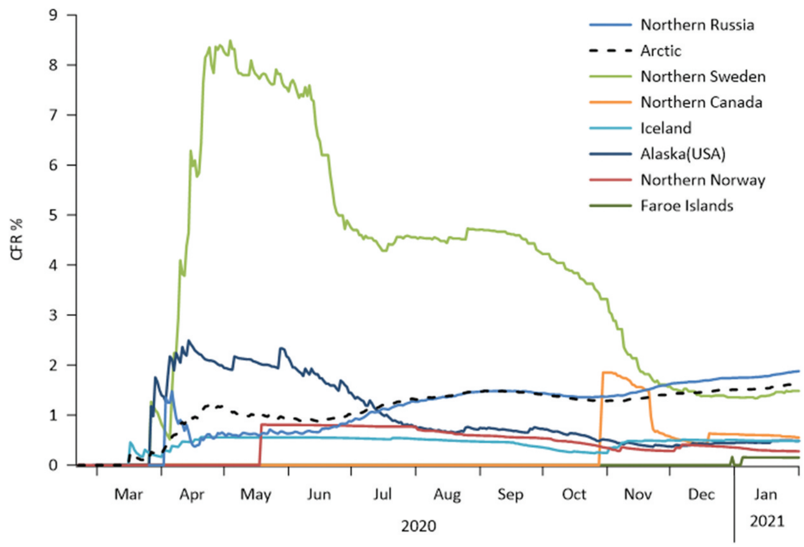

Figure 5. Case–Fatality ratio (CFR).

remote and rural areas was quite limited, especially in Northern Canada, Greenland and Alaska. They warned, however, that these places would face crisis later in the season as they would be vulnerable to the impacts of the pandemic due to isolation, restricted healthcare options and comorbidities prevalent in these areas. The "second wave" confirmed this argument, and many remote communities, especially in Alaska and Northern Russia, largely spared from the pandemic earlier, were deeply affected in the fall and winter of 2020–2021. Mathematical modelling suggests that the epidemic intensity is also lower in the second wave than in the first wave in USA and Russia as the epidemic spread outward from densely populated nodes into each country's suburban and rural areas and Arctic areas [39,40].

Although all Arctic regions registered COVID-19 cases and most had recorded deaths (with the exception of Greenland), the magnitude of the pandemic differed drastically. Greenland and Northern Canada have seen isolated spikes that were quickly brought under control with few or no fatalities. In contrast, Alaska, especially rural boroughs, experienced an explosive growth of cases and deaths, leading the Arctic in terms of infection and mortality rates during the "second wave." The case of Alaska is particularly interesting given that its October–December wave dwarfed any spikes in other Arctic jurisdictions (reaching 123 daily cases per 100,000 vs. 69 in northern Sweden, which was a distant second). Still, in most northern regions the daily confirmed cases and mortality rates were lower than in the southern parts of their countries (Table 1 and 2), which was also true during the "first wave" [7]. A notable exception was Northern Russia, where both recorded infection and death rates were higher than nationally.

Regional dynamics and typology

The spatiotemporal dynamics of the pandemic, and the"second wave" in particular, varied considerably by region. Petrov et al. [7] developed aregional typology of the pandemic in the Arctic at the early stages (February–July 2020), andsome of the same patterns emerged during the subsequent period. However, there were anumber of stark changes that impacted the regional groupings.

Shockwaves. These regions experienced an early onset of the pandemic in the spring of 2020 with a rapid spike in both cases and deaths. The "second wave" was also characterised by quickly escalating COVID-19 infection and mortality rates, which rather precipitously subsided. Sometimes, multiple spikes were observed. This group consists of Iceland, Faroe Islands, Northern Norway, and Northern Finland. Although the dynamics vary among these jurisdictions considerably, with the most notable deviation in the Faroe Islands, where there is an additional spike in summer, the pattern is quite distinct from elsewhere in the Arctic. All of these regions instituted tough prevention and mitigation measures early in the pandemic and continued with restrictive policies throughout the year. Due to aggressive policy implementation, these jurisdictions were able to overcome the "first wave" by May 2020 [e.g. 26]. Nevertheless, the second wave hit all 4 countries, although at

Table 1. COVID-19 pandemic in the Arctic regions on 31 January 2021.

Country/ Territory	Cases, cumulative	Deaths, cumulative	Cases, per 100,000	Deaths, per 100,000	CFR, %
Arctic	412,154	6,719	3,370	54.9	1.6
Iceland	*6,011*	*29*	*1,650*	*7.9*	*0.5*
Greenland	27	0	53	0	0
Faroe Islands	654	1	1,348	2.1	0.2
*Denmark **	*198,960*	*2,145*	*3,435*	*37.0*	*1.1*
Alaska (USA)	53,323	260	7,524	36.7	0.5
USA	*26,321,351*	*450,117*	*7,952*	*136.0*	*1.7*
Northern Finland	3,364	32	420	n/a	n/a**
Finland	*45,482*	*677*	*820*	*12.2*	*1.5*
Northern Canada	543	3	393	2.2	0.6
Canada	*788,197*	*20,144*	*2,088*	*53.4*	*2.6*
Northern Norway	2,164	6	440	1.2	0.3
Norway	63,262	567	1,164	10.4	0.9
Northern Sweden	20,748	308	4,997	74.2	1.5
Sweden	566,957	11,591	5,613	114.8	2.0
Northern Russia	325,317	6,112	3,530	66.3	1.9
Russia	3,825,739	72,456	2,621	49.6	1.9

*Data for Denmark proper.
**Finland reports fatalities using different spatial units than cases.

different times and with different intensities. Iceland's "second wave" commenced in mid-September with infections peaking in early October, while their peak in deaths was lagged 3–4 weeks later in mid-November. From the beginning of the pandemic, Iceland used isolation, quarantine and contact tracing to spatially limit COVID-19 [41]. Faroe Islands exhibited 2 infection peaks in the latter part of 2020, 1 in August, and 1 that peaked much later in December. Similar to Faroe Islands, Northern Norway and Northern Finland recorded 2 distinct "second wave" infection spikes, but the first sub-peak of the second wave was in November and the second in January. Finland's second January peak was much more muted than Norway's.

Protracted Waves. Northern Sweden underwent protracted "first" and "second" waves with an unsteady, but continued growth in cases and deaths (Figures 3 and 4). By taking a herd-immunity approach, the Swedish government emphasised personal responsibility, that contrasted with much more proactive approaches implemented by its Nordic neighbours [42,43]. Compared to Northern Norway and Finland, Northern Sweden has suffered a sustained "second wave" whose peak oscillated, with little sign of abatement as of January 2021. It was not until 18 December 2020 that the Swedish Government directed its people to wear masks [44]. As a result of limited mitigation efforts, the absolute and relative indicators of COVID-19 incidence in Northern Sweden were noticeably higher than elsewhere in the Arctic (Figures 3 and 4).

Table 2. Regional typology of COVID-19 pandemic dynamics in the Arctic: summary characteristics (February 2020–January 2021).

Type of dynamic	Regions	Key epidemiological characteristics	Public health response
Shockwaves	Iceland, Faroe Islands, Northern Norway, Northern Finland	Early onset with a rapid spike in both cases and deaths. The "second wave": spike in COVID-19 infection and mortality rates that precipitously subsided. Sometimes, multiple spikes were observed. Low CFR.	Aggressive policy intervention: early, immediate and relatively strict prevention and mitigation measures.
Protracted Waves	Northern Sweden	Protracted "first wave" and strong "second wave". High and protracted growth in incidents and deaths, relatively high FCR.	Soft policy intervention: loose restrictions, especially early in the pandemic Absent/weak (Sweden) or highly variable (Alaska) quarantine measures,
Tidal waves	Northern Russia	Relatively late start, intensive growth of infections and deaths during both waves. High infection and death rates. Spikes (corresponding to the outbreaks at industrial facilities). Relatively high CFR.	Highly variable quarantine measures and enforcement. Early relaxation of restrictions. Overreliance on pharmaceutical measures (vaccine development).
Tsunami Wave	Alaska (USA)	Later start and mild "first wave"; drastic increase in infections and deaths during the "second wave", especially in rural areas. Very high confirmed cases and mortality rates during the "second wave" (highest in the Arctic).	Highly variable quarantine measures and enforcement. Quick relaxation of restrictions in some areas. Rapid and effective implementation of vaccination in January–March 2021.
Isolated splashes	Northern Canada,	Greenland	No significant proliferation of the pandemic, isolated cases, few or no deaths.
Very strict		prevention measures, isolation, quarantine.	

Tsunami Wave: In Alaska, anti-epidemic measures were undertaken relatively early, albeit varying across the state. Rural and remote locations were nearly completely isolated while major urban centres were slower to institute restrictions [18,45]. The "second wave" in Alaska mirrored the lower 48 states with a dramatic peak of infections in late November and early December. During these months, rural Alaska boroughs were circumpolar "hot spots" of COVID-19 posting high infection rates. A wave of deaths also followed. Infections have steadily fallen since mid-December, and Alaska has had intensive vaccination efforts, making it a leading region in the Arctic [31]. Recent evidence suggests that, in contrast to the devastation that 1918–1921 Spanish Flu pandemic wrought on Indigenous populations in Alaska, local efforts by Indigenous leaders, NGOs and local municipalities, and early targeted inoculation through the public and Native American health care systems, has greatly limited the impact of COVID-19. In fact, in some communities upwards of 75% of their populations have been vaccinated by the beginning of March 2021 [46].

Tidal Waves: Northern Russia generally followed the national pattern of the COVID-19 pandemic [7]. The onset of confirmed cases in the "first wave" started relatively late, but maintained growth through July. Thereafter, infections declined, but Russia has seen a substantial "second wave" that began in early September and culminated in mid-December (Figure 4). Some criticism has been levelled at the Russian Government for being less prepared for the "second wave" (Sauer 2020) rather concentrating their efforts into a vaccine, which was approved early into the "second wave", although not widely distributed until much later [47].

Isolated Splashes: this group includes Northern Canada and Greenland. In early 2020, these areas remained largely unaffected by the pandemic. Travel bans, self-isolation and closures were among stiff anti-pandemic policies imposed by these jurisdictions [48]. In effect, Northern Canada and Greenland did not have the "first wave" and were described as "pre-pandemic" [7] as late as August 2020. A large "second wave" could have had devastating repercussions for these regions (cf. Alaska) given their high vulnerability (remoteness, public health issues, etc.). However, continued restrictions and other public health measures, coupled with Indigenous coping strategies, such as prolonged stays on the land [16], minimised the proliferation of the pandemic (Connolly et al., 2021). Both Northern Canada and Greenland suffered a rather small "second wave" that hit late in November and December (Figure 4).

Although data at the community level are limited, it is also interesting to point out some evidence of the difference between more urbanised and more remote, rural regions. The pandemic generally started later in more remote areas due to their relative isolation. The "first wave" was also more severe in urban communities. For example, in Alaska COVID-19 cases were first recorded in Anchorage and Fairbanks, and only 3 weeks before any rural area. While both urban areas had spikes of cases and deaths in April, most rural regions in Alaska did not have a significant spread until June. However, during the "second wave" many rural regions, especially in Alaska and Northern Russia, quickly caught up in respect to per capita cases and fatalities or exceeded urban locales. This pattern reveals that remoteness in rural areas is likely to delay the onset of the pandemic, but may be a source of additional morbidity and mortality during subsequent waves. Thus, the delayed start of the pandemic should be utilised to prepare for the imminent arrival of the virus in more remote, rural areas.

Insights from mobility and climate data

Mobility metrics, especially using Google Mobility Reports (GMR), have been examined in relation to COVID-19 mitigation policies and/or occurrence in multiple locations or regions [49; 50, 51]. In spring 2020, Petrov et al. [7] illustrated a reduction in COVID-19 incidence rate across the Arctic that coincided with a sharp drop in workplace mobility from GMR across all countries (no mobility data for Russia) approximately 3 weeks before. During the "second wave", mobility signals were also seen across the Arctic. Specifically, steep reductions in trips to parks (generally outdoor spaces, according to GMR) mobility preceded a rise in case rates approximately 3–6 weeks later. Similar to the park mobility reduction, there were smaller but evident rises (~5–10%) in residential mobility preceding case rise accompanied by reductions in grocery, retail, and transit station mobility. This pattern was seen in Alaska and Northern Finland, Sweden, and Norway. In general, the parks and residential mobility reduction closely followed a reduction in temperatures starting in late August through September (regional mean daily temperatures derived from ERAF-Land reanalysis products, Google Earth Engine Data Catalog 2021). Although the GMR data are unavailable from Iceland and Russia, the reduction in temperatures preceded the fall rise in case rates in those countries also.

Conclusions

The onset of the COVID-19 pandemic in the Arctic took place on 21 February 2020. The analysis of its spatiotemporal dynamics in the first year demonstrates the occurrence of two distinct waves. The "second wave" observed from September 2020 to January 2021 (with some variations across regions) was much more severe in terms of both COVID-19 infections and fatalities. Although all northern regions were affected by the pandemic, the "second wave" had particularly strong impacts in Alaska, Northern Russia and Northern Sweden. Many rural Alaska communities posted exceptionally high infection rates in fall of 2020. This pattern is consistent with the spread of the COVID-19 pandemic from more urbanised areas to rural districts. In contrast, Northern Canada and Greenland, with more consistent and strict preventive and mitigation measures, were able to minimise morbidity and mortality due to COVID-19 by relying both on the public health system and Indigenous knowledge. In Alaska, however, the difficult epidemiological situation has been alleviated by an effective vaccination programme commenced in the winter of 2020–2021. Based on the spatiotemporal patterns of the COVID-19 dynamics we identified 5 regional types of the pandemic: Shockwaves (Iceland, Faroe Islands, Northern Norway, and Northern Finland), Protracted Waves (Northern Sweden), Tidal Waves (Northern Russia), Tsunami Wave (Alaska), and Isolated Splashes (Northern Canada and Greenland).

The COVID-19 pandemic is not disappearing despite widespread preventive and mitigation measures and vaccination. As the pandemic progresses, an increasing volume of evidence becomes available to examine COVID-19 impacts on Arctic regions and communities. COVID-19 is not only inflicting severe health damage to the Arctic residents. Preliminary reports [e.g. 19, 21] and testimonials published on publicly available portals indicate that communities have rather different experiences [52, 19]. These challenges vary from price hikes to border closures that disrupt access to vitally important goods and traditional activities [53–63]. Further work should be directed to analyse immediate and long-term impacts of the COVID-19 pandemic on diverse Arctic communities, including gender, socioeconomic, demographic, cultural and other implications. Lessons learned from this polar region may be particularly helpful in addressing infectious disease disparities among vulnerable indigenous populations in other areas of the world as well, not just for COVID-19, but for future emerging infectious diseases that are likely to become more frequent and serious in future years.

Limitations

As discussed previously [7], the COVID-19 data have multiple reporting, accuracy and access issues. We used only publicly available datasets that relied on national/regional definitions and data collection, management and publication practices. Thus, the results may be affected by under- or mis-reporting, conflicting definitions or instrumentation issues (such as the quality of administered COVID-19 tests), among others. To partially alleviate this, we examined aggregates and longer-term trends rather than individually reported numbers.

This research also did not assess the impact of vaccinations, which in some parts of the Arctic began in late December, but most likely did not exert substantive influence on the pandemic until February].

Acknowledgments

The authors are grateful to Paula Carvalho De Castro, Jonathan Voss and Iain Miller for their help with this work. The research is supported by NSF PLR # 2034886.

Disclosure statement

No potential conflict of interest was reported by the author(s).

Funding

This work was supported by the National Science Foundation [2034886].

ORCID

Andrey N. Petrov http://orcid.org/0000-0003-1345-2842
Tatiana Degai http://orcid.org/0000-0002-5201-7555
Alexander Savelyev http://orcid.org/0000-0001-7849-7035

References

[1] Li R, Pei S, Chen B, et al. Substantial undocumented infection facilitates the rapid dissemination of novel coronavirus (SARS-CoV-2). Science. 2020;368(6490):489–493.

[2] Lai S, Bogoch II, Ruktanonchai NW, et al. Assessing spread risk of Wuhan novel coronavirus within and beyond China, January-April 2020: a travel network-based modelling study. medRxiv. 2020.02.04.20020479; doi: https://doi.org/10.1101/2020.02.04.20020479.

[3] Peeri NC, Shrestha N, Rahman MS, et al. The SARS, MERS and novel coronavirus (COVID-19) epidemics, the newest and biggest global health threats: what lessons have we learned? Int J Epidemiol. 2020;49(3):717–726.

[4] Yamana T, Pei S, Shaman J. Projection of COVID-19 cases and deaths in the US as individual states re-open May 4,

2020. MedRxiv. 2020. https://doi.org/10.1101/2020.05.04.20090670.
[5] Dibner KA, Schweingruber HA, Christakis DA. Reopening K-12 schools during the COVID-19 pandemic: a report from the National Academies of Sciences, Engineering, and Medicine. Jama. 2020;324(9):833–834.
[6] Thomas DS, Jang S, Scandlyn J. The CHASMS conceptual model of cascading disasters and social vulnerability: the COVID-19 case example. Int J Disaster Risk Reduct. 2020;51:101828.
[7] Petrov AN, Welford M, Golosov N, et al. Spatiotemporal dynamics of the COVID-19 pandemic in the arctic: early data and emerging trends. Int J Circumpolar Health. 2020;79(1):1835251.
[8] Jungsberg L, Turunen E, Heleniak T, et al. Atlas of population, society and economy in the Arctic. Stockholm, Sweden: Nordregio; 2019.
[9] Heleniak T. The future of the Arctic populations. Polar Geogr. 2020;1–17. doi:10.1080/1088937X.2019.1707316
[10] Hathaway E. D. (2021). American Indian and Alaska Native People: Social Vulnerability and COVID-19. The Journal of rural health : official journal of the American Rural Health Association and the National Rural Health Care Association, 37(1), 256–259. https://doi.org/10.1111/jrh.12505.
[11] United Nations. (2020, March 30). COVID-19 and indigenous peoples | United Nations For Indigenous Peoples. United Nations. https://www.un.org/development/desa/indigenouspeoples/covid-19.html/
[12] Arrazola J, Masiello MM, Joshi S, et al. COVID-19 mortality among American Indian and Alaska native persons—14 States, January–June 2020. Morbidity Mortality Weekly Rep. 2020;69(49):1853.
[13] Hatcher SM, Agnew-Brune C, Anderson M, et al. COVID-19 among American Indian and Alaska native persons—23 States, January 31–July 3, 2020. Morbidity Mortality Weekly Rep. 2020;69(34):1166.
[14] Napoleon H . Yuuyaraq: the way of the human being. Publications Centre, Centre for Cross-Cultural Studies, College of Rural Alaska, University of Alaska Fairbanks, Fairbanks, AK; 1991.
[15] Sköld P. Escape from catastrophe: the Saami's experience with smallpox in eighteenth-and early-nineteenth-century Sweden. Social Sci Hist. 1997;21(1):1–25.
[16] Richardson L, Crawford A. COVID-19 and the decolonization of indigenous public health. CMAJ. 2020;192(38):E1098–E1100.
[17] Kuitunen I, Renko M. Lessons to learn from the current pandemic for future non-pharmaceutical interventions against the respiratory syncytial virus–nationwide register-study in Finland. Infect Dis (Lond). 2021 Jun;53(6):476-478
[18] Nolen LD, Seeman S, Bruden D, Klejka J, Desnoyers C, Tiesinga J, Singleton R. Impact of Social Distancing and Travel Restrictions on non-COVID-19 Respiratory Hospital Admissions in Young Children in Rural Alaska. Clin Infect Dis. 2020 Sep 5:ciaa1328. doi:10.1093/cid/ciaa1328.
[19] Arctic Council. COVID-19 in the Arctic: briefing document for senior Arctic officials. 2020. Available from: https://oaarchive.arctic-council.org/handle/11374/2473
[20] Kiddell-Monroe R, Ranta M, Enook S, et al. Inuit communities can beat COVID-19 and tuberculosis. Lancet Public Health. 2020;5(6):e312.
21 Indigenous Russia . 2020. The COVID 19 impact on indigenous peoples of the Russian Arctic, Siberia, and the Far East. Available from: https://indigenous-russia.com/archives/6552.
[22] Retter G-B Indigenous peoples and COVID-19: challenges to achieving SDGs. Arctic (Inuit Nunaat and Sapmi) regional report. 2020.
[23] Zavaleta-Cortijo C, Ford JD, Arotoma-Rojas I, et al. Climate change and COVID-19: reinforcing Indigenous food systems. Lancet Planet Health. 2020;4(9):e381–e382.
[24] Bogdanova E, Andronov S, Morell IA, et al. Food sovereignty of the indigenous peoples in the Arctic zone of Western Siberia: response to COVID-19 pandemic. Int J Environ Res Public Health. 2020;17(20):7570.
[25] Grydehøj A, Kelman I, Su P. Island geographies of separation and cohesion: the coronavirus (COVID-19) pandemic and the geopolitics of Kalaallit Nunaat (Greenland). Tijdschrift Voor Economische En Sociale Geografie. 2020;111(3):288–301.
[26] Helgason D, Eythorsson E, Olafsdottir LB, et al. Beating the odds with systematic individualized care: nationwide prospective follow-up of all patients with COVID-19 in Iceland. J Intern Med. 2021;289(2):255–258.
[27] Potravnaya EV, Sleptcov AN. Impact of the coronavirus pandemic on the life of Arctic regions in population estimates. Sotsiologicheskie Issledovaniya. 2020;7:144–147.
[28] Einarsson N, Nymand Larsen J, Nilsson A, et al. (2004). Arctic human development report. Stefansson Arctic Institute.
[29] Dicker R C, Coronado F, Koo D, et al. Principles of epidemiology in public health practice; an introduction to applied epidemiology and biostatistics. Atlanta, GA: Centers for Disease Control and Prevention; 2006.
[30] Google. 2021. Google mobility reports. Available from: https://www.google.com/covid19/mobility/
[31] ArcticVAX. (2021). Arctic COVID-19 vaccination. [Cited 2021 Mar 23]. Available from: https://univnortherniowa.maps.arcgis.com/apps/opsdashboard/index.html#/babca707eeac450c8604afc38230608b
[32] Cacciapaglia G, Cot C, Sannino F. Second wave COVID-19 pandemics in Europe: a temporal playbook. Sci Rep. 2020;10(1):1–8. doi: 10.1101/2021.02.21.21252147.
[33] Xu S, Li Y. Beware of the second wave of COVID-19. Lancet. 2020;395(10233):1321–1322.
[34] Zhang SX, Marioli FA, Gao R. A second wave? What do people mean by COVID waves? A working definition of epidemic waves. MedRxiv. 2021.
[35] Ioannidis, J. P., Axfors, C., & Contopoulos-Ioannidis, D. G. (2021). Second versus first wave of COVID-19 deaths: Shifts in age distribution and in nursing home fatalities. Environmental Research, 110856
[36] El Aferni, A., Guettari, M. & Tajouri, T. Mathematical model of Boltzmann's sigmoidal equation applicable to the spreading of the coronavirus (Covid-19) waves. Environ Sci Pollut Res (2020). https://doi.org/10.1007/s11356-020-11188-y.
[37] Merow C, Urban MC. Seasonality and uncertainty in global COVID-19 growth rates. Proc Nat Acad Sci. 2020;117(44):27456–27464. doi: 10.1101/2020.04.15.20064980 .
[38] Bontempi E. The Europe second wave of COVID-19 infection and the Italy "strange" situation. Environ Res. 2021;193:110476.

[39] El Aferni, A., Guettari, M. & Tajouri, T. Mathematical model of Boltzmann's sigmoidal equation applicable to the spreading of the coronavirus (Covid-19) waves. Environ Sci Pollut Res (2020). https://doi.org/10.1007/s11356-020-11188-y.

[40] Rader B, Scarpino S, Nande A, et al. Crowding and the epidemic intensity of COVID-19 transmission. MedRxiv. 2020.

[41] Scudellari M. How the pandemic might play out in 2021 and beyond. Nature. 2020;584(7819):22–25.

[42] Kamerlin SC, Kasson PM. Managing coronavirus disease 2019 spread Wwith voluntary public health measures: Sweden as a case study for pandemic control. Clin Infect Dis. 2020;71(12):3174–3181.

[43] Yan B, Zhang X, Wu L, et al. Why do countries respond differently to COVID-19? A comparative study of Sweden, China, France, and Japan. Am Rev Public Administration. 2020;50(6–7):762–769.

[44] Claeson M, Hanson S. COVID-19 and the Swedish enigma. Lancet. 2021;397(10271):259–261.

[45] Spelsberg S. Real rural: COVID-19 lands in a small Alaska Port Town. Emergency Med News. 2020;42(11):16–17.

[46] Herz N, Anchorage APM. Unscathed: these Alaska villages are reaching herd immunity — without a single case of COVID-19. *Alaska Public Media*. 2021 Feb 25. Available from: https://www.alaskapublic.org/2021/02/25/unscathed-these-alaska-villages-have-seen-no-covid-19-cases-and-some-are-nearing-herd-immunity/

[47] Jones I, Roy P. Sputnik V COVID-19 vaccine candidate appears safe and effective. Lancet. 2021;397(10275):642–643.

[48] McCoy LG, Smith J, Anchuri K, et al. Characterizing early Canadian federal, provincial, territorial and municipal non-pharmaceutical interventions in response to COVID-19: a descriptive analysis. CMAJ Open. 2020;8(3):E545.

[49] Basellini, U., Alburez-Gutierrez, D., Del Fava, E., Perrotta, D., Bonetti, M., Camarda, C. G., & Zagheni, E. (2021). Linking excess mortality to mobility data during the first wave of COVID-19 in England and Wales. Population Health, Volume 14, 2021, 100799, ISSN 2352-8273, https://doi.org/10.1016/j.ssmph.2021.100799

[50] Hakim AJ, Victory KR, Chevinsky JR, et al. Mitigation policies, community mobility, and COVID-19 case counts in Australia, Japan, Hong Kong, and Singapore. Public Health. 2021. DOI:10.1016/j.puhe.2021.02.001

[51] Sulyok M, Walker M. 2020. Community movement and COVID-19: a global study using Google's community mobility reports. Epidemiol Infect. 148. DOI: 10.1017/S0950268820002757.

[52] COVITA. Arctic COVID-19 web portal. [cited 2021 Mar 23] https://arcticcovid.uni.edu

[53] Basellini U, Alburez-Gutierrez D, Del Fava E, et al. Linking excess mortality to mobility data during the first wave of COVID-19 in England and Wales; 2021.

[54] Bryant P, Elofsson A. Estimating the impact of mobility patterns on COVID-19 infection rates in 11 European countries. PeerJ. 2020;8:e9879.

[55] Connolly M, Griffiths K, Waldon J, et al. Overview: the international group for indigenous health measurement and COVID-19. Stat J IAOS. n.d.;1–6. Preprint.

[56] Hansen KL, Melhus M, Høgmo A, et al. Ethnic discrimination and bullying in the Sami and non-Sami populations in Norway: the SAMINOR study. Int J Circumpolar Health. 2008;67(1):99–115.

[57] Indigenous Russia. The COVID 19 impact on indigenous peoples of the Russian Arctic, Siberia, and the Far East – iRussia. n.d.. [cited 2021 Mar 15]. https://indigenous-russia.com/archives/6552

[58] Ioannidis JP, Axfors C, Contopoulos-Ioannidis DG. Second versus first wave of COVID-19 deaths: shifts in age distribution and in nursing home fatalities. Environ Res. 2021;195(110856):110856.

[59] Ossimetha A, Ossimetha A, Kosar CM, et al. Socioeconomic disparities in community mobility reduction and COVID-19 Growth. Mayo Clin Proc. 2021;96(1):78–85.

[60] Sauer P. 'We're in hell': Russia's second wave of covid-19 is catching the regions off guard. The Moscow Times. [cited 2020 Oct 27]. https://www.themoscowtimes.com/2020/10/27/were-in-hell-russias-second-wave-of-covid-19-is-catching-the-regions-off-guard-a71851

[61] Traynor K. Arrival of Covid-19 vaccine cheers Alaska hospital's staff. Am J Health SysPharm AJHP. 2021;78(5):367.

[62] Wang H, Yamamoto N. Using a partial differential equation with Google Mobility data to predict COVID-19 in Arizona. Math Biosci Eng. 2020;17(5):4891–4904.

[63] Zhu D, Mishra SR, Han X, et al. Social distancing in Latin America during the COVID-19 pandemic: an analysis using the stringency index and Google community mobility reports. J Travel Med. 2020;27(8):taaa125.