Symposium Report: Emerging Threats for Human Health – Impact of Socioeconomic and Climate Change on Zooanthroponosis in the Republic of Sakha (Yakutia), Russia

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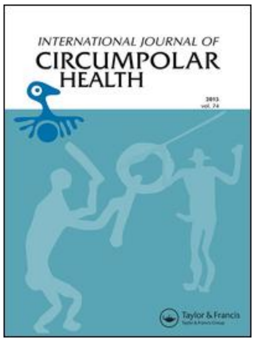

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Symposium report: emerging threats for human health – impact of socioeconomic and climate change on zoonotic diseases in the Republic of Sakha (Yakutia), Russia

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ABSTRACT

Population growth, socio-cultural and economic changes as well as technological progress have an immediate impact on the environment and human health in particular. Our steadily rising needs of resources increase the pressure on the environment and narrow down untainted habitats for plants and wild animals. Balance and resilience of ecosystems are further threatened by climate change, as temperature and seasonal shifts increase the pressure for all species to find successful survival strategies. Arctic and subarctic regions are especially vulnerable to climate change, as thawing of permafrost significantly transforms soil structures, vegetation and habitats. With rising temperature, the risk of zoonotic diseases in the Republic of Sakha (Yakutia) has also increased. As vegetation periods prolong and habitats broaden, zoonotic pathogens and their vectors find more favourable living conditions. Moreover, permafrost degradation may expose historic burial grounds and allow for reviving the vectors of deadly infections from the past. To assess the current state of knowledge and emerging risks in the light of the "One Health" concept, a German-Russian Symposium took place on 13 August 2018 in Yakutsk, Russian Federation. This symposium report presents the main findings generated from presentations and discussions.

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Introduction

According to a review by Asokan et al. [1], zoonoses constitute >60% of all known infectious diseases and 75% of emerging infectious diseases. Approximately 40% of fungi, 50% of bacteria, 70% of protozoa, 80% of viruses and 95% of helminths that infect human beings are zoonotic. Understanding the underlying complex interactions between biological, social, and ecological systems will be key to combat and prevent zoonotic diseases, requiring the "One Health" approach [2,3] which integrates "effort[s] of multiple disciplines working locally, nationally and globally to attain optimal health for people, animals and the environment" (American Veterinary Medical Association [4]). In line with this concept, Lyubov V. Budatsyrenova from the Regional Office of the Russian Federal Service for Surveillance of Consumer Rights

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Protection and Human Wellbeing (Rospotrebnadzor) in the Republic Sakha (Yakutia) opened the scientific sessions of the Symposium with an overview of zoonoses in the Republic of Sakha in a One Health setting. Sakha (or Yakutia) covers one-fifth of the landmass of the Russian Federation and is characterised by the extreme weather conditions of (sub-)arctic taiga and tundra landscapes. For a long time, there have been natural foci of infectious diseases common to humans and animals such as rabies, anthrax, leptospirosis, tularaemia, listeriosis, pseudotuberculosis, yersiniosis, haemorrhagic fever with kidney syndrome and others [5–8]. The traditional lifestyle of indigenous peoples in Yakutia, which is characterised by herding of livestock (e.g. reindeer, cattle and horses), farming, hunting and fishing, tightly connects them with their animals and the environment in general. This direct and continuous exposure explained not only the high prevalence of zoonotic diseases among the indigenous population [9] but also accounted for the epidemiologically significant outbreaks of zoonotic diseases in animals and humans [5] during the last centuries. Analysing the statistics available from federal and regional sources, a decrease of cases could be observed over time (Table 1). At present, only sporadic cases of zoonotic diseases are being recorded (see annual State Reports of the Rospotrebnadzor, online [10] and Figures 1 and 2), but there is rising concern that changing climatic conditions may soon challenge the population with newly or re-emerging zoonotic diseases.

In contrast to the prevalence of zoonotic diseases in livestock (see Zoonotic diseases of horses Section and Table 3) and according to the openly available annual State Reports (data available since 2003), no cases of highly dangerous infections like rabies, anthrax, and leptospirosis have been reported for humans in the last decades. The last case of rabies was registered in 1973–74 with four fatalities including three children. The last outbreak of anthrax was registered in 1993 in the diamond mining district Mirninskiy Ulus. The first infection with (an imported) Lime disease was reported in 2007. As Budatsyrenova pointed out in her talk, a local case with tick-borne encephalomyelitis occurred in Yakutia for the first time in 2018.

This overall positive trend can be attributed to several factors. Budatsyrenova focused on two of them, i.e. monitoring and preventive measures. Sanitary and epidemiological surveillance in Yakutia is performed jointly by local representatives of Federal Rospotrebnadzor together with experts from the District Veterinary Agencies and public health authorities. In all Russian State Scientific Centers standardised laboratory diagnostics and protocols are now available that allow to unequivocally identify a wide range of pathogens (microbiologically and genetically) and to establish their sources, reservoirs, and mode of transmission. In collaboration with scientific institutions, the timely detection of epidemic infection processes and efficiency of countermeasures in outbreak situations is possible. During annual field trips to different regions of the Republic Sakha, rodents, birds, arthropods, as well as corresponding water and soil samples are collected. These materials are examined in biohazard containment laboratories for the presence of pathogens. Details were provided and put into a chronological perspective for tularaemia, pseudotuberculosis, yersiniosis, tick-borne encephalitis, avian influenza, listeria, anthrax, leptospirosis and rabies. Dependent on the incidence, risk level, and availability, vaccinations are conducted for certain risk groups (e.g. against anthrax, rabies, tick-borne encephalitis) or on a broader public scale (e.g. tularaemia in high-risk districts, avian influenza).

Table 1. Statistics on the prevalence of selected zoonotic diseases (individual cases of new infections) in the Republic of Sakha from 1950–2018.

Zoonoses	1950–1960	1960–1970	1970–1980	1980–1990	1990 – 2000	2000 – 2010	2010 – 2018
Diphyllobothriasis	*n.d.a*	*n.d.a*	*n.d.a*	*n.d.a*	35,201	25,014	12,597
Yersiniosis	*n.d.a*	*n.d.a*	*n.d.a*	221	25	14	30
Pseudotuberculosis	*n.d.a*	*n.d.a*	179	556	45	25	18
Encephalomyelitis	*n.d.a*	*n.d.a*	*n.d.a*	*n.d.a*	5	2	2
Lyme disease	*n.d.a*	*n.d.a*	*n.d.a*	*n.d.a*	1	6	6
Brucellosis	23	49	69	19	57	14	5
Rabies	0	0	4	0	0	0	0
Echinococcosis	*n.d.a*	*n.d.a*	*n.d.a*	*n.d.a*	100	122	72
Trichinosis	*n.d.a*	*n.d.a*	*n.d.a*	*n.d.a*	187	35	2
Tularaemia	806	1353	19	0	0	1	0
Anthrax	8	0	8	3	0	0	0
Equine Strangles	0	0	4	0	0	0	0
Leptospirosis	0	0	0	6	0	0	0
HFKS (Haemorrhagic fever with kidney syndrome)	0	0	0	0	0	0	1

Data source: Russian Federal Service for Surveillance of Consumer Rights Protection and Human Wellbeing (Rospotrebnadzor); n.d.a. = no data available

Figure 1. Data on the spread of natural focal infections of bacterial and viral aetiology on the territory of the Republic of Sakha (Yakutia).

Source: Kershengolts, B.M., Cherniavsky, V.F., Repin, V.E., Nikiforov, O.I., Sofronova, O.N [11].: *Influence of Global Climate Changes on Realisation of Potential of Infectious Diseases among Population of the Russian Arctic, an example of Yakutia, in: Human Ecology/Ecologiya Cheloveka (6), pp. 34–39, p. 35 (in Russian).*

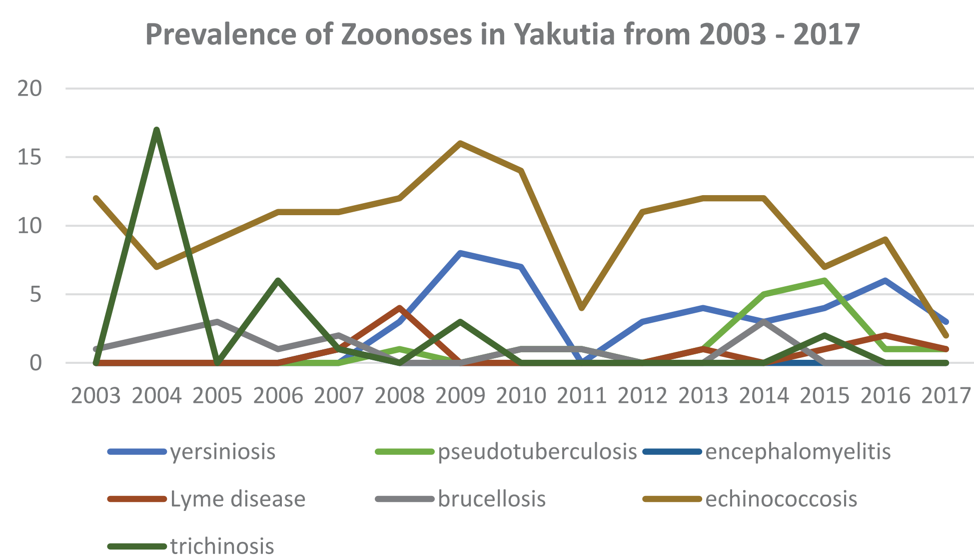

Figure 2. Statistics on the prevalence of zoonotic diseases (individual cases of new infections) in the Republic of Sakha.
Data source: Annual State Reports of the Regional Office of the Rospotrebnadzor in Yakutia (Online: http://14.rospotrebnadzor.ru/275), own visualisation.

There is a special interest in paleo-microbiological research, as thawing permafrost soil and especially the exposition of burial sites pose a high risk of reactivation of infections from the past [see O1, P1 in supplementary material]. Budatsyrenova presented their analyses of a more than 18,000 year old Oymyakonsky mammoth revealing living *Kurthia* spp. and other viable thermotolerant aerobic bacteria.

Zoonoses: a selection

Anthrax

Another threat concealed in frozen burial sites throughout Yakutia is anthrax, as Mikhail P. Neustroev from the Yakut Research Institute of Agriculture pointed out in his talk. First evidence about anthrax cases in Yakutia dates back to 1811 when 175 horses and 8 cattle died in the Kolyma district [12,13]. To date, the Russian inventory registers 285 risk sites in Yakutia [10]. However, this inventory takes into account human settlements only, neglecting specific burial sites of animals outside villages as has been noted in similar studies [Cherkasskiy 2002; 14]. Neustroev and G.T. Dyagilev presented their analyses of archival documents and reports of the Veterinary Department of Yakutia. For the period from 1811 to 1993, the infection with anthrax and associated mortality of domestic and wild animals was registered in 739 disadvantaged settlements and in 244 permanently disadvantaged settlements. Problem areas of anthrax are most likely associated with burial sites. Disadvantaged settlements are characterised by repeated outbreaks and fatalities in animals and humans. The number of dead domestic and wild animals was 78.017, with cattle accounting for 29.480 (37.7%), horses accounting for 35.995 (46.1%) and deer for 12.542 (16.2%). Neustroev and Dyagilev summarised results of their analyses in a comprehensive anthrax register [unpublished work]. Based on the severity of incidence (repeated outbreaks and degree of disadvantage) administrative districts of Yakutia are classified into four epizootic risk zones A – D (Table 2).

Multiple outbreaks in the same areas seem to indicate persistent local sources of the infection, most likely due to the long-term survival of the respective pathogen, especially in permafrost soils. Therefore, the threat of anthrax outbreaks remains high, consistent with the results of a forecasting model developed by Neustroev's team. Complementing these findings, Wolfgang Beyer from the University of Hohenheim in Stuttgart presented practical methods for the detection of *Bacillus anthracis* from environmental samples, including specimens suspicious to contain spores of intentionally released bacilli. Furthermore, he described their toolbox for forensic and molecular-epidemiological investigations of outbreaks and the investigation of the life cycle of members of *Bacillus cereus* sensu lato. Beyer also introduced the audience to the development and pre-clinical testing of non-living vaccines and novel therapeutics against anthrax. Last but not least, the role of temperate phages in the life cycle of *B. anthracis* and the benefits of lytic phages in decontamination of *B. anthracis* was discussed.

Table 2. *Risk zones for anthrax outbreaks and degree of disadvantage according to Neustroev and Dyagilev* [unpublished work].

Zone A	high level of incidence (17 to 25 outbreaks in total), 9 administrative districts of Yakutia
Zone B	average level of incidence and disadvantage (6 to 15 outbreaks), 9 administrative districts of Yakutia
Zone C	low level of incidence and recurrence risk (1 to 5 outbreaks), 12 administrative districts
Zone D	free of anthrax, cases of anthrax have never been recorded, 5 districts, situated mainly in tundra areas of the polar regions of Yakutia

Echinococcosis

Echinococcosis affects >1 million people at any one time and is recognised by the World Health Organisation (WHO) as one of four priority neglected zoonotic diseases, along with rabies, cysticercosis, and foodborne trematodes. Two forms of the disease are important, both occurring in Yakutia: Cystic Echinococcosis (CE) and Alveolar Echinococcosis (AE). CE is one of the most common zoonotic diseases and endemic in the Republic of Sakha, as Ludmila M. Kokolova from the Yakut Research Institute of Agriculture stressed in her introductory remarks. Being endemic, CE poses a great danger to humans, livestock, pets, and wild animals. According to statistics, the incidence of echinococcosis in Yakutia is 3 times higher than average numbers for the Russian Federation and in the Far Eastern Federal District even 4.5 times higher. *Echinococcus* metacestode in humans, i.e. the larval form of *Echinococcus* once it has been ingested by an intermediate host, can occur through contact with infested dogs (~57% of cases), the skinning of wild carnivores of the family *Canidae* (~28%), working on fur farms (~14%) and occasionally by eating contaminated meat products [15]. According to patient registers, 35.5% of Yakut patients with *Echinococcus* metacestodes are over the age of 60 years; 55.3% of the patients are women.

In this context, atremendous increase in the number of stray dogs in Yakutsk (capital town of Yakutia)during

Table 3. Statistics on the prevalence of selected zoonotic diseases in horses in the Republic of Sakha. 1 – number of disadvantaged farms, 2 – number of animals diseased, n.d.a. – no data available (Neustroev et al. 2018a).

Zoonoses \ Year	1980 – 1990	1990 – 2000	2000 – 2010	2010 – 2018
Salmonella Abortion (1)	3	35	98	39
Equine Strangles (1/2)	162/10,609	79/2929	168/800	41/67
Rhinopneumonia (1/2)	*n.d.a.*	*n.d.a.*	142/741	36/132
Leptospirosis (1/2)	*n.d.a.*	*n.d.a.*	125/1077	174/587

the last 10 years is noteworthy. As a result, soil contamination in gardens, playgrounds, and recreation areas may pose additional risks for humans, as dogs are the prevalent host of many helminth species, including *Echinococcus* spp. Kokolova et al. also presented their studies in dogs, wild carnivorous animals (arctic foxes, red foxes, wolves, lynx, wolverine), small rodents (Siberian lemmings, voles), reindeer, roe deer and elk. Parasitising in two stages, *Echinococcus granulosus* sensu lato (larva) could be detected in the parenchymal organs of domesticated and wild reindeer, roe deer, elk, and human. The sexually mature stage of *Echinococcus granulosus* s.l. (tapeworm) was localised in the small intestine of domestic and wild carnivores, e.g. dogs, wolves, arctic and red foxes (for exact numbers, see O8 in supplementary material.

Alveolar Echinococcosis (AE) is caused by various genotypes of one species, *E. multilocularis*, which is prevalent in the cold and temperate climates throughout the northern hemisphere. It is a primary wildlife parasite, transmitted in lifecycles between wild canids (mainly foxes) and rodents. Humans are accidentally infected, but the resulting disease is malignant with unsatisfactory treatment options. Kokolova's group found *E. multilocularis* in arctic and red foxes, dogs, and rodents, but less often as compared to *E. granulosus* s.l. In humans and other mammals, almost no infections have been recorded [15,16]. Thomas Romig from the University of Hohenheim cited studies on the occurrence of an AE genotype in Northern Yakutia that was previously thought to be restricted to America. Considering the vast North–South extension of Yakutia, he speculated about the presence of different lifecycles (involving different genotypes with divergent pathogenicity in humans), e.g. in arctic tundra and boreal forest zones. Whether such differences may or may not be caused by adaptive mechanisms or are linked to long-distance migration of foxes and wolves remains to be investigated. There has been a report about a specific transmission between domestic dogs and synanthropic rodents in central Yakutia, but no details on this have been published yet.

Both, Kokolova and Romig, concluded that *Echinococcus* transmission in Yakutia (and the resulting risk for humans and livestock) are intense, and the contributions of different *Echinococcus* species and genotypes are complex and little understood. Joint research and, in particular, molecular characterisation of systematically sampled parasite isolates will help to identify important transmission pathways and enable evidence-based control and prevention campaigns.

Diphyllobothriasis

The impact of anthropogenic activity on the prevalence of another tapeworm, *Diphyllobothrium latum* (also fish or broad tapeworm, now reclassified as *Dibothriocephalus latus*), was assessed by T.A. Platonov from the Yakut State Agricultural Academy [P6 in supplementary material]. He noted that with high anthropogenic load on waterbodies, the degree of infestation of fish with the plerocercoids of *Diphyllobothrium latum* gradually decreases. Parasites are able to withstand only a certain level of pollution, and depend on the wellbeing of their hosts. Therefore, the parasitological situation in waterways and reservoirs is an indicator of its sanitary state. Similar investigations have been performed in different regions of Yakutia and/or with a special focus on economically relevant fish species [see P15 in supplementary material].

The Annual State Reports show a high prevalence of Diphyllobothriasis in Yakutia with a declining trend (see Figure 3 and Table 1). The dietary habits of the population, i.e. consumption of raw or not properly cooked

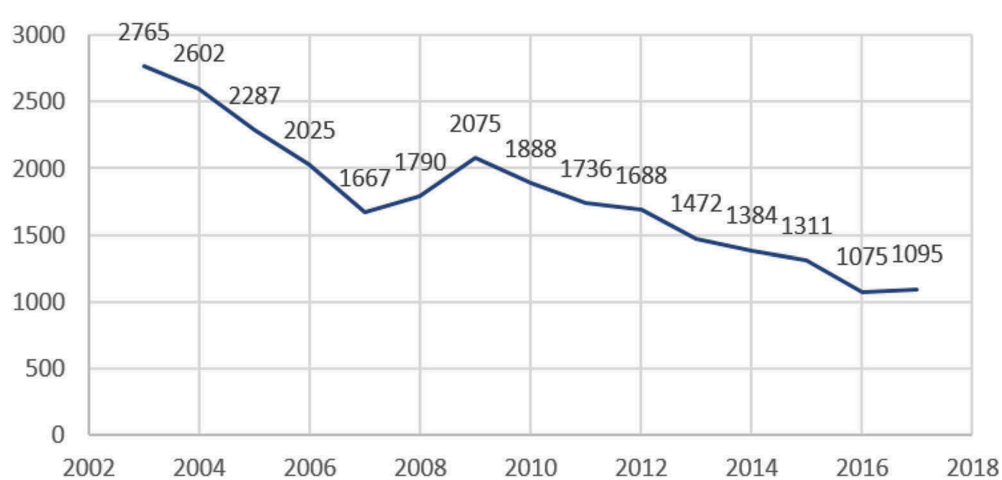

Figure 3. Prevalence of Diphyllobothriasis in Yakutia from 2003–2017 (individual cases).
Data Source: Annual State Reports of Regional Office of Rospotrebnadzor in Yakutia, online: http://14.rospotrebnadzor.ru/275 (own visualisation).

fish is assumed the main source of this finding [17]. Moreover, high prices for imported drugs for the treatment of the disease prevent a proper cure of people infected (Rospotrebnadzor, State Reports 2006, p. 162, 2008, p 185 f.).

Arthropod-mediated zoonoses

Alexander D. Reshetnikov from the Yakut Research Institute of Agriculture addressed zoonotic diseases transmitted through blood-sucking arthropods in the context of global warming. With increasing temperatures, the habitats of blood-sucking arthropods expand to the North. Neither wild and domestic animals nor people have sufficient immunity, which dramatically increases the harmfulness of vector-borne zoonotic diseases. Since the first report of tick-borne encephalitis in the Far East by E. N. Pavlovsky in 1939 [18,19], parasitologists have identified a range of infections and infestations transmitted through blood-sucking insects [20–22]. Although – due to the harsh climate, isolated settlements and limited infrastructure – the majority of the territory of Yakutia is unfavourable for spreading infectious diseases in epidemiological terms, the emergence of novel and previously undetected vectors for zoonotic diseases poses a threat for public health, and might also become critical from an economic point of view. In 2008, piroplasmosis eradicated up to 77% of reindeer herds in Gornyi District (Central Yakutia) amounting to an economic loss of several million Russian Rubles.

For the last years, hitherto in Yakutia unrecorded species (e.g. *Ixodes persulcatus)* potentially transmitting parasitic diseases have been reported: *Hybomitra montana* and *H. nigricornis* have been found in coastal tundra regions, *Chrysops divaricatus, Chr. suavis* and *Hybomitra aequetincta* were observed in lowland pastures, and in the basin of the Kolyma river the Blandford fly *Simulium posticatum* has been encountered.

Cases of human and animal filariasis, the most dangerous forms caused by *Dirofilaria repens* and *Dirofilaria immitis* (heart roundworm found in dogs), have become more frequent. Mosquitoes, as their intermediate host and vector, are most abundant and aggressive in July. Local scientists regard this new disease as a significant threat to human health, especially in light of the increasing occurrence of straying dogs in Yakutsk. As the main reasons for the invasion of new species in the fauna of Yakutia, Reshetnikov pointed out (I) increased immigration of citizens and animals from other regions of the Russian Federation and neighbouring countries, and (II) climate and seasonal changes allowing the survival of invasive species. Reshetnikov concluded his talk with an overview of protective measures developed and gave an outlook on research topics yet to be addressed.

Viral hepatitis E

Hepatitis E virus (HEV) infection is the most common cause of acute viral hepatitis worldwide and can take waterborne, foodborne, or zoonotic transmission routes. For the four genotypes responsible for most infections in humans, HEV genotypes 1 and 2 are obligate human pathogens while HEV genotypes 3 and 4 are mostly zoonotic [23], with the latter two being found in a variety of animal species [24]. Sergey I. Semenov from the Research Center of the Institute of Medicine at the North-Eastern Federal University in Yakutsk started his talk with the notion that one-third of the world's population may be infected with HEV. According to the WHO, 20 million HEV infections develop every year, 16,5% of them being symptomatic [25]. Although Hepatitis E is mostly asymptomatic, it can pose a risk during pregnancy. In many countries, Hepatitis seroprevalence differs among regions and in Europe for instance can range from less than 0.03% to 52% [26]. This highly variable range can most likely be attributed to the socioeconomic circumstances of people and their general health status [27]. People living in rural areas, in particular farmers and hunters, are evidently more prone to zoonotic infections as compared to people without continuous contact to animals. Semenov and his group could confirm this observation for Yakutia. In pastoral areas, markers for viral hepatitis E (a-HEVIgG) were detected in 21.8% of the population surveyed, among reindeer breeders the rate was 16.6%. In general, there seems to be a high prevalence of viral hepatitis infections in the Yakut population including all types of hepatitis viruses known to date [see P31 in complementary material].

Mirko Faber from the Robert Koch Institute in Berlin compared these findings with the situation in Germany, where nearly 3000 clinical Hepatitis E cases have been reported in 2017, mainly caused by the consumption of contaminated pork and game meat.

Bovine tuberculosis

Galina P. Protodyakonova from the Yakut State Agricultural Academy presented results on the epizootiological situation of bovine tuberculosis (Tb) in the Republic of Sakha and shared her view on the diagnosis and prevention of tuberculosis of cattle in Yakutia. Starting out with the pathology of tuberculosis and describing the influence of adverse environmental factors in the Far North, Protodyakonova then reflected on historic specifics contributing to the spread of Tb. With the import and mass crossbreeding of local Yakut cattle with European breeds in the early 19th century and under conditions of extensive livestock farming and insufficient feeding, the deterioration of cattle health and epizootic state on tuberculosis became manifest [28]. Due to the lack of effective anti-tuberculosis measures, the unimpeded spread of tuberculosis among cattle led to an endemic situation. Between 1950 and 1980, Tb was reported in all cattle farms of the Republic of Sakha. Not surprisingly, the detection frequency of bovine mycobacteria from people with tuberculosis also increased. In 1981, a number of resolutions of the government of the USSR on additional measures to combat tuberculosis were issued. The State Agricultural Committee of the Yakut ASSR put into action the "Program of measures for the improvement of livestock farms and recovery from tuberculosis of cattle" in 1986, including diagnostic, hygienic, and other preventive measures that proved extremely successful. By joining efforts for the implementation of this programme, the Department of Veterinary Medicine of Yakutia and the Scientific and Practical Center for "Phthisiology" in close collaboration with the farmers could reduce the number of Tb cases significantly by 1988 already [29]. However, surveys in 1996 and 2001 still revealed sporadic cases of tuberculosis in herds of cattle at small and private farms.

In this context, Protodyakonova discussed the value of PCR-based detection and other diagnostic methods for Tb, but also addressed problems with non-specific tuberculin reactions, the latter being a result of non-Tb, i.e. atypical mycobacteria [see also P11 in supplementary material].

Zoonotic diseases of horses

Yakut horses are not only the pride of the Yakut people but also an important economic factor. Counting about 170 thousand heads, Yakutian horse breeding ranks first in the Russian Federation. Therefore, zoonotic infections are a serious threat for horse breeders. Mikhail P. Neustroev and Nadezhda P. Tarabukina drew attention to infections such as Brucellosis, Salmonella abortion (first reported in 1937), Equine Strangles and Rhinopneumonia (since 1996). Since 2003, spreading of Leptospirosis is observed [30, Neustroev et al. 2018a]. Together, these most common infections cause significant financial damage for breeders. As epidemiological issues and transmission pathways have not been elucidated entirely, research is needed to close this knowledge gap and to implement effective measures for prevention and treatment.

Other zoonoses

During the poster sessions, other studies on zoonotic diseases relevant to Yakut livestock were presented. For horses, studies on Rhinopneumonia [P13], Strangles [P12], *Trichodectes Pilosus* [P9] and Strongilyatoses [P8] were displayed. Other investigations focused on reindeer infections like Brucellosis [P14] or Helminthiasis [P7]. Mycotoxicosis in farm animals [P21] and the influence of feed, genetic background and farming conditions were discussed in several other posters and during breaks.

Preventive measures

Immunomodulation

The (re)emergence of zoonoses and the ever-growing threat of antimicrobial resistance call for preventive measures and effective therapeutics on a global scale. Research in these areas has enabled tailor-made approaches including improved hygienic regimes, novel vaccines and antimicrobials, the use of bacteriophages, as well as highly specific immunomodulatory treatments. However, the adaptability and (co-)evolution of microbes, as well as their intra- and interspecies gene exchange render scientific efforts an endless endeavour [31].

Ayan N. Nyukkanov from the Yakut State Agricultural Academy presented their research and experiences with immunomodulation in cattle with zoonotic infections. For the first time in veterinary science and under experimental conditions, they tested the recombinant interleukin IL-1β in cattle with cryptosporidiosis. This fundamentally new approach for cryptosporidiosis uses a recombinant interleukin synthesised at the State Scientific Research Institute for Biopharmaceuticals of the Ministry of Health and Industry of the Russian Federation. The use of this recombinant immunostimulant proved to be effective not only when cryptosporidiosis was already clinically manifest, but also when administered simultaneously with the pathogen in an experimental setup. The recombinant IL-1ß drug restored the normal content of leukocytes in peripheral blood, enhanced blast transformation of lymphocytes, and the production of IL-2. All the changes observed upon administration of the drug are consistent with a significant boost of the immune system, allowing for an effective struggle against invasive agents in the cattle treated. Even prior to infection, IL-1β showed preventive effects and led to a better health status of treated animals. Drug effectiveness depended on thedose, frequency of administration and individual parameters of the animal treated. Recombinant IL-1β has an advantage over antibiotics, as it is able to stimulate innate immunity and subsequent body defence mechanisms without having toxic or allergic effects.

In a complementary talk, Neustroev and Tarabukina focused on their immunomodulatory approach for preventing infectious diseases in horses. During the long autumn/winter period, the spread of viral diseases such as influenza and rhinopneumonia among breeds of horses is notable. Not surprisingly, a decrease in the level of immunobiological reactivity of foals and mares was observed and could be correlated with an increase of stress factors and viral infections [32–34]. Both researchers presented preliminary results on the complementary use of immunomodulators and inactivated vaccines to improve the protection of livestock [work in progress, unpublished results].

Probiotics

Currently, in the Russian Federation there are efforts and active developments towards the introduction of probiotics into feeding regimes of livestock in order to boost their health and reduce the use of pharmaceuticals [P17 in complementary material]. The Yakut Research Institute of Agriculture has developed a number of innovative probiotic preparations based on biologically active, natural strains of *Bacillus subtilis* isolated from the permafrost soils of Yakutia [P18]. The observed and/or proposed immunostimulatory effects of these products on animals, crops, and the environment [P4] need to be further analysed and related to the underlying pathways and bioactive molecules.

Zoonoses and the One Health dimension

The One Health approach is an accepted concept to investigate zoonoses and fighting infectious diseases [35], as various factors influence their occurrence and transmission dynamics. In addition to comprehensive bio-medical studies of the pathogens, their vectors and hosts, one also needs to take into account the impact of climate, ecosystems, food and feed safety, public and veterinary health systems, socioeconomic drivers and cultural habits in order to develop successful strategies to deal with zoonotic outbreak scenarios and develop preventive measures.

Climate change, soil dynamics, land use and habitats

The influence of global climate change on the natural environment of the continental permafrost zone in Yakutia and in particular, potential effects on zoonoses were discussed by Roman V. Desyatkin from the Institute for Biological Problems of Cryolithozone, Siberian Branch of the Russian Academy of Sciences. Permafrost ecosystems respond to global warming quite rapidly. In fact, warming in subarctic regions has been reported to be 10 times faster than the global average value [36] and leads to accelerated permafrost thawing, increasing wildfire frequency and enlarged total lake area [37]. The 2–3°C rise in mean annual air temperature over the last three decades already has exerted a considerable impact on the state of permafrost landscapes and ecosystems in Eastern Siberia. With higher ground temperatures ranging from 0.4°C to 1.3°C, the seasonal melt deepens and cryogenic processes are intensified. In forest-free areas, the development of thermokarst reshapes the landscape and triggers changes in the ecology and land use. In addition, many animals and plants have extended their habitats northward heralding a general shift of geographic and natural zones. This shift contributes to an invasion of new plant and animal species into the northern areas, including crop pests and pathogens.

Sergey Blagodatskiy and Holger Pagel from the University of Hohenheim extended this scenario by discussing further aspects, e.g. the migration of people and animals, availability of soil resources for agriculture and animal husbandry and the emission of greenhouse gases from land and soil. Particularly greenhouse gas emissions may become critical due to a positive feedback loop: additional CO_2 and CH_4 emitted in response to climate warming will increase the greenhouse effect and further accelerate the rise of the land surface temperature. The major source of greenhouse gas emissions from soil is the mineralisation of soil organic matter, a process strongly controlled by temperature and moisture. Keeping natural processes and anthropogenic activities in balance ensures resilient ecosystems and “soil health”, i.e. the capacity of soil to function according to its potential and management strategies [38,39]. Both are considered essential for maintaining human well-being and the conservation of biodiversity. The latter was the focus of a poster presentation [P28] describing the experience and perspectives for the preservation of agro-biodiversity under changing permafrost conditions. Rapid melting of permafrost due to projected warming in Yakutia could affect several components of “soil health” including, e.g. increasing risk of arable land losses due to thermokarst processes and elevated risk of diseases due to opening of burial sites.

Effects of socioeconomic and cultural changes on health

Vyacheslav I. Shadrin from the Institute for Humanities Research and Indigenous Studies of the North, Siberian Branch of the Russian Academy of Science, shed light on new health risks for indigenous peoples of Yakutia in connection with global change, zoonotic diseases being one of them. The term indigenous peoples of the North in the Russian Federation comprise 41 ethnic groups with approx. 240.000 individuals in total. In the Republic of Sakha, the ethnic groups of Evenki, Even, Yukaghir, Dolgan, Chukchi and also Russian Arctic old-settlers comprise 40,000 indigenous peoples. Most of them live in their original territories (65% being rural) and pursue a traditional way of life. With climate and other global changes, inhabitants of the Far North face new challenges, all more or less related to health issues and several of them directly influencing also the occurrence and transmission of zoonoses:

(1) Traditional occupations are based on the knowledge of their ancestors accumulated over thousands of years. The ability to forecast weather conditions was crucial to choose the most suitable conditions for nomadic migration, hunting, fishing, and other activities. Unpredictable weather changes and altered water regimes negatively affect the traditional economies and threaten the lives of both humans and animals. Being confronted with more and atypical natural disasters (sharp temperature shifts, storms, floods and increased precipitation) the indigenous notion of "We are part of our land and of our water" changes rapidly to "The nature doesn't trust us anymore". Liliya I. Vinokurova, also from the Institute for Humanities Research and Indigenous Studies of the North, elaborated on this aspect based on her interview material collected in rural areas of Yakutia for the last 10 years. She compared the perception of climate and weather changes of different residential groups and extracted historical facts of ecological and health phenomena in rural everyday life.
(2) Prolonged heat periods, extended wildfires, smoke, etc., lead to more cases of illness and previously unknown health conditions like asthma. There are also concerns about the exposure to ultraviolet radiation and industrial pollution.
(3) Permafrost thawing reveals ancient burial sites of animals and humans died of severe infectious diseases.
(4) Invasive species spread novel pests and diseases.
(5) Wild animals (reindeers, bears, and wolves) exhibit changed behaviours causing new threats to livestock and humans.
(6) Water safety is one of the major health issues of both humans, and animals. In recent years, the pollution of water has sharply increased due to the thawing of permafrost.
(7) Infrastructure problems aggravate due to increased erosion of shores, destruction of roads, houses and air bases. Earlier melting of rivers reduces or in some places shuts down the use of the winter roads, which is *the* important logistics and mobility network in rural areas.
(8) Industrialisation and mining in vulnerable ecosystems raise considerable ecological concerns. Climate change further increases the availability of mineral resources and leads to a shift from traditional land use to industrial exploitation.
(9) One of the most drastic social changes concerns dietary patterns, characterised by the reduction of natural products and increased consumption of processed food. Especially, people relocating to towns need to cope with dietary changes. They also undergo other cultural changes, like the type of housing, work (mental replacing physical work), socialisation, and increasing flood of information. All these factors lead to stress and destabilisation of health [see also P32].

The role of the food chain

In the context of dietary changes, Konstantin M. Stepanov from the Yakut Science Centre of Complex Medical Problems highlighted the unique composition and nutritional value of animal and vegetable raw material for Yakut food consumption. Stepanov provided information about biologically active substances in deer and data about the unique properties of reindeer meat and wild berries. Complementing this information, several posters summarised findings for other foodstuff [P33, P34 in the complementary material] and food hygiene [P2-4], the latter being crucial to prevent transmission of food-borne zoonoses.

Behavioural aspects

In her talk, Elena P. Ammosova from the Research Center of the Institute of Medicine, North-Eastern Federal University stressed another important aspect, i.e. the attitude towards health among indigenous peoples under modern conditions. The majority does not recognise responsibility for their health, and therefore lack commitment to a healthy lifestyle and preventive measures. This attitude changes with age, most likely triggered by the awareness of deterioration of well-being and the occurrence of chronic diseases. Ammosova reasoned that the skills and self-preserving behaviour of the indigenous peoples of the North, which previously helped them to survive in harsh climatic conditions, have become inadequate in light of the current challenges. Therefore, novel concepts and measures need to be developed to preserve and protect public health.

Bridging knowledge systems in nutrition and health research

Stefanie Lemke, who is affiliated with the Research Center for Agroecology, Water and Resilience at Coventry University, delivered the final presentation of the Symposium. By summarising many of the points addressed during the oral and poster sessions, she linked not only nutrition and health but also agricultural, socioeconomic and cultural aspects, in line with the One Health concept.

Lemke drew special attention to the role of local and traditional food and knowledge systems for achieving more sustainable food production and consumption. Public health-care systems have often neglected indigenous worldviews and practice, resulting in barriers to health-care and education. Based on examples of good practice, Lemke illustrated how bridging Indigenous and Western research approaches can lead to co-designing public health policies and programmes that promote sustainable and healthy nutrition and lifestyles [40]. This requires an openness for different worldviews, participatory methods, and respectful partnership between researchers and local actors.

Conclusions & perspectives

During the Symposium, the current state of knowledge on zoonotic diseases in the Republic of Sakha was summarised. The findings presented support current research that connects anthropogenic changes in land use to intensified contact between people and ecological systems [41,42]. By sharing more habitats, the potential for transmission of zoonotic pathogens increases. However, the differences in host responses to modified landscapes among mammal orders suggest that these changes are unlikely to affect all zoonotic diseases consistently. In line with McMahon and colleagues, who stress the need to understand the disease ecology and other influencing factors of pathogens and parasites depending on the respective ecological and cultural contexts, the participants of the symposium agreed that further research, subsequent measures and policy need to be disease- and context-specific and consider the One Health perspective.

The Symposium and subsequent discussions among participants generated innovative ideas to further analyse the impact of socioeconomic and climate change on human, animal and environmental health in the Republic of Sakha. Future research will also focus on novel approaches for diagnostics, risk management, preventive measures, and treatment options.

Literature and supplementary material (program & abstract book)

The Program & Abstract Book can be downloaded from the website the Hohenheim Research Center for Health Sciences, University of Hohenheim, Stuttgart: https://health.uni-hohenheim.de/fileadmin/einrichtungen/gesundheitswissenschaften/Downloads/Yakutsk-Program-and-Abstract-Book-09-12-2018.pdf

Data repository/availability of data and materials/consent for publication

The article uses archive data from open sources and unpublished results of Russian authors. All authors agreed to the publication of their data and declare that there is no conflict of interests.

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References

[1] Revich BA, Podolnaya MA. Thawing of permafrost may disturb historic cattle burial grounds in East Siberia. Glob Health Action. 2011;4:8482.

[2] Davis MF, Rankin SC, Schurer JM, et al. Checklist for one health epidemiological reporting of evidence (COHERE). One Health. 2017;4:14–21.

[3] Trinh P, Zaneveld JR, Safranek S, et al. one health relationships between human, animal, and environmental microbiomes: a mini-review. Front Public Health. 2018;6:235.

[4] American Veterinary Medical Association. One Health: A New Professional Imperative: One Health Initiative Task Force: Final Report. July 15, 2008. [Internet] [cited 2020 Jan 23]. Available from: https://www.avma.org/sites/default/files/resources/onehealth_final.pdf.

[5] Chernyavsky VF, Nikiforov OI, Repin VE, et al. Epizootologo-epidemiological potential of natural focal infections in Yakutia and its dynamics under modern conditions. Yakut Med J. 2009;1(25):58–61.

[6] Egorov IY, Fedulova AG, Kochetov TI. Infectious diseases in Yakutia. Yakutsk: Reference book; 1994.

[7] Egorov IY, Fedulova AG, Kochetov TI. Epidemiological features of infectious and parasitic diseases in the Republic of Sakha (Yakutia). Yakutsk: Sakhapoligrafizdat; 1997.

[8] Egorov IY, Maramovich AS, Botvinkin AD. Epidemiological surveillance of especially dangerous and natural focal infections in the Far North. Yakutsk: Kuduk; 2000.

[9] Burtseva TE, Uvarova TE, Tomsky MI, et al. The health of populations living in the indigenous minority settlements of northern Yakutia. Int J Circumpolar Health. 2014;73:25758.

[10] [Rospotrebnadzor] Russian Federal Service for Surveillance of Consumer Rights Protection and Human Wellbeing. 2018. State Report: On the state of sanitary and epidemiological welfare of the population in the Republic of Sakha (Yakutia) in 2017. [cited 2018 Nov 30]. Available from: http://14.rospotrebnadzor.ru/275

[11] Kershengolts BM, Cherniavsky VF, Repin VE, et al. Influence of global climate changes on realization of potential of infectious diseases among population of the Russian Arctic, an example of Yakutia. Hum Ecol. 2009;6:34–39.

[12] Ognev NI. Veterinary service in Yakutia from 1853 to 1919. Sci Notes Yakutsk State Univ. 1962;13:87–97.

[13] Dyagilev GT, Neustroev MP. On the history of anthrax in the Yakutsk region in the 19th century. Actual Issues Vet Biol. 2010;4:3–7.

[14] Abdrakhmanov SK, Mukhanbetkaliyev YY, Korennoy FI, et al. Maximum entropy modeling risk of anthrax in the Republic of Kazakhstan. Prev Vet Med. 2017;144:149–157.

[15] Ignatieva ME, Samoylova IY, Budatsyrenova LV, et al. Epidemiological situation on biohelminthoses in the Republic of Sakha (Yakutia). Far East J Infect Pathol. 2017;(33) 33:25–32.

[16] Kokolova LM, Platonov TA, Verkhovtseva LA, et al. The role of parasitic diseases in human pathology. Russ Parasitological J. 2013;2:43–47.

[17] Scholz T, Kuchta R. Fish-borne, zoonotic cestodes (Diphyllobothrium and relatives) in cold climates: A never-ending story of neglected and (re)-emergent parasites. Food and waterborne parasitology. Vol. 4, 2016. p.23–38. doi:10.1016/j.fawpar.2016.07.002.

[18] Pavlovsky YN. Natural focality of vector-borne diseases in connection with the landscape epidemiology of zooanthroponosis. Moscow: Medicina; 1964.

[19] Litvin VY, Korenberg EI. Natural focality of diseases: the development of the concept by the end of the century. Parasitology. 1993;3:179–191.

[20] Kolesova GG, Reshetnikov AD, Sleptsov ES, et al. Dirofilariosis of carnivorous in Yakutia, the method of isolation filarial larvae from the blood of dogs. Russ J Parasitol. 2013;3:87–91.

[21] Reshetnikov AD, Barashkova AI, Prokopyev ZS 2014. Materials of the 5. International Scientific and Practical Conference on November 30, 2014. Part I, Belgorod. Theoretical and applied aspects of modern science, 141–143.

[22] Barashkova AI, Reshetnikov AD. Diptera blood-sucking insects of the agrocenoses of Yakutia and protection against the gnat of farm animals. Belgorod: Epicentr; 2015.

[23] Kamar N, Izopet J, Pavio N, et al. Hepatitis E virus infection. Nat Rev Dis Primers. 2017;3:17086.

[24] Rodríguez-Lázaro D, Hernandez M, Cook N. Hepatitis e virus: a new foodborne zoonotic concern. Adv Food Nutr Res. 2018;86:55–70. DOI: 10.1016/bs.afnr.2018.04.002

[25] World Health Organization (WHO). 2018. Hepatitis E. Key facts. 19 September 2018. [cited 2018 Dec 03]. Available from: https://www.who.int/news-room/fact-sheets/detail/hepatitis-e

[26] Aspinall EJ, Couturier E, Faber M, et al. Hepatitis E virus infection in Europe: surveillance and descriptive epidemiology of confirmed cases, 2005 to 2015. Euro Surveill. 2017;22:26.

[27] Leblebicioglu H, Ozaras R. Hepatitis E virus infection in Turkey: a systematic review. Ann Clin Microbiol Antimicrob. 2018;17(1):17.

[28] Ognev NI, Newman HN, 1976. The history of the spread of tuberculosis and brucellosis in the territory of the Yakut ASSR. Brucellosis and tuberculosis of farm animals: Proceedings of the scientific-production conference (March 15-16, 1975, Yakutsk), p. 16–20.

[29] Kornilov AA, Ivanov EA, Kondrat'eva MN. Statistics of tuberculosis in the Republic of Sakha (Yakutia). Prob Tuberculosis. 1999;2:12.

[30] Neustroev MP, Petrova SG 2017. Features of epizootology of Salmonella abortion of horses in Yakutia. Proceedings of the XX International Scientific and Practical Conference "Agricultural science and agriculture at the turn of the century"; (May 25 - September 7, 2017, Novosibirsk), p. 93–97.

[31] Labro M-T. Immunomodulation and infection: back to the future. Expert Rev Anti Infect Ther. 2012;10(3):245–247.

[32] Neustroev MP. Strangles of horses in Yakutia. Novosibirsk: Siberian Branch of the Russian Academy of Agricultural Sciences; 2000.

[33] Neustroev MP, Petrova SG, Elbyadova EI, et al. Features of the epizootology of viral horse abortions in Yakutia. Vestnik Far East Branch Russ Acad Sci. 2018a;3:137–140.

[34] Neustroev MP, Petrova SG, Elbyadova EI, et al. Prevention and treatment of viral and bacterial diseases of young horses. Trends Dev Sci Educ. 2018b;43(7):52–54.

[35] Bidaisee S, Macpherson CNL. Zoonoses and one health: a review of the literature. J Parasitol Res. 2014;2014:874345.

[36] Schuur EAG, McGuire AD, Schädel C, et al. Climate change and the permafrost carbon feedback. Nature. 2015;520(7546):171–179.

[37] Boike J, Grau T, Heim B, et al. Satellite-derived changes in the permafrost landscape of central Yakutia, 2000–2011: wetting, drying, and fires. Global Planet Change. 2016;139:116–127.
[38] Doran JW. Soil health and global sustainability: translating science into practice. Agric Ecosyst Environ. 2002;88 (2):119–127.
[39] Wall DH, Nielsen UN, Six J. Soil biodiversity and human health. Nature. 2015;528(7580):69–76.
[40] Lemke S, Delormier T. Indigenous Peoples' food systems, nutrition and gender: conceptual and methodological considerations. Matern Child Nutr. 2017;13(S3):e12499.
[41] Gibb R, Redding DW, Chin KQ, et al. Effects of land use on zoonotic host communities: a global correlative analysis. Lancet Planet Health. 2018;2:S2.
[42] McMahon BJ, Morand S, Gray JS. Ecosystem change and zoonoses in the Anthropocene. Zoonoses Public Health. 2018;65(7):755–765.