Modelling Bluetongue Risk in Kazakhstan

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Research

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Abstract

Background: Bluetongue is a serious disease of ruminants transmitted by biting midges (*Culicoides* spp). Serological evidence from livestock and the presence of at least one vector competent spp of *Culicoides* suggests that transmission of bluetongue is possible and may have occurred in Kazakhstan.

Methods: We estimated the relative risk of transmission using a mathematical model of the reproduction number R_0 for bluetongue. This model depends on livestock density and climatic factors which affect vector density. Data on climate and livestock numbers from the 2778 local communities were used. This together with previously published model parameters was used to estimate R0 for each month of the year, which was rescaled to give a relative risk of transmission. These relative risks were mapped using kernal density estimates using R statistical software and mapping tools.

Results: The results suggest that transmission of bluetongue in Kazakhstan is not possible in the winter from November to March. Assuming there are vector competent species of *Culicoides* endemic in Kazakhstan, then low levels of risk first appear in the south of Kazakhstan in April before spreading north and intensifying reaching maximum levels in northern Kazakhstan in August. The risk decline in September with only a low risk of transmission in October.

Conclusion: These results should aid in surveillance efforts for the detection and control of bluetongue in Kazakhstan by indicating where and when outbreaks of bluetongue are most likely to occur.

Background

Bluetongue (BT), a viral disease of ruminants transmitted by biting midges (*Culicoides* spp.). BT is widely distributed in Africa, Asia, Australia, South America and North America. Bluetongue Virus (BTV), the causative agent of BT disease of ruminants, has now been identified on all continents except Antarctica [1, 2, 3, 4, 5]. Hematophagous *Culicoides* insects are biological vectors that transmit BTV from infected to susceptible ruminants, thus the global distribution of BTV coincides with the distribution of competent *Culicoides* insect vectors and appropriate climatic conditions. Specifically, BTV exists in an extensive band that includes tropical, subtropical, and temperate regions of the world between latitudes of approximately 40° North and 35° South. Exceptions include regions of Asia and western North America, where BTV infection of ruminants occurs as far as 50° North [6, 7] and, most recently, northern Europe. Serologically positive animals have been previously reported in Kazakhstan [8] and in Xinjiang in neighbouring China [4]. Cattle imported from Russia into Kazakhstan have also been reported as seropositive [9]. The present distribution and risk of bluetongue in Kazakhstan is unknown. It is also unknown the extent of suitable vectors of the virus, although the vector competent species *Culicoides obsoletus* has been found in eastern Kazakhstan [10, 11]. Adult *Culicoides* are killed by cold winter temperatures, and BTV infections typically do not last for more than 60 days, which is not long enough for BT infected animals to remain infectious to the vectors for the duration of the winter. However, in inner Mongolia, which also has cold winters, BT appears to be endemic [12] indicating that the virus can continue to transmit following long periods when the vector in inactive. Therefore it seems that the virus somehow survives in overwintering midges or animals.

The risk of transmission is believed to be affected by the ruminant density, summer temperature and rainfall. Density of livestock effects the transmission between animals and the *Culicoides* vector whilst higher temperatures and rainfall are required for vector activity. Thus an important part of developing a risk map for Kazakhstan is to model climate data with livestock density to estimate risk of transmission. This has been combined with models for the basic reproduction number which will indicate the risk of transmission.

Methods

Basic reproductive number of bluetongue

The basic reproduction number, R_0, is defined as the expected number of secondary cases caused by one infectious individual introduced into a naïve population. It is a measure of the success of invasion into a population; if the value of R_0 is higher than 1, an outbreak of the infectious agent is possible, whereas if R_0 is less than 1, the infection will die out [13]. Maps indicating the value of R_0 can be used to identify areas with a higher probability of a major outbreak after an introduction. This concept has been used to develop risk maps for directly transmitted diseases such as foot-and-mouth disease [14]. Therefore to model the areas of relative risk for bluetongue in Kazakhstan, established models for R_0 were used.

The basic reproduction number of bluetongue has been defined by [15] as:

$$R_0 = \sqrt{\frac{a^2 bcqvh_c}{\gamma_c(h_c + h_s)^2\mu(q+\mu)} + \frac{a^2 bcqvh_s}{\gamma_s(h_c + h_s)^2\mu(q+\mu)}}. \qquad (1)$$

This is where c = the transmission probability following a bite by an infected *Culicoides*, g_c and g_s are the rate of loss of infectiousness in cattle and sheep respectively (1/g is the duration of infectiousness), *v* the local density of *Culicoides*, *a* is the reciprocal of the length of the gonotrophic cycle, h_s and h_c are the population densities of sheep and cattle, *c* is the transmission probability from cattle or sheep to *Culicoides* following a bite, *b* is the transmission efficiency from *Culicoides* to host, *a* is the *Culicoides* biting rate, *q* is the rate at which the *Culicoides* becomes infectious and *m* is the *Culicoides* mortality rate. Furthermore, *a*, *q* and *m* are temperature dependent and *v* is dependent on climatic conditions. The values for the various parameters are given in Table 1.

The relationship between vector density *v* and temperature and precipitation was from [16], where Ti is the daily temperature (in this case the mean monthly temperature) and $T_{i\text{-}37i}$ is the mean temperature for the proceeding 37 days (in this case the mean temperature of the preceding month) and $P_{i\text{-}100j\text{-}16}$ the mean precipitation for the preceding days 100 to 16. All other parameters are from [15].

Data

Data for the cattle and sheep populations were provided to the 3rd administrative level (Selski Okrug – SO) [17]. This resulted in 2778 data points. The area of each SO was also obtained from [17] and this together with the sheep and cattle populations reported it was possible to estimate the livestock density for each SO (ie h_c and h_s in equation 1). Climatic data for the main settlement in each SO was obtained from data at [18].

Analysis and mapping

All data was entered into an excel Spreadsheet and analysis and mapping using R [19]. The Basic reproductive number was estimated for each SO based on climatic data and livestock populations from equation 1. R_0 for each SO was calculated for each month of the year. The calculated R_0 was re-scaled to between 0 and 100 with 100 representing the highest calculated R_0 and 0 when no transmission occurred to give a relative R_0 for each of the 2778 data points for each month of the year. The kernal density estimates were calculated for each data point using the coordinates of the main settlement in each SO. This was achieved using the kde function from the ks package in R [20]. The kernal density estimates were mapped onto contour map for the months when transmission of BTV was hypothesized to occur and the maps were drawn in R using the packages rgdal [21] and maptools [22].

Table 1
Parameter values for the basic reproductive ratio

Parameter	Value
b	1
c	0.05
g_c	0.04
g_s	0.125
v	$\mathrm{loge}(v+1) \sim -0.856 + 0.076T_{i,i} + 0.048T_{i-37,i} + 2.913P_{i-100j-16}$
a	$a \sim 0.00017T(T\text{-}3.7)(41.9\text{-}T)^{1/2.7}$
q	$q \sim 0.0003T(T\text{-}10.4)$
m	$m \sim 009\exp(0.16T)$
T = average mean temperature of the month in question	

Results

The relative risk of outbreaks of bluetongue is displayed for the months April-October. The model indicated that transmission was unlikely to occur from November to March. Transmission risk appeared initially mainly in the south Kazakhstan region. This spread across the southern regions, South Kazakhstan, Jambyl and Almaty, regions in May. By June there was a low risk in the northern Parts of Kazakstan with a high risk in the southern Districts. Transmission risk peaked in August in the north and north east regions of Kazakhstan by which time transmission risk was staring to decrease in the south. In September transmission risk was decreasing in all regions and in some areas in the south the risk had disappeared. By October the risk of transmission across Kazakhstan was low and disappeared by the end of the month. The relative risk of transmission for the months April to October is illustrated in Fig. 1.

Discussion

These results obtained clearly indicate there is a heterogeneity of risk, both geographically and temporally, of bluetongue outbreaks in Kazakhstan. Across the whole country in winter months the risk is negligible. This is because it is too cold for the vector to be active with mean temperatures across most of Kazakhstan being below freezing from November to March. In April temperature are sufficiently high for vector activity in the south and this spreads north with a peak transmission in northern areas in August. In addition the activity of vectors is dependent on rainfall. Southern areas such as around Shymkent have relatively low rainfall in the summer months from June to September compared to the wetter spring months of March to May and will be a factor in the reduced transmission in these areas. In contrast Petropavl in the north has its highest rainfall in the summer months. Much of central Kazakhstan has very low rainfall year round which is associated with the low risk of transmission in these areas.

This analysis was based on the R_0 associated with the BTV vector *Culicoides*. The model for R_0 was a generic model which was not species specific [15] but the temperature and rainfall dependency of the vector population was based on work for *Culicoides obsoletus.* A potential weakness of the study is that whilst we used the logistic regression model of [16] to model v ,the local density of *Culicoides*, we had to use mean monthly temperatures for the current month and previous month and mean precipitation data as proxies for the actual daily temperature and mean temperatures and precipitation. This was due to availability of the data and we were trying to project possible risk based on long term climatic factors rather than the risk described over a small number of seasons. Despite this limitation, *C obsoletus* has been described in various regions of Kazakhstan [10, 11] and hence a model utilizing methods based on *C. obsoletus* would be the most relevant to this study.

There are a number of other *Culicoides* spp endemic to the region. A review by Sprygin et al. (2014) [23] suggested that 23 species of *Culicoides* have been detected in Kazakhstan including widespread species such as *C. reconditus, C. fascipennis* and *C. vexans*. *Culicoides brevifrontis* and *Culicoides manchuriensis* have been found in Akmola Oblast [24]. Although there are well over 1000 species of *Culicoides*, only about 17 are known to be vector competent for BTV. The duration of viraema is less than 2 months in small ruminants and cattle [25, 26] and this presents a possible limiting factor for transmission as the virus should not be able to overwinter in cattle or sheep when there is no *Culicoides* activity. In Southern Europe, Turkey and Iran *C. imicola* is an important vector of BTV and in the warmer parts of these regions the short viraemia in farm animals does not limit the transmission of BTV because of the more favourable climatic conditions. No data for *C. imicola* in Kazakhstan could be found, although it has been found in northern Iran [27] just across the Caspian Sea. Modelling has suggested that favourable conditions for *C. imicola* may be present in the southern most parts of Kazakhstan [28]. Other vectors may be implicated in the spread of BTV northwards in Europe [29]. For example, *C. scoticus* in addition to *C. obsoletus* has been shown to be an efficient vector [30].

Transmission in Switzerland has been described at altitudes as high as 1500 meters in Lenzerheid in Canton Grisons. There winter minimums are c -10^{o}C and summer maximums of 18^{o}C and there are only 2 months with mean temperature of above 12.5^{o}C. In Lenzerheid the conditions compare unfavourably to most of southern Kazakhstan and summers are cooler and shorter than in northern Kazakhstan. For example in Shymkent in the far south of Kazakhstan there are 7 months with a mean temperature above 12.5^{o}C and winter minimums average – 6^{o}c whilst summer highs average 34^{o}C. In Petropavl, in the far north of Kazakhstan winter lows average – 21^{o}C with summer highs averaging 25^{o}C with just 3 months where the mean temperature is above 12.5^{o}C. In addition there is some evidence that the virus may be able to overwinter in some vectors in northern Europe rather than in viraemic animals. This suggests that if vector competent species of *Culicoides* are endemic to Kazakhstan then there is a risk of outbreaks of bluetongue and the data displayed in Figs. 1 would represent the relative risk. However, in regions where there is the absence of vector competent species then transmission of bluetongue is not possible. It is worth noting that serological evidence of BTV has been previously reported in Kazakhstan [8]. Thus, if true, there are likely to be vector competent species in Kazakhstan and a mechanism other than viraemia in livestock by which the virus can persist through the winter and transmit from one season to the next. *C. obsoletus* has been found in some districts of Kazakhstan [10, 11] such as East Kaszakhstan. Seropositive cattle which had been imported from Russia were found in this region of Kazahstan [9] illustrating the risk of outbreaks. However the extent and distribution of this and other vector competent species is unknown and therefore represents an important data gap for understanding the risk of transmission of BTV in Kazakhstan.

Declarations

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Availability of data: All data used in the analysis can be obtained from the URLs provided [17, 18].

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Ethics declarations

No human or animal subjects were involved in this study, so ethical approval is not necessary and there are no ethical issues arising from this manuscript.

Consent for publication

Not applicable.

Availability of data and materials

All data used in the analysis can be obtained from the URLs provided [17, 18].

Competing Interests

None

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Contributions

SA concept and design of the study. All authors were involved in the study design. AS grant holder. BK, YM, AK,AU, AZ data collection. PT data analysis, drafting the manuscript. All authors read and approved the final manuscript.

Competing interests

The authors declare that they have no competing interests.

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Figures

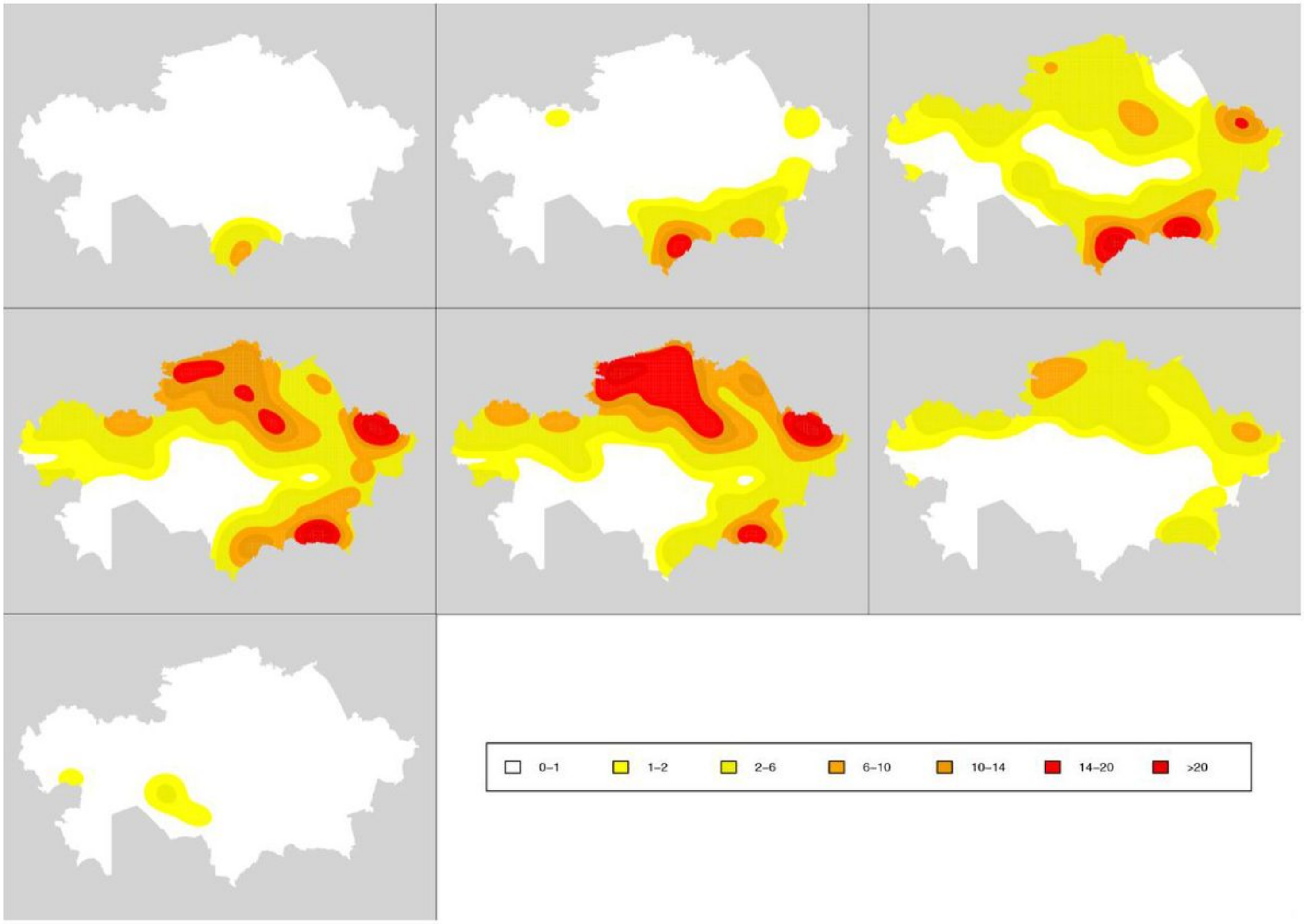

Figure 1

Relative risk of transmission of bluetongue in Kazakhstan in April (top left), May (top middle), June (top right), July (middle left), August (middle), September (middle left) and October (bottom left).