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# The use of high-resolution remote sensing for plague surveillance in Kazakhstan

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ABSTRACT

Bubonic plague, caused by the bacteria *Yersinia pestis*, persists as a public health problem in many parts of the world, including central Kazakhstan. Bubonic plague occurs most often in humans through a flea bite, when a questing flea fails to find a rodent host. For many of the plague foci in Kazakhstan the great gerbil is the major host of plague, a social rodent well-adapted to desert environments. Intensive monitoring and prevention of plague in gerbils started in 1947, reducing the number of human cases and mortalities drastically. However, the monitoring is labour-intensive and hence expensive and is now under threat due to financial constraints. Previous research showed that the occupancy rate of the burrow systems of the great gerbil is a strong indicator for the probability of a plague outbreak. The burrow systems are around 30 m in diameter with a bare surface. This paper aims to demonstrate the automatic classification of burrow systems in satellite images using object-oriented analysis. We performed field campaigns in September 2007 and May and September 2008 and acquired corresponding QuickBird images of the first two periods. User's and producer's accuracy values of the classification reached 60 and 86%, respectively, providing proof of concept that automatic mapping of burrow systems using high-resolution satellite images is possible. Such maps, by better defining great gerbil foci, locating new or expanding foci and measuring the density of great gerbil burrow systems could play a major role in a renewed monitoring system by better directing surveillance and control efforts. Furthermore, if similar analyses can separate occupied burrow systems from empty ones, then very-high-resolution images stand to play a crucial role in plague surveillance throughout central Asia.


## 1. Introduction

Bubonic plague is best known for the disastrous effects that it had in the mid 14th century. This outbreak of bubonic plague, more commonly referred to as the Black Death, was one of the deadliest pandemics in human history. Death toll estimates greatly vary but it is believed that in southern Europe around 75% of the population fell victim and in central Europe around 50% of the population died from this disease.

Although plague is now absent from Europe and can be treated with antibiotics, it persists on all other continents except for Australia. In North America, human cases occur but plague is mainly a conservation concern as it plays havoc with efforts such as re-introductions of the black-footed ferret. Most human cases reported to the World Health Organization (WHO) now come from Africa, and in places like Madagascar, Tanzania and the DR Congo it is a serious public health issue with frequent human cases and deaths (Davis et al., 2004; Laudisoit et al., 2007). In central Asia too, plague remains a public health concern.

Plague is a vector-borne disease, i.e. the disease is spread by arthropod vectors that live and feed on hosts (Gage and Kosoy, 2005). In the steppe areas of Kazakhstan the hosts are great gerbils *Rhombomys opimus*. Transmission happens through bites of infected fleas that earlier fed on infected hosts. In the late 1940s, the Soviet government began an intensive monitoring and control programme to prevent outbreaks of human plague in Central Asia. Within this monitoring system samples (of fleas and rodents) were collected from 10 by 10 km areas ("sectors") and tested for plague by the Anti Plague Institute of Kazakhstan. The PreBalkhash focus (one of at least 18 plague foci in Kazakhstan) alone has over 350 such sectors spread out over an area of thousands square kilometers. The monitoring programme is very labor intensive and expensive and in this study we investigate how high-resolution earth observation may contribute to the monitoring programme and in controlling the outbreaks of bubonic plague. The monitoring programme would greatly benefit from information about the whereabouts of the great gerbils (their burrows), the degree of occupancy of the burrows and the dynamics of the great gerbil population over the seasons and the years.

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Remote sensing has been recognized before as a potential information source to study plague (Beck et al., 2000), but has not been applied yet. Other studies on vector-borne diseases did use remote-sensing data through including a range of imagery (Beck et al., 2000; Curran et al., 2000). Many of these studies used satellite images to derive information on vegetation cover, landscape structure and water bodies (Beck et al., 2000), which link to infection risk at different spatial and temporal scales (Curran et al., 2000). Remote sensing images have been classified into habitats for the vectors of malaria, trypanosomiasis, tick-borne encephalitis and Lyme disease (Graham et al., 2004). No studies on mapping burrow systems of the great gerbil or other rodents with remote sensing were found in literature. Davis et al. (2008) used satellite images to conceive a model for the spatial spread of plague.

Davis et al. (2004) showed that the risk of human infections of plague can be predicted by the occupancy rate of the burrow systems in the previous 2 years. In this paper we aim to provide proof of concept that it is possible to reliably extract burrow-system locations from very-high-resolution imagery. A larger project, set to begin in 2009, will focus on the distinction of occupied burrow systems from empty ones and the development of a monitoring system in which remote sensing plays a key role.

## 2. The Bubonic plague system

The great gerbil (*R. opimus*) is a desert rodent of approximately 300 g in size (Fig. 1C) and is the major host of the plague bacterium (*Yersinia pestis*) in the Asian deserts and steppes. Great gerbils are social animals and live in family groups in underground burrow systems comprising a complex network of tunnels and chambers until a depth of several meters. The underground burrow system protects the family from predators and extreme temperatures. The various chambers serve as storage space for food, as well as being sleeping and nursing nests. A typical family group comprises of one adult male, one or more adult females and their immature offspring (Davis et al., 2004).

Burrow systems are semi-permanent features of the landscape and exist for many years (Dubyanskiy & Romanov, 1994). Historic fieldwork data (1956–1986) from Atyrau at the Caspian Sea in western Kazakhstan reveal that occupancy of burrow systems lasts on average for 11 years. The maximum period of continuous occupancy was over 24.5 years (occupancy started before 1956). Burrow systems would remain abandoned for periods ranging from a few months to 10–12 years. Besides *occupied* or *empty*, burrow systems can also be *visited*. This means that they are used for shelter or food storage and signs of gerbil activities are observed, but they are not occupied by a family group. Many studies have linked outbreaks in abundance of the gerbil population with variability of the numbers of human cases of plague (Randall & Rogovin, 2002).

The vectors of the bubonic plague are primarily fleas that inhabit the burrow system of the great gerbil. The gerbil is known for its heterogeneous response to plague, some individuals succumb to plague infection quickly and die, while others are quite resistant to plague. Infectious fleas have easy access to great gerbils living together in the same burrow system but limited access to families living in neighboring burrow systems. Adult gerbils are believed to visit neighboring burrow systems up to 400 m away, though dispersal movements from sub-adult males seeking to establish a new family group can be much further, up to 5 km (Randall & Rogovin, 2002).

In this study we investigate the possibilities of using high-resolution earth observation to map and monitor location and density of the burrow systems of the great gerbils. The burrow systems vary in size but are often large, more or less circular constructions with a diameter of 15 to 40 m (Fig. 1A and B). The vegetation above and around the burrow system disappears, most likely due to herbivory by great gerbils and reduced soil water availability above the burrow system (Fig. 1B). The individual burrow systems are often connected by small trails and tracks resulting in star-like spatial patterns. The discs of bare earth that form above the burrow systems, especially for the circular burrow systems, are clearly visible on very-high-resolution satellite images (Fig. 2A). By

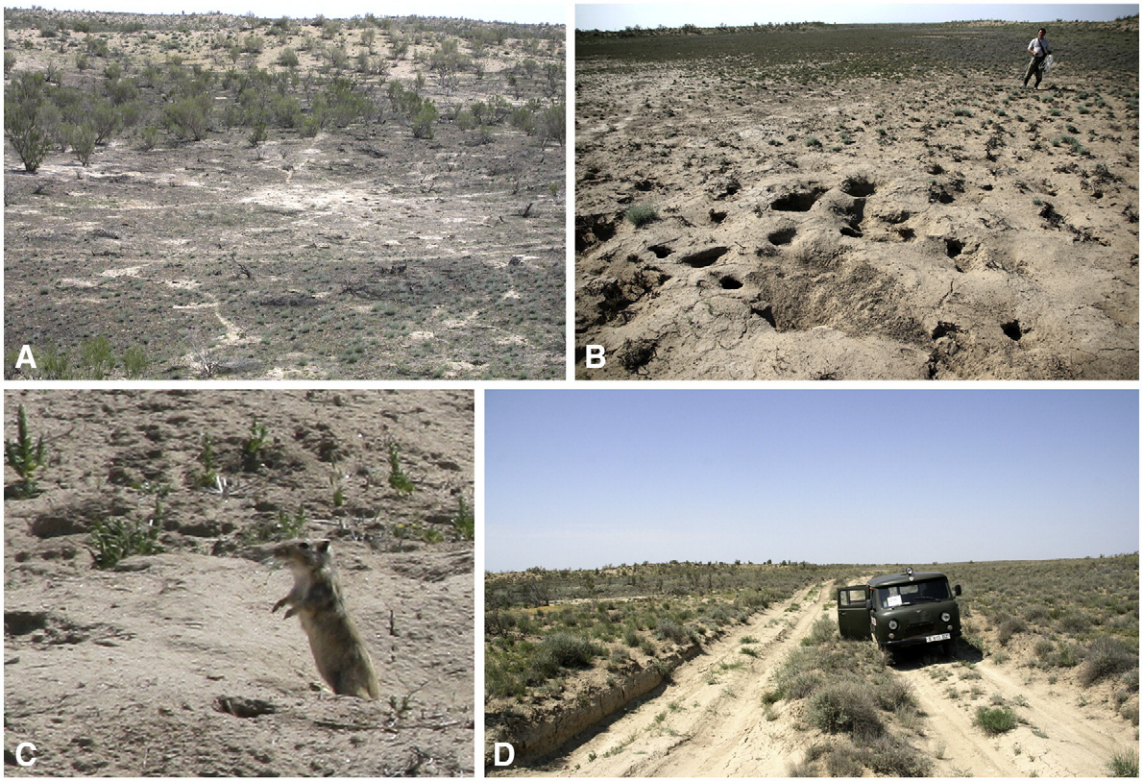


**Fig. 1.** A. Burrow system with trails to satellite systems and other burrow systems. B. Burrow system with entrances visible in the front. C. Great gerbil (*Rhombomys opimus*) on a burrow system. D. Steppe landscape of the study area.