Livestock and Marco Polo sheep: assessing the risk of health conflicts in Afghan Big Pamir, Asia

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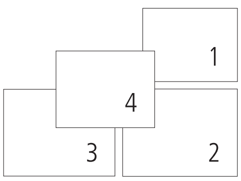

Cover photos:

1. A Wakhi assistant examines the remains of a Marco Polo sheep recently preyed by wolves after being wounded by a hunter, Big Pamir, September 2008.
2. A domestic yak is fitted with a GPS-collar. Stored positions are regularly communicated to a satellite, Big Pamir, May 2008.
3. Two female Marco Polo sheep graze in the barren mountain slopes of their high-altitude summer range, Big Pamir, September 2008.
4. Wakhi herders of the Shikargah grazing area display proudly the dominant ox of their herd, Big Pamir, September 2008.

All photographs: WCS Ecosystem Health Project Team
Maps: Mr. Rohullah Sanger, WCS

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GENERAL INTRODUCTION

Horizontal inter-species transmission is a central mechanism in the emergence of diseases in wild-living populations (Ostherhaus, 2001; Richomme et al., 2006). The probability for a pathogen to cross the species barrier from a 'source' to a 'receptor' species depends on the type of pathogen, on the susceptibility of the receptor and on the rate of efficient direct (from animal to animal) or indirect (via environmental contamination or vector transmission) contacts between the species. The contact rate between the source and the receptor is intimately linked to the relationship between these species and the likelihood of sharing the same habitat (Cleaveland et al., 2001; Woolhouse et al., 2001).

In mountainous areas, the abundance of domestic animals leads to forced cohabitation between them and their wild counterparts. The spillover of contagious diseases from domestic to wild-living ungulates has been largely reported during the last 25 years (Foreyt and Jessup, 1982; Frölich et al., 2002; Hudson et al., 2002) with sometimes detrimental effects at population level in rare wild ungulates (Callan et al., 1991; Dagleish et al., 2007). Domestic and wild-living ungulates are competitors for food, which results in pasture sharing and, thus, in the transmission of infectious agents, especially indirectly transmitted ones.

Afghanistan is a mountainous country that supported in the recent past large populations of free-living mountain ungulates (Habibi, 2003). Yet, most of these populations have been destroyed or suffer serious habitat degradation and over-hunting. Afghan Pamirs still host populations of Marco Polo sheep or argali (*Ovis ammon polii*) and Siberian ibex (*Capra sibirica*), yet they are under threat of disappearance due to uncontrolled hunting and alleged competition with livestock for suitable habitat. Although in theory cross-species transmission of diseases between livestock and wild ungulates could operate in both ways, in Afghan Pamirs the risk of population collapse for wild ungulates seems to far overstep the anecdotic likelihood of livestock being impacted by a pathogen indigenous to wild ruminants. Indeed livestock in Afghan Pamirs are a renewable human resource, quickly replaced in the event of massive mortality such as affecting them during harsh winters (Ostrowski, 2006; Ostrowski et al., 2007), whereas wildlife currently suffers overutilization and competition for food resources, allowing only limited productivity. Any relevant contagious pathogen introduced into such pressurized population could have disastrous effects on the short term. Therefore, within the proposed plan to protect remnant populations of wild ungulates in Afghan Pamirs, one may legitimately question whether livestock pose a significant health risk to wild ungulates and especially to the most threatened species, the iconic Marco Polo sheep. The purposes of the present study are 1/ to compile the results of our scientific investigations related to health issues in the sympatric populations of domestic sheep (*Ovis aries*), goats (*Capra hircus*), yak (*Bos grunniens*) and Marco Polo sheep in Pamir-e-Buzurg (Big Pamir) in Afghanistan, and 2/ to provide scientific foundation for the development of policies aimed at reducing the risk of disease spillover from livestock to argalis. Based on the lessons harvested from this pilot project, we hope that the method we developed could be applied and adopted across the fragile altitude ecosystems in Asia.

BACKGROUND

This document has been written in the continuity of our 2006 and 2007 reports (Ostrowski, 2006; Ostrowski et al., 2007). To summarize our earlier investigations, we have studied Wakhi livestock herds in Big Pamir since 2006, recording their species composition, numbers, ownership, range use, and transhumance patterns. We also assessed their health status based on clinical examinations and questionnaire investigations. After analyzing the data collected during our 2006 mission, we decided that we needed to further investigate the range used by livestock and to quantify disease prevalence in the area, as both sets of information are essential to our understanding of the risk of cross-species dissemination of pathogens between livestock and wild ungulates. Therefore, from 2007, we carried out field surveys to 1/ document the range used by Wakhi livestock in western Big Pamir, in areas where Marco Polo sheep are still known to survive (Habib 2006; 2008), and 2/ collect blood samples from livestock (overall 480 blood-samples from sheep and goats and 31 from yaks), to test their exposure to a number of pathogens that may pose a disease risk both to them and to the wild ungulates they may encounter. We identified the Central Veterinary Laboratory at Kabul (CVL-Kabul), a facility depending of the Ministry of Agriculture, as the principal technical partner to carry out laboratory analyzes. We provided them with testing kits and collaborated in training Afghan staff at sampling animals, processing collected materials and analyzing them.

Our results are presented in four chapters: 1/ Range use of Wakhi livestock in western Big Pamir; 2/ Parasite collection and serological screening carried out on this same population of livestock; 3/ Synthesis on the risk of cross-species dissemination of pathogens in the proposed Big Pamir protected area; and 4/ Recommendations to reduce the risk of disease spillover between livestock and wild sheep.

The work carried out since 2006 is starting to clarify the complex issue of livestock disease epidemiology in the Afghan Pamir ecosystem and more importantly to bring some insights into the risk of disease spillover between domestic and wild ungulates in the Pamir Mountain range.

PART I. RANGE USED BY WAKHI LIVESTOCK IN BIG PAMIR

Introduction

In 2006 we interviewed 80% of Wakhi herders pasturing their herds in Big Pamir. They provided us with information about the seasonal movements and the geographical extent of the range used by their livestock in summer in Big Pamir. In addition, while visiting each settlement, we consistently scanned with binoculars the mountain slopes for livestock herds, and pinpointed upon sighting their estimated position on a 1/50 000 map. Finally we visited several areas reputedly located at the fringes of pasture areas and recorded sightings of livestock and indirect markers of their recent presence (fresh droppings, tracks, and carcasses). Pasture areas were then delimitated on a 1/50 000 map, digitalized and processed using ArcView 3.2 software by Mr. Haqiq Rahmani, at WCS office in Kabul. Examination of produced maps and discussion with local land users showed however that the interview method was inadequate to accurately assess the reality of the range use, particularly in the roughest locations where likelihood of contacts with argalis was deemed higher. In addition it provided no information on the utilization of mountain range by domestic yaks which are typically left unattended for most of the summer and are the more likely to come into direct contact with Marco Polo sheep (R. Harris and J. Winnie, pers. comm.). In 2007 we therefore started a study of range use of mixed herds of sheep and goats based on data collected with hand-held GPS units by Wakhi herders. In 2008 we extended this work to other groups of sheep and goats in western Big Pamir and to domestic free-ranging yaks which were equipped with GPS collars. Part I presents the results of GPS data collection.

Objectives

The work carried out in summers 2007 and 2008 was dedicated at documenting as accurately as possible the extent of summer range use by Wakhi livestock in Big Pamir, particularly in an area where a remnant population of Marco Polo sheep still occurs. Because sheep and goats in each settlement are tended in one large herd, we tried to be as exhaustive as possible with the dataset collected from tended groups of these small ruminants, in particular by monitoring all the large herds of Shikargah grazing area. We could be only indicative for yaks as too many independent groups of yaks use estival pastures. We monitored 5 herds of yaks.

Methods

Study area

We worked in the west of Big Pamir, Wakhan District, Badakhshan Province (Figure 1). Locally known as Pamir-e-Kalan or Pamir-i-Buzurg, the Big Pamir comprises the main block of mountains at the western end of the Pamir Knot between the fork of the Pamir and Wakhan rivers. It encompassed high mountains that culminate at 6700–6900 m and high plateaus that average between 3900 and 4700 m in elevation. The Big Pamir extends over about 5,500 km² of Wakhan. A notable part of the western Big Pamir was once included in the so-called Big Pamir Wildlife Reserve encompassing about 700 km² (Haqiq Rahmani, pers. comm.).

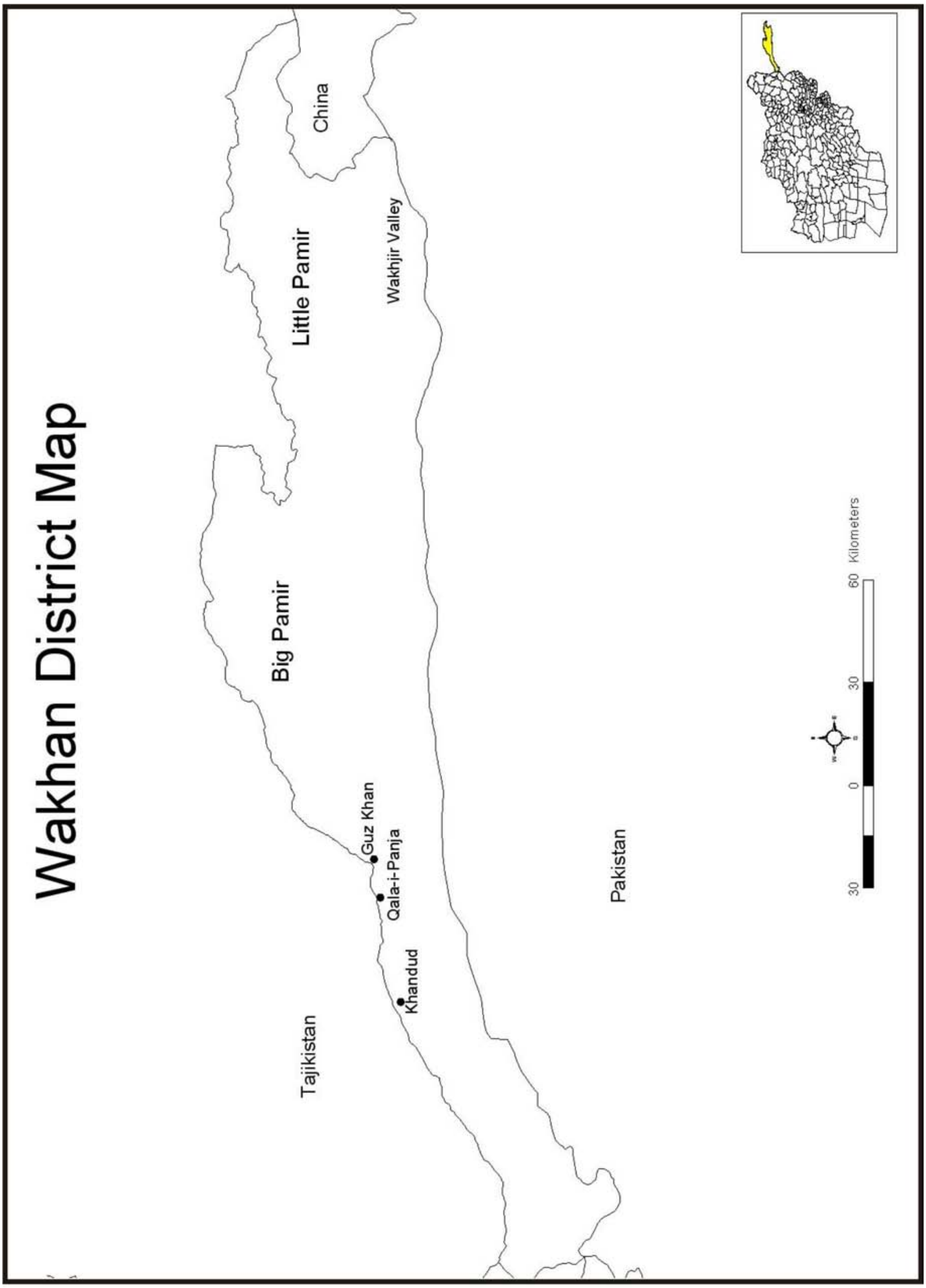


Figure 1. Map of the Wakhan district, Badakhashan province, Afghanistan

Although designated a reserve, it has never been legally established, and between 1968 and 1977 has functioned as a hunting reserve for foreigners, managed by the Afghan Tourist Organization. Before that, part of the area was a royal hunting reserve of the former king Muhammad Zahir Shah (Petocz et al., 1978). Wakhi occupy with their herds a large part of this area between early May and late October (Ostrowski, 2006; Ostrowski et al., 2007). In autumn most of them migrate back to the Wakhan Valley where winter is less rigorous than in highlands. Only a handful of shepherds with few livestock stay in lower reaches of Pamir valleys where winter graze/browse may still remain accessible during milder winters. Should winter strike very cold and snowy these livestock may suffer considerable mortality due to starvation and extreme weather conditions (Ostrowski et al., 2007).

Location of pasture areas and settlements in Big Pamir

In 2006 and 2007 we identified the summer pasture areas and settlements of the Wakhi community in Big Pamir according to information published by Shahrani (2002), or provided to us by Mr. Amin Uddin, Mr. Shah Ismail's (one of the two spiritual leaders of the Wakhi community) youngest brother in Qila-e Panja on 23 July 2006 and by Mr. Kok Aslam, Kirghiz leader of Big Pamir on 30 June 2007. We visited all these pasture areas and settlements in 2006 and 2007 (Ostrowski, 2006; Ostrowski et al.; 2007). We regularly updated information concerning possible uses of new pasture areas with elders of each settlement.

GPS data collected by Wakhi herders

Because available data on the distribution of Marco Polo sheep collected by Petocz (1973) and more recently by Habib (2006; 2008) suggested that livestock herds pasturing in Shikargah area were the most likely to come into contact with wild sheep, we focused our attention on four Wakhi settlements in Shikargah Valley, which we visited between 20 and 23 June 2007. In each of them we identified with the help of the camp elder a herder willing to collaborate with us and trained him at using a GPS unit (Garmin 60 CSx or Garmin eTrex). On 24 June 2007, we also visited Nakchirshitk camp in Manjulak grazing area where Marco Polo sheep had also been observed in summer 2006 (Habib, 2006) and proceeded similarly. While on our way back from Kirghiz area in Big Pamir we revisited on 12 July 2007 the herder in Nakchirshitk camp and changed the GPS unit for a more user-friendly model. Herders were shown how to change the batteries of their GPS unit, switch it on and off, acquire a location and store it into the memory (Plate 1). We let them operate the unit by themselves under our supervision for a couple of hours. We instructed the herders to position themselves within their herd before marking a position, two to three times per day between 6:00 am and 4:00 pm. In order to build up their level of responsibility towards the work we asked them not to 'subcontract' the duty to another herder if occasionally they were not in charge of the conductance of the herd, and agreed to pay them 50$/month (the cost of a big adult *Turki* sheep) upon completion of the work.

The five GPS units were retrieved from herders in September 2007 after the survey of Wakhi livestock in Little Pamir (Ostrowski et al., 2007). Preliminary data concerning these GPS unit deployment were compiled in 2007 (Ostrowski et al. 2007).

Plate 1. Dr Ali Madad Rajabi teaches Wakhi herders how to use a GPS handheld unit, under the supervision of the elder (far right) of the settlement in Shikargah, Big Pamir, 26 June 2007.

Although range use was not analyzed we provided in this report information concerning the efficiency of data collection and altitudinal grazing trends throughout summer. In 2008, we decided to re-deploy the GPS units with the same herders to increase the size and accuracy of the data set. Also we identified three additional pasture areas where sheep and goats might come into contact with wild ungulates; Senin in the north-west of Shikargah, Asan Katich in the south and Aba Khan in the north-east, and provided GPS handheld units to herders in these areas. Background information concerning GPS deployments is provided in Table 1.

Free-ranging domestic yaks equipped with GPS collars

Because observations made in 2006 and 2007 of Marco Polo sheep in Big Pamir suggested that free-ranging domestic yaks were susceptible to come into direct contact with Marco Polo sheep in summer pastures (Rich Harris and John Winnie, pers. comm.), we also equipped 5 yaks with GPS collars (4 Tellus GPS, TVP Positioning AB, Sweden, and 1 satellite/GPS PTT, North Star Science and Technology, USA) in May 2008 (Plate 2). At the end of summer we relocated the animals with the help of their owners, retrieved the units and downloaded the GPS locations stored 'on-board'. Background information concerning GPS collar deployments is provided in Table 2.

Plate 2. Dr Ali Madad Rajabi with a free-ranging domestic yak, which he has just fitted with a GPS collar, with the help of his Wakhi owner, Big Pamir, 30 May 2008. The GPS collar monitors the movement of this big bull and the herd it leads, locations being stored on-board. Data were successfully retrieved in September 08.

Data analysis

We plotted the locations recorded by GPS handheld units and by radio collars in an ArcView 3.2 (Environmental Systems Research Institute 1999) shape file. Each handheld unit and collared animal has a point shape file, with date, time of first and last telemetry fix, number of animals in group, and notes recorded into the attribute table. We used the local nearest-neighbor convex-hull construction (LoCoH) (Getz and Wilmers, 2004) to estimate the size of the range used by each monitored herd of sheep and goats or yaks. The LoCoH algorithms work by creating convex hulls around each point in the data set and then iteratively joining these hulls together from smallest to largest into isopleths. The 10% isopleth contains 10% of the locations while the 100% isopleth encompasses all the points. The smaller the hull, the more heavily used the region. Therefore, isopleths can be used to determine how frequently a region is used. Compared to other methods for constructing home ranges, the LoCoH method presents several advantages. In mountainous areas, the LoCoH density isopleths have been shown to approximate the true area represented by the data better than kernel or alpha-hull methods, while the Minimum Convex Polygon method has been criticized for dramatically overestimating the home-range area in the presence of outliers (Burgman and Fox, 2003).

Table 1. Background information on GPS units provided to Wakhi herders in Big Pamir, in summers 2007 and 2008.

Grazing area	Settlement	Garmin GPS type	Period of deployment in 2007	Period of deployment in 2008
Shikargah	Qabal Gah	eTrex & 60 CSx	June 20 – September 17	June 3 – September 18
Shikargah	Dara Big	eTrex & 60 CSx	June 23 – September 17	May 31 – September 18
Shikargah	Kund-a-Thur	60 CSx	June 22 – September 11	June 2 – September 27
Shikargah	Mulung Than	60 CSx	June 22 – September 15	June 14 – September 19
Shikargah	Asan Katich	60 CSx	No	June 2 – September 19
AliSu/ Aba Khan	AbaKhan	60 CSx	No	May 29 – September 18
Manjulak	Nakchirshitk	eTrex & 60CSx	June 25 – September 17	May 30 – September 21
Senin	Senin	eTrex & 60CSx	No	May 9 – September 16

Table 2. Background information on radio-collared free-ranging domestic yaks, Big Pamir, summer 2008.

System configuration	Provider	Age (yr) of the yak	Sex of the yak	Period of deployment
On-board storage	TVP Positioning AB	8	M	May 31 – September 29
On-board storage	TVP Positioning AB	4	M	May 31 – September 17
On-board storage	TVP Positioning AB	7	M	May 30 – September 21
On-board storage	TVP Positioning AB	5	F	June 2 – September 25
Satellite communication	NorthStar Science and Technology	3	F	June 2 – September 20

Table 3. Home range estimates of 8 herds of sheep and goats in Afghan Big Pamir during summers 2007 and 2008 based on local convex-hull (LoCoH) method, including number of locations, *k*, herd size and average densities.

Herd name	No. locations	[1]Area LoCoH (km^2)	*k*	[2]Average herd size	Sheep and goat density (animals/km^2)
Qabal Gah	395	26.8	15	823	30.7
Dara Big	363	37.1	25	542	14.6
Kund-a-Thur	400	24.5	20	573	23.4
Mulung Than	254	32.1	15	581	18.1
Asan Katich	161	25.1	20	437	17.4
Nakchirshitk	375	38.5	20	881	22.9
Aba Khan	62	29.9	20	490	16.4
Senin	210	28.3	20	665	23.5

[1]Home range. [2]Ostrowski 2006, Ostrowski et al. 2007

LoCoH isopleths also have the property of conversing to the true area represented by the data as the number of data points increases, thus the method is particularly well-suited when there is a lot of observational data (this is the case for GPS collar). We used the LoCoH Homerange Generate ArcView extension to estimate the home range area for each radiocollared yak or monitored herd of sheep and goats (see Getz and Wilmers, 2004 and Ryan et al., 2006 for details). This extension uses the locations to create the convex hull with each location and its *k*-1 nearest neighbors. Because the *k* parameter is user-selected, we ran this method for *k* values of 10, 15, 20, 25, 30, 35 to identify the plateau that gives stable-area values across a range of *k* values, representing the estimated area of the range use, considered further as 'home range'. In addition we refined the choice of *k* by excluding as far as possible constructions that included obviously non-accessible areas for livestock. This selection process followed the 'minimum spurious hole covering' rule (Getz and Wilmers, 2004) and we report *k* values for estimated LoCoH 'home-range' areas (Table 3).

Results

Assessment of summer range use of tended herds of sheep and goats in Big Pamir

Qabal Gah and Dara Big — Both herds graze in summer areas located in the upper Shikargah Valley on both sides of the river Istimoch (Figure 2). Livestock graze the valley floor and the slopes on both sides of the river. Throughout summer Wakhi and their livestock progressively move towards higher reaches of the valley and graze to elevations of 4500–4700 m (Ostrowski et al., 2007). Then in late summer settlements and livestock gradually move back to lower reaches of the valley. This pendular movement spans over 6 months. At the end of September, or if weather conditions allow, as late as the end of October, all livestock move back to the Wakhan Valley. The pasture will then remain free of domestic grazers between October and the end of May (c. 7–8 months). Drs J. Winnie and S. Ostrowski did an aerial survey of Big Pamir on 20 May 2008 and confirmed that at this date the Shikargah area was free of livestock, including free-ranging domestic yaks (Figure 3 and Plate 3a). LoCoH method for calculating summer home ranges of tended herds of sheep and goats yielded a higher estimate for Dara Big (37.1 km^2) than for Qabal Gah (26.8 km^2) (Table 3). Home ranges of both herds had little overlap except in lower reaches of the valley in early summer, the Dara Big herd exploiting the area located north of the river and the one of Qabal Gah the area located south of it. Based on livestock counts made in 2006 (Ostrowski, 2006), average sheep and goat densities were 14.6 animals/km^2 in Dara Big and a high 30.7 animals/km^2 in Qabal Gah (Table 3). The implication of such high livestock density for the risk of cross-species disease dissemination will be discussed in Part II.

Kund-a-Thur and Mulung Than — These herds use also the Shikargah grazing complex but west and south-west of Qabal Gah and Dara Big (Figure 2). As in Qabal Gah and Dara Big, livestock and settlements move progressively to higher altitudes across summer, to reach a maximal grazing altitude at c. 4750 m. These pastures remain free of livestock between late October and late May as confirmed by the results of an aerial survey we did on 20 May 2008 (Figure 3) and the results of GPS studies.

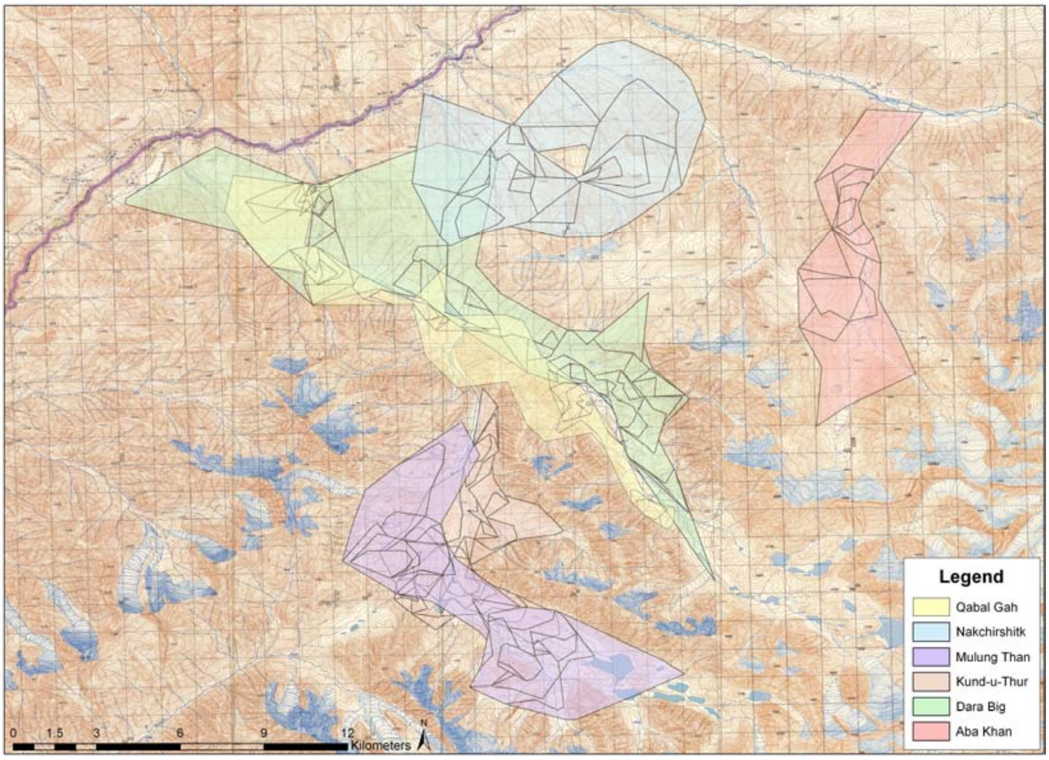


Figure 2. Topographic representation of western Big Pamir, with summer home range estimates for 5 herds of sheep and goats (Nakchirshitk and Aba Khan is the same herd in two different seasons), based on local convex-hull (LoCoH) method, summer and autumn 2007. Three herds using Senin, Asan Katich and Aba Khan were also monitored in summer 2008 but are not plotted on this map (see Figure 4).

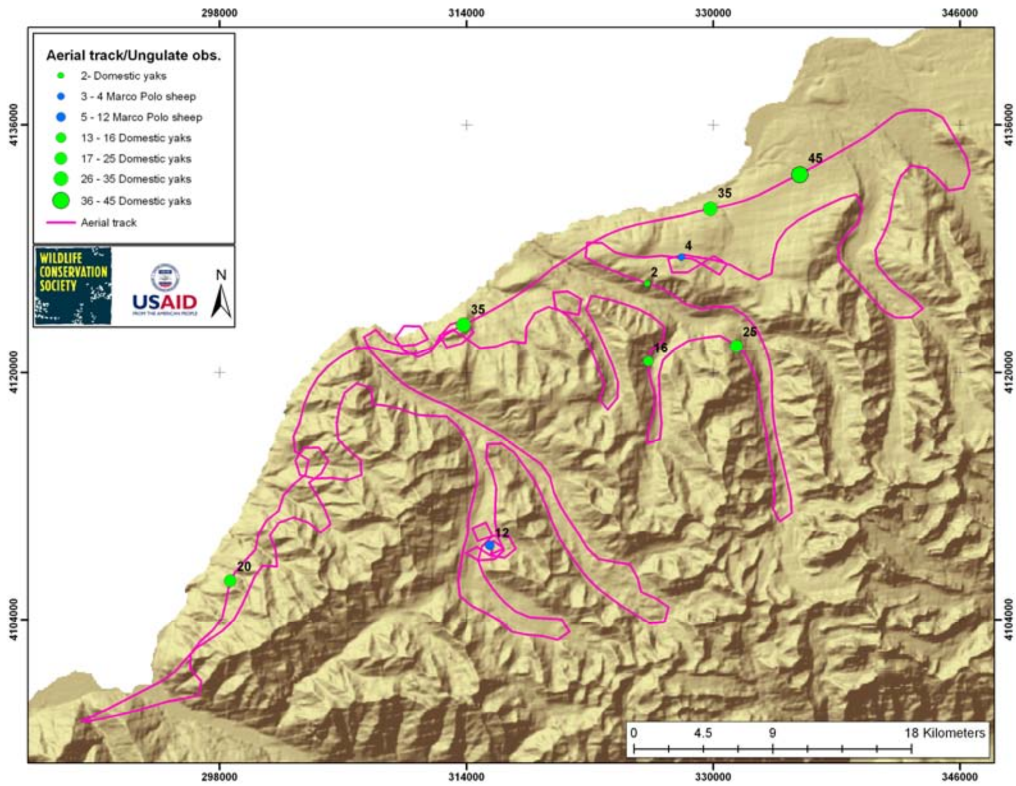


Figure 3. Cartographic relief depiction of western Big Pamir, Afghanistan, showing the aerial survey carried out on 20 May 2008. Sightings of Marco Polo sheep and groups of yak are plotted on the map.

Plate 3a (Top left). Aerial picture of the 'Shikargah fork'. To the left, the valley occupied by Dara Big and Qabal Gah settlements in summer, to the right the valley to Kund-a-Thur, Mulung Than and Asan Katich summer settlements. Plate 3b (Top right). The Asan Katich grazing area photographed from the sky in spring before domestic grazers 'invade' the area. Plate 3c (Bottom). Aerial photograph of the upper reaches of Senin grazing area in spring. The three pictures were taken at the occasion of an aerial survey of wild and domestic ungulates in western Big Pamir on 20 May 2008.

LoCoH method for calculating summer home range areas of tended herds of sheep and goats yielded slightly lower estimates for Kund-a-Thur (24.5 km^2) than for Mulung Than (32.1 km^2) (Table 3). Home ranges of Kund-a-Thur and Mulung Than overlapped little with Asan Katich but overlapped over 15% of their respective areas. Based on livestock counts and estimates made in 2006 and 2007 (see Ostrowski et al., 2007 for full discussion), average sheep and goat densities were 23.4 animals/km^2 in Kund-a-Thur and 18.1 animals/km^2 in Mulung Than (Table 3).

Asan Katich — The herd of Asan Katich grazes immediately south and south-east of Kund-a-Thur and Mulung Than (not represented on Figure 2 but see Figure 4). The assemblage of grazers of Asan Katich is more complex as it involves groups of livestock coming directly from the upper Wakhan Valley and Kund-a-Thur in late summer (see Ostrowski et al., 2007 for more details). The area is free of livestock between late October and early June (Plate 3b). Summer home range area of the tended herd of sheep and goats in the area was 25.1 km^2. Based on livestock counts made in 2007 (Ostrowski et al., 2007) the average density of sheep and goats in this area was 17.4 animals/km^2 (Table 3).

Nakchirshitk — Nakchirshitk herd utilizes Manjulak grazing system, north of Shikargah (Figure 2). Manjulak encompasses a vast grazing area where 2200–2300 sheep and goats gather in summer (Ostrowski, 2006). We followed only one of the three large herds grazing the area (Ostrowski, 2006) and therefore we have only a partial understanding of the range used by small ruminants in this area. However the observations we made in summer 2006 showed that there was considerable overlap (>75%) in the range used by these three herds, suggesting that our estimate of the home range of the monitored herd should be reasonably close to the range-use area of Manjulak herds at large. We estimated the home range of the Nakchirshitk herd at 38.5 km^2, translating into an average livestock density of 22.9 animals/km^2 (see Ostrowski, 2006 for population size estimate) (Table 3). Noteworthily a number of livestock remain in Manjulak grazing area during winter, using the lower parts of this area along the Pamir River and grazing also in Aba Khan for 2.5 months in autumn.

Aba Khan — Aba Khan is part of the Ali Su/Aba Khan valley drainage system located north-east of Shikargah (Figure 2). In summer Aba Khan is grazed by one large herd joined in autumn by animals from Nakchirshitk which will eventually return to Manjulak grazing area in late November or early December. In summer the herd of sheep and goats grazes up to a maximum altitude of c. 4950 m, one of the highest recorded grazing altitudes for sheep and goats in the whole Pamir Mountain range. Livestock continues to use lower reaches of Aba Khan grazing area in winter. We estimate the home range area of the tended herd of sheep and goats at 29.9 km^2, which translates into an average livestock density of 16.4 animals/km^2 (for the number of sheep and goats in this area we refer to direct counts made by Drs. Hafizullah and Ali Madad in October 2007) (Table 3).

Senin —This grazing area is the westernmost of Big Pamir, situated on the north-facing mountain slopes overhanging the lower course of Pamir River (Plate 3c) (not represented on Figure 2 but refer to Figure 4) The area is located a day walk from Goz Khun village in the Wakhan Valley and because of this may be used year-round when winter is mild. The area is grazed in an ascending pattern across summer up to 4700 m of altitude, similarly to what is seen in other grazing areas in Pamir. We estimate the home range of the tended herd of sheep and goats at 28.3 km^2, which translates into an average livestock density of 23.5 animals/km^2 (see Ostrowski et al., 2007 for population size estimate) (Table 3).

Assessment of home range of free-ranging herds of domestic yaks in Big Pamir

The groups of yak monitored with GPS collars displayed remarkably variable uses of their habitat. The home range of the herds varied between 11.2 and 361.9 km^2 (Table 4).

Table 4. Summer home-range estimates based on local convex-hull (LoCoH) method for 5 herds of free-ranging domestic yaks in Big Pamir, Afghanistan, during summer 2008, including number of locations, *k*, and number of individuals in each herd.

Herd No.	No. locations	[1]Area (km^2) LoCoH	*k*	Herd size
1	1369	41.4	25	15
2	1209	44.5	25	15
3	1295	11.2	25	21
4	1324	16.8	25	25
5	332	361.9	20	25

[1]Home range

Altitudinal usage of mountain extended over 2254 m, ranging from 3199 m and an impressive 5453 m. Four of the five herds we followed had a home range that more or less overlapped those of other herds in their respective grazing areas (Figure 4). Yet, herd #5 with the largest home range of 361.9 km^2 overlapped several sheep and goat grazing areas. It is important to understand that we have not monitored yaks of western Big Pamir as exhaustively as sheep and goat herds in the same area. While we believe to have documented the range use of 80–85% of the sheep and goats in the study area, we have equipped with GPS unit one individual in only 5 herds of yak totaling 101 animals, monitoring only 15% of the estimated ~600 yaks present in western Big Pamir during summer (Ostrowski et al., 2007). Also unlike Wakhi sheep and goats, which at 85–90% are moved out of Big Pamir in winter, an unknown number of yaks freely range in the area during winter. We observed nearly 200 of them (33% of the estimated summer population) in 7 different groups during our flight over western Big Pamir on 20 may 2008 (Figure 3). The majority was seen in lower reaches of valleys afferents to the Pamir River. Interviews of Wakhi herders in 2006 and 2007 already suggested that ~150 yaks overwinter regularly in western Big Pamir, mainly in the Ali Su / Aba Khan drainage system.

Summary 1 — According to the surveys carried out in 2007 and 2008, the western Big Pamir is grazed up to an altitude of 4950 m by 10 large herds of sheep and goats totaling nearly 6500 animals between May/June and September/October. The average home range and density of 8 of these herds, totaling nearly 5000 small ruminants, were 30.2±5.3 km^2 (min: 24.5 km^2, max: 38.5 km^2) and 20.8±5.2 animals/km^2 (min: 14.6 animals/km^2, max: 30.7 animals/km^2), respectively. All but two of these herds migrate to the Wakhan Valley in autumn, leaving pastures free of domestic grazing until the end of May. The two overwintering herds retain only the strongest animals and are joined by one large herd utilizing Jermasirt grazing area in summer (an area located north-east of the study site that we surveyed in 2006). The three groups exploit lower reaches of the Manjulak and Aba Khan / Ali Su grazing areas throughout winter. We have also monitored the movements of 5 groups of free-ranging domestic yaks totaling about 100 individuals. Their home ranges extended over an average of 95.2 km^2 (min: 11.2 km^2, max: 361.9 km^2) between 3199 m and 5453 m in altitude. Although the groups we monitored moved in October to the Wakhan Valley, we estimate that 150 to 200 yaks or about a third of the summer population remains in Big Pamir during winter, the majority of them using pastures in Manjulak, Aba Khan and Jermasirt grazing areas. Understanding accurately the range-use pattern of livestock in Big Pamir will help assess the risk of disease spillover to wild ungulates.

PART II. LIVESTOCK EXPOSURE TO SELECTED PATHOGENS IN BIG PAMIR

Introduction

In Afghanistan the reduction of veterinary services and vaccination programs during the last twenty years combined with the effect of drought, overgrazing and civil strife have resulted in widespread occurrence of livestock disease outbreaks. Diseases such as Peste des Petits Ruminants (PPR), Foot and Mouth Disease (FMD), sheep pox, anthrax, and enterotoxaemia are endemic in the country and often occur as annual epizootics. PPR, anthrax and enterotoxaemia are remarkably effective at killing livestock whereas FMD and sheep pox have a direct effect on food security; they reduce milk production in dairy cows and yaks, decrease fertility and incapacitate breeding bulls and oxen. Although all these diseases are common in Afghanistan, it is not known to which extent they also affect livestock in the remote Wakhan district of Badakhshan. In addition, other diseases commonly found in sheep and goats in west Asia, such as brucellosis, Q fever, chlamydiophilosis, toxoplasmosis or blue tongue have rarely or never been recorded in Afghanistan because of the lack of epidemiological surveillance. Part II presents original information on the exposure of livestock in Big Pamir to a variety of infectious agents.

Objectives

In 2006 and 2007 we investigated the presence of a selection of pathogens in the Wakhi livestock population of Big Pamir via clinical examinations of diseased animals and questionnaire surveys (Ostrowski, 2006). We identified two broad types of syndromes that were currently affecting Wakhi herds and could pose a threat to wild ungulates as well. We categorized them as 'abortive' and 'stomatitis-ulcerative' syndromes. We hypothesized that among possible infectious etiologies the abortive syndrome could be caused by brucellosis, Q fever, chlamydiophilosis, toxoplasmosis bluetongue, or foot-and-mouth disease (FMD), while rinderpest and again bluetongue and FMD could be involved in the stomatitis/ulcerative syndrome, so we decided to track the serological signature of the presence of infectious agents responsible for these diseases.

Methods

Study area

The study area is the same as described in Part I. In addition we carried out blood and ectoparasite sampling in the upper Wakhan district, Badakhshan province, on livestock returning from Big Pamir, in winter 2006/2007, and about to join Pamirs in spring 2008.

Clinical examination of livestock and interview of herders

Refer to the method described in Ostrowski, 2007 and Ostrowski et al., 2008.

Sample collections

Randomly selected livestock in grazing areas surveyed with GPS technology or in the upper Wakhan Valley were blood-sampled in the evening, upon their return to the night corral of Wakhi settlement.

Plate 4 (Top). Blood sampling animals in remote Afghan Pamir Mountains implied a heavy logistical organization. Here a working camp of the ecosystem health team showing three protective plastic boxes containing the liquid nitrogen dry shippers, disposed in the shade of one of the mission's tents, Big Pamir, 19 September 2008. Plate 5 (Bottom). Frozen sera samples in dry shippers were transported in protective containers, often on camel backs. The return journey to Kabul from Big Pamir took an average of 6 days, Big Pamir, 13 May 2008.

Between 5 and 10 ml of blood were drawn aseptically in plain or EDTA vacutainers (Terrumo®, USA) via jugular venipucture. EDTA blood samples for bluetongue RT–PCR testing were kept in a cool box regularly supplied with cool-packs refrigerated overnight in close-by rivulets (T_{water} ~6–9°C). Blood in plain tubes was allowed to clot at 15–22°C for 3–4 hours and centrifuged for 4–5 minutes with a manual centrifuge (Hettich, Germany). Sera (c. 1.5 ml) were pipetted and stored in cryovials at −196°C in liquid nitrogen dry shipper (Taylor–Wharton, USA) (Plates 4 and 5). The cool box and dry shippers were moved by yak or camel in Pamirs, then from Goz Khun village to Feyzabad, the provincial capital, by car and eventually airplane to Kabul where samples were stored either at 4–8°C (EDTA) or –20°C (sera).

Fecal samples (5–6 pellets, that is, 6–9 g of fresh fecal matter) were retrieved directly from the rectum of sheep for quantitative coprology. Feces were stored in 1:3 proportions in 10% neutral buffered formalin solution (w/v 4% formaldehyde) before being processed in Kabul. Specimens of endoparasites were washed in sterile normal saline at ambient temperature for 1–2 hours and then immersed and stored in ethanol 70°. Ectoparasites were immediately stored in ethanol 70°.

Serological investigations

Toxoplasmosis, chlamydiophilosis and Q fever — Sera were analyzed by CVL–Kabul, Afghanistan, with semi-quantitative competitive enzyme-linked immunosorbent assays (ELISA) (CHEKIT® Tests, Idexx laboratories, USA) that we provided to them. All laboratory work at CVL–Kabul was supervised by Drs S. Yingst and M. Habib. We asked the Central Institute for Animal Disease Control of Lelystad, The Netherlands (CIDC–Lelystad), to re-test 55 samples for Q fever (CHEKIT® Tests, Idexx laboratories, USA) under ISO/IEC 17025 research standards. Qualitative results of both laboratories matched rigorously. We also tested in-situ vaginal swabs of animals with a recent history of abortion as well as conjunctival swabs of animals with eye impairments, with a qualitative antigen (i.e. LPS antigen common to Chlamydiophila genus) detection test for chlamydiophilosis (Speed® Chlam, France).

Brucellosis — Serological tests for brucellosis suffer lack of specificity (false positive results) and cannot always distinguish reactions due to *B. melitensis* from cross-reactions to other bacteria, particularly *Yersinia enterocolitica* O:9. One way to discriminate false positive from true positive reactions is to apply different tests with different specificity levels (Godfroid, 2002). We used the buffered *Brucella* antigen tests or Rose Bengal (RB) plate agglutination tests (Bengatest®, Synbiotics, France) as primary investigation. Then, all doubtful or positive samples, as well as 50 randomly chosen negative samples to RB test, were re-analyzed with complement fixation test (in-house procedure) and a competitive ELISA (Prionics AG, Switzerland). RB screening was either performed directly by us or by the CVL–Kabul. Confirmation tests were all done at the CIDC–Lelystad.

Bluetongue — Sera were tested for the presence of antibodies against the VP7 protein of BTV with competitive ELISA either at CVL–Kabul (Pourquier® ELISA bluetongue competition, Institut Pourquier, France) or CIDC–Lelystad (ID–VET bluetongue competitive ELISA, ID–VET, France; ISO/IEC 17025 accredited research). According to producers, these assays were not cross-reacting with closely related Epizootic Hemorrhagic Disease (EHD) orbiviruses. Because of the relatively high prevalence detected at CVL–Kabul, 40 samples were re-checked by CIDC–Lelystad. Results were matching at 100%. Eventually 22 blood samples collected on seropositive sentinel sheep and preserved on EDTA at 4–8°C were tested by RT–PCR ('in-house' procedure, Magnapure / Light Cycler) at CIDC–Lelystad for the presence of circulating BTV nucleic acids (ISO/IEC 17025 accredited research).

Foot-and-mouth disease — Sera were tested for FMD antibodies with a competitive NS ELISA (Prionics AG, Switzerland) at CIDC–Lelystad. Four positive yak samples were also tested with virus neutralization test (VNT) ('in-house' prescribed test) against serotypes O1 Manisa, Asia-1 Shamir and A10-Holland at the same facility.

Rinderpest — Sera were tested against rinderpest antibodies with a solid-phase competitive ELISA ('in-house' procedure, Pirbright, UK) at CVL–Kabul. The test is based on the ability of positive test sera to compete with a rinderpest anti-H protein MAb for binding to rinderpest antigen. The presence of such antibodies in the test sample will block binding of the MAb, producing a reduction in the expected color reaction following the addition of enzyme-labeled anti-mouse IgG conjugate and a substrate/chromogen solution. As this is a solid-phase assay, wash steps are required to ensure the removal of unbound reagents. Both MAb and standardized rinderpest antigen are directly available from the Office International of Epizooty Reference Laboratory for Rinderpest in Pirbright, UK (please consult the OIE Web site at: http://www.oie.int/eng/OIE/organisation/en_LR.htm).

Epidemiological sentinel study

In early spring 2008 we randomly selected 30 adult sheep in Avgarch and Kipkut, two villages of upper Wakhan, in order to better understand the timing of exposure to BTV of this species. All animals were clinically healthy upon selection and were identified with numbered plastic neck collars (Plate 6). We took blood from them on 6 April, then on 31 May, one day before spring transhumance to Big Pamir, and eventually on 24–26 September 2008 about a week prior to autumn transhumance back to the Wakhan Valley. All samples were handled and processed as described above.

Quantitative coproscopy

We did these analyses at WCS headquarter in Kabul. Samples were allowed to sediment for one month before being processed. Supernatant formalin was then carefully removed from vials to avoid re-suspending the feces. Formalin-saturated feces were thoroughly homogenized, 3.0g±0.09 g, passed through a 500 µm-mesh strainer and mixed with 42 ml of a flotation solution (360 g of saccharose and 540 g of sodium nitrate in 1000 ml of water) at 20°C (di Felice and Ferretti, 1962). Density of the solution was checked with a glass hydrometer (range 1.300–1.400) and maintained at 1.320 (±0.01) throughout the work. Immediately after mixing, 0.30 ml of the suspension was introduced in the two cells of a McMaster counting slide (Hawksley, UK). Flotation process was allowed to operate for 5 minutes before the counting cell was examined under the ×10 objective of a light microscope (Swift M4000-D, Japan).

Plate 6. One of the 30 healthy sheep selected as an epidemiological sentinel in transhumant herds of small ruminants. It is identified with a numbered plastic collar and will be sampled prior and after spring and autumn transhumances respectively to evaluate its exposure to bluetongue orbiviruses, Big Pamir, 6 April 2008.

All eggs which lay within the lined centimeter square of the counting chamber were counted. Each counted egg represented '50 eggs per gram of feces. This calculation was based on the fact that the depth of chamber is 1.5 mm and consequently the volume of fluid examined is 0.15 ml, which is 1/300th of the original volume of 45 ml, made up of 42 ml of flotation solution and 3 g of feces. Therefore each egg counted represented 300 eggs per 3 g of feces, which is equivalent to 100 eggs per g. Because two chambers were systematically counted the total count was multiplied by 50 instead of 100. The main drawback of this method is its lack of sensitivity, since infestation rates lower than 50 eggs per gram cannot be detected.

Parasite identification

Specimens of endoparasites collected in necropsied sheep were shipped to the Royal Veterinary College in London, UK, where they were identified by Dr M. Fox. Ticks were sent to the US Naval Military Research Unit 3 (NAMRU-3) in Cairo, Egypt, and identified by Dr H. Waseef. Eventually diptera were shipped to the Natural History Museum in London, UK, and identified by Dr N. Wyatt. Horseflies were also examined by Dr Z. Khabirov, entomologist at the Institute of Zoology of Dushanbe, Tajikistan.

Results

Clinical investigations of infectious disorders in livestock of Big Pamir

Gastrointestinal disorders — Sheep and goats in Big Pamir are affected by gastro-enteric disorders usually translating into episodes of diarrheas. The pattern of occurrence of these disorders was consistent in Wakhi and Kirghiz pastures and was described in previous reports (Ostrowski, 2006; Ostrowski et al., 2007). The causes of diarrheic events are unknown, but they occurred most often in spring when animals access newly grown vegetation. This pattern suggests *Clostridium perfringens* enterotoxaemia. However, adult and subadult small ruminants also died of diarrheic disorders later in spring and in summer, which may evocate other infectious agents. Heavy stocking densities, overgrazing, crowded night housing and inexistent sanitary management could also favor outbreaks of coccidiosis or cryptosporidiosis in lambs. Infections with *Salmonella* can cause diarrhea in small ruminants of all ages. Bluetongue orbivirus can also be responsible for diarrheic events in sheep but we are not sure that *Culicoides* vectors of the disease exist at the altitude of summer pastures. PPR morbillivirus may be present in the small ruminant population of Big Pamir as suggested by Aga Khan Development Network (AKDN) veterinarians based in Ishkeshim who reported of past episodes of nasal discharge and profuse diarrheas associated with severe salivation (resulting possibly of necrotic stomatitis), a syndrome reported with PPR. However we did not note clinical symptoms evocative of a recent exposure to PPR morbillivirus during the surveys we carried out between 2006 and 2008.

Respiratory disorders — During summer 2007 investigations, we estimated the prevalence of respiratory disorders in small ruminants at 5–10% in adults and <15% in subadults (Ostrowski et al., 2007). The recorded clinical symptoms included sporadic coughs, dyspnea, and most often mucopurulent nasal discharge. Respiratory disorders seemed to frequently become chronic. We did not observe severe respiratory disorders such as acute pneumonias and pleurisy, two commons symptoms in acute forms of contagious caprine pleuropneumonia (CCPP) or pasteurellosis. It was difficult to figure out from the interviews whether these respiratory disorders caused a significant mortality, in particular among young animals.

Abortions / stillbirth — According to the interviews of herders in 2006 and 2007 abortions and stillbirths are very common in winter and early spring, which would correspond to late-pregnancy abortions for sheep and goats. However this problem affects all categories of livestock including yak, cattle and Bactrian camels. The numbers of abortions reported via questionnaire investigation certainly underestimated the reality as many cases may have been overlooked. It was difficult to know whether abortions occurred close to parturition time. The expected poor body condition of females at the end of winter must certainly predispose them to abortions at this period of the year. However many infectious agents such as foot-and-mouth disease picornavirus, *Brucella* spp., *Coxiella burnetii*, *Toxoplasma gondii*, and *Chlamydiophila* spp. can also be causative (see in present report results of serological screenings for exposure to *Brucella* spp., *Chlamydiophila* spp., *Coxiella burnetii*, and *Toxoplasma gondii*).

Plate 7a (Top). An emaciated subadult domestic yak (*Bos grunniens*) with quadrupedal lameness due to necrotic lesions of the feet following exposure to foot-an-mouth disease virus (Asia 1 serotype), Big Pamir, 26 September 2008. Plate 7b (Bottom). A close up of the interdigital and coronal necrotic lesions of the foot of a yak exposed to foot-and-mouth disease virus two weeks earlier, Big Pamir, 26 September 2008.

Foot-and-mouth disease (FMD) —According to the Wakhi interviewed in 2006, FMD is a relatively new disease in the Wakhan Valley and Pamirs. Seemingly the disease appeared in their livestock between 1992 and 1995 when large herds of small ruminants originating from

Panshir and Badakhshan started using the Wakhan corridor to reach livestock markets of northern Pakistan. Kabul, the secular marketing outlet for these livestock populations, was no longer accessible, destroyed by interethnic wars of succession. Contaminated herds moving through the corridor arguably have spread the disease among Wakhi livestock. From an historical point of view, the story is believable since Wakhan and Pamirs were renowned for centuries as livestock production areas where non-native domestic animals were seldom introduced (Dr Farman Ali, AKDN, pers. comm.). However from an epidemiological point of view this is a more questionable theory since FMD has been endemic for a long time in neighboring areas of Pakistan, Afghanistan and Tajikistan. During our summer visits between 2006 and 2008 we observed on several occasions lame sheep and yaks in pastures with interdigital or coronal foot lesions that could have resulted from initial lesions of FMD. Yet, we did not record typical febrile cases with mouth vesicles in cattle, yaks or small ruminants. Wakhi report in unison about regular outbreaks of a disease that affects the feet and mouth of their sheep, goats, cattle, yaks, and Bactrian camel simultaneously. Horses and donkeys are not affected. During winter 2006/2007 survey, we noticed in Karich village in the upper Wakhan, cattle presenting dullness, anorexia, fever (39.2°C), lameness of one or two feet and intense salivation (Ostrowski, 2006). Examination of feet and mouth revealed ulcers between claws and in the oral cavity. However we did not see vesicles or blisters. Morbidity was maximal as 100% of the cattle of the village were affected within 5 days, but no mortality was yet reported when we visited the area. Virological investigations carried out at CVL–Kabul on collected mouth swabs failed to confirm the etiology. In summer 2008 however young yaks (< 1 year-old) in Big Pamir were affected in large numbers with a disease very suggestive of FMD. Although we did not record typical febrile cases with mouth vesicles but only necrotic interdigital and coronal foot lesions (Plates 7a and 7b), serological investigations confirmed that these animals had been recently exposed to FMD virus (see results of serological screenings). The disease is likely to be endemic in livestock in Big Pamir.

Contagious ecthyma (Orf) — This infectious dermatitis, caused by a Parapoxvirus, affects primarily lips of young animals. In Wakhi settlements such as Jabar Khan (Jermasirt) it affected 10 to 15% of lambs and kids in summer 2006 (Ostrowski, 2006). Similarly numerous lambs and kids were also affected by this disease in other grazing areas of Western Big Pamir. All interviewed herders confirmed that the disease was common in young animals.

Keratoconjunctivitis — During our winter 2006/2007 survey, we observed sporadic cases of keratoconjunctivitis in adult goats in upper Wakhan villages. According to the interviews, the disease affected mainly goats and to a lesser extent sheep, after autumn transhumance. Wakhi believed disease outbreaks were linked to livestock consuming a specific plant, locally called *kurkamal*, which only grows at lower altitudes in the Wakhan Valley. Unfortunately we could not collect any specimen when we visited the concerned villages in early December 2006. Clinical examination of 7 cases revealed that the disease always affected both eyes but usually not to the same extent. Presumably one eye was affected before the other. Clinically the disease started as a mild conjunctivitis seemingly evolving from the internal canthus. Soon cornea was opacified by a faint haze which was due to edema and possibly cellular infiltration. The lesion progressed preferentially from the limbus towards the center possibly as an inflammatory response to an external aggression. Bilateral keratoconjunctivitis precluded trauma as a possible origin. At the initial stage of the disease we did not observe any signs of anterior uveitis. Retina and its visible vascularization showed no lesions. At a later stage, complete corneal opacification made it difficult to see internal parts of the eyes. We did not see a progress of the disease towards corneal ulceration, but saw varying degrees of lacrimation. Apparently animals did not present symptoms of systemic infection during the disease. They started losing condition when they became blind and could not find forage. Several animals recovered spontaneously whereas others died of starvation or after a fatal fall in the mountain. We do not know of plant intoxication causing keratoconjunctivitis in ruminants. A group of Kirghizes from Big Pamir whom we met in winter mentioned that a similar disease affected their yaks in altitude pastures where *kurkamal* does not occur. However irritants such as pollens, grasses or thorny plants may predispose to or aggravate such disease. In 2007 and 2008, we investigated the presence keratoconjunctivitis in Pamirs but could not find a single affected yak. Among known pathogens that can be responsible for keratoconjunctivitis in cattle, *Moraxella bovis*, a bacteria transmitted by flies, is the commonest. Since the peak of fly activity seems to occur later in the summer (mid July to mid August) it is possible that our survey was carried out too early in the season to observe cases of keratoconjunctivitis in yak. Infectious bovine rhinotracheitis (IBR) virus and *Mycoplasma* spp. can also produce transient corneal opacification and conjunctivitis. In sheep and goats rickettsiae and *Mycoplasma conjunctivae* have also been associated with keratoconjunctivitis. Infection with *M. conjunctivae* causes temporary blindness. This agent has been recorded in domestic livestock worldwide (Jones, 1991) and in wild mountain ungulates in Europe and North America (Mayer et al., 1997; Tschopp et al., 2005; Jansen et al., 2006). When associated with *Moraxella ovis* the disease can increase in severity (Dagnall, 1994).

Mastitis — We did observe sporadic cases of severe mastitis in sheep and goats in 2006, but we did not investigate the etiological agent.

Parasites in livestock of Big Pamir

Endoparasites — In Big Pamir, we collected feces samples from 65 sheep in summer 2007 and autumn 2008. Quantitative coproscopy of these samples revealed that 93.8% (95%CI: 85.0%–98.3%) of the tested animals shed between 50 and 3500 unsporulated coccidian oocysts per gram of feces. Only 13.8% (95%CI: 6.5%–24.7%) of them shed nematode eggs, always ≤100 per gram of feces; which belonged to strongylid, *Strongyloides* spp. or *Trichuris* spp. (Table 5). Low nematode infestation was corroborated by our examination of eight healthy subadult/adult sheep slaughtered for meat which presented no visible nematode specimens in their digestive tract. Likewise we found no trematodes in examined livers. Large scale field examination of sheep and goat droppings occasionally revealed the presence of tapeworm bell-shaped proglottids in fresh feces. In 2006 however, five slaughtered subadult sheep presented *Moniezia* spp. (possibly *benedeni*) anoplocephalid tapeworms in their duodenum.

Table 5. List of endoparasites and ectoparasites found in domestic sheep in Big Pamir, Wakhan district, Badakhshan province, Afghanistan, 2006–2008.

Agent	Category	Name	Specimen	Location
Endoparasite	Nematode	*Trichuris* spp. (possibly *ovis*)	Eggs	Feces
	Nematode	*Strongyloides* spp.	Eggs	Feces
	Nematode	Strongylid (possibly *Nematodirus* spp.)	Eggs	Feces
	Cestode	*Moniezia* spp. (possibly *benedeni*)	Adults	Duodenum
	Protozoa	Unsporulated coccidian oocysts	Eggs	Feces
Ectoparasite	Acaria	*Psoroptes ovis*	Adult	Skin
	Acaria	*Ornithodoros lahorensis*	Adult	Skin
	Diptera	*Melophagus ovinus*	Adults	Skin
	Diptera	*Tabanus* spp. (*hunnorum* or *montanus reinigianus*)	Adult	Skin
Unconfirmed ectoparasites	Acaria	*Sarcoptes scabiei*	?	?
	Diptera	*Wohlfahrtia magnifica*	?	?

Moniezia is recognized as a relatively nonpathogenic organism in sheep although heavy infestation such as that observed in subadult sheep of Pamir may result in mild unthriftiness and digestive disturbances. The absence of nematode and trematode in the slaughtered animals and the relatively low prevalence of sheep with nematode eggs shed in feces (typically <25%) are remarkable and confirm the low exposure of sheep and goats to these parasites in Big Pamir.

Ectoparasites — The sheep ked (*Melophagus ovinus*) is one of the most widely distributed external parasites of sheep. We found adult specimens in all the 180 sheep examined in Wakhi livestock in 2006 and 2007, sometimes in heavy infestations (>50 specimens/animal) (Table 5). The high infestation rate found in sheep of Pamirs may be related to the rapid spread of the parasite when animals are densely assembled during the night. The skin irritation created by the parasite causes sheep to rub and bite themselves. The fleece becomes thin, ragged and dirty, while wool can be permanently discolored in patches. Although *Melophagus ovinus* spends its entire life on its host, we did not find any in the sheep from Big Pamir we examined in December 2006 when they were back to the Wakhan Valley. On the other hand, in winter sheep, cows and yaks were often heavily infested with *Ornithodoros lahorensis* (Fam: Argasidae) ticks. The discovery of *O. lahorensis* in Wakhan has significant biological, veterinary, and medical implications. *Ornithodoros lahorensis* is thought to be originally a parasite of the urial (*Ovis orientalis*), and other wild-living artiodactyls resting beside cliffs. It is now a notorious parasite of sheep, goats, camels and cattle, especially in stone stables and dwellings, in steppe and mountain deserts from sea level to 2900 m altitude in Kashmir, Tajikistan, Uzbekistan and Turkmenistan and southwest Asia (northern Pakistan to Syria), and Southeast Europe (Turkey, Bulgaria, Greece, ex Yugoslavia) (Filippova, 1966; Hoogstraal, 1985). In Wakhan we found the tick has high as Karich village (3200 m altitude) and it is said to occur in Sarhad-e-Broghil (~3400 m) in upper Wakhan.

The 2-host life cycle of *O. lahorensis* is exceptional among argasid ticks (Hoogstraal and Aeschlimann, 1982). The larva remains on the host for three to six weeks during fall or winter and detaches as an engorged third-instar nymph which rests in a crevice and molts to an adult in spring. After mounting another host, the adult feeds within an hour or two but can ingest as much as 228 mg of blood. After mating the egg incubation period is two to six weeks. The mated fed or unfed females deposit batches of 300 to 500 eggs during warm months. Unfed larvae can survive for a year, unfed adults for 18 years. Tremendous population densities often develop between bricks and stones, under plaster, and in cracks of roof supports of stables. One can rapidly determine whether a stable is heavily infested by searching for nymphal pelts entangles in cobwebs on walls, in corners and over windows. The contemporary success of *O. lahorensis* in this artificial environment, with a regular supply of hosts, results from its exceptional life-cycle adaptation originally associated with small flocks or herds of free-living wild ungulates (Hoogstraal, 1985). Many Argasidae-transmitted salivary toxins or arboviruses cause irritation or febrile illnesses in man. Wakhi always feared to touch the ticks and knew they could kill their livestock. *O. lahorensis* parasitism of domestic animals causes anemia, toxic reactions and paralysis. This tick also transmits the agents of brucellosis and piroplasmosis. The agents of tularemia (*Francisella tularensis*) and Q fever (*Coxiella burnetti*) have been reported to be transmitted among domestic animals, and possibly to man, by this tick in Eurasia. Wherever *O. lahorensis* occurs, its potential role in the epidemiology of vectorborne disease agents of man and domestic animals should be investigated. Between 2006 and 2008 we examined more than 450 sheep and goats in Big Pamir, none beared ticks while in summer pastures. We believe there are several explanations to the lack of tick infestation in high Pamirs. For example, it is likely that in spring, when sheep and goats leave the Wakhan Valley and their infested winter stables, the ambient temperature is still too low to allow the hatching of tick eggs and a spring reinfestation. In addition should any larvae or adult tick accompany transhumant animals to Pamir, the roofless, weather-exposed stone corrals of Pamir settlements would provide a very poor environment for ticks to complete their life cycles. Paradoxically while livestock have presumably acquired *O. lahorensis* long time ago when sharing the altitude habitats of their natural wild hosts, nowadays with decreased number of wild ungulates they are seldom infested when visiting high pastures, but only when they return to their winter stables at lower altitudes, where the tick has found a remarkably comfortable and safe habitat. In winter 2006 we observed cases of psoroptic scabies (*Psoroptes ovis*) infestation in three sheep in lower Wakhan. The acaria parasite affected the woolly parts of their body. They were biting and scratching themselves as a result of intense itching, presented large areas of alopecia with scaly lesions and were emaciated (Ostrowski, 2006). The parasite has been reported to impact the demography of desert bighorn sheep (*Ovis canadensis*) in the USA (Boyce and Weisenberger, 2005). We did not observe clinical cases of sarcoptic scabies (*Sarcoptes scabiei*), a parasitic disease with reported disastrous impact in populations of wild mountain ungulates [Blue sheep (*Pseudois nayaur*) – Dagleish et al, 2007, Spanish ibex (*Capra pyrenaica*) – Leon-Vizcaino et al., 1999]. However we heard of a 'skin disease' affecting goats in winter pastures of Pamir, goats usually dying of emaciation and coldness before spring. During summer 2006 we also noticed outbreaks of *Tabanus* spp. horseflies infesting livestock and man. Two species of horseflies are found in Tajik Pamirs just across the border to our study site, *T. hunnorum* and *T. montanus reinigianus*, the former one being reported to the height of 4760 m (Sychevskaya and Chinaev, 1967). Horseflies cause painful wound and a significant blood loss when many of them feed on an animal for several hours a day during summer. Reputedly they can carry several pathogens on their mouth parts and body, including the agents of anthrax (*Bacillus anthracis)*, anaplasmosis (*Anaplasma* spp.), and tularemia. Although we have not observed such cases, Wakhi shepherds reported to us that genital and udder myiasis in sheep and sometimes cattle and yak is relatively common during spring and early summer. These ectoparasitosis are however not caused by Tabanid flies. Instead we confirmed the presence in Afghan Pamirs of adult specimens of *Wohlfahrtia magnifica* (Diptera: family Sarcophagidae) a species known to cause wound and genital myiasis in livestock, including in Band-i-Amir, Bamiyan Province (S. Ostrowski, pers. obs.). At least seven species of cattle gnats belonging to genus *Eusimulium*, *Cnephia* and *Tetisimulium* are reported from Tajik Pamirs, noteworthily around Zorqul Lake, and are very likely to occur also in the Afghan Pamirs. *Aedes caspius dorsalis* a Culicidae mosquito, aggressive during the day, with limits of activity between 8 and 22°C, is spread in Pamirs up to an altitude of 4100 m (Sychevskaya and Chinaev, 1967). *Aedes* spp. mosquitoes are vectors of a number of arboviruses (particularly Togavirid viruses) responsible for severe hemorrhagic fevers in tropical and sub-tropical areas. It is not known whether Culicidae mosquitoes of the genus *Culicoides*, known to act as vectors for a number of viruses, including bluetongue orbiviruses, are present in Big Pamir.

Results of serological screening in livestock of Big Pamir

Toxoplasmosis — Toxoplasmosis is the result of infection by *Toxoplasma gondii*, an obligate intracellular protozoan parasite in the phylum Apicomplexa. It is found worldwide, in part because oocysts are highly resistant to environmental conditions and remain infectious for as long as 18 months in water or warm, moist soils. Yet, they do not survive well in arid, cool climates. Members of the Felidae are the definitive hosts. Most mammals and birds can serve as intermediate hosts and among domestic animals, infections are most common in cats, sheep and goats. In adult sheep and goats toxoplasmosis is usually asymptomatic; however, infection acquired during pregnancy can cause abortion, stillbirths or resorption of the fetus. Congenitally infected lambs have a high mortality rate. Clinical cases of toxoplasmosis in wild ungulates are rarely documented and presumably of rare occurrence. A total of 14% and 9.1% of the tested sheep and yak were seropositive to *T. gondii* respectively (Table 6). **This infectious agent therefore seems to be common in Wakhi livestock.** Dry and relatively cool conditions of Pamirs in summer suggest however that oocysts are more likely to persist in the Wakhan Valley than in altitudinal pastures. Although the parasite is presumably common in Afghanistan at large, these results constitute to our knowledge the first serological evidence of livestock exposure to *T. gondii* in Afghanistan. (Table 6)

Chlamydiophilosis —Chlamydiophilosis is here restricted to the infection by *Chlamydiophila abortus*, an obligate intracellular bacterium reported from most sheep-raising countries except Australia and New Zealand. *C. abortus* elementary bodies can remain infective in the environment for months if the temperature is freezing or near freezing.

Table 6. Prevalence (95% Confidence Interval) of antibodies to infectious agents in sera of domestic sheep and yaks in Big Pamir, Wakhan district, Badakhshan province, Afghanistan, 2006–2008.

	Sheep		Yak	
Agent[a]	P/T[b]	CI[c]	P/T	CI
Toxoplasma gondii	60/428	(10.8 – 17.7)	2/22	(1.1 – 29.2)
Chlamydiophila abortus	6/332	(0.6 – 3.9)	0/29	(<10.3%)
Coxiella burnetii	40/332	(8.7 – 16.0)	6/25	(9.3 – 45.1)
Brucella melitensis / abortus	0/480	(<0.6%)	0/24	(<12.5%)
BTV	59/237	(19.5 – 30.9)	8/25	(14.9 – 53.5)
FMDV	39/76	(39.6 – 62.9)	18/24	(53.3 – 90.2)
RPV	0/56	(<5.3%)	0/24	(<12.5%)

[a]BTV = bluetongue virus, FMDV = foot-and-mouth disease virus, RPV = rinderpest virus. [b]P/T = number of positive reactors/number of samples tested. [c]CI = 95% Confidence Interval in %

The agent is known to cause outbreaks of abortions in sheep and goats, and occasionally in wild ungulates such as deers and llamas. Pregnant ruminants shed large numbers of *C. abortus* in the placenta and uterine discharges when they abort or give birth. Sheep and goats can also be chronic carriers. Serological prevalence in Wakhi livestock was low with only 1.8% of the tested sheep positive to this infectious agent and none found positive among tested yaks (Table 6). In addition none of the 6 sheep we investigated after a recent history of abortion/stillbirth, and none of the 4 goats with keratoconjunctivitis responded positive to the Chlamydiaceae LPS-antigen test. **Results suggest that C. abortus is relatively uncommon in the study site**.

Q fever — Q fever is a highly contagious zoonotic disease caused by the intracellular pathogen *Coxiella burnetii*. The organism is an obligate intracellular parasite and is currently classified in the family Coxiellaceae and order Legionellales. Many domesticated and wild animals carry *C. burnetii*. Q fever has been found worldwide, in part because *C. burnetii* is extremely persistent in the environment and can be spread over long distances by the wind. In most cases the infection is asymptomatic; however infected domestic ruminants may present abortions near term, stillbirth, retained placenta, infertility, small and weak offspring and sometimes post-parturition complications. In sheep 5–50% of the flock may be affected. *C. burnetii* has also been isolated from wild animals including wild ruminants. Abortive effect in captive wild ruminants has frequently been suspected based on seroconversion events. In Big Pamir, 12% and 24% of the sheep and yak tested positive to *C. burnetii* respectively (Table 6). **This infectious agent seems to be common in livestock in Afghan Pamirs.** Although it is presumably common in Afghanistan at large, these results constitute to our knowledge the first documented cases of livestock exposure to *C. burnetii* in Afghanistan.

Brucellosis — In sheep and goats, brucellosis is mainly caused by *Brucella melitensis*, a Gram-negative coccobacillus which is a facultative intracellular pathogen. Infection in sheep and goats can spill over into wild ruminants; *B. melitensis* infections have been reported in Alpine ibex (*Capra ibex*) in Italy and chamois (*Rupricapra rupricapra*) in the French Alps. However there is no evidence that these animals serve as reservoir hosts for domesticated sheep and goats. *B. melitensis* is very contagious to humans. In animals it is usually transmitted by contact with the placenta, fetus, fetal fluids and vaginal discharges from infected animals. The predominant symptoms in naturally infected sheep and goats are abortions, stillbirths and the birth of weak offspring. In wild chamois, this organism has been linked to orchitis, polyarthritis, blindness and neurological signs, but not abortion. Thirty-eight sheep sera tested were doubtful or weak positive with RB test, but none of them were confirmed positive with ELISA and CF tests. **We indeed found no confirmed positive cases of brucellosis in the 504 animals tested**. Precise information is not available on the situation of brucellosis in Afghanistan. In neighboring Tajikistan a recent cross-sectional serological survey in central and south-eastern provinces, using a method similar to the one we employed in Afghan Pamirs, reported a prevalence ranging between 2.1% in cattle to 5.8% in sheep out of 13626 animals tested (Jackson et al., 2007). Considering the lack of specificity of serological tests for brucellosis these frequencies may constitute maximal values. Overall it seems that brucellosis is of relatively low prevalence in this macro-region.

Bluetongue — It is an insect-born viral disease of ruminants, transmitted by *Culicoides* sp. hematophagous midges. Direct transmission between animals is not possible and therefore geographical distribution of the diseases is limited to areas where *Culicoides* vectors occur, roughly in terrestrial areas extending between latitudes N 40° and S 35°. Among domestic animals, clinical disease occurs most often in sheep, resulting in erosions and ulcers of the mucous membranes, dyspnea or lameness from muscle necrosis and inflammation of the coronary band of the foot. Some strains of virus can result in high mortality rates. But bluetongue infection can also be asymptomatic, presumably when it occurs in populations which have been in contact with the virus for long time. The virus belongs to the order Orbivirus and family Reoviridae and 24 serotypes have been identified worldwide. Bluetongue viruses (BTV) are closely related to the viruses of the epizootic hemorrhagic disease (EHD) which is one of the most important diseases of deers in North America. BTV can also cause severe diseases in wild ungulates, including the white-tailed deer (*Odocoileus virginianus*) and the desert bighorn sheep (*Ovis canadensis*). In Big Pamir, 24.9% and 32% of the sheep and yak respectively tested positive to the VP7 protein of BTV (Table 6). In the absence of known cross-reactivity with other viruses (e.g. rotavirus), and despite lack of positive results with RT–PCR investigations, **it seems that BTV is unexpectedly common in livestock in Wakhan, yet it is debatable whether it actively circulates in Pamirs**. Although *Culicoides*, the only known vector of BTV, have colonized a great variety of habitats from sea level to a maximal altitude of 4100 m in Tibet, their presence in Pamir pastures (between 3600 and 4500 m asl on average) is not confirmed. It is also noteworthy that on 31 May 2008, just before leaving to Big Pamir pastures, 56.7% (17/30) of the 'sentinel' sheep were serologically positive to BTV, but only 30% (9/30) were still seropositive on 26 September 2008 at the end of the summer stay in Pamir. Likewise, none of the seronegative animals prior to spring transhumance seroconverted positive while in altitude pastures, whereas 8 sheep seropositive prior to transhumance converted negative by the end of summer. It is also interesting to note that one animal seroconverted positive between 6 April and 31 May when in the Wakhan Valley (2800–3200 m), and before leaving to Pamir. Eventually no circulating viral nucleic acids were detected in tested seropositive sheep (14 prior to and 8 after transhumance). All these observations suggest that BTV might not circulate actively in Pamirs.

Foot-and-mouth disease (FMD) — This is an extremely contagious viral (family Picornaviridae) disease of cloven-hoofed domestic and wild animals. It is endemic in most of Asia (including the Middle East), Africa, and South America. There are 7 immunologically distinct serotypes and over 60 subtypes. The disease is endemic in Afghanistan and occurs as an annual epizootic. It has a direct effect on food security as it drastically reduces milk production in cows, reduce their fertility rate and incapacitate breeding bulls and oxen. A new serotype (Asia 1) has been identified in Afghanistan in March 2001 (S. Yingst / CVL–Kabul pers. comm.), bringing the total of known serotypes to three for the country. The virus is very stable at low temperatures and can survive in frozen tissues. It may persist for days to weeks in organic matter under moist and cool temperatures. It is however inactivated on dry surfaces and by UV radiation (sunlight). Transmission primarily occurs by respiratory aerosols and direct or indirect contact with infected animals. Sheep and goats are considered maintenance hosts, and sometimes present very mild signs. Cattle are generally the first species to manifest signs of FMD and are therefore considered 'indicators' of this disease. Recovered or vaccinated cattle exposed to diseased animals can be healthy carriers for 6 to 24 months; sheep can be carriers for 4 to 6 months. In Big Pamir, 51.3% and 75% of the sheep and yak respectively had antibodies against FMD (Table 6). Two non-vaccinated yaks tested with VNT had positive antibody titers against Asia-1 Shamir serotype (and not serotypes A and O) indicating that at least this FMD type actively circulates in Wakhan/Pamirs. **The disease seems to be endemic in livestock in the study site and probably in the rest of Wakhan and Pamirs**.

Rinderpest — Rinderpest virus (RPV) is classified in the genus *Morbillivirus* in the family *Paramyxoviridae.* The virus is highly contagious and causes an acute to subacute disease of artiodactyls. The disease is characterized by necrosis and erosions in the gastrointestinal tract resulting in severe diarrhea, dehydration, and death. Morbidity and mortality rates often exceed 90%. Recently however, unapparent infections have been more common in cattle. The virus spreads by contact between infected and susceptible animals. Wild ungulates exhibit a wide range of clinical signs, ranging from very severe in kudu (*Tragelaphus strepsiceros*), African buffalo (*Syncerus caffer*), giraffe (*Giraffa camelopardalis*), and eland (*Tragelaphus oryx*) to mild or nonspecific signs in species such as impala (*Aepyceros melampus).* None of the 60 sheep and 20 yaks tested showed antibodies against RPV, suggesting that **the disease is presumably absent in the study site**.

Summary 2 — Clinical examinations of Wakhi livestock revealed the presence of gastrointestinal, respiratory, and abortive disorders of undiagnosed etiologies. We recorded clinical symptoms and lesions of foot-and-mouth disease, contagious ecthyma (Orf), keratoconjunctivitis and psoroptic mange. Serological screening showed that livestock are exposed to *Toxoplasma gondii*, *Chlamydiophila abortus*, *Coxiella burnetii*, foot-and-mouth disease picornavirus Asia 1 and blue tongue orbivirus. Yet bluetongue virus seems to circulate among livestock in the Wakhan Valley only and not in Pamirs, whereas FMDV is endemic in all Wakhan at large. We found no serological evidence of exposure to *Brucella* spp. and rinderpest morbillivirus. Livestock also present marginal parasite load with few eggs of Strongylid/*Trichuris* spp. recovered from feces. Coccidia are commonly present in sheep but with no observable clinical effects. Among ectoparasites *Melophagus ovinus* is very common in sheep particularly in Pamirs, whereas the argasid tick *Ornithodoros lahorensis* is abundant during winter in infested stables of Wakhan villages. We have not detected *Sarcoptes scabiei,* the agent of sarcoptic mange, but this parasite deserves more investigations, particularly in domestic yaks, because of its recognized impact in wild mountain ungulates worldwide.

PART III. RISK OF DISEASE SPILLOVER FROM LIVESTOCK TO ARGALI IN BIG PAMIR

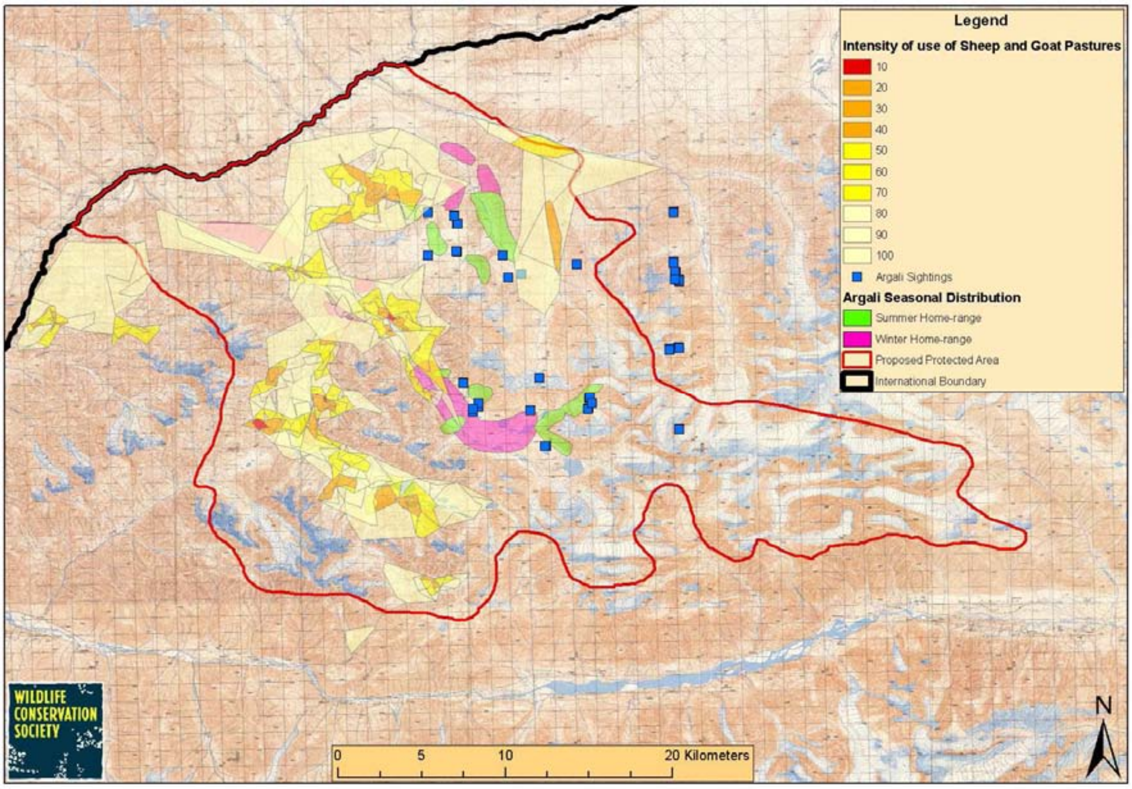
Introduction

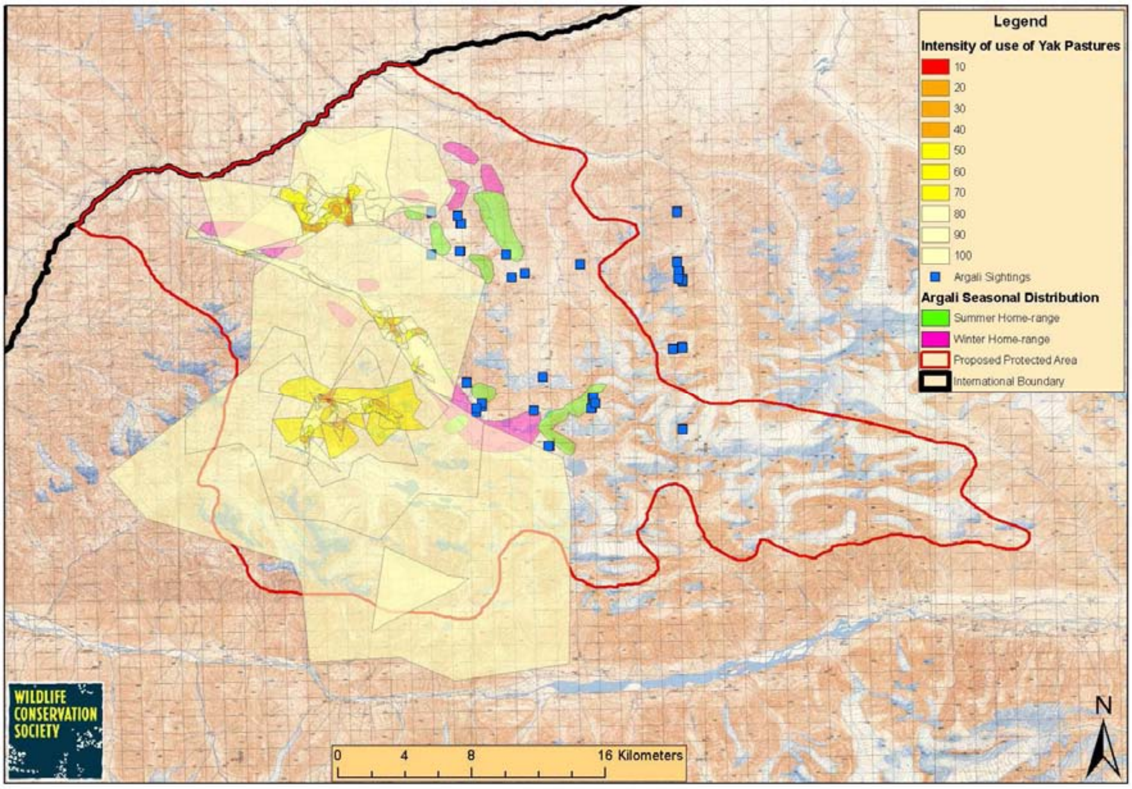
The transmission of infectious agents between individuals occurs either through direct contact, through contact with a contaminated environment or via living vectors such as insects or acaria. In mountainous areas in Europe, the abundance of domestic herds and the increase of wild-living populations –partly due to human manipulation such as introduction or reinforcing–, have led to increased cohabitations. As a matter of fact the spillover of disease from domestic to wild-living ungulates has been largely reported in Europe during the last 20 years. In Afghan Pamirs, domestic and wild-living ungulates are competitors for food, which should result in pasture sharing and, thus, to the possible transmission of infectious agents. However unlike what is observed in Europe and North-America, wild ungulates are heavily and unsustainably hunted and no human manipulation has ever allowed a re-stocking of these persecuted populations. We therefore hypothesize that aspects of disease spillover between wild and domestic ungulates are likely to be different in an area such as Afghan Pamirs compared to what has been described in mountain ecosystems of Europe and North-America.

Risk of disease spillover by direct contact

The effectiveness of a direct contact depends on the brief survival of the infectious agent in the environment, particularly in aerosols, and on the distance between the 'source' and the 'receptor' individuals. Laboratory studies have shown that pathogens with an enhanced ability to survive outside hosting cells and tissues (existence of an envelope or other protective structures) may be more resilient in the environment and probably more infective than those fragile outside their cellular environment. The effectiveness of infectious aerosol according to the distance between the source and the target has been rarely studied. Dixon et al. (2002) showed that strains of *Mannheimia haemolytica* (formerly known as *Pasteurella haemolytica*) nebulized into a wind tunnel can remain viable over a distance of ~20 m.

However this estimate applies to an infectious agent that is known to poorly survive in aerosols (Gilmour et al., 1990). In addition the measurements were carried out in a horizontal setting, and distance effectiveness of such aerosol may prove even greater in mountain areas with significant vertical distances. In the present study we assumed conservatively that a direct contact could occur when the simultaneous locations of a wild individual and a domestic were within a 100-m horizontal distance. The important finding arising from the present study is that argalis in Big Pamir avoid direct contacts with tended herds of livestock. GPS study demonstrated that in summer there is little overlap between the home ranges of tended groups of sheep and goats and argalis (Figure 4). Marginal contact zones exist in the south of the Nakchirshitk/Manjulak and Aba Khan areas. However in these areas as well as in other interface zones the possibility of contact between wild and domestic ungulates cannot be inferred only from the virtual presence of both species in a given area and field investigations are necessary to estimate them. We therefore interviewed between 2006 and 2008 the shepherds and elders of 75 Wakhi households pasturing their livestock in Big Pamir during summer. We asked them about the possibility of direct contacts between their herds of sheep and goats and Marco Polo sheep (i.e. observations of a Marco Polo sheep and a domestic animal within a 100-m horizontal distance). None of the respondents had made such observations. Nowadays Marco Polo sheep are shy of men and dogs and do not approach tended herds closer than several hundred meters. Such avoidance behavior is probably linked to a significant level of persecution and may also suggest a decreasing number of Marco Polo sheep in Big Pamir. These results were also confirmed by Drs. J. Winnie, R. Harris and B. Habib, all studying wild ungulates in Big Pamir during the same period of time, as well as our team. None of us ever observed close contact between Marco Polo sheep and tended herds of sheep and goats. During winter however argali are known to shift their range use to areas of lower altitudes where winter vegetation is still accessible. Herders in Nakchirshitk and Aba Khan/Ali Su, the only two areas with overwintering groups of sheep and goats in the study site, mentioned that argali sometimes come close to their tended groups of sheep and goats, although not less than 100 m. They also mentioned that during very harsh winters weakened or debilitated argali may occasionally come in the vicinity of settlements. In such circumstances they are usually killed by shepherds or their dogs. Direct contacts between livestock and argali may however occur in the case of free-ranging domestic yaks. Both Drs. John Winnie and Rich Harris (pers. comm. in 2007) have observed free-ranging groups of domestic yaks in relatively close contact with argali particularly in Aba Khan/Ali Su area. We made similar observations in October 2007 in upper Manjulak grazing areas where we saw on one occasion grazing argali and domestic yaks in a mixed group. Both species seem to tolerate each other very well. Although GPS study of home ranges of yak herds did not demonstrate an obvious sharing of their 'home ranges' with argali (Figure 5), we only monitored the movements of 5 out of an estimated 25 groups of yaks summering in Big Pamir. In view of the very large home range of one of the monitored groups (~362 km^2), and the ability of yaks to access the roughest terrains at altitudes sometimes exceeding 5000 m, there is no doubt that the home range of several non-monitored groups may overlap to a great extent with recognized home ranges of argali in Big Pamir.





From top to bottom: Figure 4. Local convex-hull (LoCoH; color polygons) home range estimates for 8 herds of sheep and goats monitored with handheld GPS by their shepherds in western Big Pamir, Afghanistan, in summers 2007 and 2008. Figure 5. Local convex-hull (LoCoH; color polygons) home range estimates for 5 herds of yak with GPS radiocollars in western Big Pamir, Afghanistan, summer 2008. Frequencies of utilization of each home range are represented with color-coded isopleths, the 10% isopleth contains 10% of the locations; and the 100% isopleth encompasses all the points. The smaller the hull, the more heavily used the area.

In the absence of serological indications of exposure of yaks to rinderpest and brucellosis, the main disease of concern from the point of view of a risk of spillover to argali via direct contact is foot-and-mouth disease. A total of 75% of the tested (non-vaccinated) yaks had antibodies against the FMD picornavirus and we have shown that Asia-1 type actively circulated in domestic yaks in Big Pamir in summer 2008. Similarly to most cloven-hoofed mammals, argali are certainly susceptible to FMD, although it is unknown to which extent the disease could impact their populations.

Sarcoptic and psoroptic manges could pose also a risk of direct-contact transmission to wild ungulates should yaks of Afghan Pamirs become infested. Fortunately we have found no clinical evidences of mange infestation in examined yaks. The disease, with severe itching and chronic inflammation of large areas of the skin, especially of the back, is known from domestic yaks in Nepal (Joshi, 1982).

Summary 3 — Results of direct observations, questionnaire and GPS studies, suggest that in Big Pamir the risk of spillover of infectious agents by direct contact from tended herds of sheep and goats to argalis is low during summer. In winter, the risk may be higher because of an increased competition for reduced food resources. Yet, this risk level is counterbalanced by the fact that 80–90% of all sheep and goats are gone from Pamir pastures at that time. In return there is a genuine risk of disease spillover via direct contact between free-ranging yaks and argali in all seasons, because of shared pastures and existence of direct contacts (<100 m). Our serological investigations have shown that yaks are exposed to a number of infectious agents, among which foot-and-mouth disease picornavirus seems to be of highest concern for Marco Polo sheep. Mitigating exposure of yaks to transmissible diseases is probably the best option to reduce this risk.

Risk of disease spillover by indirect contact

The transmission of many infectious agents to wild ungulates can also occur through indirect contact with a soil contaminated with excreta from domestic ruminants. *Toxoplasma gondii*, *Coxiella burnetii*, *Chlamydiophila abortus* and coccidial oocysts are extremely resistant in the environment (see Part II) particularly for the two latter agents in cold conditions. In Big Pamir average soil temperatures measured in August 2007, in a high-altitude pasture area (Aba Khan Valley, 4460 m asl) shared by livestock and argalis was 11.6°C±4.4°C (mean±SD). In the middle of a snowless winter in 2008, the average soil temperature in January, at the same location was -14.2°C±2.5°C (S. Ostrowski, unpub. data.). Likewise in upper Manjulak grazing area, an area of lower elevation (4150 m asl), where domestic and wild ungulates also share pastures in summer (see previous paragraph), the average air temperature was 10.5°C±4.7°C in June 08 the hottest month this summer. The thermal environment of Pamirs appears ideal to the persistence of infectious agents outside their hosts (Table 7). But persistence of infectious agents may also depend on other microclimatic factors such as humidity level and UV radiations, as well as upon land cover characteristics such as vegetation height. Pamirs are relatively dry areas, receiving little rainfalls during summer. Because of the altitude and overgrazing any infectious agent contaminating the soil would be exposed to intense UV radiations during summer.

Table 7. Monthly average air temperatures (T_a±SD in °C) recorded with Hobo Pro temperature loggers (Onset, USA) in locations of upper Aba Khan Valley (4460 m), upper Nakchirshitk/Manjulak grazing area (4150 m), and Sang-e-Kalan/TilaBai Valley in eastern Big Pamir (4000 m) between June 2007 and September 2008.

Month	Aba Khan (4460 m)	Nakchirshitk (4150 m)	Tila Bai (4000 m)
July 07	–	–	9.4±5.5
August 07	6.6±4.8	–	7.8±4.6
September 07	4.6±7.3	–	5.4±5.6
October 07	−5.3±5.0	–	−3.9±4.9
November 07	−9.1±4.0	–	−6.6±5.1
December 07	−15.1±3.6	–	−9.8±9.3
January 08	−18.3±4.7	–	−15.9±5.5
February 08	−15.7±5.7	–	−13.5±5.5
March 08	−7.4±5.3	–	−5.9±3.9[3]
April 08	−3.5±4.3	–	–
May 08	2.9±6.8[1]	–	4.5±3.9
June 08	–	10.5±4.7	12.5±6.0
July 08	–	10.4±4.8	15.9±5.7
August 08	–	8.3±4.7	14.9±5.4
September 08	–	3.4±4.4[2]	10.2±6.1[4]

[1]Measurements for the first 28 days only. [2]Measurements for the first 26 days only. [3]Measurements for the last 20 days only. [4]Measurements for the first 23 days only.

For these reasons we believe that the end of summer and autumn, before snow covers the ground, and when humidity level is increased and exposure to UV radiation reduced, is theoretically the best period for the indirect transmission of infectious agents. In addition, when shed or excreted in autumn, microclimatic factors would favor pathogen survival perhaps until spring. GPS studies demonstrate that summer livestock grazing areas in upper Shikargah and eastern Manjulak include winter grazing areas for Marco Polo sheep (Figure 4). This is of concern in regard of the risk of indirect transmission of pathogens to argalis. Within these shared pastures we have attempted to determine the areas of highest risk of transmission. LoCoH algorithms offer the possibility to assess the density of utilization of an area (see Part 1) (Table 8). As already stated the algorithms create convex hulls around each point in the data set and then iteratively join these hulls together from smallest to largest into isopleths. The 10% isopleth contains 10% of the locations; the 100% isopleth encompasses all the points. The smaller the hull, the more heavily used the region Therefore, these isopleths can be used to determine how frequently a region is used. Assuming a positive relationship between the frequency of utilization of an area and its level of soil contamination with potential infectious agents, the intensity of utilization could therefore constitute a proxy to the risk of indirect transmission of pathogens to wildlife. Under such assumption the shared pastures in eastern Manjulak (Figure 4) appear of relatively lower indirect transmission risk than several focal areas in upper Shikargah, essentially around summer settlements.

Table 8. Home-range estimates according to density of utilization using local convex-hull (LoCoH) method for 8 herds of sheep and goats and 5 herds of free-ranging domestic yaks in Big Pamir, Afghanistan, during summer 2008. The 10% isopleth contains 10% of the locations; the 100% isopleth encompasses all the points. The smaller the hull, the more heavily used the region.

Herd name	*k*	Area (km^2) LoCoH isopleths 100	90	80	70	60	50	40	30	20	10
Qabal Gah	15	26.8	6.8	3.6	2.4	1.2	0.7	0.3	0.03	0.008	0.002
Dara Big	25	37.1	23.9	13.5	9.6	5.8	3.4	1.1	0.6	0.4	0.1
Kund-a-Thur	20	24.5	15.8	10.2	6.7	5.0	3.4	2.3	1.1	0.2	0.04
Mulung Than	15	32.1	18.7	13.7	8.9	6.8	4.7	3.4	2.2	1.2	0.3
Asan Katich	20	25.1	11.2	7.2	7.2	5.2	2.2	1.7	0.3	0.02	–
Nakchirshitk	20	38.5	18.1	13.0	10.2	7.5	4.6	2.7	1.3	0.2	0.007
Aba Khan	20	29.8	13.2	12.5	7.8	7.8	5.1	2.5	–	–	–
Senin	20	28.3	13.8	4.1	2.9	1.8	0.9	0.3	0.08	0.02	0.004
Yak herd 1	20	41.4	9.8	6.3	4.8	3.4	2.1	1.2	0.5	0.3	0.06
Yak herd 2	20	44.5	12.4	7.8	4.2	2.4	1.6	1.0	0.6	0.2	0.1
Yak herd 3	20	11.2	5.1	3.1	2.3	1.2	0.8	0.4	0.3	0.1	0.002
Yak herd 4	20	16.8	4.1	2.8	1.7	1.4	0.9	0.6	0.3	0.2	0.05
Yak herd 5	25	361.9	116.2	44.1	19.0	7.1	2.2	1.1	0.7	0.2	0.001

It is also important to keep in mind that data collected in 2008 by the Marco Polo sheep study team (J. Winnie et al.), when included in the GIS database, will unquestionably improve our understanding of the current distribution of argalis in Big Pamir. Indeed we predict that the extent of known range-use for this species will be remarkably increased. In support of this hypothesis, one may see that the group of 12 argalis we recorded during the aerial survey in May 2008 (Fig. 3) was not within a known winter home-range area as proposed in Figure 4. As a matter of fact, and stressing our concerns about the possible risk of indirect transmission of infectious agents, this group of argalis was present in an area (Kund-a-Thur) highly frequented by livestock during summer (compare Figs. 3 and 4).

Information about livestock frequency of utilization will be integrated into the GIS modeling of the area. We also provide at the end of this report, as informative illustrations, 13 maps of grazing areas used by domestic sheep/goats and yaks detailing their intensity of utilization with a color-code (Appendices 1 to 13).

With the exception of rinderpest virus which is fragile in the external environment and bluetongue virus exclusively transmitted by insects, all other tested pathogens have the potential to be indirectly transmitted to wild ruminants. *Brucella* spp., *Toxoplasma gondii*, *Coxiella burnetii* and *Chlamydiophila abortus* are able to survive months on the ground, but they are most often excreted with infected genital secretions or abortion products. Most abortions in Wakhi livestock occur at the end of pregnancies (Ostrowski, 2006; Ostrowski et al., 2007) in late winter and early spring. At that time of the year the vast majority of Wakhi sheep and goats are not yet in Big Pamir, and the relatively low number of animals (<1000) in western Big Pamirs use only the lowest reaches of valleys that wild ungulates very rarely visit (refer to Figure 2 as well). Nevertheless interviewed Wakhi herders told us that yaks could occasionally roam at high altitudes even in winter and early spring. Indeed we observed their presence at high altitudes during winter 2006, but in the north-facing slopes of the Indu Kush in upper Wakhan (Ostrowski, 2006). In such circumstances the risk of disease transmission to wild ungulates via contamination of winter pasture with abortive tissues would be increased. Because yaks come into contact with Marco Polo sheep and share their altitude pastures they unquestionably constitute the greatest epidemiological risk to them. Fortunately, yaks are ten times less numerous than domestic sheep and goats in Big Pamir (600–700 versus 8000–9000 in summer), and they utilize pastures more parsimoniously. Although mean home ranges of sheep/goat herds (29.5 km^2±4.52 km^2) were smaller than those of yaks (95.2 km^2±149.8 km^2) they were not significantly different because of the large variability of yak home range distribution (median test; χ^2=0.34, *df*=1, *P*=0.55). Yet, and more importantly, areas of high density use (arbitrarily set as ≤ isopleth 50%) within home ranges were twice smaller for yaks (1.5 km^2±0.6 km^2) compared to sheep and goats (3.1 km^2±1.7 km^2) (χ^2=5.24, *df*=1, *P*=0.02).

Summary 4 — Results of direct observations, questionnaire and GPS studies, suggest that in Big Pamir the risk of disease spillover between domestic sheep/goats and argalis via contaminated soil is probably marginal during summer. It increases in winter, when argalis visit pastures at lower altitudes which are intensively foraged by domestic sheep and goats during summer. Autumn offers ideal survival conditions to many pathogens excreted in the environment; average air and soil temperatures are <10°C, exposure to UV radiations is reduced compared to summer, and humidity increases. Such conditions prevail also in winter but likelihood of infective contacts is decreased when snow covers the ground. Owing to their free-ranging behavior, untended yaks can also pose a great risk of indirect transmission of diseases to argalis, especially in spring when a number of females are known to abort. Infected genital secretions and abortion products may then pose a significant risk to argalis. We have identified and mapped areas of greatest livestock utilization in Big Pamir (see Appendices). This will help future managers of a protected area in western Big Pamir to better mitigate health conflicts between livestock and wild sheep via optimizing land use plans.

Risk of disease spillover via vector transmission

The transmission of infectious agents to wild ungulates can also occur with the help of living vectors, among which Diptera insects and a variety of Acaria are the most likely to occur in Pamirs. Out of the seven screened diseases only bluetongue requires an insect vector to be transmitted from one host to the other. As previously stated (Chapter 2), *Culicoides* midges responsible for bluetongue orbivirus transmission have been found at altitudes as high as 4000 m, in the Tibetan plateau (Mellor et al., 2000). Likewise in Afghan Big Pamir they may also occur along Pamir River and its appended marshland habitats as high as Zorqul Lake at an altitude of 4100–4200 m. Because of the low summer temperatures recorded in Afghan Pamirs, it is however unlikely to observe BTV transmission by *Culicoides* at altitudes frequented by argalis, typically higher than 4400 m. BTV infection rates and rates of virogenesis within vector *Culicoides* have been shown to be temperature dependent (Mullens et al., 1995). At reduced average air temperatures (T_a), infection and virogenesis rates fall, the time to earliest transmission is extended, and midges' survival rate is enhanced. Viral replication was not detected in midges maintained at or below 15°C, transmission was never recorded at these T_as, and the apparent infection rate rapidly fell to zero. In August 2007, one of the hottest month this year, the average T_a in upper Aba Khan Valley was 6.6°C±4.8°C (Table 7), that is, well below the thermal conditions allowing virogenesis and transmission of BTV. In fact a similar 'non-transmission' situation is likely to occur across all livestock pastures and settlements at altitudes exceeding 4000 m where we measured T_as in July and August 07 of 15.9°C±5.7°C and 14.9C±5.4°C, respectively (Table 7). This information could be incorporated into a GIS elevation model, mapping lower and higher risk areas of BTV transmission according to the 15°C isothere (calibrated at an altitude of 4000 m in 2007). We suggest that BTV is unlikely to circulate in summer pastures at large in Pamirs and to spillover to wild ungulates. This hypothesis is corroborated by our serological findings on sentinel sheep (see Part II).

Unlike *Culicoides*, Tabanid horseflies have been found active during summer at altitudes exceeding 4500 m. Dr. J. Mock (pers. comm.) visiting Wakhi settlements reported being literally assaulted by horseflies on July 2006 when traveling through Big Pamir high passes, at altitudes exceeding 4500 m. Tabanid flies can carry pathogens on their mouth parts and potentially transmit them to argalis. Likewise other flies can also contribute to the dissemination of pathogens via contaminated mouth parts. Among many, *Moraxella* spp. and *Mycoplasma conjunctivae*, known to be responsible for keratoconjunctivitis in mountain ungulates, are of greatest concern. Little, however, can be done to prevent such vectored transmission.

Ticks do not seem to pose a great risk of disease transmission from livestock to argalis. As stated earlier *Ornithodoros lahorensis*, an Argasid tick commonly found in upper Wakhan during winter does not appear to infest livestock when they move to Pamirs. Explanations about this dual infestation related to geographical location and season have been offered in Part II. Paradoxically ticks could actually be one of the rare disease transmission mechanisms operating from argalis to livestock. There is an abundant Russian literature about infestation of urial with *O. lahorensis* in Central Asia (Kusov et al., 1966; Mel'chakova et al., 1969; Kusov and Mel'chakova, 1971), yet little is known about tick infestation of argalis. For example Kusov et al. (1966) were unsuccessful during winter to find ticks on argalis in the Katu-Tan Mountains in Kazakhstan where they massively parasitized domestic sheep. Argalis only hosted the flea *Vermipsylla dorcadia*. They however claimed, yet without demonstrating it, that studies of *O. lahorensis* ticks collected from urials revealed the larval ability to feed and perform all 3 molts on the urial, the Siberian ibex, the argali and the domestic sheep. Still according to these authors adult specimens of this tick refused to feed on these ungulates or on laboratory animals (Kusov and Mel'chakova, 1971). Kuima (1975) was the first to confirm the presence of adult and larval ticks in argalis in Tajik Pamirs, yet not *O. lahorensis* as expected but *Hyalomma anatolicum* an Ixodid tick known to transmit the zoonotic arbovirus responsible for Congo Crimean hemorrhagic fever. To which extent argalis in Afghan Pamirs are infested with ticks is undocumented. As a matter of fact it would be interesting to investigate whether ticks can survive and complete their life cycle in the extreme habitats used by argalis in Big Pamir. As a matter of fact argalis in Big Pamir are confined to very high and rugged terrains, by no means the preferred habitat for this species known to favor high rolling or broken but not rugged hills in other parts of its distribution range (Schaller, 1998). It is likely that this unusual range use in Afghan Big Pamir results from anthropogenic pressures and it remains undocumented how parasitic organisms, such as ticks, have adjusted their life history traits to the cold hypobaric extreme of their host habitat. Urial infested with *O. lahorensis* as well as a variety of other tick species (e.g. *Haemaphysalis sulcata* or *Hyalomma asiaticum*) were also reservoirs of *Anaplasma* sp. and *Theileria* sp., two intracellular protozoa of significant veterinary concern when affecting livestock (Mel'chakova et al., 1969).

Summary 5 — Development and survival rate of ectotherms such as insects and acaria are temperature-dependent. In the case of bluetongue, viral replication is not detected in midges maintained at or below 15°C, transmission is never recorded at these temperatures, and the apparent infection rate rapidly falls to zero. In Big Pamir during summer air temperature rarely exceeds 15°C for prolonged durations in areas located above 4000 m of altitude, and humidity level is low. Such conditions are inadequate for most invertebrates to maintain and transmit infectious agents between ungulate species. Sporadically however species such as Tabanid horseflies can mechanically transport pathogen agents on their mouth parts to great elevations. Ticks seem to be absent in livestock when summering in Pamir pastures. Although little is known about ectoparasites of argalis, several species have the theoretical capability to transmit indigenous pathogens to livestock encroaching intrusively into argali's shrinking habitat.

PART IV. RECOMMENDATIONS AND CONCLUSION

Recommendations

Data collected during summers 2007 and 2008 extend our knowledge and understanding of range use of the main livestock herds in the west of Big Pamir. By the time we wrote this report, data on Marco Polo sheep collected in summer/autumn 2007 and summer 2008 by Dr J. Winnie and his Wakhi collaborators were not yet accessible, but when added to the current dataset, they will unquestionably improve the delineation of the contact zones between argalis and livestock. Yet, observations of Marco Polo sheep made in summer 2006 (Habib, 2006) and summer 2007 (R. Harris, pers. comm.) already strongly suggest that sheep and goats, which constitute the bulk of livestock species in Pamirs, only share marginally grazing areas with wild sheep in summer. This conclusion is based on observational work carried out on argalis, interviews of herders and on available information provided by GPS studies of livestock herds. It is also based on the very likely hypothesis that Marco Polo sheep in summer do not use livestock-used pastures during night. In winter, the meager forage remaining accessible to herbivores may drive argalis into closer proximity with sheep and goats although few livestock stay in Pamirs in this season. It is also possible that at this time of the year argalis may move 'en-masse' to the south-eastern facing slopes of Big Pamir in Tajikistan where competition with livestock is reduced. This hypothesis was however not supported by trophy-hunting outfitters we have interviewed in Tajikistan in September 2008 (Mr. Shovqat, pers. comm.). As a matter of fact we know very little about possible interactions between livestock and argalis outside summer grazing period and it therefore appears primordial to extend our knowledge of home ranges of livestock outside summer in Big Pamir. We make two recommendations to improve the epidemiological understanding of the interface:

Set of recommendations 1

1.1. Input all locations of argali observations, including the most recent ones into the 'Living Landscape' database of WCS and refine with GIS modeling the spatial land-use patterns for livestock and argalis

1.2. Extend data collection of livestock home range in western Big Pamir to winter season (currently on-going), and input the dataset in the 'Living Landscape' database.

To conclude based on our knowledge of livestock health in Big Pamir, pastoral practices, and occurrence of wild ungulates in the area, the risk of direct horizontal transmission of pathogen agents between sheep / goats and argalis is low in summer because of the quasi-absence of contacts. In winter such risk needs more thorough investigations.

In Big Pamir the main risk of disease transmission to argalis through direct contacts involves domestic yaks which are left untended in high altitude pastures, including in winter. Yaks and argalis tolerate each other and have occasionally been reported to utilize the same pastures at the same time. We also produced evidences that yaks in Pamirs are exposed to a variety of infectious agents, among which the picornavirus responsible for foot-and-mouth disease is probably of greatest concern to the health of argalis because of its high contagiousness and documented impact in a variety of wild ruminant species. We have shown that serotype Asia 1 actively circulated in yaks and probably other livestock species in Big Pamir in summer 2008. Although we do not know to which extent argalis are susceptible to the disease, consequences of a FMD outbreak in any threatened population of wild ungulates already supporting a variety of anthropogenic pressures, such as unrestricted hunting and competition on forage, will have to be carefully anticipated in any landscape management plan. Sarcoptic mange, a contagious disease transmitted via direct contacts and known to impact wild ungulates worldwide, also requires more attention. Although *Sarcoptes scabiei*, the responsible mite remains to be documented in Wakhan and Afghan Pamirs, it occurs in livestock populations 'around' Wakhan; in northern Pakistan and Gorno Badakhshan in Tajikistan, suggesting that its non-occurrence in livestock in our study site is questionable and deserves certainly more investigations. In addition the ectoparasite is known to affect other taxonomic orders such as carnivores or even marmots which could very well play a yet undescribed role in the spatial epidemiology of the disease. We hereby make three recommendations that aim at decreasing the risk of disease transmission between free-ranging domestic yaks and Marco Polo sheep:

Set of recommendations 2

2.1. In the absence in Wakhan of sanitary or prophylactic activities conducted by the Ministry of Agriculture, we recommend in collaboration with the Ministry of Agriculture to approach AKDN as an implementing development organization and provide to them a set of recommendations that could both improve the health status of domestic yaks and decrease the risk of disease spill-over to Marco Polo sheep. WCS Afghanistan could also support technically a fund raising initiative for AKDN as the implementing partner. Technical recommendations include:

2.1.1. Put in place a perennial identification system for domestic yaks (e.g. ear-tags) utilizing Pamirs. The database will be centralized by AKDN.

2.1.2. When occurring in the Wakhan Valley, quarantine for 8 weeks yaks developing infectious disease syndrome before they are authorized to move to Pamir pastures. Quarantine events should be monitored and supervised by AKDN veterinary services with the help of the two paraveterinarians installed in upper Wakhan by WCS in 2007–08.

2.1.3. Three weeks before spring transhumance to Pamirs vaccinate against FMD all yaks, and booster their immune response by re-vaccinating them during the month following their return from Pamirs. The vaccine should be effective at least against serotypes A, O and Asia 1. Repeat the operation annually. Again this initiative would be supervised by AKDN veterinary services with the help of the paravet work force.

2.1.4. In summer vaccinate against FMD all yaks staying in Pamirs during winter and not vaccinated in spring.

2.2. Extend progressively annual prophylactic interventions against FMD to cattle, Bactrian camels and small ruminants.

2.3. Investigate thoroughly the clinical presence of sarcoptic mange in livestock. Treat and quarantine for one month any specimen showing clinical signs of sarcoptic/psoroptic mange. Treat without quarantine the herd of yaks in contact with the affected individual(s).

To expert eyes several of these outlined recommendations may give the impression that we disregard the importance of recognized epidemiological peculiarities, such as the fact that a vaccinated and clinically healthy animal can still disseminate FMD virus, or that a recovering hoofstock could excrete FMD virus for longer than 8 weeks, or that sarcoptic mange requires at least two injections of ivermectin three weeks apart to be eradicated from an infested animal. We do acknowledge that the proposed interventions are unlikely to eradicate FMD or, should it exists, sarcoptic mange in yaks, but only reasonably increase the specific protection level in this relatively small population of livestock (c. 600-700 animals) and lower the risk of disease spill-over to wildlife. Taking into account the peculiarities of local husbandry practices and the impoverished socio-economic situation of Wakhis, stamping-out, the only recognized efficient strategy for elimination of FMD in hoofstock is obviously not considered.

Wild ungulates and in particular argalis may also be exposed to livestock pathogens by indirect contacts via contaminated environment. For example, tapeworm eggs, coccidia and *Toxoplasma* oocysts, *Chlamydiophila abortus* and *Coxiella burnetii* bacteria or contagious ecthyma poxvirus, all known to occur in the area can survive in the environment for extended periods of time and may present a disease threat to susceptible species weeks to months after being excreted. It is evidently impossible to prevent argalis from using pastures of sheep and goats especially during winter, yet it is feasible to reduce the level of environmental contamination by livestock, focusing primarily at most frequently utilized areas. We make four recommendations of prophylactic and sanitary order that could be instructed to Wakhi herders and teams of appointed game guards should a protected area is created:

Set of recommendations 3

3.1. Stillborn and abortive products of any livestock species must be buried or best incinerated when encountered, and never left to scavenging carnivores which will disseminate infectious agents on the ground before feeding on the remains. This operation will have to be taught to herders in order to avoid the risk of zoonotic transmissions during handling.

3.2. Aborting females and those producing a stillborn should be quarantined in the vicinity of the camp for at least three weeks following abortion or stillbirth.

3.3. At the end of summer season, areas intensively utilized by sheep and goats (see appendices) should be inspected thoroughly by teams of appointed game guards. Carcasses and all livestock products apart of feces should be buried, or best, incinerated on site.

3.4. In the event of a reported severe epidemic event in a settlement during summer, game guards should visit it at the end of the grazing season, and help herders bury or incinerate carcasses and all disseminated livestock products apart of feces. Quicklime should be spread across the settlement, inside and around livestock corrals.

Researchers who have recently investigated the Big Pamir ecosystem from the stand points of range quality (Dr. D. Bedunah), biodiversity (Dr. B. Habib), Marco Polo sheep ecology (Drs. J. Winnie and R. Harris) or health issues (us) concur to report that because of their numbers and husbandry practices, livestock impose an unsustainable pressure on the ecosystem, and that their populations should be reduced or at least better managed (see activity reports e.g. Bedunah 2007, Habib 2006, Ostrowski et al. 2007). In an impoverished agro-pastoral economy such as the one practiced by Wakhis, reducing numbers of livestock grazing Pamirs would sound as shooting oneself in the foot if non carefully apprehended and communicated to local land users. It is very likely that future managers of a protected area in

Big Pamir will face tremendous resistance from local people to reduce the number of livestock utilizing Pamirs. Yet, while such painful policy would affect the livelihood of a great number of Wakhi families in summer, it would only affect a few families during winter, and yet removing domestic grazers from western Big Pamirs in winter would greatly benefit the ecosystem. It will offer more time for the vegetation to recover from summer grazing, allocate more vegetation resources to wildlife at a time of food shortage, and reduce the risk of disease spillover from livestock to wildlife. Although composed of few families, the community of people concerned by a livestock removal policy during winter will have to be economically supported via alternative livelihood offers or privileged services. They could be offered jobs with local NGOs or in the staffing of a new protected area. Also during first years extra fodder/grains as well as free veterinary services could be provided to their livestock as an incentive to keep them in Wakhan. Because such strategy may open a chain-reaction of other problems, such as increased density of livestock in the Wakhan Valley, increased competition on winter forage and social conflicts the policy will have to be implemented gradually over several years to allow adjustments and pragmatic treatment of unforeseen consequences. Should this first step succeeds on the relatively small scale (<1000 animals) of overwintering livestock in western Big Pamir, a further or concomitant approach could also consist at zoning grazing areas via a more restrictive land use planning. This would require an active and prolonged consultation with communities. The aim of such policy would be to reduce progressively the home range of tended livestock herds without decreasing the number of livestock. In theory many empirical solutions would be worth investigating with local communities to their benefit and the conservation of their natural resources. We make two recommendations of socio-economic order that could help delineate a future strategy:

Set of recommendations 4

4.1. Identify the Wakhi families utilizing Big Pamir during winter, particularly in Manjulak/Ali Su/ Aba Khan areas, and understand the principles of their grazing rights.

4.2. Investigate alternative economical resources or privileged services that would be acceptable to families agreeing to keep less livestock in Pamirs, remove livestock in winter or collaborate in a land-use zoning system.

Obviously the socio-economic investigations will have to be made in total transparency with local people, but also in full collaboration with AKDN and with the approval of community leaders. Eventually proposing a revisited land use plan will be of little value if argali hunting remains uncontrolled, this threat will have to be preliminarily addressed.

Conclusion

The descriptive approach of livestock/argali interface developed in Big Pamir could be exported to other geographical areas involving a similar assemblage of species. Two important epidemiological traits emerge from the present study and could be adopted across other fragile mountain ecosystems: 1-When hunting is unrestricted and actively practiced at wild ungulate's expenses; direct contacts between tended livestock and wild ungulates are limited. 2-As a corollary in a situation of increased competition with livestock and concomitant overhunting, direct contacts with wild ungulates will mainly involve unattended livestock. In Big Pamir, the landscape model that will include our dataset could also be used to better understand the interface between livestock and Siberian ibex. Most of the conclusions drawn from the risk of disease spillover from livestock to argalis are relevant to ibexes as well. This wild Capridae species does not come in direct contact with livestock in Afghans Pamir but is likely to share pastures with free-ranging domestic yaks.

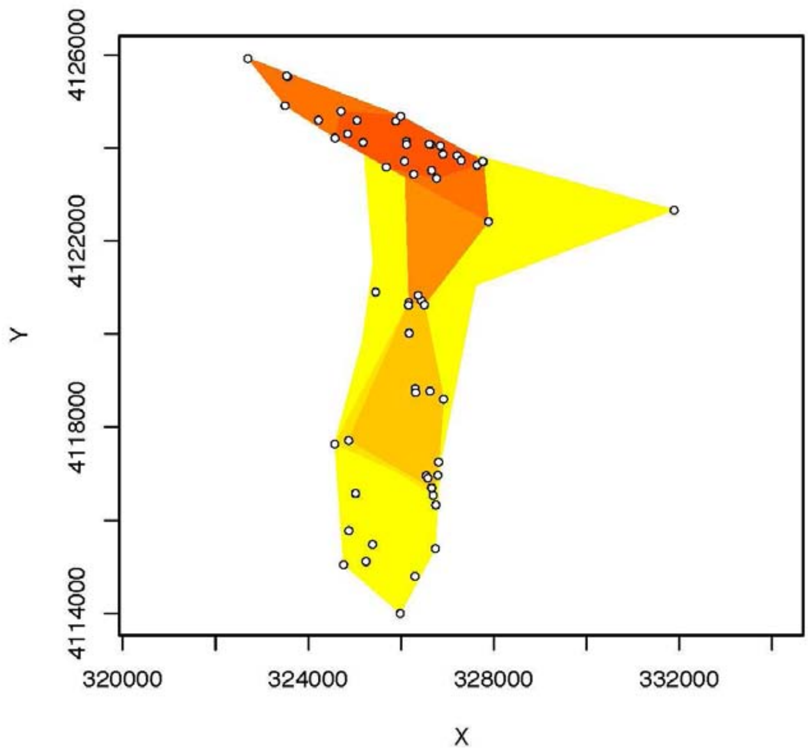
In the present work we have found that the risk of cross species dissemination of infectious agents between livestock and argalis in Big Pamir is relatively limited. We hypothesize that this is primarily due to the chronic hunting pressure affecting wild ungulates. In such circumstances argalis restrict their home range to the safest and most inaccessible terrains of the Big Pamir massif where the likelihood of infective contacts with livestock is low. We do not know to which extent being forced to 'live at the extreme' of its biome affects the ecological fitness of this population on the long term. Only from the aspects of health risk, thriving in the hypoxic and hypobaric extreme seems rewarding because of decreased contact rates with livestock, lack of insect reservoirs of infectious agents, and the poor environmental conditions for bacteriogenesis. Yet such benefits could be counterbalanced by a higher physiological cost and a higher stress level. Chronic stress translates into prolonged over production of glucocorticoid hormones due to impaired homeostasis, a situation that may have harmful effects on organisms, such as reduced immune function and reduced ability to combat infections (Munck et al., 1984). Consequently we project that in Big Pamir any conservative measure aimed at extending the range and biomass available to argalis at livestock's expense will have to be implemented carefully and most importantly very progressively to allow physiological and immunological adjustments to operate. Removing domestic grazers from Pamirs will theoretically drive argalis to more contaminated surroundings, more vector species, in brief, to a 'more infectious world'.

APPENDICES

Locations (points) and local convex-hull (LoCoH; color polygons) home range estimates for herds of sheep and goats monitored with a handheld GPS or for radio-collared yaks are provided in Appendices 1 to 13. Data were collected in western Big Pamir, Afghanistan, in 2007 and 2008. Frequencies of utilization of each home range are represented with color-coded isopleths (see Figures 4 and 5), the 10% isopleth contains 10% of the locations; and the 100% isopleth encompasses all the points. The smaller the hull, the more heavily used the area. The darker is the color of the polygon, the higher the frequency of utilization, and the higher the risk of environmental contaminations with shed infectious agents.

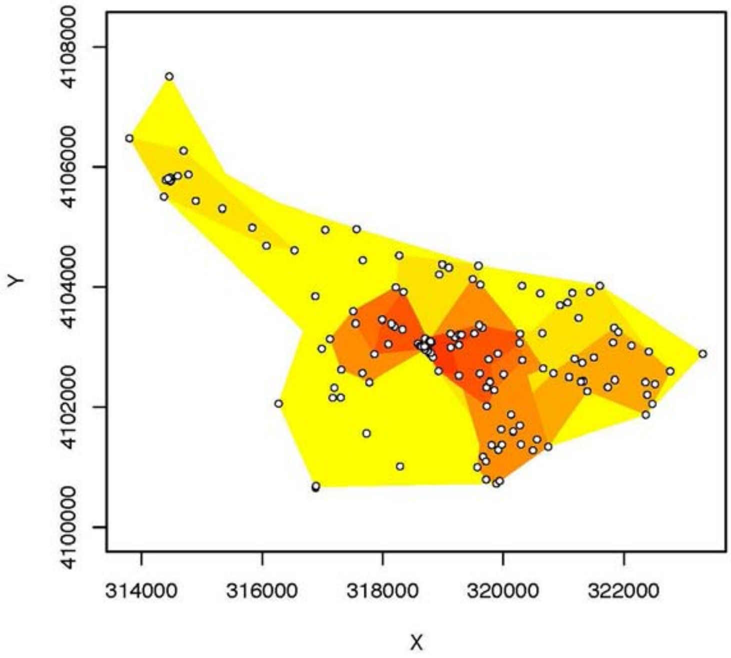
Appendix 1. Home range estimates for Aba Khan herd

Locations (points) and local convex-hull (LoCoH; color polygons) home range estimates for the herd of sheep and goats in Aba Khan monitored with a handheld GPS, Big Pamir, Afghanistan, autumn 2007 and summer 2008.



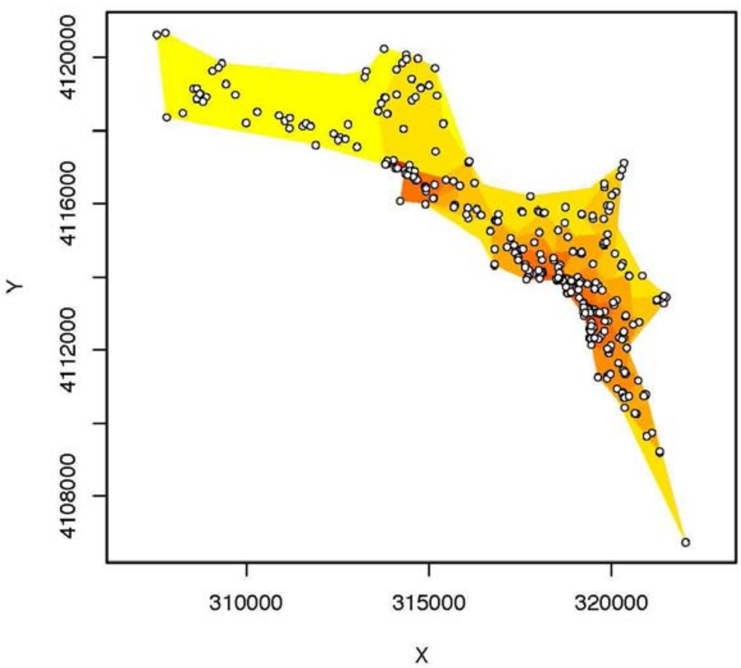
Appendix 2. Home range estimates for Asan Katich herd

Locations (points) and local convex-hull (LoCoH; color polygons) home range estimates for the herd of sheep and goats in Asan Katich monitored with a handheld GPS, Big Pamir, Afghanistan, summer 2008.



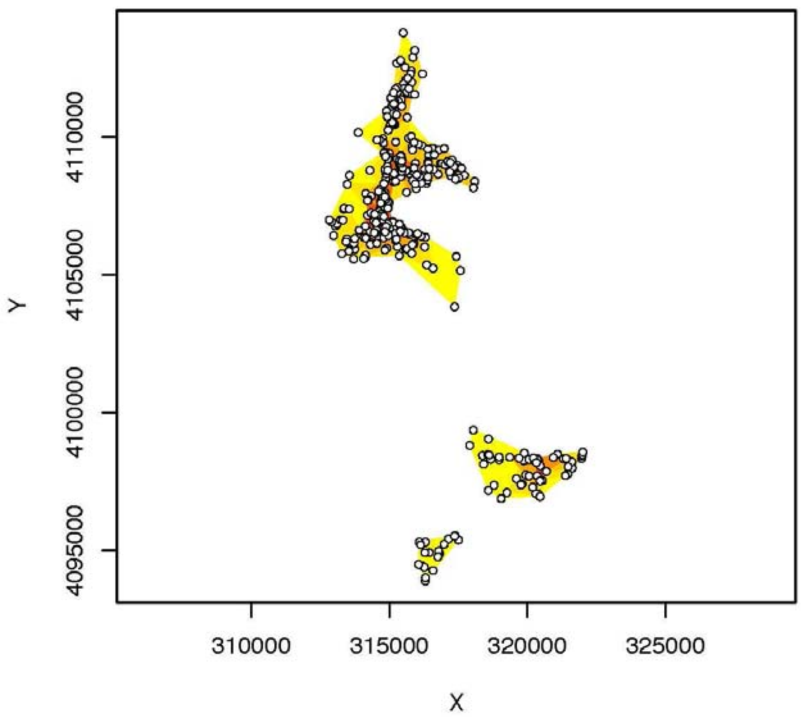
Appendix 3. Home range estimates for Dara Big herd

Locations (points) and local convex-hull (LoCoH; color polygons) home range estimates for the herd of sheep and goats in Dara Big monitored with a handheld GPS, Big Pamir, Afghanistan, summers 2007 and 2008.



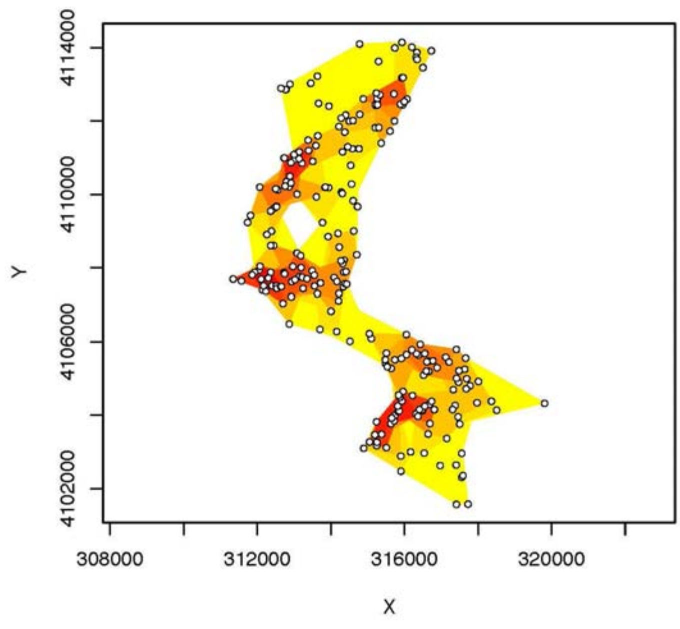
Appendix 4. Home range estimates for Kund-a-Thur herd

Locations (points) and local convex-hull (LoCoH; color polygons) home range estimates for the herd of sheep and goats in Kund-a-Thur monitored with a handheld GPS, Big Pamir, Afghanistan, summers 2007 and 2008.



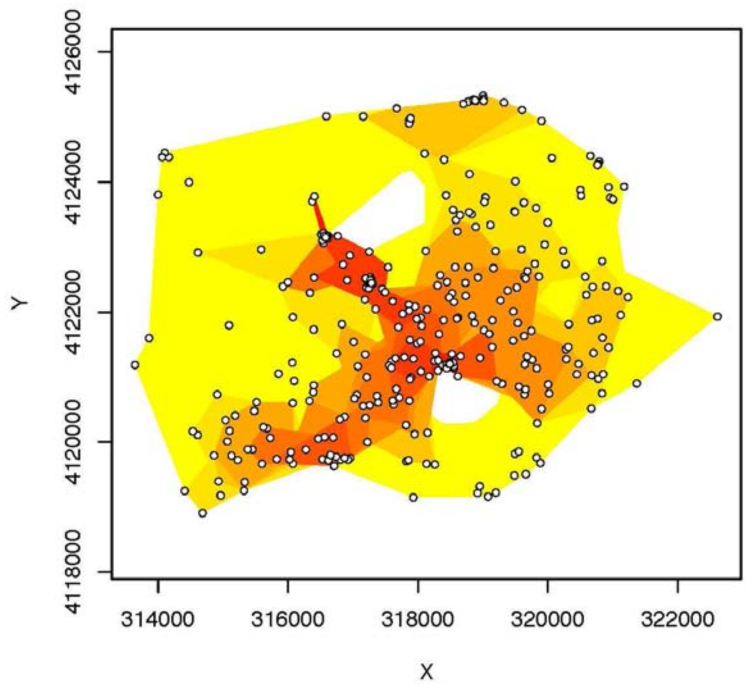
Appendix 5. Home range estimates for Mulung Than herd

Locations (points) and local convex-hull (LoCoH; color polygons) home range estimates for the herd of sheep and goats in Mulung Than monitored with a handheld GPS, Big Pamir, Afghanistan, summers 2007 and 2008.



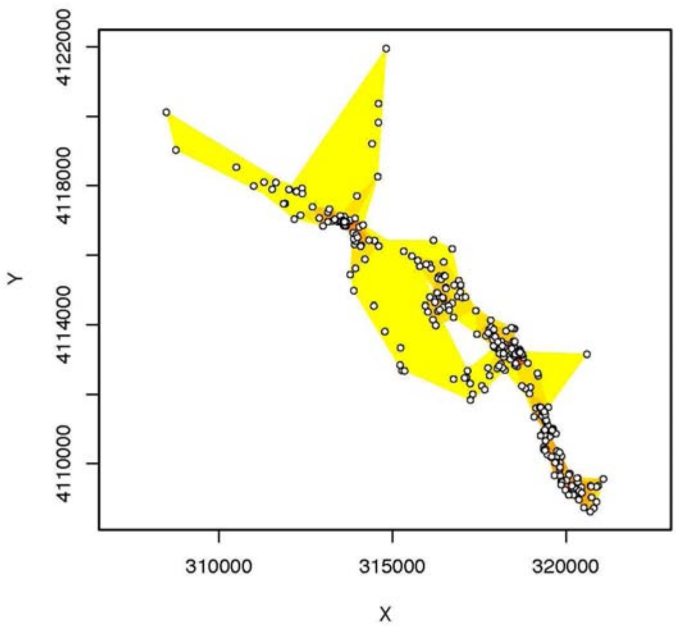
Appendix 6. Home range estimates for Nakchirshitk herd

Locations (points) and local convex-hull (LoCoH; color polygons) home range estimates for the herd of sheep and goats in Nakchirshitk monitored with a handheld GPS, Big Pamir, Afghanistan, summers 2007 and 2008.



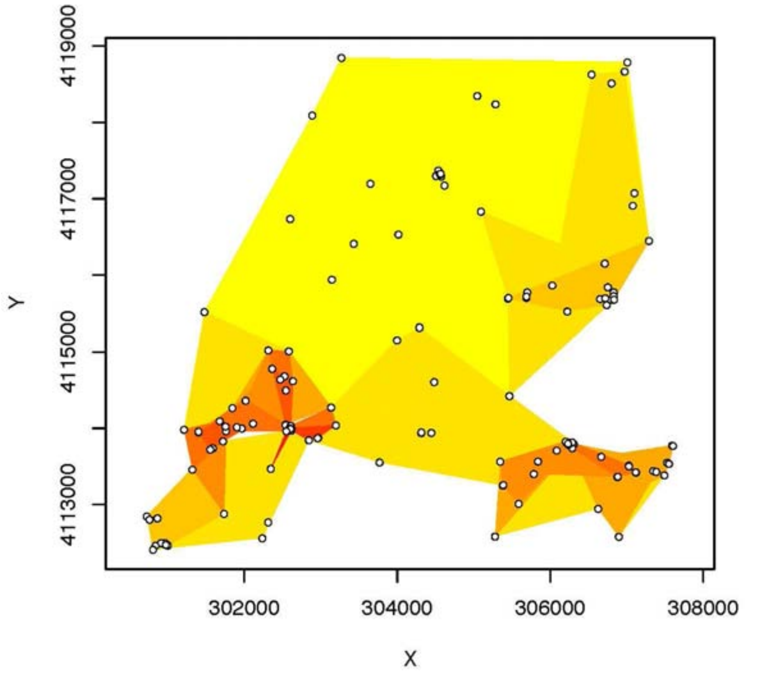
Appendix 7. Home range estimates for Qabal Gah herd

Locations (points) and local convex-hull (LoCoH; color polygons) home range estimates for the herd of sheep and goats in Qabal Gah monitored with a handheld GPS, Big Pamir, Afghanistan, summers 2007 and 2008.



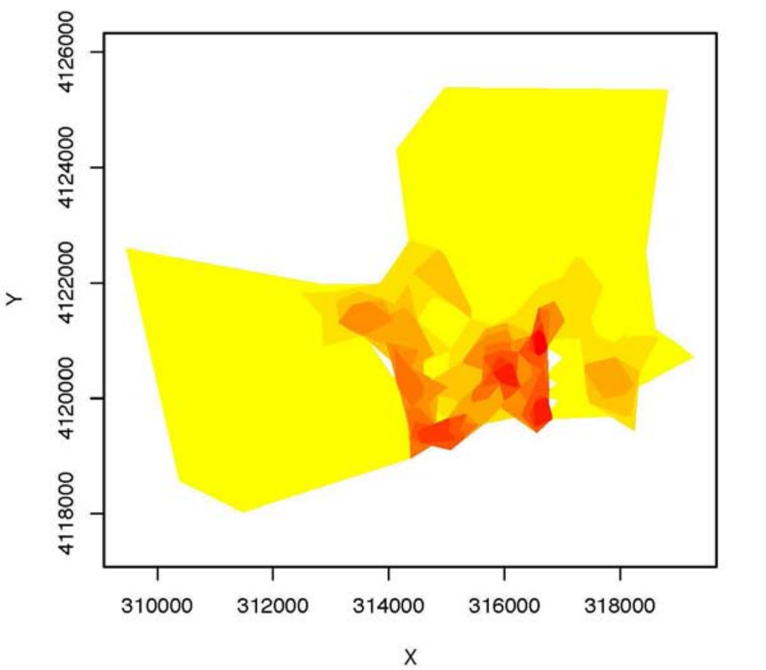
Appendix 8. Home range estimates for Senin herd

Locations (points) and local convex-hull (LoCoH; color polygons) home range estimates for the herd of sheep and goats in Aba Khan monitored with a handheld GPS, Big Pamir, Afghanistan, summer 2008.



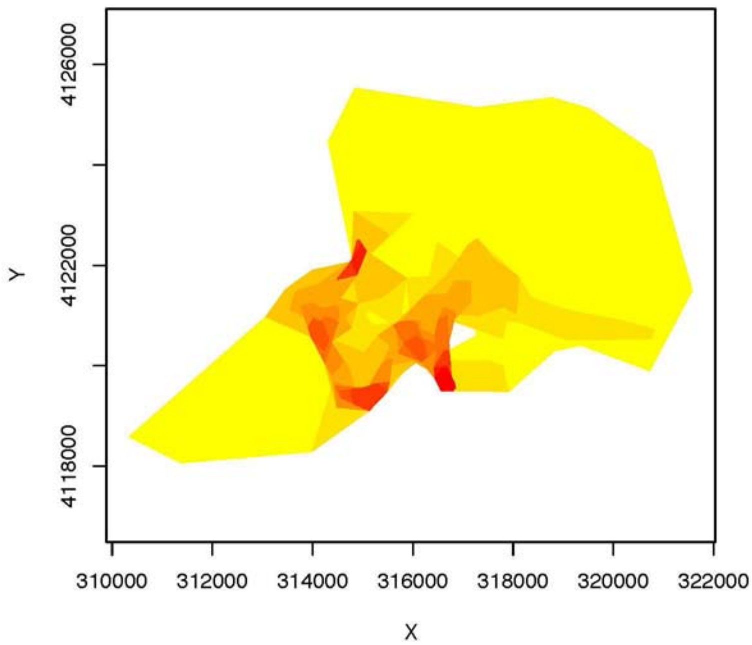
Appendix 9. Home range estimates for herd n°1 of free-ranging yaks

Local convex-hull (LoCoH; color polygons) home range estimates for herd no.1 of free-ranging domestic yaks monitored with a radio-colored individual. Western Big Pamir, Afghanistan, summer 2008.



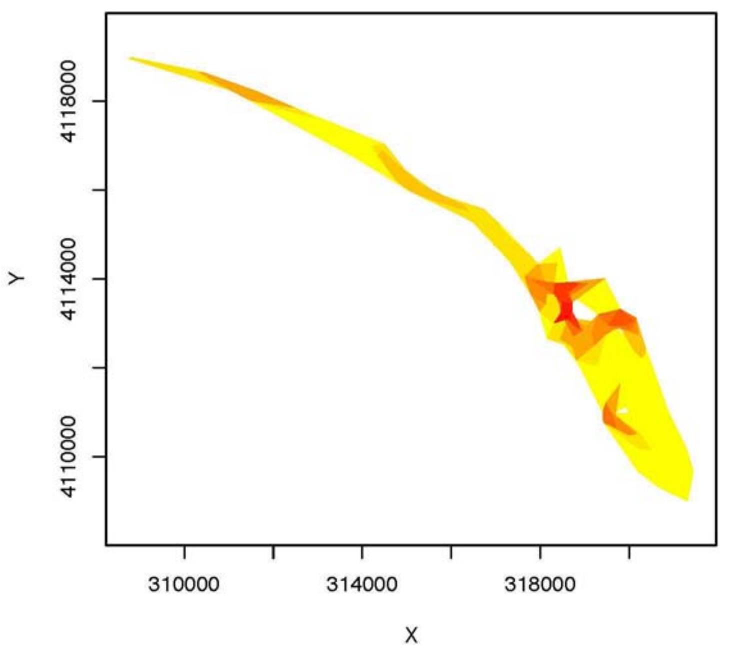
Appendix 10. Home range estimates for herd n°2 of free-ranging yaks

Local convex-hull (LoCoH; color polygons) home range estimates for herd no.2 of free-ranging domestic yaks monitored with a radio-colored individual. Western Big Pamir, Afghanistan, summer 2008.



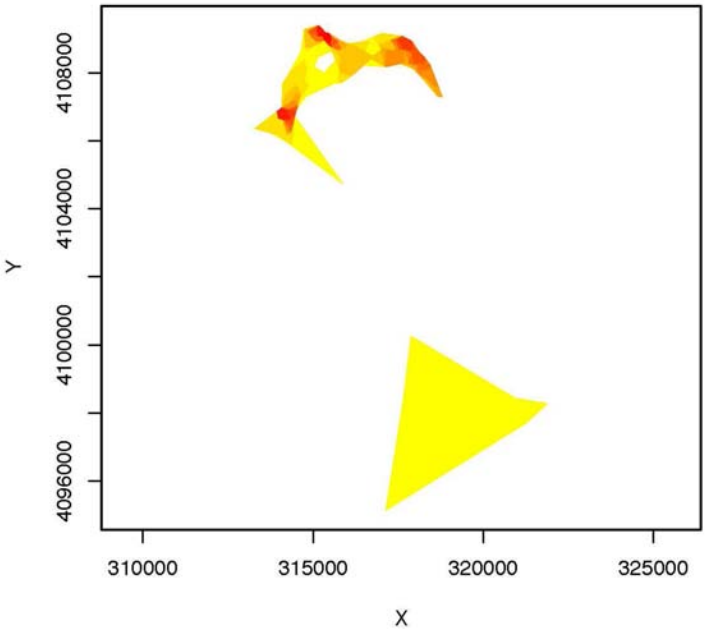
Appendix 11. Home range estimates for herd n°3 of free-ranging yaks

Local convex-hull (LoCoH; color polygons) home range estimates for herd no.3 of free-ranging domestic yaks monitored with a radio-colored individual. Western Big Pamir, Afghanistan, summer 2008.



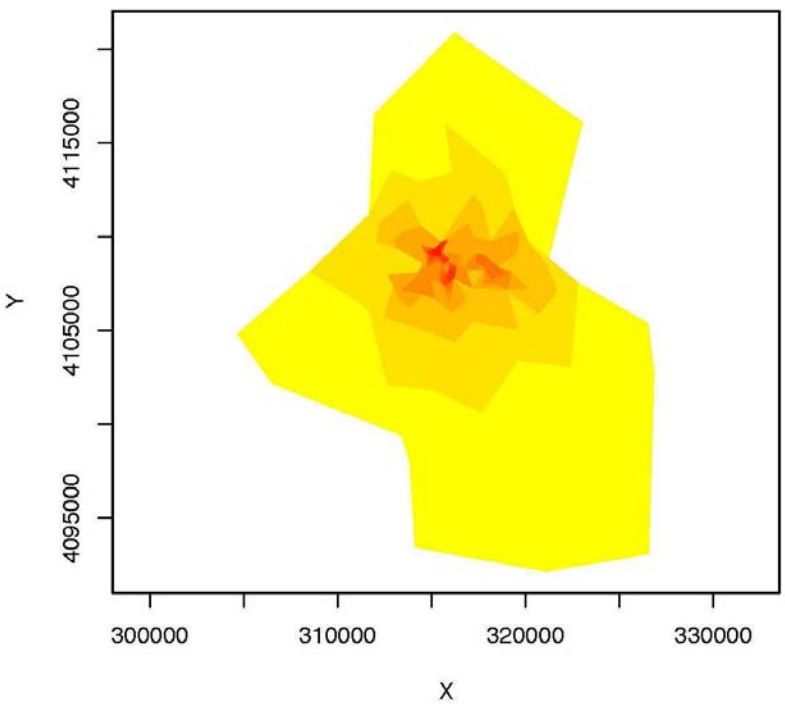
Appendix 12. Home range estimates for herd n°4 of free-ranging yaks

Local convex-hull (LoCoH; color polygons) home range estimates for herd no.4 of free-ranging domestic yaks monitored with a radio-colored individual. Western Big Pamir, Afghanistan, summer 2008.



Appendix 13. Home range estimates for herd n°5 of free-ranging yaks

Local convex-hull (LoCoH; color polygons) home range estimates for herd no.5 of free-ranging domestic yaks monitored with a radio-colored individual. Western Big Pamir, Afghanistan, summer 2008.



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