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Den Habitat Characteristics of Tibetan Foxes (*Vulpes ferrilata*) in Shiqu County, Sichuan Province, China

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Zheng-Huan Wang, Xiao-Ming Wang, and Aleksei A. Chmura (2008) Den habitat characteristics of Tibetan foxes (*Vulpes ferrilata*) in Shiqu County, Sichuan Province, China. *Zoological Studies* **47**(4): 445-454. The Tibetan fox (*Vulpes ferrilata*), an endemic canid living on the Tibetan Plateau above 3000 m, is listed by the IUCN as having insufficient data, with only limited information available on its ecology. It is also an important definitive wild host of a lethal zoonotic, alveolar echinococcosis (AE), caused by the tapeworm, *Echinococcus multilocularis*. Understanding the habitat ecology of Tibetan foxes will benefit the conservation of the species and provide greater understanding of the transmission mechanisms of AE. Shiqu County is a typical plateau pasture area, located in western Sichuan Province, on the eastern edge of the Tibetan plateau. It is a high human AE endemic area where Tibetan foxes are abundant. Thus, we studied the Tibetan fox's den habitat characteristics during 2001 to 2003 here, documenting 153 dens. We hypothesized that (1) the Tibetan fox should den on slopes with an open landscape and near rivers, and (2) fox dens should be located in areas where extreme temperature conditions are moderated, and den entrance azimuths should avoid the prevailing direction of strong winds to ensure a moderate microclimate in this cold, dry, and unpredictable steppe climate. All dens were found to be located on slopes and significantly more dens were distributed in areas with an open landscape. Den entrance obliquities and slope gradients were significantly related (z = -0.303, p = 0.762). Entrance azimuths and slope aspects were concentrated in a westerly direction. Distances from dens to a river (814 ± 317 m) did not violate a random distribution (z = -0.487, p = 0.626). Significantly more pika burrows were found around abandoned fox dens than around active dens. We concluded that Tibetan fox dens are distributed on slopes, avoid a direct southern slope aspect, and are located in open habitats. River distances and entrance exposure directions were not statistically significant factors in Tibetan fox den habitat selection.
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Key words: Den, Habitat, Sichuan, Tibetan fox, *Vulpes ferrilata*.

The Tibetan fox (*Vulpes ferrilata*) is only found on the Tibetan plateau of China, Nepal, and northern India, at elevations of 3000-5300 m (Feng et al. 1986, Nowak 1999, Clark et al. 2007). Although listed as an endangered species in China (Wang and Xie 2004), information on Tibetan fox biology and ecology is limited (Zheng 1985, Feng et al. 1986, Piao 1989, Schaller 1998, Dai 2004). The Tibetan fox is not on the IUCN Red list, and CITES is also unable to comment on a conservation strategy for the species. IUCN stated that: “all aspects of the fox’s natural history need study” (Sillero-Zubiri et al. 2004).

Habitat loss has become one of the main threats to the survival of endangered species in China (Ding and Wang 2004, Wang et al. 2004, Linderman et al. 2005). Typically, the Tibetan fox lives in alpine grasslands and shrub-grasslands (Feng et al. 1986, Wang et al. 2003 2007). However, because of the increasing damage

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caused by human and human-induced activity (e.g., overgrazing), the quantity and quality of natural Tibetan alpine grasslands are being diminished (Shi and Zhong 2001, Lan 2004, Wang 2005). In order to evaluate the impacts of habitat loss on the Tibetan fox, its pattern of habitat use must be thoroughly studied.

Tibetan foxes are the main definitive wildlife host of the tapeworm, *Echinococcus multilocularis* (Qiu et al. 1995), while their prey of small mammals, including pikas (*Ochotuna* spp.), Tibetan woolly hares (*Lepus oiostolus*), and rodents such as *Microtus* spp., *Alticolai* spp., and *Cricetelus* spp. (Zheng 1985, Feng et al. 1986, Schaller 1998), are the main wild intermediate hosts on the eastern Tibetan Plateau, western China (Eckert et al. 2001). *Echinococcus multilocularis* causes a lethal zoonosis, alveolar echinococcosis (AE), with carnivores (mainly canids) as the definitive hosts. Humans and small mammals that ingest *E. multilocularis* eggs in feces of infected definitive hosts will suffer AE. AE has an extensive geographic range in the northern hemisphere (Eckert et al. 2001), and untreated human AE can result in > 90% fatal outcomes (Craig 2004). Therefore, AE is believed to be the most serious parasitic zoonosis in temperate and arctic regions of the northern hemisphere (Vuitton et al. 2003). Western China is one of the most important endemic regions, particularly pasture areas of eastern Tibet, where increasing contact among wildlife, dogs, and humans has resulted in increased morbidity and mortality due to AE in local human populations (Li et al. 2005). Although stray dogs in this area are thought to be the main risk for transmitting AE to humans because of their free-ranging behavior and close relationship with humans (Li et al. 2005), dogs are the agents linking the wildlife AE reservoir and humans (Craig 2004). Therefore, in order to better understand the transmission mechanisms of AE, it is important to understand how it is maintained in wildlife. Consequently, the behavior of the definitive wild host (i.e., Tibetan foxes) especially its habitat use patterns for predicting its distribution should be studied because of its importance in transmitting AE in wildlife (Wang and Wang 2006a).

Tibetan foxes are typical of many fox species (e.g., Arctic foxes, *Alopex lagopus*; sand foxes, *V. corsac*; swift foxes, *V. velox*, etc.) living in arid, cold, and open habitats, where dens are used for breeding and year-round for refuge from predation and extreme climatic conditions (Schaller 1998, Wang et al. 2003 2004). Thus den habitat characteristics and factors influencing den habitat selection are important components of the ecology of Tibetan foxes. We hypothesized that (1) the Tibetan fox should den on slopes with an open landscape near rivers; and (2) fox dens should be located in areas where extreme temperature conditions are moderated, and den entrance azimuths should avoid the prevailing strong wind direction to ensure a moderate den microclimate in this cold, dry, and unpredictable steppe climate.

MATERIALS AND METHODS

Study area

Our study area was in Shiqu County, Ganzi Autonomous Prefecture, Sichuan Province, a typical plateau pasture area of western China. Elevations in this region range 4140-4500 m. Mean annual precipitation is < 600 mm (SCACC 2000), with July to early-Aug. being the only snow-free period. The average minimum temperatures were -24.7°C in Jan. and 2.6°C in July. Average maximum temperatures were 4°C in Jan. and 17°C in July (Shiqu Meteorological Station 2003, unpublished data). Habitat is primarily grassland and short shrubs. Sedges of the genus *Kobresia* are the dominant grassland species, while shrub communities are dominated by *Potentilla fruticosa*, *Spiraea* spp., and *Salix* spp. with aboveground heights of < 70 cm (CGSV 1980). Gentle rolling hills with large broad valleys bounded by mountain ridges are the major landscape features. Rivers and creeks drain into the valleys, creating small islands and wetlands; roads cross the valley bottoms.

The human population density is 2.47 individuals/km^2 (SCACC 2000). However, a number of villages and fenced areas for winter foraging are located in the study area. Large herds of domestic yaks, sheep, and horses are kept, especially near riparian areas. For example, in the 2 main villages in the research area, Derongma and Eduoma, approximate 70,000 livestock, mainly yaks, were kept (SCACC 2000). Dog ownership is popular in Shiqu County, and large numbers of domestic and stray dogs can be observed in and around human settlements (Li et al. 2005). Recently, Shiqu County was reported to have the world's highest village human AE infection rate at 6.2% (Li et al. 2005).

Tibetan foxes are the most abundant wild canid species in Shiqu County. Other wild carnivores include wolves (*Canis lupus*), brown bears (*Ursus arctos*), Eurasian badgers (*Meles meles*), steppe polecats (*Mustela eversmanni*), and alpine weasels (*Mustela altaica*). Large herbivores include Tibetan gazelles (*Procapra picticaudata*) and wild asses (*Equus hemionus*). Black-lipped pikas are the most abundant small mammals (SCACC 2000), and are the main prey species of Tibetan foxes (Zheng 1985, Schaller 1998). Meanwhile, Himalayan marmots (*Marmota himalayana*) and woolly hares (*Lepus oiostolus*) are also common in this area.

Den identification and characteristics

We carried out this research in a 230 km^2 study area which included 9 valleys. Tibetan fox dens were located by a thorough walking survey with 4 people spaced at 50 m intervals in this area. Human settlements, fenced areas, and muddy wetlands in the study area were excluded because no Tibetan fox dens were found according to our previous surveys. Therefore, the exact area surveyed in this research was about 160 km^2. The walking survey was done twice during July-Aug. 2001 and 2002. All dens found in 2001 and 2002 were revisited in Aug.-Nov., 2003, and new dens were recorded. Den locations were recorded by a global-positioning system and imported into Arc View 3.2a (ESRI 2000) on a digital map of the research area (provided by Mark Danson, University of Salford, Salford, UK in 2001).

Tibetan fox dens were distinguished from those of marmots' by the presence of tracks, fresh feces, fox hair, trampled vegetation, a dirt ramp, and prey remains at the den entrance, or by direct observation of a fox or marmot near the den (Zhang et al. 1999, Wang et al. 2007). Fox feces is smaller than that of wolves or dogs. We considered a den occupied by foxes only if fox feces was moist. A dirt ramp is a mound of soil at the den mouth, which has been excavated from a den, and is a very useful index for indicating den use (Egoscue 1956). Fox footprints and basking individuals could be seen on the dirt ramps. Dirt ramps at old or abandoned Tibetan fox den entrances will quickly erode or disappear under the encroaching vegetation (Wang et al. 2007). We only included dens in our analysis that we considered to be fresh or active.

For each den, we quantified the the slope gradient, the slope aspect, and the distance to the nearest river (hereafter, called river distance) on the digital map. A 3-dimensional elevation model was made based on the 50 m contour layer of our digital map, and the slope gradient and aspect of the landform were measured by Arc View 3.2a. The slope gradient was then divided into 3 classes: gentle (0°-15°), moderate (15°-30°), and steep (> 30°). Rivers and creeks comprise the only permanent water in the study area. Therefore, distance to the nearest water was measured by generating a straight line to the nearest river or creek measured on a river-distribution shape file in the digital map. River distance data were grouped into 4 categories: 0-500, 500-1000, 1000-1500, and > 1500 m. Den locations were separated into 4 categories (hereafter called slope ranks) based on the position on the slope: flat (i.e., on the area of the plain forming the bottom of the valley), low (the 1st 1/3 of a slope from the bottom), middle (the middle 1/3), and high (the top 1/3). We recorded the number of entrances, and measured the maximum diameter of entrances, den entrance azimuths, entrance lengths, entrance obliquities (i.e., the inclination of the entrance from the horizontal), and substratum type (e.g., soil or rock). In multi-entrance dens, the number of entrances was counted; however, only active entrances were measured. Inactive entrances were distinguished by the presence of vegetation, rough surfaces (frequented den entrances had level, smooth dust from the frequent passage of foxes), spider webs, and other detritus or even a collapsed entrance mouth. We defined the den entrance length as the distance from the den mouth to the 1st corner in the den tunnel. We classified vegetation near dens using 5 × 5 m^2 plots centered on the dens (hereafter, called fox den plots). Within each fox den plot, we counted pika burrows during each survey season. We distinguished pika burrows from other species' by the presence of pikas, pika feces, and latrines.

In order to test whether selection of the slope gradient, slope aspect, and river distance of fox den sites was significant, data on these 3 parameters had to be compared to random points in the research area. Random points were generated via Excel equal to the number of dens (n = 153), and these were checked on the digital map or in the field to avoid those located in human settlements, fenced areas, or muddy wetlands. The slope gradient, slope aspect, and river distance data of the random points were obtained from the digital map by the same methods described above.

We obtained meteorological data on wind speed and direction in July 2002 and Jan. 2003 from Shiqu Meteorological Station. No data were available for 2001.

Vegetation classification and sampling

All of our Tibetan fox dens were found in valleys. Therefore, we designed line transects on the digital map to cover all of the area of rolling hills surveyed for Tibetan fox dens. The surveyed area was divided into 4 sub-areas according to the accessibility by vehicle. In each sub-area, we ascended to and walked along the mountain ridge. Whenever a valley was encountered, sampling lines (i.e., 2 sampling lines, a and b, at a 90° angle, Fig. 1) were set up at the center of the valley. Line a began at the mountain ridge and went down the slope from the top of the valley to the flat area at the bottom, and stopped at a county road or river, while line b stopped at the 2 edges of the valley (Fig. 1). When conducting line transect surveys, 5 × 5 m^2 vegetation plots were sampled at 150 m intervals. We excluded all vegetation plots for which a fox den was found within a 150 m radius. In total, 40 km of line transects was walked covering the 9 valleys. However, only approximate 30 km of line transects was used in this research. We excluded 10 km of line transects because it went across areas occupied by large herds, human settlements, or fenced areas. Vegetation in those transected areas might not be representative (Wang et al. 2007).

In both vegetation and fox den plots, we classified vegetation into 4 categories (Wang et al. 2007): grasslands, in which vegetation covered no less than 60% of the area and which was composed of herbaceous plants, with an aboveground height of ≤ 20 cm; shrubs/grassland, in which herbaceous plants and short shrubs had a total cover exceeding 60% and an aboveground height of ≤ 20 cm; shrubs, in which > 40% of the area was covered by shrubs and > 60% by herbaceous plants, with an average aboveground height of shrubs of > 30 cm; and disturbed areas, in which > 50% of the plot was covered by bare soil and gravel.

Analyses

There are 3 circular parameters: slope aspect, fox den entrance azimuth, and wind direction. The slope aspect distribution of fox dens was first compared with that of the random points by a Watson and Williams 2-sample test to evaluate if the slope aspect distribution of dens significantly differed from that of the random points (Zar 1999). If the result was positive, slope aspect data as well as those for den azimuths and wind direction were tested for circular uniformity using the Rayleigh test (Zar 1999). If a circular uniform distribution could be rejected, a *V*-test was used to determine if the parameter distributions significantly aggregated to mean angles, and what the values of those angles were (Zar 1999). Slope aspect and azimuth data were also divided into 3 classes: sunny (112.5°-202.5°), half-sunny (22.5°-112.5° and 202.5°-292.5°), and shady (292.5°-22.5°) (Zhang et al. 1999).

Slope gradients of the fox dens and random points were compared using the Mann-Whitney *U*-test. Entrance obliquity and fox den slope gradient data were sine-transformed and tested for normality using a 1-sample Kolmogorov-Smirnov (K-S) test. When normality was rejected at α = 0.05 for either the entrance obliquity or den slope gradient, a Wilcoxon signed-ranks test was used to test if the entrance obliquity of a fox den entrance was influenced by the gradient of the slope where the den was located. The Mann-Whitney *U*-test was used to test if slope gradients of single- and multiple-entrance dens differed. Distances from the random points to the nearest river were measured and also compared with those of fox dens using the Mann-Whitney *U*-test.

Bonferroni *Z*-statistics were used to analyze den habitat vegetation characteristics by comparing habitat vegetation types used in proportion to habitat vegetation type availability. Background vegetation composition patterns in the surveyed areas were evaluated from the vegetation plot data, and confidence intervals for the observed proportion of each vegetation type were constructed. If the expected available proportion of a vegetation type was outside the confidence interval, then that vegetation type was judged to be used non-randomly (Neu et al. 1974, Byers and Steinhorst 1984).

The Mann Whitney *U*-test, 1-sample K-S test, Wilcoxon *Z*-test, and the Bonferroni *Z*-statistics were performed in STATISTICA 6.0 (Statsoft 2003) and SPSS 12.0 (SPSS 2002). Circular parameter analyses were performed using EXCEL (Microsoft 2003). Data are given as the mean ± the standard deviation (SD).

RESULTS

We found 153 Tibetan fox dens in the

research area including 106 single- and 47 multiple-entrance dens with a mean entrance number of 3.77 ± 2.58. The maximum diameter of the entrance, the entrance length, and the substratum of the den of 91 den entrances were measured, while the obliquity of the den entrance and the slope gradient of the den site of 115 den entrances were recorded (Table 1). All fox den slope aspects and 201 entrance azimuths from the 153 Tibetan fox dens were tested for circular uniformity. Slope aspect distributions significantly differed from those of the random points ($F_{(1,304)}$ = 4.445, $p < 0.05$, Watson and Williams 2-sample test). Circular normality was rejected for both entrance azimuths ($z_{(n = 201)}$ = 26.433, $p < 0.001$, Rayleigh test) and slope aspects ($z_{(n = 153)}$ = 54.778, $p < 0.001$, Rayleigh test). Both entrance azimuths and slope aspects were concentrated to the west, (half-sunny class). The mean den entrance azimuth was 261° ($V_{(n = 201)}$ = 60.023, $p < 0.001$, *V*-test), and the mean slope aspect was 271° ($V_{(n = 153)}$ = 97.961, $p < 0.001$, *V*-test). Circular uniformity was rejected for wind direction in Jan. 2002 ($z_{(n = 31)}$ = 28.182, $p < 0.001$, Rayleigh test), but not in July 2003 ($z_{(n = 28)}$ = 2.121, $p > 0.05$, Rayleigh test). The mean wind direction was 255° ($V_{(n = 31)}$ = 29.557, $p < 0.001$, *V*-test) in Jan. 2002. Mean wind speeds were 2.8 ± 1.15 m/s (n = 31) in winter and 0.99 ± 0.59 m/s (n = 28) in summer. The strongest wind was 5.8 m/s from the west, recorded in Jan. 2004.

All fox dens were located on slopes, and 125 fox dens (81.7%) were found on the low and middle slope ranks (Fig. 2). The fox den slope gradient distribution did not significantly differ from that of the random points ($z_{(n = 153, 153)}$ = -0.056, p = 0.956, Mann-Whitney *U*-test), although the majority of dens (126, 82.3%) were located on gentle and moderate slope gradient classes (64 dens or 41.8% on gentle slopes and 62 dens or

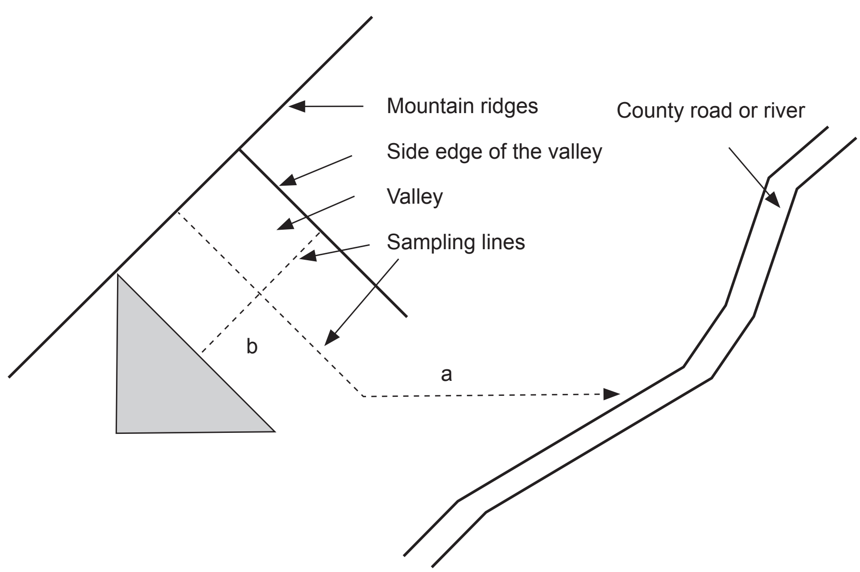

Fig. 1. Right-angle cross sampling line design in a surveyed valley (adapted from Wang et al. 2007). Dashed lines a and b show the cross sampling lines which were set up at the center of a valley. Line a runs down the slope from the top of the valley to the flat area at the bottom, while line b runs transversely from the 2 edges of the valley.

Table 1. Structural characters of Tibetan fox dens in Shiqu County, Sichuan Province (adapted from Wang and Wang 2006b)

Structural character (mean ± SD, *n* = 91)		Substratum (*n* = 91)		Entrance obliquity (mean ± SD, *n* = 115) (°)	Slope gradient (mean ± SD, *n* = 115) (°)
Maximum diameter of entrance (cm)	Entrance length (cm)	Soil	Rock		
24.9 ± 7.15	170.0 ± 88.43	77 (84.6%)	14 (15.4%)	28.3 ± 10.62	27.7 ± 13.94

40.5% on moderate slopes). Fox den entrance obliquity was influenced by the den slope gradient (Table 1), because their data distributions did not significantly differ ($z_{(n = 115, 115)} = -0.303$, $p > 0.05$, Wilcoxon signed-ranks test). The slope gradient distributions of the single- (*n* = 106) and multiple-entrance den classes (*n* = 47) significantly differed ($z_{(n = 106,47)} = -4.017$, $p < 0.001$, Mann-Whitney *U*-test). Multiple-entrance dens were more likely to be on steeper slopes than single-entrance dens. The mean distance of dens from a river was 814 ± 371 m (*n* = 153). However, the river distance of the den did not significantly differ from a random distribution ($z_{(n = 153, 153)} = -0.487$, $p > 0.05$, Mann-Whitney *U*-test), although most dens were found in the 2nd class (i.e., 500-1000 m) (74 dens or 48.4% of all dens, Fig. 3).

We sampled vegetation on 179 plots along the line transects. Tibetan fox dens were not randomly distributed in the 4 vegetation classes ($X^2_3 = 42.356$, $p < 0.001$). Therefore, the Bonferroni *z*-statistics could be used. Dens were located significantly more often than expected in grasslands, and were not found in shrubs. The proportion of dens in disturbed areas and shrub/grasslands did not differ from the expected values according to habitat availability (Table 2).

Of 94 dens used by Tibetan foxes in 2002 (44 of which were first located in 2001), 22 were abandoned in 2003. There was a significantly greater number of pika burrows near these abandoned fox dens in 2003 than in 2002, when the dens were active. In contrast, among the 72 dens active in both years, there were significantly fewer pika burrows in 2003 than in 2002 (Table 3).

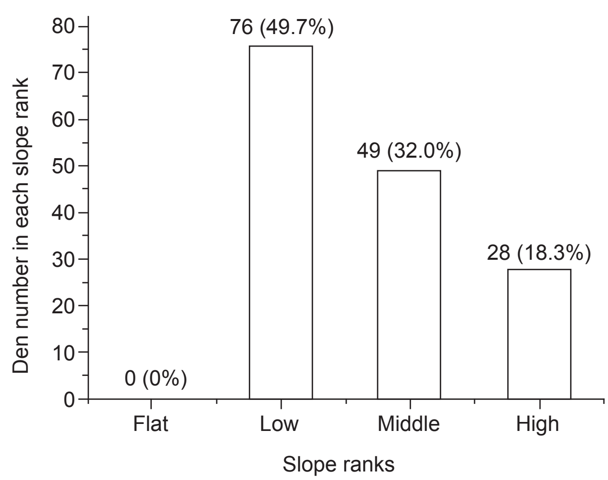

Fig. 2. Tibetan fox den numbers in different slope rank classes in Shiqu County. Slope ranks: flat includes the plains area at the bottom of the valley; low indicates the 1st 1/3 of the slope from the bottom; middle is the 2nd 1/3; while high indicates the highest 1/3 to the top of the slope. The exact number of Tibetan fox dens found in each category is given at the top of each histogram, and the percentage is in brackets.

Table 2. Use and availability of vegetation classification of Tibetan fox den plots

Vegetation classification	Expected proportion of total surveyed area P_{ie}[a] (number) (*n* = 179)	Proportion of Tibetan fox den plots (*n* = 153)	
		Observed P_{io} (number)	P_{io} 95% Bonferroni intervals for P_{io}
Disturbed area	0.117 (21)	0.150 (23)	$0.070 \le P_{1o} \le 0.230$
Grassland	0.559 (100)	0.784 (120)	$0.692 \le P_{2o} \le 0.876$
Shrubs and grasslands	0.117 (21)	0.065 (10)	$0.010 \le P_{3o} \le 0.121$
Shrubs	0.207 (37)	0 (0)	-[b]

[a]We used the proportion of the 179 vegetation plots in the 4 vegetation classes as the expected proportion of the total surveyed area. [b]No Tibetan fox den was detected in shrub vegetation.

DISCUSSION

The Tibetan fox is a small fox with an average weight of 4.3 ± 0.7 kg (*n* = 7), average chest girth of 36.7 ± 2.8 cm (*n* = 7), and average shoulder height of 31.1 ± 4.3 cm (*n* = 14, Wang, unpubl. data). Comparing the Tibetan fox shoulder height with the mean maximum diameter of den entrances (Table 1), entrances of Tibetan fox dens are narrow relative to the fox body size. The keyhole-shaped entrance is believed to provide denning species access while preventing entrance to larger, threatening species (e.g., wolves, dogs, and brown bears) (Arjo et al. 2003). Our data indicated that Tibetan foxes make use of both single- and multiple-entrance dens, although single-entrance dens were the majority in this study. Multiple-entrance dens have also been reported in other fox species, particularly for raising offspring (Storm et al. 1976, Nielsenet al. 1994, Zhou et al. 1995, Arjo et al. 2003).

That den entrance obliquity correlated with the slope gradient, and no den was found in flat areas (Fig. 2) suggesting that Tibetan foxes choose slopes when excavating dens. Use of slopes to facilitate good drainage conditions of dens is considered crucial for a variety of denning species (Prestrud 1992, Uraguchi and Takahashi 1998, Pruss 1999, McLoughlin et al. 2002), and the soil in Shiqu County is generally sandy with good drainage (CGSV 1980). It should be physically easier to dig and remove soil from dens on slopes (Uraguchi and Takahashi 1998), and soil is the primary type of substrate of Tibetan fox dens (Table 1).

Entrances of Arctic fox (*Alopex lagopus*) dens were found to have southerly aspects (Danilov 1961, Prestrud 1992, Nielsen et al. 1994). Danilov (1961) hypothesized that the prevailing wind direction was a significant factor influencing fox den entrance azimuths, and by facing south and avoiding the prevailing winds, Arctic fox dens provide thermal and microclimatic advantages (Prestrud 1992, Nielsen et al. 1994). Studies by Zhang et al. (1999) on red fox (*V. vulpes*) dens and Arjo et al. (2003) on those of the kit fox (*V. macrotis*) support this hypothesis. However, Zagrebel'nyi (2003) reported that Arctic fox den entrance azimuths on the Commander Is., Russia, showed no significant correlation to the prevailing wind direction. Pruss (1999) came to a similar negative conclusion on the Canadian prairie. In our study, both entrance azimuths and slope aspects were significantly concentrated in the west, and the predominant wind direction in winter

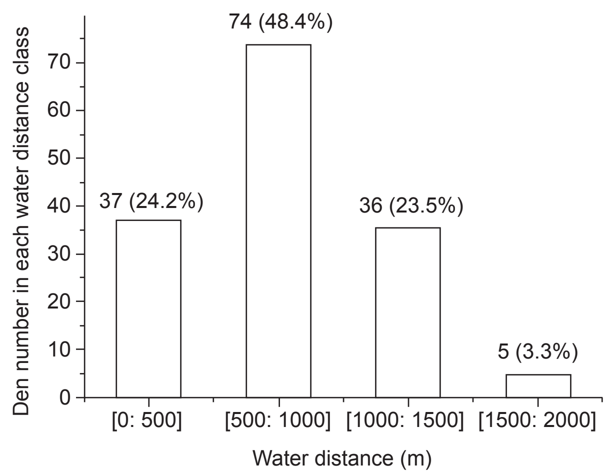

Fig. 3. Tibetan fox den numbers in different water resource distance classes in Shiqu. The river distance axis is classified into 4 categories: 0-500 ([0: 500]), 500-1000 ([500: 1000]), 1000-1500 ([1000: 1500]), and 1500-2000 m ([1500: 2000]). The exact number of Tibetan fox dens found in each category is given at the top of each histogram, and the percentage is in brackets.

Table 3. Paired-sample *t*-test of variations in the numbers of pika burrows in Tibetan fox den plots in 2002 and 2003

		Mean ± SD	Paired-sample *t*-test	Significance *p*
Abandoned[a] (*n* = 22)	2002	16.2 ± 10.9	-2.964	< 0.01
	2003	23.6 ± 13.5		
Active[b] (*n* = 72)	2002	17 ± 13.8	6.649	< 0.001
	2003	9.2 ± 8.3		

[a]Tibetan fox dens used in 2002 but found abandoned in 2003. There were significantly more pika burrows found around fox dens in 2003 than in 2002. [b]Tibetan fox dens found to be active in both 2002 and 2003. There were significantly more pika burrows found around fox dens in 2003 than in 2002.

is from the southwest. Wind in Shiqu County is not strong year round (SCACC 2000), and summer wind directions in Shiqu did not differ from random. Because of the variability of wind speed and direction in Shiqu County, it might not be a factor in den habitat selection by Tibetan foxes.

A disproportionate number of Tibetan fox dens were located on half-sunny slopes (i.e., westerly direction). In the northern hemisphere, south-facing slopes have higher soil temperatures than slopes with other exposures (Danilov 1961). Chesemore (1969) suggested that locating dens with a southern orientation produces a warmer microclimate in dens. Danilov (1961) and Smits et al. (1988) also reported that soil temperatures outside den areas were lower than those within dens. We hypothesized that Tibetan foxes avoid direct southern slopes to avoid extremely high temperatures in summer. Although the annual average temperature in Shiqu County is low, the highest ground temperature under the sunshine can exceed 37°C in summer (Wang, unpubl. data). Since Tibetan foxes make use of dens during the daytime and the mean depth of the dens was < 60 cm (Wang and Wang, 2006b), dens might heat up relatively easily. Therefore, a half-sunny slope aspect may provide Tibetan foxes with more-moderate daytime microclimatic conditions within the dens than under a sunny slope aspect.

Some studies have suggested that foxes living in xeric areas may locate their dens near permanent water bodies (Hillman and Sharps 1978, Russell 1983). We frequently documented Tibetan foxes drinking water from creeks at dawn and dusk (Wang et al. 2004). Rivers and creeks in Shiqu County were found in all valleys where we located Tibetan fox dens. Moreover, a low physiological demand for water and behavioral strategies have been documented in fox species living in xeric areas (Golightly and Ohmart 1984). The random distribution of the river distance to fox dens suggests that water availability does not strongly influence the selection of den sites.

Predation is a key biological factor affecting habitat use patterns of prey species. Potential predators of Tibetan foxes include domestic dogs, wolves (*Canis lupus*), the Golden Eagle (*Aquila chrisaetos*), and Upland Buzzard (*Buteo hemilasius*) (Wang 2005). Among them, dogs are the main cause of death of Tibetan foxes in our study area, and dogs were abundant at our research site (Wang 2005). We observed 16 deaths of Tibetan foxes caused by dogs during our fieldwork (Wang et al. 2007). Tibetan fox dens occur significantly more often in open area with short vegetation, and were not found in shrubs (Table 2). In fact, foxes were often observed foraging, roaming, and basking in open areas (with short grass cover) (Wang et al. 2007), which are also favored by dogs (He et al. 2000). Multiple authors (Pruss 1999 and Kamler et al. 2003 studying the swift fox (*V. velox*) and Koopman et al. 1998 and Harrison 2003 studying the kit fox) suggested that open areas allow earlier detection of predators versus the shrubby areas of our study site which could make it difficult for foxes to detect predators.

Black-lipped pikas are the main prey of the Tibetan fox (Zheng 1985, Schaller 1998) and were abundant at our study site (Wang 1993, SCACC 2000, Wang et al. 2004, Raoul et al. 2006). Habitats used frequently by the Tibetan fox are also favored by black-lipped pikas (Wang 2005). We found pika burrows in all of the Tibetan fox den plots. Fluctuations in the numbers of pika burrows in Tibetan fox den plots during consecutive years suggest that food availability may partially explain den habitat use by foxes (Table 3). Pikas are considered to be 1 source of grassland degradation on the Tibetan Plateau (Shi and Zhong 2001, Lan 2004), and poisoning programs are ongoing (Jing et al. 2006) with potential secondary poisoning and mortality for many species which use pikas as a food source. Black-lipped pikas are the main intermediate hosts of *E. multilocularis* with the highest infection rate of 9.4% (24/256) in Shiqu County, while the infection rate of Tibetan foxes by *E. multilocularis* in Shiqu was 59.1% (13/22) which was more than 5 times greater than that of dogs (11.5%, 12/104) (Qiu et al. 1995). Recently, a new species, *E. shiquicus*, was discovered in Tibetan foxes and pikas in Shiqu County (Xiao et al. 2005). Therefore, studying the dynamic relationships between Tibetan fox habitat selection and pika density fluctuations is important to studies of Tibetan fox ecology, biological control of pikas, and echinococcosis epidemiology. We also suggest that in order to fully understand the behavioral ecology of Tibetan foxes and the mechanisms of *E. multilocularis* transmission in wildlife and the human environment, diets and infection rates of Tibetan fox and dog populations should be thoroughly studied. Meanwhile, telemetry studies on Tibetan foxes, domestic dogs, and stray dogs should be conducted, and their time-spatial relationships should be studied.

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