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Effects of highway traffic on diurnal activity of the critically endangered Przewalski's gazelle

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Abstract. Highway traffic is considered to be one of the factors that influence survival of wildlife. Przewalski's gazelle is a critically endangered species that lives in the Qinghai Lake watershed of western China. To learn the impacts of traffic on activity patterns of Przewalski's gazelle, we investigated the relationship between traffic flow and diurnal behaviours of the gazelle on the eastern shore of Qinghai Lake, where a highway was built in 2002. During the summers of 2005 and 2006, we collected traffic data on the highway and observed the activity of the Przewalski's gazelle population in the area. The results of statistical analysis showed the following: (1) frequency of behaviours such as standing, locomotion, foraging and resting differed among the 15 1-h sampling periods (daytime); (2) numbers of total vehicles, heavy vehicles and light vehicles were significantly different among the daytime hours; (3) there was a positive correlation between the frequency of resting of the gazelles and the number of passing vehicles, and a negative correlation between the frequencies of foraging and alert responses and the number of passing vehicles; (4) by comparing our results with those of a previous study on the gazelles at this site, before the construction of the highway, we found that the diurnal rhythms of foraging, standing and resting have changed markedly (e.g. the three peaks of foraging at 1300, 1600 and 1800 hours in 1996 changed to two peaks of foraging at 0600 and 2000 hours). Our results suggest that the highway traffic may have caused a change in diurnal activity of Przewalski's gazelle, with the animals tending to keep away from the highway when the traffic flow is high. We suggest traffic-control measures to reduce disturbance to, and thus enhance conservation of, this highly threatened species.

Introduction

Patterns of activity evolve to allow animals to adapt to their environment by using resources effectively and minimising the risk of predation. Activity patterns of animals are influenced by environmental factors and can be changed by the animal itself (Daan 1981; Gese *et al*. 1989; Gross *et al*. 1995; Ciucci *et al*. 1997; Seddon and Ismail 2002). Studies have shown that highways and railroads have a negative effect on the survival and reproduction of wildlife (Waring *et al*. 1991; Ciucci *et al*. 1997; Lodé 2000; Swarthout and Steidl 2003). Therefore, it is essential to learn how highway traffic affects the survival of endangered animals. Groot Bruinderink and Hazebroek (1996) found that highway traffic was responsible for killing ungulates in Europe. Kerley *et al*. (2002) reported that roads decreased the survival and reproductive success of the Amur tiger (*Panthera tigris altaica*). Many ungulate species, such as the chiru (*Pantholops hodgsoni*), Tibetan gazelle (*Procapra picticaudata*), Przewalski's gazelle (*Procapra przewalskii*), kiang (*Equus kiang*) and wild yak (*Bos grunniens*) that live on the Qinghai–Tibet Plateau have been negatively affected by vehicle traffic (Schaller 1998). Moreover, Yin *et al*. (2006) also reported a negative influence of the Qinghai–Tibetan railway and highway on the migration of wild ungulates in the Qinghai–Tibet Plateau.

It has been shown that vehicle traffic interferes with movements and activity patterns of wild ungulates, such as elk (*Cervus elaphus*) (Creel *et al*. 2002; Wisdom *et al*. 2004; Naylor 2006), mule deer (*Odocoileus hemionus*) (Wisdom *et al*. 2004), caribou (*Rangifer tarandus*) (Cameron *et al*. 1992; James and Stuart-Smith 2000), white-tailed deer (*Odocoileus virginianus*) (Kilgo *et al*. 1998) and Mongolian gazelle (*Procapra gutturosa*) (Ito *et al*. 2005). Jiang *et al*. (2007, 2009) found that moose tended to avoid areas within 3 km of roads and red-deer bed-site occurrence was affected by roads. However, there are few data on the effects of highways or railroads on the diurnal rhythm of animal activity.

Przewalski's gazelle was present in many areas of western China some 120 years ago (Jiang *et al*. 2000). However, because of the loss and fragmentation of habitat, the population of Przewalski's gazelle has declined to 300 individuals in six small isolated populations confined to the Qinghai Lake region (Jiang *et al*. 1994, 1995). A highway-network construction around the Qinghai Lake in 2002, and associated fencing along the highway and on the pastures, formed barriers to free

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movement of the wild animals. As a result, populations of Przewalski's gazelle have been fragmented (Jiang 2004). Population viability analysis suggested that Przewalski's gazelle could become extinct within 200 years if conservation measures are not immediately implemented (Li and Jiang 2002). Although measures aiming at conserving the critically endangered Przewalski's gazelle have been brought into practice (Jiang 2004), there has been no consideration of behavioural responses of animals to highway traffic.

The aim of the present study was to investigate the relationship between the traffic flow on the new highway and the subsequent changes in activity patterns of Przewalski's gazelle. We hypothesised that activity patterns of the Przewalski's gazelle along the highway had changed because of heavy traffic flow. To test this hypothesis, we analysed the activity pattern of Przewalski's gazelle and its response to traffic flow. We compared the current activity pattern of Przewalski's gazelle with that quantified in a previous study undertaken before the highway was built. We discuss these results in the broader context of the relationship between human disturbance and the survival of Przewalski's gazelle.

Methods

Study area

Our field work was carried out in the Hudong area, located on the eastern shore of the Qinghai Lake (36°41′N–37°55′N, 99°50′E–100°56′E). The landscape of Hudong is a mosaic of sand dunes, alpine steppe and alpine meadow. Hudong has an altitude of 3250–3400 m a.s.l. Mean annual temperature is 16.1°C, with the minimum temperature (−29°C) in January and the maximum temperature (24°C) in July. Mean annual precipitation is ~394.4 mm. A section of the new highway around the Qinghai Lake across the distribution area of Przewalski's gazelle in Hudong was built in 2002 (Fig. 1). Nomadism is still in practice in the Qinghai Lake region, where Tibetan and Mongolian herdsmen move their livestock from ranches on mountain slopes of high altitudes in summer to the study area in winter. In Hudong, there was a small population of Przewalski's gazelle of ~70 individuals during our study period. All the gazelles usually segregate into several groups. Except for the highway construction in 2002, the density of human population, livestock density and nomadic mode in this area have not changed much (Jiang 2004).

Observation of the behaviours

Przewalski's gazelle mingled with livestock on pastures, particularly during the rut in December, because the study area is the winter ranges for livestock (You 2005). Thus, to avoid livestock presence, we carried out our observations in summer (August 2005 and July 2006). We conducted observations every 3 days. On each observation day, we chose and observed one gazelle group of ~10 gazelles among the several groups. We used the scan sampling method (Lehner 1996) to observe the focal gazelle group from 0600 to 2100 hours. We observed each individual for 1 min and then observed the next individual until all individuals had been observed in the group. The intervals between observation bouts were 10 min. The behaviours recorded included 'standing', 'foraging', 'locomotion' (walking but engaged in activities other than foraging), 'resting' (sitting or standing), 'rumination' and 'alert response' (stare, walking away and flee). In addition, to compare the activity patterns of gazelles before and after the highway was built, we obtained data from Chen (1996).

In Chen's study (Chen 1996), each individual gazelle was observed for 10 min and the behaviour recorded from 0700 to 2000 hours, from March to October in 1996. After a 5-min resting interval, the next individual was observed. Each individual was observed until all individuals in the group had been observed. For the purpose of comparison with the

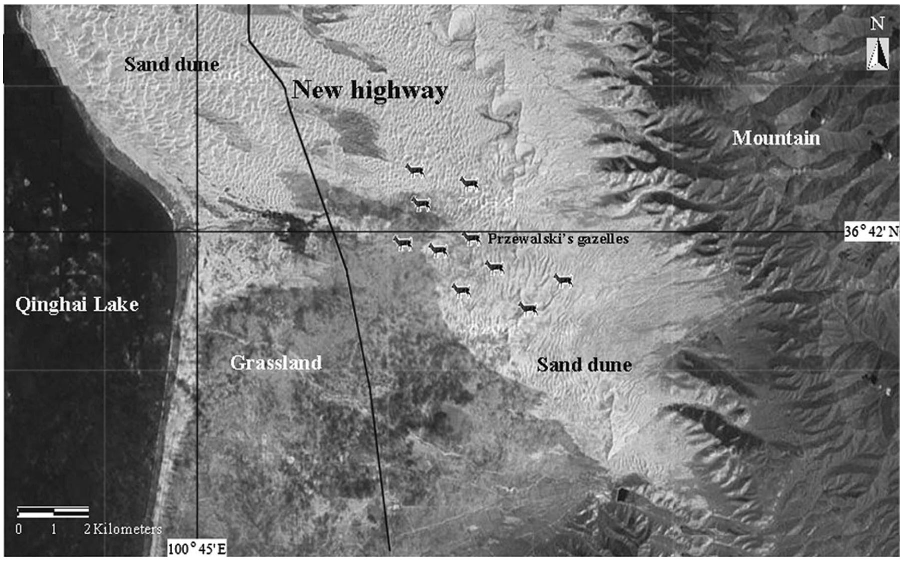

Fig. 1. A new highway, which forms the ring highway around the Qinghai Lake, which bisects the range of Przewalski's gazelles in Hudong, Qinghai, China.

present dataset, we used only Chen (1996) data collected from July and August.

We used geopraphic positioning system (GPS) to mark the activity site of the gazelle in the field. After transferring all sites into MapSource 6.3 (Garmin, Olathe, KS), we used distance/ bearing tool to measure the distance between the activity site of the gazelle and the highway.

Traffic data

On each day of sampling behavioural data, we continuously recorded the total number of all vehicles passing along the highway from 0600 to 2100 hours. We divided the vehicles into the following three categories: (1) heavy vehicles such as trucks and coaches; (2) medium-sized vehicles such as minibuses, pickups and sport-utility vehicles; and (3) light vehicles such as sedans and motorcycles.

Statistical analysis

We pooled the data on the frequency of behaviours of gazelles (or traffic flow) into 1-h intervals and presented the data as means ± standard error. The data were not normally distributed, despite being transformed with power or log transformation (one sample Kolmogorov–Smirnov test, $P < 0.05$). Therefore, we used Kruskal–Wallis H test to test the differences in the frequency of each behaviour of gazelle among the 15 1-h-long sampling periods (totalling 15 h of sampling each day). One-way ANOVA was used to test the differences in the distance between the gazelles and the highway and the differences in the traffic flow among the 15 sampling hours. We also calculated Pearson correlation coefficients of each behavioural type and traffic-flow level. $P < 0.05$ was considered significantly different for all statistical tests. We converted both our and Chen's data to a proportion of behavioural frequency by counting the percentage of frequency of each behaviour in all behavioural occurrences. Chi-square test was used to test the differences in the proportion of each behaviour between Chen's study and the present data.

Results

Activity pattern of Przewalski's gazelle

During our study period, the smallest group was composed of four and the largest of 22 gazelles. Distance between the gazelles and the highway varied from 1 to 4 km, or more. The distance between gazelles and the highway showed significant difference among the 15 daytime hours ($P < 0.001$, $F_{14,28} = 61.66$; 1-way ANOVA; Table 1). On the basis of our observations, there was no evidence showing that gazelles crossed the highway and were killed by vehicles. In daytime, when the traffic volumes are heavy, gazelles tend to rest in sand dunes where there is less vegetation. Whereas when the traffic becomes light, they start to feed and move to the grassland.

Frequencies of standing, locomotion, foraging and resting showed significant differences among the 15 daytime hours (standing: $P = 0.008$, $\chi^2 = 29.918$, d.f. = 14; locomotion: $P = 0.008$, $\chi^2 = 29.537$, d.f. = 14; foraging: $P = 0.008$, $\chi^2 = 42.277$, d.f. = 14; resting: $P < 0.001$, $\chi^2 = 42.137$, d.f. = 14; Kruskal–Wallis H test for all; Table 1). One obvious peak of frequency of standing occurred at 1800 hours, and four peaks of locomotion occurred at 0600, 1100, 1300 and 1700 hours. Two peaks of foraging occurred at 0600 and 2000 hours, respectively. Three peaks of frequency of resting occurred at 1000, 1200 and 1400 hours. There was no difference among the 15 daytime hours in the frequency of rumination and alert response (rumination: $P = 0.298$, $\chi^2 = 16.260$, d.f. = 14; alert response: $P = 0.737$, $\chi^2 = 10.334$, d.f. = 14, Kruskal–Wallis H test for both; Table 1).

Temporal pattern of traffic flow

Mean numbers of total vehicles, heavy vehicles and light vehicles showed significant differences among the 15 daytime

Table 1. Hourly changes in the frequency of different behavioural activities of the Przewalski's gazelles and the distance between the gazelles and the highway

*The means are significantly different within the column ($P < 0.05$, d.f. = 14; Kruskal–Wallis H test for behavioural data, 1-way ANOVA for distance data)

Time	Behavioural frequency per 30 min (mean ± s.e.)						Distance
(hours)	Standing	Locomotion	Foraging	Resting	Rumination	Alert response	(km)
0600	0.50 ± 0.50	4.25 ± 2.25	4.00 ± 2.83	0.00 ± 0.00	0.00 ± 0.00	0.75 ± 0.75	0.86 ± 0.23
0700	0.62 ± 0.27	1.08 ± 0.26	1.77 ± 0.66	0.54 ± 0.31	0.00 ± 0.00	0.08 ± 0.08	1.43 ± 0.59
0800	0.92 ± 0.29	0.88 ± 0.37	0.68 ± 0.34	1.36 ± 0.51	0.68 ± 0.28	0.20 ± 0.10	2.58 ± 0.43
0900	0.33 ± 0.29	1.19 ± 0.43	0.19 ± 0.11	1.48 ± 0.39	0.29 ± 0.17	0.05 ± 0.05	2.57 ± 0.55
1000	0.92 ± 0.50	0.69 ± 0.38	0.15 ± 0.15	4.15 ± 1.14	0.31 ± 0.31	0.08 ± 0.08	3.64 ± 0.24
1100	0.00 ± 0.00	3.00 ± 1.34	0.00 ± 0.00	2.40 ± 1.50	0.40 ± 0.40	0.00 ± 0.00	3.91 ± 0.27
1200	0.91 ± 0.58	0.82 ± 0.44	0.00 ± 0.00	4.36 ± 1.28	0.36 ± 0.36	0.09 ± 0.09	4.14 ± 0.31
1300	0.33 ± 0.33	2.50 ± 1.20	0.33 ± 0.33	2.17 ± 1.38	0.33 ± 0.33	0.00 ± 0.00	4.29 ± 0.40
1400	1.22 ± 0.66	0.78 ± 0.52	0.44 ± 0.29	4.78 ± 1.93	0.44 ± 0.44	0.11 ± 0.11	3.74 ± 0.44
1500	0.75 ± 0.48	1.00 ± 1.00	0.50 ± 0.50	1.75 ± 1.75	0.00 ± 0.00	0.25 ± 0.25	3.89 ± 0.32
1600	0.29 ± 0.29	2.14 ± 1.08	0.29 ± 0.29	2.57 ± 1.23	0.29 ± 0.29	0.00 ± 0.00	3.50 ± 0.26
1700	1.33 ± 1.33	3.67 ± 0.88	1.67 ± 1.20	0.00 ± 0.00	0.00 ± 0.00	0.67 ± 0.67	3.68 ± 0.18
1800	2.28 ± 0.48	2.00 ± 0.70	0.22 ± 0.10	0.94 ± 0.00	0.00 ± 0.00	0.33 ± 0.28	2.84 ± 0.30
1900	1.45 ± 0.44	2.45 ± 0.57	1.23 ± 0.34	0.05 ± 0.05	0.00 ± 0.00	0.45 ± 0.23	2.57 ± 0.48
2000	0.33 ± 0.33	1.22 ± 0.46	2.44 ± 0.75	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	2.29 ± 0.55
χ^2 value	29.918*	29.537*	42.277*	42.137*	16.260	10.334	61.665*

hours (total vehicles: $P < 0.001$, $F_{14,28} = 4.731$; heavy vehicles: $P = 0.003$, $F_{14,28} = 3.368$; light vehicles: $P < 0.001$, $F_{14,28} = 4.902$; 1-way ANOVAs for all; Fig. 2). Traffic volume of these types of vehicles was higher at midday (from 1100 to 1500 hours) (Fig. 2). However, no difference of mean number of medium-sized vehicles was found among the 15 daytime hours ($P = 0.215$, $F_{14,28} = 1.406$, 1-way ANOVA; Fig. 2).

Correlations between the behaviour of gazelles and traffic flow

There was a positive correlation between the frequency of resting and the number of heavy vehicles ($P < 0.05$, d.f. = 14; Pearson correlation test; Table 2). Furthermore, the most significant positive correlations were found between the frequency of resting and the number of total vehicles, medium-sized vehicles and light vehicles ($P < 0.01$, d.f. = 14; Pearson correlation test; Table 2). There was a negative correlation between the frequency of alert response and the number of total vehicles ($P < 0.05$, d.f. = 14; Pearson correlation test; Table 2). Furthermore, there were negative correlations between the frequency of foraging and the number of total vehicles, medium-sized vehicles and light vehicles ($P < 0.01$, d.f. = 14; Pearson correlation test; Table 2).

Comparison of the activity patterns of gazelles before and after building of the highway

The diurnal rhythm of behaviours such as foraging, standing and resting was significantly different before and after the highway was constructed (foraging: $P < 0.001$, $\chi^2 = 147.326$, d.f. = 12; standing: $P = 0.073$, $\chi^2 = 37.539$, d.f. = 12; resting: $P < 0.001$, $\chi^2 = 178.677$, d.f. = 12; chi-square test for all; Fig. 3). For example, the three peaks of foraging at 1300, 1600 and 1800 hours in 1996 changed to two peaks of foraging at 0600 and 2000 hours in 2005/2006 (Table 1). However, the diurnal rhythm of locomotion seemed unchanged ($P = 0.082$, $\chi^2 = 19.257$, d.f. = 12; paired *t*-test; Fig. 3).

Discussion

Effects of highway traffic on the activity pattern of Przewalski's gazelle

Diurnal or crepuscular activity patterns relate to sunrise and sunset, with the cyclic pattern of activity allowing animals to

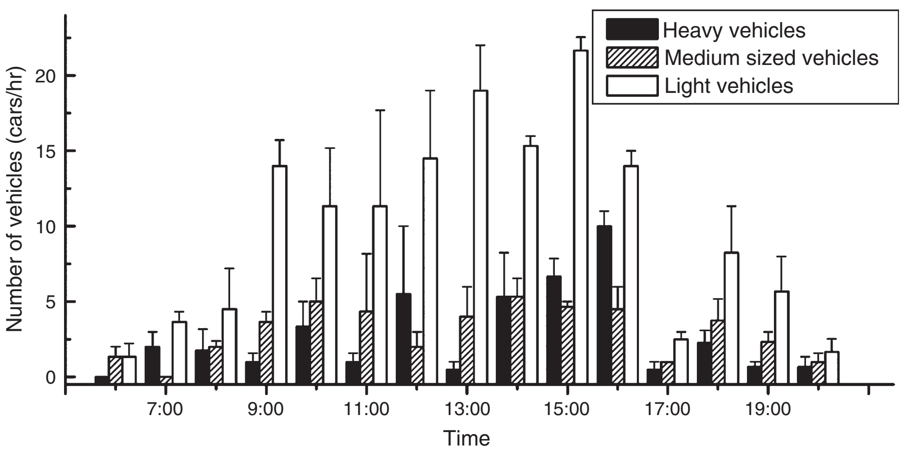

Fig. 2. Passing vehicles during the 15 daytime hours on the highway (mean + s.e.).

Table 2. Correlations between the different behavioural activities of Przewalski's gazelle and the traffic flow
*$P < 0.05$ (2-tailed correlation), **$P < 0.01$ (2-tailed correlation)

Traffic flow	Standing	Locomotion	Alert response	Foraging	Resting	Rumination
Total vehicles ($n = 15$)						
r	–0.125	–0.403	–0.514*	–0.734**	0.741**	0.369
P	0.657	0.136	0.050	0.002	0.002	0.176
Heavy vehicles ($n = 15$)						
r	–0.026	–0.415	–0.349	–0.445	0.580*	0.202
P	0.926	0.124	0.203	0.096	0.023	0.470
Medium-sized vehicles ($n = 15$)						
r	–0.008	–0.238	–0.393	–0.688**	0.669**	0.404
P	0.978	0.393	0.147	0.005	0.006	0.136
Light vehicles ($n = 15$)						
r	–0.174	–0.366	–0.502	–0.719**	0.667**	0.335
P	0.536	0.180	0.057	0.003	0.007	0.223

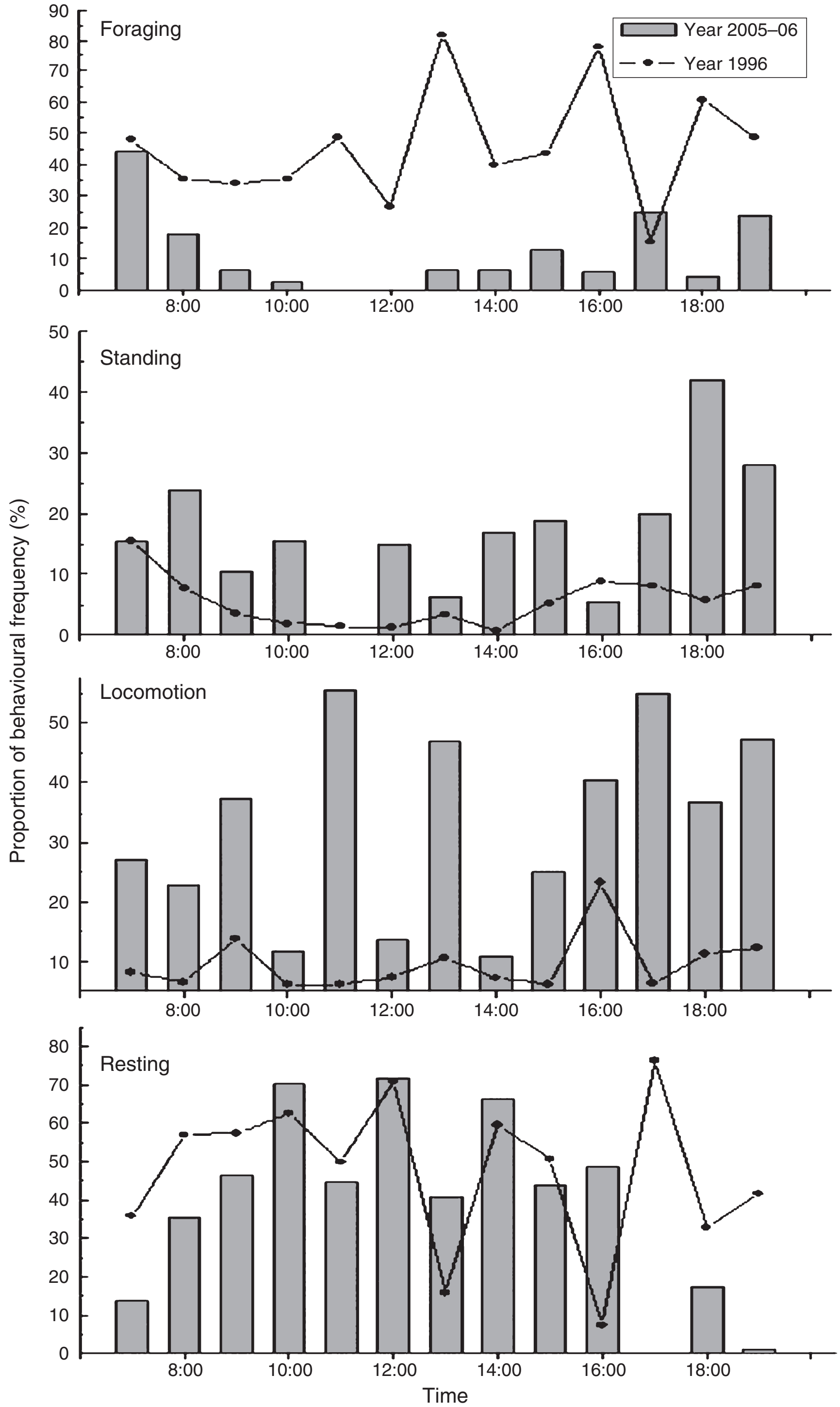

Fig. 3. Comparison of activity patterns of Przewalski's gazelle before 1996 and in 2005/2006, after the highway was built.

use resources and minimise predation risk (Smith 1980). Chen *et al*. (1997) reported that to cope with the food limitation in this arid area, Przewalski's gazelle had to spend more time in foraging than did related species (e.g. Mongolian gazelle, *Procapra gutturosa*) living on the Mongolian plateau. (Chen *et al*. 1997; Li *et al*. 1999). The three foraging peaks at 1300, 1600 and 1800 hours observed before the construction of the highway illustrate that Przewalski's gazelle is naturally a diurnal animal (Li *et al*. 1999). Additionally, that gazelle should move and feed after midday is understandable, given the relatively low temperatures (<24°C at its highest in July) in this area.

Our analysis suggested that the activity pattern of Przewalski's gazelle had changed from diurnal (Chen *et al*. 1997) to crepuscular during the 10-year period from 1996 and 2005. During this time the human population density, livestock density and pastoral practices in the area have changed little (Jiang 2004). Therefore, it is reasonable to attribute the changes in activity patterns as a response to traffic flow on the new highway, which bisects the species' original habitat.

Human activity and the future of Przewalski's gazelle

Disturbance to wild animals caused by humans is more detrimental if the disturbance is frequent and unpredictable (Phillips and Alldredge 2000; Steidl and Anthony 2000; McClennen *et al*. 2001). The ring highway is known to be a barrier that restricts movement of Przewalski's gazelle (Jiang 2004). In addition, there is some evidence that wolf (*Canis lupus*) predation on gazelles in the Hudong area has increased since the construction of the freeway (Liu and Jiang 2003). Annual mortality owing to predation increased markedly from 9.26% in 1996 (Jiang *et al*. 2001) to 20.83% in 2006 (Z. You, Z. Jiang, C. Li and D. Mallon, unpubl. data). Scheel (1993) suggested that the predation risk of ungulates relates to their activity pattern and habitat use. Because wolves are nocturnal, the gazelles' concentrated activity at dawn and dusk may increase their probability of encountering a wolf.

Our data showed that although the correlations between gazelle behaviours and traffic varied among different vehicle types, all types of vehicles influenced behavioural responses. We did not assess the increased trends of traffic volumes, although we predict that the future of the gazelles will be pessimistic because of the expected increase in traffic volumes in coming years following the Program of Western China Development (Harris 2007).

Management implications

To reduce the possible influence of the highway on Przewalski's gazelle, we suggest the following:

(1) Reduction in the disturbance effect of highway traffic flow may induce gazelles to return to their normal patterns of behaviour, and to this end a traffic-control program should be developed and implemented. Because traffic flow may affect the activity patterns of animals, we should control the intensity of the traffic flow (e.g. by reducing the number of medium-sized and light vehicles in the traffic) around midday when gazelles show their natural foraging peak. Conservation of Przewalski's gazelle might be enhanced if more vehicles were encouraged to pass through the highway at night.

(2) Because pasture availability for both livestock and gazelles is limited in the Hudong area of Qinghai Lake, we should consider reducing grazing intensity of livestock (especially along the sand dunes) and setting aside more steppe habitat. This would enhance the grazing opportunities for Przewalski's gazelles away from the highway.

Conclusion

In brief, the present study indicated that highway traffic has caused a change in the diurnal activity of Przewalski's gazelle. This may have had knock-on effects, such as increased vulnerability to predation. Furthermore, we suggest that behavioural evasion of traffic by Przewalski's gazelle is likely to result in negative effects such as habitat loss, food limitation and health condition, as has been observed in red and roe deer (Jiang *et al*. 2007, 2008). Thus, it is necessary to consider the effects of highway traffic on animal behaviour, and incorporate this into conservation practice.

Acknowledgements

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