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Research Article

Experimental Observation and Analysis of Traffic Impact on Tibetan Antelopes on the Qinghai-Tibet Highway

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Highways that cross natural reserves are an intrusion with a nonnegligible negative impact on the behavior of wild animals and have numerous and diverse ecological impacts on wildlife near road areas. Field experiments were carried out to collect traffic flow data on the Qinghai-Tibet Highway on the Qinghai-Tibet Plateau, China, and the behavior of the Tibetan antelope crossing the highway was observed. The relationships between the percentage of antelopes successfully crossing the highway and the different traffic flows were analyzed. The results demonstrate that the traffic volume is the main factor affecting the success rate of Tibetan antelopes when crossing the highway, displaying a nonlinear negative correlation. Furthermore, the behavioral responses of the Tibetan antelopes within 500 m of the Qinghai-Tibet Highway before and after different parking behaviors were observed and the proportions of the different behaviors exhibited by the Tibetan antelopes affected by different driver parking behaviors were analyzed. Parking behaviors were found to have the most significant effect on Tibetan antelope behavior within 400 m of the highway, where parking with somebody getting out having the most prominent impact. The results of this study can guide engineering measures to protect wildlife in the plateau region.

1. Introduction

Highways that cross natural reserves are an intrusion and have numerous and diverse ecological impacts on wildlife. Growing evidence has shown that road traffic has a non-negligible negative impact on wild animals. The impacts of increasingly dense road networks include the destruction and degradation of habitat [1], animal avoidance of the road vicinity [2], wildlife population fragmentation and isolation [3], and even a reduction in reproductive success [4], which may cause the endangerment and extinction of some wildlife and ultimately disrupt the local ecological balance. Furthermore, vehicular traffic on the road is a source of disturbance to wildlife. The effects range from vehicular mortality due to collisions with wildlife to hindering wildlife movement and affecting animal behavior nearby roads [5–7].

Global concern for the effects of roads on wildlife first commenced with gathering vehicular mortality data [8]. Road kills are a direct embodiment of the negative impact of road traffic on wildlife. Basic enumeration studies on roadkill rates have been conducted by researchers for various animals around the world. For instance, Baskaran and Samson estimated the road kills of animals on state highways at Mudumalai Tiger Reserve in India to analyze the effect of vehicular traffic on wild animals [5, 9]. In addition, Pereira et al. evaluated the temporal variation in anuran mortality rates on two highways in the Brazilian semiarid zone over a one-year period [10], and a field investigation was conducted by Wang et al. to assess the road mortality of native vertebrates on the Ring Changbai Mountain Scenic Highway in China from 2009 to 2012 [11]. Researchers have also attempted to propose management strategies to reduce vehicle-caused wildlife mortalities. Fedorca et al. suggested the implementation of sustainable landscape management planning strategies to mitigate wildlife-vehicle collisions [12]. The proper design of animal passages was analyzed by Collinson and Wang in their studies on roadkill reduction in Africa and China, respectively [13, 14].

In addition to the direct negative effects of road traffic on wildlife due to roadkill incidents, road traffic also indirectly affects wildlife by hindering the movement of animals and affecting their behaviors. For some species, roads and traffic can act as barriers to movement and lead to resource (such as food, mates, and breeding sites) inaccessibility on the other side [6]. Especially for migratory ungulates, road traffic introduces artificial barriers that threaten animal populations [15]. Jaeger et al. discussed the ways in which roads and traffic affect animal populations and created a model based on animal populations and road characteristics to study road avoidance behavior [16]. D'Amico et al. assessed the factors that potentially cause road avoidance in ungulates in a heterogeneous road network [17]. Most researchers generally believe that the factors causing road traffic to act as a barrier to wildlife movement are the road itself, road emissions (traffic noise, lights), and vehicles [18].

Crossing the highway is a rather difficult task for most wildlife, especially when it has heavy traffic [19]. Shepard used radiotelemetry data on terrestrial vertebrates to test their propensity for crossing roads and their movement rates [1]. Andrews and Gibbons analyzed the behavioral responses of snakes to roads and vehicles and their crossing speed using field experiment data [20]. Jacobson et al. indicated that wild animals exhibited various response strategies of avoidance, speeding across, pausing, or failing to respond to vehicles when crossing roads [21]. Vehicular traffic can interfere with the behavior of animals and thus reduce their chances of successfully crossing roads. Moreover, the negative impact of vehicular traffic on animals crossing roads is also related to the intensity of traffic along the road. Grilo et al. investigated how individuals respond in their behavior toward a highway and its traffic intensity by radiotracking barn owls and stone martens [22], and Colino-Rabanal and Lizana reviewed the responses of herpetofauna to traffic volume [23]. In summary, vehicular traffic can affect the distribution and activity patterns of various wildlife species by affecting animal behaviors around roads [24, 25].

In China, the Qinghai-Tibet Plateau is a unique region with a high altitude and fragile ecological environment, and many distinctive and endangered wildlife species are distributed around this area [26]. The Tibetan antelope is a flagship species of the Qinghai-Tibet Plateau and is classified as near threatened by the International Union for the Conservation of Nature (IUCN). Seasonal migration is one of the main characteristics of Tibetan antelope ecology and reproduction [27]. However, the Qinghai-Tibet Highway cuts across the migration grounds of Tibetan antelopes, which negatively impacts this species. No animal passage was set up on the Qinghai-Tibet Highway when it was originally constructed. The impacts of migration and protection measures on Tibetan antelopes have received attention in recent years [28, 29]. Vehicles on the Qinghai-Tibet Highway are known to have an impact on the behavior of Tibetan antelopes crossing the highway and around the highway. Moreover, some driving behaviors of drivers can also interfere with Tibetan antelope behavior.

Although many researchers have focused on the impact of roads on migration in the Tibetan antelope, little research has been carried out on how traffic flow and parking behavior affect the behaviors of Tibetan antelope groups. In this study, the impacts of different traffic flows and parking behaviors on the population behavior of Tibetan antelopes were examined. Field experiments were carried out to measure the traffic flow and observe the behavior of the Tibetan antelope crossing the highway. The relationships between the percentage of antelopes successfully crossing the highway and different traffic flows were analyzed. Furthermore, different parking behaviors and the behavioral responses of the Tibetan antelope within 500 m of the Qinghai-Tibet Highway were observed. The proportions of the different behaviors of the Tibetan antelope affected by the different parking behaviors were analyzed.

The remainder of this manuscript is organized as follows. Section 2 introduces the field experiments and data collection process. In Section 3, the results obtained from the analysis of the collected field data are presented and discussed in detail. Section 4 provides a discussion of these results and insights for future research. The key findings of the study are summarized in Section 5.

2. Materials and Methods

The Qinghai-Tibet Highway traverses the annual migration path of Tibetan antelopes and is a barrier to their migration. Vehicles on the road will thus inevitably have an impact on this species. The objective of this study was to determine the disturbance to Tibetan antelopes caused by road traffic. Field experiments were designed to analyze the effects of traffic flow and parking behaviors on the behaviors of Tibetan antelope groups. First, traffic flow data and the highway crossing behaviors of Tibetan antelope were recorded at selected fixed positions. Then, bivariate correlation analysis was used to analyze the relationship between the traffic volume in different periods and the percentage of antelopes successfully crossing the highway at that time. Second, the behavioral responses of Tibetan antelopes before and after parking behaviors are observed (e.g., no parking, parking, and parking and somebody getting out) at different distances from the highway were recorded. The relationships between the proportion of antelope behaviors and the different parking behaviors at different distances from the highway were established based on the data analysis. All statistical analysis was performed in the SPSS statistics 19.0, with $p < 0.005$ as the standard for the significance test.

2.1. Research Area. This study was conducted along the Qinghai-Tibet Highway from Kunlun Mountain Pass (K2900, 4767 m ASL) to Wudaoliang (K3005, 4800 m ASL) (Figure 1). The southeast side of the road is Sanjiangyuan Nature Reserve, and the northwest side is Hoh Xil National Nature Reserve. The geographic structures of the research area include a plateau mountain and plateau grassland, and it is a high-altitude environment with a wide view, entirely without trees or shrubs. This is a favorable habitat for many ecologically important large ungulates and hosts a large number of Tibetan antelopes in particular [26]. Seasonal

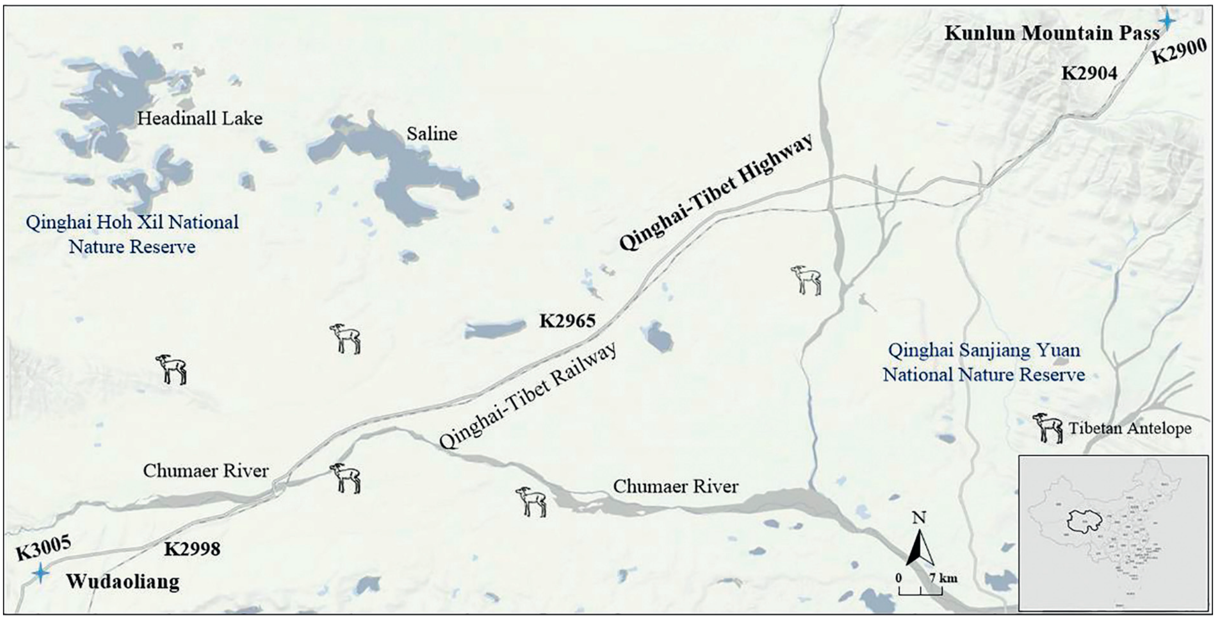

Figure 1: Map of the survey area.

migration is one of the main characteristics of Tibetan antelope ecology and reproduction, and the migration season usually occurs from June to August [29]. The Qinghai-Tibet Highway traverses the annual migration path of Tibetan antelopes, which need to cross the highway for reproduction. The section of the Qinghai-Tibet Highway extending from Kunlun Mountain Pass (K2900) to Wudaoliang (K3005) has always been the main migration corridor [30]. It is also one of the few areas without grazing along the highway, and the influence of other human factors on Tibetan antelopes is reduced, which ensures that the main influencing factors are roads and traffic. Thus, this 105-km-long stretch of the highway was selected for the survey.

2.2. Tibetan Antelope Behavioral Characteristics. Significant differences are observed in the behavioral characteristics of Tibetan antelopes depending on the research objective [31]. For the purpose of this study, such behaviors can be classified as follows: vigilance, foraging, movement, and others. Table 1 presents the main behavioral variables.

2.3. Field Experiment. To establish the experimental site, the selected 105-km-long stretch of the highway was surveyed for four full daytimes from June 1 to 4, 2018, before the field experiment was performed. Based on the results of the field survey and statistical data from the reserve, three key nodes in the research area along the migration path of Tibetan antelope were identified: K2904 (i.e., the wildlife channel between the Kunlun Mountains and Qingshui River on the Qinghai-Tibet Railway), K2965 (i.e., Chubei Channel on the Qinghai-Tibet Railway), and K2998 (i.e., the channel between the Chumar River and Hoh Xil on the Qinghai-Tibet Railway). The survey results indicated that a large number of Tibetan antelopes were distributed on both sides of the highway, as shown in Figure 2. The objective of this study was to evaluate the disturbance to Tibetan antelopes caused by road traffic. Therefore, the three key nodes K2904, K2965, and K2998 on the Qinghai-Tibet Highway were established as the experimental sites for determining the impact of traffic on the behavior of the Tibetan antelope.

2.3.1. Traffic Flow Data Resources. To analyze the impact of road traffic on the population behavior of Tibetan antelopes, a large amount of traffic flow data are needed. An AxleLight vehicle classification statistical instrument was used to collect traffic flow data in this study, as shown in Figure 3. This instrument uses a laser sensing method to monitor parameters, such as vehicle speed, vehicle type, and traffic volume. The device can automatically collect traffic data for assessments of traffic characteristics. Moreover, this device can automatically operate on the roadside without manual control after it is connected to a computer, which can prevent the experimenter from influencing the Tibetan antelope behavior. Qiu and Feng indicated that Tibetan antelopes do not prefer to cross highways at night [32]. Therefore, the period from 8:00 am to 19:00 pm was selected for the collection of traffic flow data and the observation of Tibetan antelope behaviors at the experimental sites.

2.3.2. Behavioral Observations. To analyze the impact of traffic flow on the behavior of the Tibetan antelopes crossing the highway, field experiments were carried out from June 6 to June 26, 2018. As previously mentioned, traffic flow data were collected by the vehicle classification statistical instrument at the selected fixed positions from 8:00 am to 19:00 pm. Meanwhile, observers observed and recorded the behavior of the Tibetan antelope crossing the highway with the help of a high-powered telescope. To prevent visual interference, observers did not appear in front of the Tibetan

Table 1: Definitions of the behavioral variables used for Tibetan antelope in this study.

Behavior	Definitions
Vigilance	Standing and watching in a certain direction with the head above the shoulder level
Foraging	Searching for, obtaining, or chewing food while standing or walking with the head below the shoulder level
Movement	Walking or running with the head parallel to or above the shoulder level
Others	Resting, playing, breastfeeding, defecating, etc.

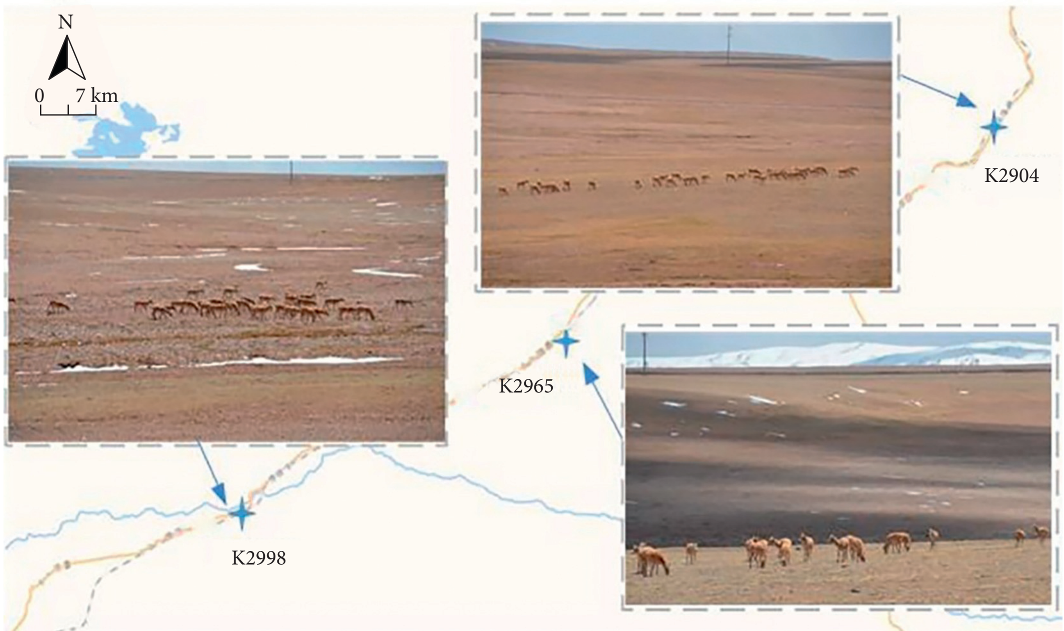

Figure 2: Tibetan antelope population on the roadside.

Figure 3: Image of the applied vehicle classification system.

antelope but stayed in the test vehicle. The percentage of Tibetan antelopes successfully crossing the highway per hour was calculated as follows:

$$P = \frac{a}{A} \times 100\%, \quad (1)$$

where P is the percentage of Tibetan antelopes successfully crossing the highway, A is the number of Tibetan antelopes trying to cross the highway per hour (entering within 30 meters of the side ditch or the subgrade slope toe), and a is the number of Tibetan antelopes successfully crossing the highway per hour (successfully getting to the other side of the highway).

To analyze the impact of parking behavior on Tibetan antelopes, the behavioral responses of Tibetan antelopes before and after parking behaviors occurred (i.e., no parking, parking, and parking and somebody getting out) at different distances from the highway were measured from June 29 to July 12, 2018. The distance from each side of the road was demarcated along the highway by using a laser range finder. Within 500 m of the roadside, signs were placed every 50 m so that the approximate behavior of the Tibetan antelopes at different distances from the road could be determined. Based on the statistical data, the average driving speed on the experimental road sections was approximately 50 km/h. Thus, a test vehicle was driven back and forth in the experimental sites at a cruising speed of approximately 50 km/h. Meanwhile, the observers sitting in the test vehicle observed and recorded the proportions of different behaviors exhibited by the antelope they passed by at different distances within 500 m of both sides of the road under different parking behaviors with the help of a high-powered telescope. The recorded observations proceeded as follows: a Tibetan antelope group was observed and recorded before the parking behaviors occurred; an additional observation was added immediately after parking was performed near the group; and a third observation was immediately added when people got out of the car.

3. Results

3.1. Changes in the Success of Tibetan Antelopes Crossing the Highway under Different Traffic Flow Conditions. In this study, the behaviors of Tibetan antelopes crossing the highway were observed at the three key nodes K2904, K2965, and K2998 on the Qinghai-Tibet Highway under different traffic flow conditions. When the influence of other human factors was excluded, traffic flow conditions were perhaps the most important factors that influenced road crossings by antelopes. For the purposes of intuitive expression, easy data collection, and simple calculation, traffic flow conditions are expressed as the traffic volume.

According to five-day observations at K2904 (i.e., the wildlife channel between the Kunlun Mountains and the Qingshui River on Qinghai-Tibet Railway) on June 6th, 9th, 14th, 17th, and 22nd, Tibetan antelopes were found to be distributed on the east side of the highway at K2904, but no antelope were observed crossing the highway. The Qinghai-Tibet Highway and railway tracks run parallel to each other. These two transportation routes have overlapping barrier effects on the migration of antelopes, and the magnitude of the barrier effect increases as the distance between the two routes decreases [28]. Further analysis showed that the distance between the highway at K2904 and the railway is less than 300 m. There is no effective safety gap between the two routes, which is the reason that Tibetan antelopes did not cross the highway at this location.

Observations at K2965 (i.e., the Chubei Channel on the Qinghai-Tibet Railway) were carried out on June 7th, 10th, 15th, 18th, and 23rd. The results showed that Tibetan antelopes were distributed on the east side of the highway at K2965, but no antelopes were observed crossing the highway. The reason for this is that the Qinghai-Tibet Railway running parallel to the highway at K2965 uses culverts as animal passages, which are too dark and narrow to ensure the security of Tibetan antelope groups moving through them.

According to seven-day observations at K2998 (i.e., the channel between Chumar River and Hoh Xil on the Qinghai-Tibet Railway) on June 8th, 11th, 16th, 19th, 24th, 25th, and 26th, it was found that a large number of Tibetan antelopes were distributed on the east side of the highway and that antelope groups crossed the highway. To analyze the association between the behavior of Tibetan antelopes crossing the highway and traffic flow conditions, bivariate correlation analysis was used to analyze the relationship between the traffic volume in different periods and the percentage of antelopes that successfully crossed the highway at that time. The results indicated that there was a significant negative correlation between the traffic volume and the percentage of antelopes that successfully crossed the highway at that time ($r = -0.586$, $p = 0.003$). Moreover, the relationship between the average hourly traffic volume on these seven days and the percentage of antelopes that successfully crossed the highway at that time was assessed, as shown in Figure 4.

As shown in Figure 4, the average hourly traffic volume throughout the daytime at K2998 is 148 pcu/h, that is, 2 or more vehicles per minute on average. The peak hour was 14:00-15:00, and the peak hour volume was 194 pcu/h. In short, the traffic volume during the daytime is at least 120 pcu/h, which will inevitably reduce the success rate of highway crossing for Tibetan antelopes. Figure 5 presents the impact of traffic on the Tibetan antelopes crossing the highway.

Tibetan antelopes generally cross the highway every morning and at midday. The reason for the preliminary analysis is that after they get to the other side of the highway, they need to have sufficient time for foraging and resting to move toward Hoh Xil. As shown in Figure 4, the rate of safe passage of antelopes crossing the road from 8:00 to 11:00 is higher than that from 11:00 to 14:00. During the period of 8:00 to 11:00, the traffic volume is low, which is conducive to Tibetan antelopes crossing the highway. The Tibetan antelope population can be large, usually approximately 71 ± 6. Therefore, the rate of safe passage can be maintained at a high level during the period of 8:00 to 11:00, especially when the rate reaches the highest value of 51% from 9:00 to 10:00.

From 11:00 to 14:00, with the increase in traffic volume, the disturbance to the Tibetan antelopes increased. The size of the Tibetan antelope population was approximately 10 to 20 during this period. Due to the small group size and heavy traffic interference, the antelopes were particularly cautious at this time. Therefore, the rate of safe passage was low from 11:00 to 14:00, approximately 15% on average. During the period from 16:00 to 17:00, only four antelope groups were observed, and a total of 63 individuals tried to cross the highway at this location. Although the traffic volume showed a downward trend, the heavy vehicle mixing ratio was high, resulting in Tibetan antelopes being at high alertness from 16:00 to 17:00. The rate of safe passage was only 11%.

3.2. Changes in Tibetan Antelope Behavior with Parking Behaviors. To ensure the scientific validity and comprehensiveness of the behavioral observation experiment, a certain test sample size must be guaranteed. Lian discussed the impacts of transportation infrastructure on a migratory herd of Tibetan antelope based on monitoring data for 1,660 Tibetan antelopes [30]. Based on the 304 individuals observed, Luo reported a strange puppet resting behavior in Tibetan antelopes [31]. In this study, to analyze the impact of parking behavior on Tibetan antelopes, 2,177 Tibetan antelopes were observed, and their behaviors, such as vigilance, foraging, movement, and others, were recorded. In addition, 196 cases with parking only and 235 cases with parking and someone getting out of the vehicle were also recorded. After a statistical analysis of the raw data, the proportions of antelope behaviors affected by the different parking behaviors (no parking, parking, and parking and somebody

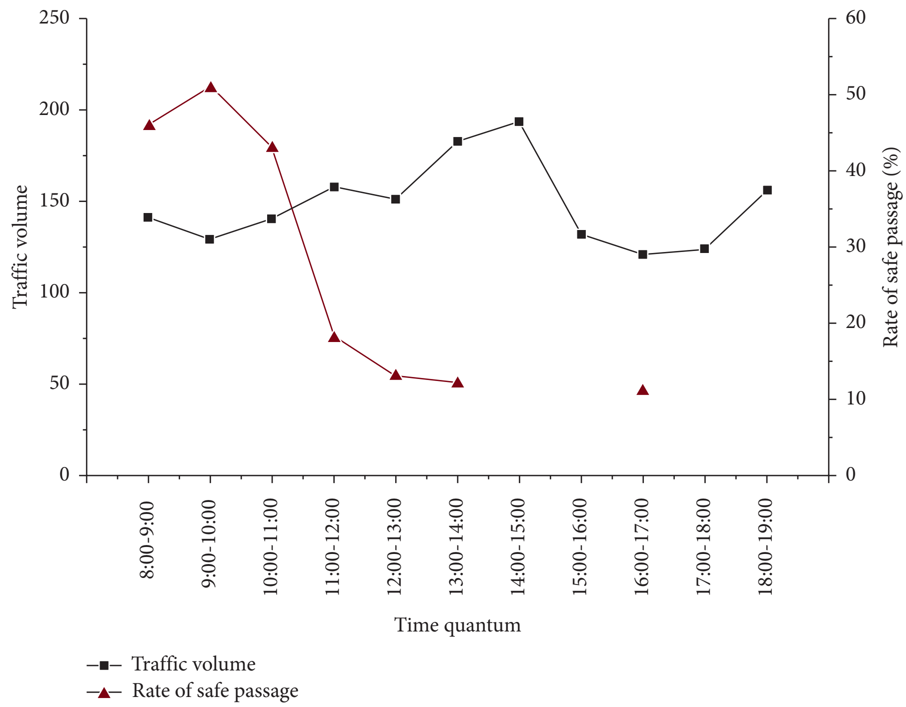

Figure 4: Hourly variation in traffic flow at K2998 and rate of safe passage of antelopes.

(a) (b)

Figure 5: Tibetan antelope population: (a) trying to cross the highway and (b) failing to cross the highway due to traffic interference.

getting out) at different distances from the highway were plotted, as shown in Figure 6. The vertical axis represents the percentage of each behavior, and the horizontal axis represents the distance from the highway.

The proportions of the four main types of Tibetan antelope behavior changed with the distance from the highway and different parking behaviors. As shown in Figure 6(a), at a distance of 0–300 m from the highway, the proportion of vigilance behavior before and after parking showed a comparatively small change, and it changed significantly when people got out of the car. No significant change occurred beyond 300 m away from the highway. Therefore, the sensitive distance for the effects of parking behavior on the vigilance behavior of the Tibetan antelopes was 0–300 m from the highway. Alert individuals in Tibetan antelope groups are more sensitive to parking and somebody getting out than to parking and nobody getting out.

As shown in Figure 6(b), the proportion of foraging behavior decreased slightly after parking behavior occurred at 0–400 m from the highway, while it decreased rapidly when somebody got out of the car. Changes beyond 400 m away from the highway were not significant. Therefore, the behavior of parking and somebody getting out has a greater impact on the foraging behavior of Tibetan antelope than the behavior of parking and nobody getting out. The sensitive distance for the effect of parking behavior on the foraging behavior of the Tibetan antelopes was 0–400 m away from the highway.

As shown in Figure 6(c), the most significant change in the proportions of movement behavior before and after parking behavior was observed at 0–150 m from the highway. In particular, there were significant increases in the proportion of movement behavior when somebody got out of the car, increasing to 100% at 50 m away from the highway. There was also a small increase in the proportions of movement behavior before and after parking behavior at 150–400 m away from the highway, but the increase was less than 3%. However, no significant change was observed

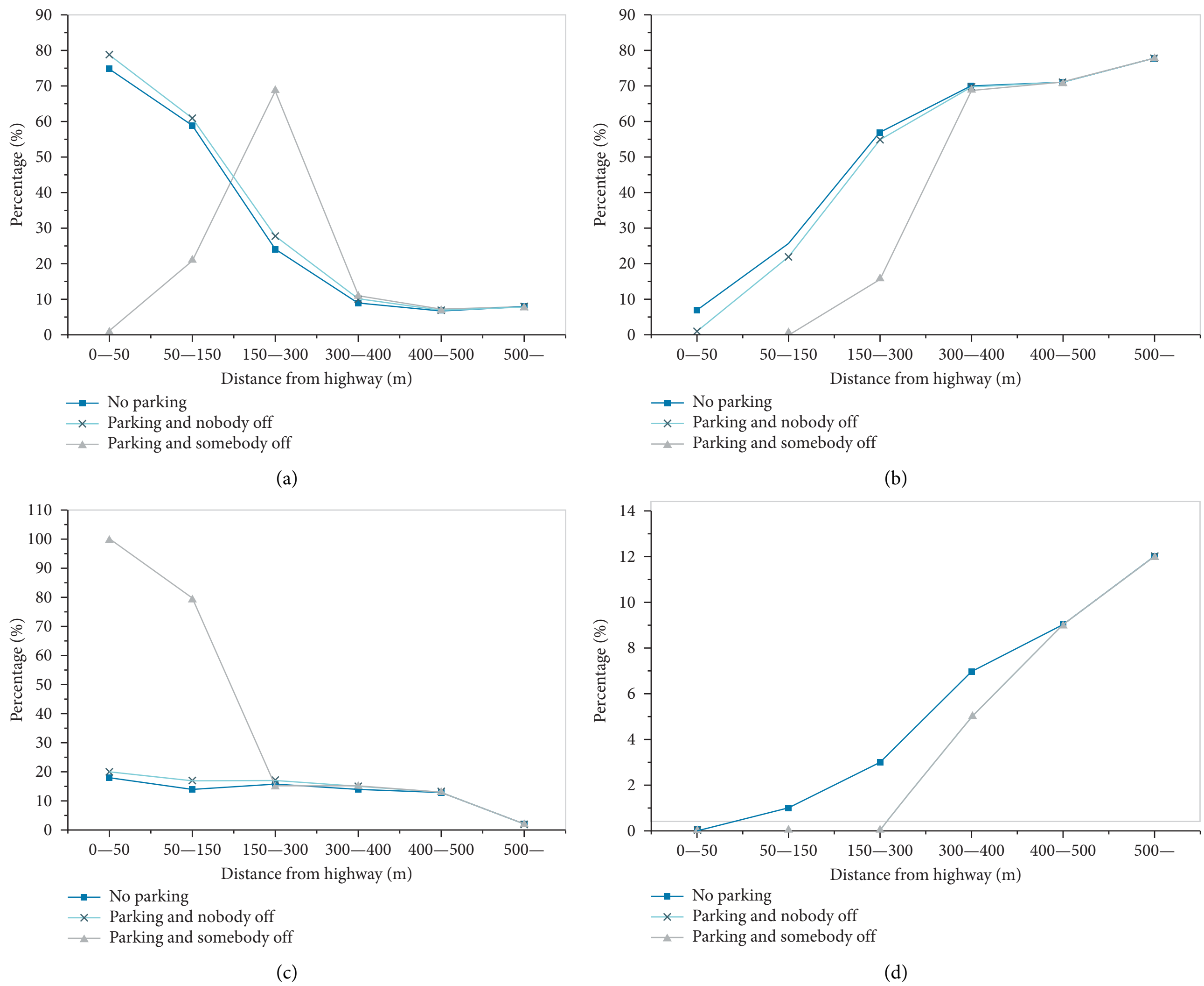

Figure 6: Changes in Tibetan antelope behavior with different parking behaviors. (a) Vigilance. (b) Foraging. (c) Movement. (d) Others.

beyond 400 m away from the highway. Therefore, the sensitive distance for the effect of parking behavior on the movement behavior of the Tibetan antelopes was 0–400 m away from the highway, and the range within 150 m was extremely sensitive. Parking with somebody getting out had the greatest impact on the movement behavior of the Tibetan antelopes.

As shown in Figure 6(d), the proportions of resting and other behaviors before and after parking with nobody getting out and parking with somebody getting out both showed significant changes at 0–400 m away from the highway. The change beyond 400 m away from the highway did not exceed 1%. Thus, the sensitive distance for the effect of parking behavior on other behaviors in the Tibetan antelope was 0–400 m away from the highway. The changes in the proportions of other behaviors due to parking with nobody getting out and parking with somebody getting out were similar.

The proportions of Tibetan antelope behaviors observed for different parking behaviors at the same distance from the highway were plotted, as shown in Figure 7.

As shown in Figure 7, different parking behaviors were found to have different impacts on all types of Tibetan antelope behaviors at various distances from the highway, and parking with somebody getting out had the most prominent effect. The significant changes in the proportions of the four evaluated kinds of Tibetan antelope behavior before and after parking occurred within 400 m of the highway. In other words, the sensitive distance for the effect of parking behavior on the behavior of the Tibetan antelopes was 0–400 m away from the highway.

At 0–400 m, the Tibetan antelopes mainly exhibited increased vigilance behavior after parking behavior occurred. When a vehicle parked near a Tibetan antelope group, some individuals stopped foraging and maintained a high degree of vigilance, which caused the foraging behavior to decrease and the vigilance behavior to increase. The Tibetan antelopes mainly exhibited increased movement behavior and decreased vigilance behavior when people got out of the car. When somebody got out of the car near the Tibetan antelopes, some individuals moved away from the highway immediately.

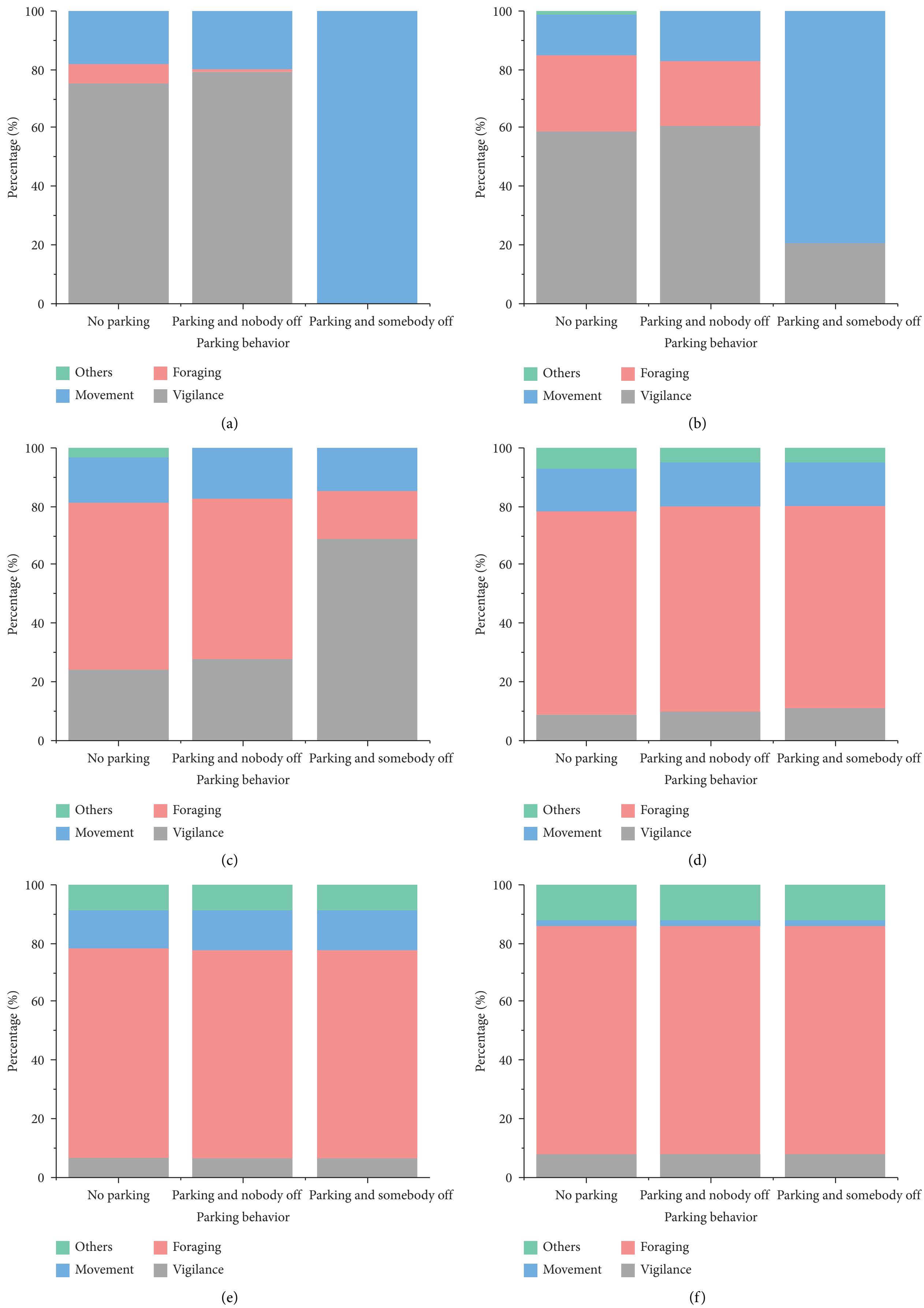

Figure 7: Changes in Tibetan antelope behavior at different distances from the highway. (a) 0–50 m. (b) 50–150 m. (c) 150–300 m. (d) 300–400 m. (e) 400–500 m. (f) 500 m and above.

4. Discussion

No animal passages were established on the Qinghai-Tibet Highway when it was originally constructed. Crossing the highway is a rather difficult task for Tibetan antelopes. The width and type of road, conditions of the surrounding area, and traffic flow along the road can impact their movement [7]. In this study, the behavior of the Tibetan antelopes crossing the highway was observed at the three key nodes on the Qinghai-Tibet Highway under different traffic flow conditions. The results showed that Tibetan antelopes prefer to cross highways in a location where the distance between the highway and the railway is large, the surrounding terrain is relatively flat and open, and there are good visibility conditions. The Qinghai-Tibet Railway was built parallel to the Qinghai-Tibet Highway, and these two transportation routes have overlapping barrier effects on the movement of Tibetan antelopes [28]. This suggests that the design of animal corridors and overlapping barrier effects should be more carefully considered when new highways are built in high-altitude areas. Vehicles on the road will inevitably interfere with wildlife. Animals may avoid vehicles on the road, waiting for a break in traffic before attempting to cross [23]. Tibetan antelopes must continuously cross the highway because of their migration characteristics. In this study, the relationships between the percentage of antelopes successfully crossing the highway and the different traffic flows were analyzed based on experimental data. The traffic volume was found to be the main factor affecting the success rate of Tibetan antelopes crossing the highway, showing a nonlinear negative correlation. To ensure that Tibetan antelopes can cross highways, some measures can be taken during migration periods, including short-term road closures and traffic control in sections where antelopes are most abundant.

The population behavior of the Tibetan antelope is affected not only by vehicular traffic but also by interference from drivers and passengers. When Tibetan antelopes appear on the side of the highway, many drivers and passengers stop or even get out of the car to get close to the antelopes due to curiosity [26]. During migration periods, Tibetan antelope groups often occur very close to the highway (usually within a few hundred meters) to find an opportunity for passage. The behavior of wild ungulates 0–500 m away from the highway was significantly different from that of individuals 2000–3000 m away [33]. The results of this study indicate that the Tibetan antelopes were most significantly affected by parking behaviors at 0–400 m away from the highway. The Tibetan antelopes impacted by parking with nobody getting out mainly exhibited increased vigilance behavior, while those impacted by parking with somebody getting out mainly exhibited increased movement behavior. Along the Qinghai-Tibet Highway, natural shelter and traffic signs may help prevent the negative effects of driving behaviors on the migration and reproduction of the Tibetan antelope population. For instance, vehicles should not be allowed to stop and sounding the horn should be banned along the key migration routes. Volunteers should be sent out to guard the migration routes when necessary.

5. Conclusions

This study was conducted to determine the impacts of traffic flow and parking behavior on the behaviors of Tibetan antelopes. Experimental observations indicated that Tibetan antelopes prefer to cross the highway where there is a large distance between the Qinghai-Tibet Highway and Qinghai-Tibet Railway and with good visibility conditions. Traffic volume is the main factor affecting the success rate of Tibetan antelopes when crossing the highway, showing a nonlinear negative correlation. Tibetan antelopes mainly cross the highway in the morning and at noon, when light traffic volume occurs.

Parking behaviors were found to have the most significant effect on Tibetan antelope behavior within 400 m of the highway, where parking with somebody getting out having the most prominent impact. The Tibetan antelopes impacted by parking with nobody getting out mainly exhibited increased vigilance behavior, while those impacted by parking with somebody getting out mainly exhibited increased movement behavior. In addition, some engineering measures to protect antelopes were proposed. The results of this study can guide road construction and engineering measures to protect wildlife in the plateau region. However, the local situation should be considered when these measures are applied. It should be noted that the present study was preliminary in nature because it took place over a short term, and the long-term impacts of road traffic on wildlife were not considered. Further research will involve year-round behavior surveillance of Tibetan antelopes and other wild animals. In addition, the behavior of the Tibetan antelope was also found to affect driver behavior. We will attempt to use advanced monitoring technology and big data to analyze the effect of the behaviors of Tibetan antelopes and other wild animals on the highway on the behaviors of drivers in the future.

Data Availability

The datasets used and analyzed during the current study are available from the corresponding author upon reasonable request.

Conflicts of Interest

The authors declare that there are no conflicts of interest.

Acknowledgments

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