

Article

The Factors Influencing Wildlife to Use Existing Bridges and Culverts in Giant Panda National Park

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Abstract: Roads, acting as barriers, hamper wildlife movements and disrupt habitat connectivity. Bridges and culverts are common structures on roads, and some of them can function to allow wildlife passage. This study investigated the effects of traffic, the surrounding landscape, human disturbance, and bridge and culvert structures on the utilization of bridges and culverts as dedicated passages by wildlife, using motion-activated infrared camera traps along a 64 km road in Giant Panda National Park, Sichuan, China. The results show that both species richness and counts of wildlife recorded at the bridge and culvert were significantly lower than those observed at sites distant from roads. No large-sized wildlife was recorded at the bridges and culverts. Human activities and traffic volume significantly and negatively affect medium-sized wildlife utilization of bridges and culverts. We conclude that bridges and culverts serve as wildlife crossings, but their efficacy is weak. This emphasizes the necessity of retrofitting bridges and culverts via mitigation facilities such as noise and light barriers, and vegetation restoration on both sides of the roads in Giant Panda National Park.

Keywords: wildlife crossing structures; bridges; culverts; traffic density; road



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1. Introduction

The construction of linear transportation infrastructure (such as roads, railways, etc.), regarded as one of the gravest threats to terrestrial ecosystems [1–3], is increasing rapidly worldwide [4,5]. Studies have demonstrated that roads negatively impact wildlife on multiple levels [6–8]. Roads cause habitat degradation and loss not only through their physical occupation but also through their noise, light pollution, etc. [9,10]. Many studies have shown that roads also lead to wildlife habitat fragmentation and population isolation [11,12]. Braschler's research showed that roads influence the dispersal and the population dynamics of small mammals, amphibians, reptiles, and invertebrates [13]. A more visible consequence is roadkill resulting from the collision of wildlife with vehicles, carnivores, small mammals, amphibians, birds, insects, etc., may be killed on the road [14,15]. Wildlife crossing structures can reduce roads' negative impacts [16,17] by concatenating habitats, mitigating the barrier effects of roads, and reducing roadkill [18,19]. Over the past 50 years, numerous dedicated wildlife overpasses and underpasses have been built worldwide, and the number has steadily increased over time [20]. However, dedicated passages for wildlife are expensive to build and maintain [21]. Given the length of roads in various types of wildlife habitats, the current number of dedicated passages for wildlife is far from sufficient. On the other hand, bridges and culverts (BC), which

are ubiquitous in the road system, have been demonstrated to serve as wildlife crossing structures, even though they were not designed initially for wildlife crossings [22–24].

Many studies have shown that road infrastructure, such as bridges and culverts, can serve as wildlife passages and decrease roadkill. For instance, in southern Portugal, carnivores were observed using existing bridges and culverts [25]. Ascensão's research found that drainage culverts resulted in a lower incidence of road mortality among small mammals, indicating that such structures may function as wildlife passages [21].

However, existing bridges and culverts are often unsuitable for wildlife to pass through and are less effective than dedicated wildlife passages in mitigating the road barrier effect [25,26]. The size and surrounding environment of bridges and culverts can have a significant impact on their usage by wildlife [27–29]. Clevenger also found that road traffic volume, noise level and road width are the main factors affecting the use of BC by wildlife, and he believed that BC may be critical for maintaining habitat connectivity, making them potentially valuable protection tools, and worthy of analysis [22]. Therefore, understanding the driving factors affecting the efficiency of wildlife utilization of BC provides essential guidance for BC reconstruction to promote wildlife connectivity. Accurately determining the driving factors is essential for ensuring the ecological efficiency of BC while reducing construction costs [17].

Giant Panda National Park (GPNP), which is inhabited by many endangered species and crossed by extensive roads, is located in one of the world's biodiversity hotspots [30,31]. Studies have revealed that roads in GPNP cause the rapid and permanent alteration and fragmentation of these naturally productive habitats, leading to extinction crises in many species that cannot adapt to such radical changes, including giant pandas (*Ailuropoda melanoleuca*) [32]. Between 2000 and 2010, there was a significant increase in road disturbances to the giant panda habitat [33], and this trend is expected to continue in the coming years as the region's economy continues to grow. It has been demonstrated that roads increase accessibility within the giant panda's habitat, reducing nearby forest coverage and habitat suitability, which in turn leads to a decrease in the presence of giant pandas in the 5 km around roads [32]. Qiu found that controlling the impacts of infrastructure, such as roads, can aid in the restoration of large areas of giant panda habitat [34]. Therefore, mitigating the negative ecological effects caused by roads is critical to conserving native biodiversity in GPNP [34]. To address the problem, managers have planned panda ecological corridors with wildlife crossing structures in some key areas, but the construction has yet to be carried out [35]. Still, widespread existing BC, providing passage for transportation over running waterways such mountain runoff, could mitigate the barrier effects of roads on wildlife habitats before these corridors are established. On the other hand, wildlife crossings in the GPNP, even if they are built, will be limited in number and distribution and should be planned preferentially for the giant panda. Therefore, BC can still be incorporated as a mitigation technology to complement the role of wildlife corridors and protect other species.

To assess the utilization of road BC by wildlife in GPNP and understand the driving factors, we employed long-term monitoring to measure activity patterns for wildlife, using camera traps in the north of GPNP, Sichuan. We further analyzed the quantified factors influencing the utilization of the BC by wildlife from the perspectives of landscape, human activities, traffic volume, and the physical dimension of the BC. The results may provide valuable information for the ecological modification of existing roads and mitigation measures for the construction of new roads in GPNP.

2. Materials and Methods

2.1. Study Area

We conducted our study in Pingwu County, north of GPNP, Sichuan, China (Figure 1). This region is located on the eastern edge of the Tibetan Plateau, where the terrain is mainly sharp mountainous. The vegetation composition is characteristic of primordial forests with a mosaic of spruce (*Picea asperata* Mast), fir (*Abies fabri* (Mast.) Craib), nanmu (*Phoebe zhennan*

S.Lee et F.N.Wei), and alpine meadows. The region has rich biodiversity and is inhabited by wildlife such as giant panda, Sichuan snub-nosed monkey (*Rhinopithecus roxellana*), and takin (*Budorcas taxicolor*). The road we focused on is a paved, busy tourist route 64 km long. Research has suggested that the road has caused habitat fragmentation for wildlife in this region [31].

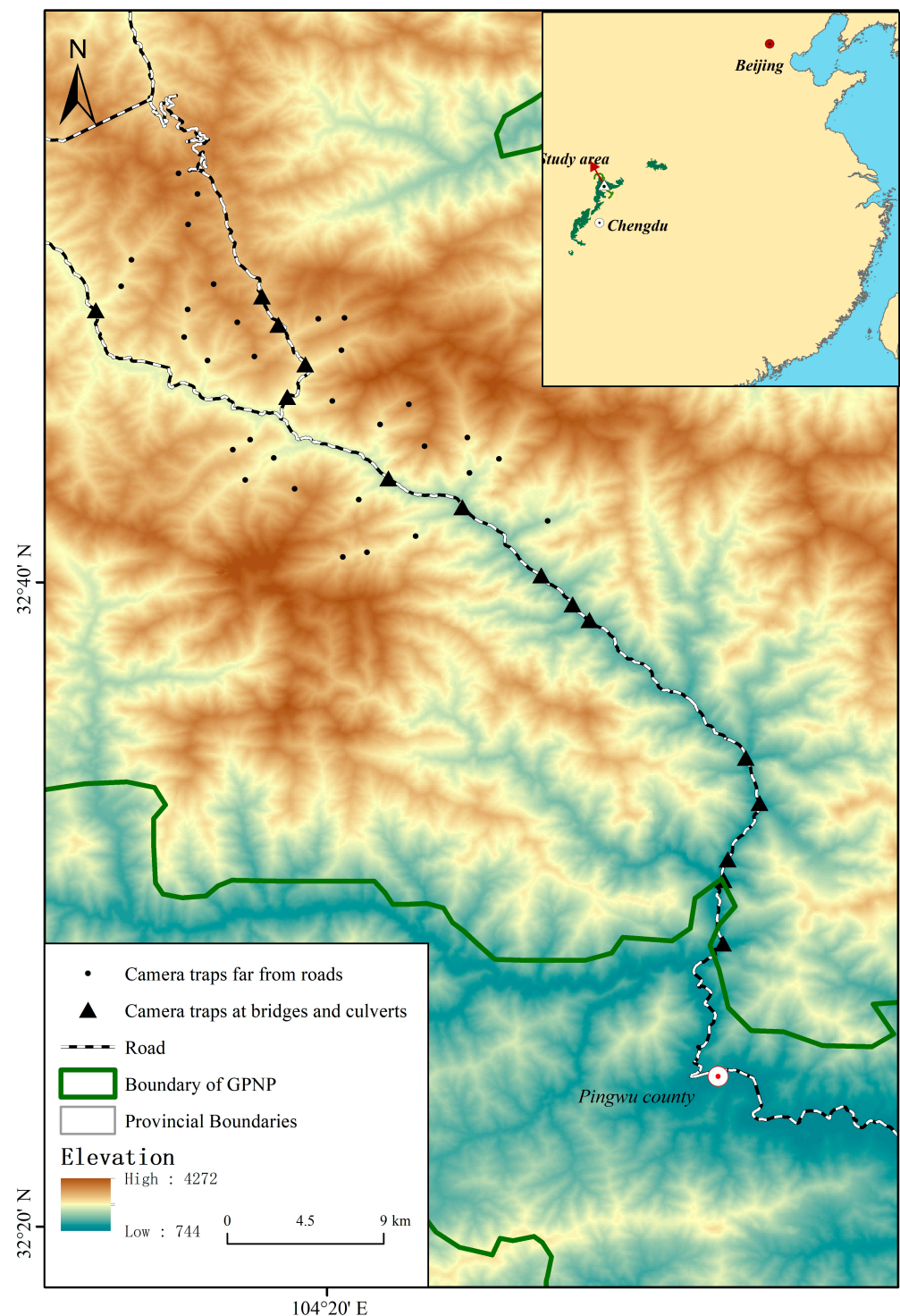


Figure 1. Study area in Pingwu county, north of Giant Panda National Park, Sichuan, China.

2.2. Camera Trap Monitoring

To quantify the utilization of BC by wildlife, 15 camera traps were deployed at bridges and culverts from October 2019 to October 2021. Those bridges and culverts provide passage for mountain runoff. Bridges provide open space (width \times height/length) in contrast to culverts. Thirty camera traps were placed on wildlife trails in mountain forests away (4.5 ± 1.7 km) from the roads in the study area to investigate the background richness and abundance of wildlife in the region. The camera traps recorded three images and a 10-s video after triggering. All camera traps operated 24 h a day, and the cameras were visited once every month to replace SD cards and batteries. Successive photo-captures (>30 min apart) of the same species were considered as an independent event [36,37].

2.3. Traffic Volume

The overpassing traffic volume was measured by 10 long-term outdoor audio recorders deployed close to the roads. The recorders continuously worked for at least 11 days. The data were downloaded, and the recorders were recharged every month. Therefore, we derived 11 days of data at each traffic monitoring site per month. The traffic was counted by recognizing vehicle sounds manually using the recorders. We ensured that there was no fork in the road between the camera trap and the nearest recorders. The traffic count for each camera trap was assigned using the nearest recorders.

2.4. Land Cover

For land cover within a 50 m radius of the camera sites, we manually mapped them on high-resolution satellite images (resolution of about 1 m or 0.5 m) from Google Earth map by visual interpretation. Land cover data for 2019, 2020, and 2021, including the distribution of scrub and woodland with a radius of 1 km at camera sites, were obtained by interpreting Landsat 8 30-m resolution satellite images in the study area [38]. After cloud removal, we only selected satellite images from May to October because vegetation was most conspicuous during this period. We chose the Random Forest algorithm as a classifier, given the superior performance of its multi-dimensional features [39]. All training and validation samples were collected based on the manual visual interpretation of high-resolution images from Google Earth. The training and validation samples were derived at a ratio of 7:3, and finally, we had 422 training polygons and 181 validation points. The overall accuracy was 83.71%, and the Kappa coefficient was 0.80. The accuracy of all classifications was above 80%.

2.5. Statistical Analysis

We fitted a generalized linear model (GLM) in a Bayesian framework to compare the differences in wildlife richness between the BC and the sites distant from roads. GLM with Gaussian distribution was used. To correct for differences in camera working days in the models, the working day of each camera was offset to account for the impact of inconsistent trapping efforts [40–42].

To compare the difference in the count of independent events for wildlife recorded between the BC and the areas far from roads, we employed generalized linear mixed models (GLMMs) in a Bayesian framework for each species, with an interaction term of species and BC/Control. Since the counts of independent events for wildlife often contain too many zeros and are overdispersed, we applied zero-inflation GLMM with a negative binomial distribution (ZINB) and logit link [43].

To investigate the factors affecting BC's utilization by wildlife, we employed GLMM in a Bayesian framework across all BC in the region. Only the data from BC sites were used in this analysis. We divided the factors potentially affecting wildlife use of BC into those related to human disturbance and vegetation coverage. We divided the factors potentially affecting wildlife use of BC into those related to human disturbance and vegetation coverage. We note that the distance from water sources and BC material have also been included as variables in other studies. However, in our study, the BC were all designed for drainage,

all had water flowing through them, and the materials were all of cement origin, so we believe those variables were unnecessary in our models. The counts of independent events for medium-sized mammals per BC were used as the dependent variable; BC openness, coverage of scrub and woodland within 50 m, coverage of scrub and woodland within 1 km, mean traffic volume, counts of independent human events, and domestic animal events were taken as the independent variables [6,44]. Mammals weighing between 1.0 and 15.0 kg were considered medium-sized according to Gehrt's and William's research [45,46].

Zero-inflated formula:

$$\text{Independent events} \sim \text{Cover1km}$$

Conditional Formula:

$$\text{Independent events} \sim \text{offset}(\log \text{Workday}) + \text{Traffic level} + \text{Human} + \text{Domestic animal} \\ + \text{Openness} + \text{Cover1 km} + \text{Cover50} + (1|\text{Camera site})$$

where *Cover50* and *Cover1 km* indicated coverage of scrub and woodland within 50 m and 1 km, respectively. We fitted the GLMM with a zero-inflation Poisson (ZIP) distribution, accounting for the overdispersion in count data. The coverage of scrub and woodland within 1 km was also used as the zero-inflation term. With a threshold of 20 vehicles per hour, traffic volumes were classified into “high” and “low” levels. The independent events of humans and domestic animal identification were used after logarithmic transformation. The coverage of scrub and woodland was transformed using arcsin transformation before analysis. As with ZINB, the working day of each camera was set as an offset, and the ID of the camera site was set as the random effect. At this stage, the independent events of the five most typically recorded medium-sized mammals were pooled for analysis, since the count of events was too low for each respective species when the model included multiple factors.

Variance inflation factor (VIF) was used to test the multicollinearity in models. Any predictor variable that has a VIF more than 5 indicates a potentially severe correlation with at least one other predictor variable and should be removed from the model [47]. No significant collinearity was detected for any of the variables in our models (Table S1).

We first built a global model with full variables, and then removed nonsignificant variables [48]. All model fits were assessed using widely applicable information criteria (WAIC) and leave one out cross-validation (LOOIC). We estimated fixed effects (means and 95% CI) from the posterior distributions for each predictor. If its 95% confidence interval did not contain zero, we considered the effect of the variable to be significantly relevant [49].

For all models in the Bayesian framework, we simultaneously used four Markov chain Monte Carlo (MCMC) sampling to obtain draws from posterior distributions, each with 3000 iterations and 1000 warm-up iterations and achieved convergence on all four chains (all coefficient estimates: $\text{rhat} = 1.00$). GLM and GLMM were built using “brms” packages [50].

To further test whether the daily wildlife activity pattern at the BC was influenced by human activity and traffic, we compared the activity patterns of medium-sized mammals at the BC with those of the same species at sites far from roads. In the R package “overlap”, the estimator suggested in the package (Dhat4 is used when the small sample number is greater than 50) was used to calculate the overlap coefficient, which is used to evaluate the transformation of animal activity patterns. The overlap coefficient ranges from 0 (no overlap) to 1 (complete overlap). To account for the successive changes of the sun's position throughout the year, we used the “sunTime” function of “Overlap” to remaps clock times to sun times (times to sunrise or sunset) [51]. Meanwhile, bootstrap simulation was undertaken 10,000 times with a 95% confidence interval. When the upper bound of the overlap coefficient within the 95% confidence interval was less than 0.90, we inferred that

there were significant alterations in the activity patterns of wild animals between the two sites [52].

3. Results

3.1. Richness and Abundance

All 45 cameras have a total sample effort of 10,961 camera-days at the BC sites and 5020 camera-days at sites far from roads. We captured 137,496 images, including 4159 images and 1391 independent events of wildlife. Cameras at the BC sites recorded only small and medium-size wildlife, while large mammals such as Tufted Deer (*Elaphodus cephalophus*) and Reeves's Muntjac (*Muntiacus reevesi*) were only recorded at the sites far from roads. (Tables S2 and S3). Five species of Galliformes were recorded at the sites far from roads, while only one species of them was recorded at BC sites. Masked Palm Civet, Yellow Throated Marten, Leopard Cat (*Prionailurus bengalensis*), Hog Badger (*Arctonyx collaris*), and Malayan Porcupine were the top five species recorded at BC sites (counts of image > 72%). Meanwhile, we captured 3683 images of human activities and 47,715 images of domestic animals at the BC sites, resulting in 512 and 3310 independent events, respectively.

The GLM results showed that, unsurprisingly, the richness of wildlife recorded at sites far from roads was significantly higher than at the BC sites (Table 1). Meanwhile, the results of the GLMM showed that the counts of independent events for each species at sites far from roads were significantly higher than those at the BC sites, except for Masked Palm Civet, Yellow Throat Marten, and Hog Badger (Figure 2).

Table 1. Summary of generalized linear model results for examining the difference in wildlife richness at sites of bridge and culvert and sites for control at sites far from roads.

Model	Variable	Coefficient	SE	Lower95%	Upper95%	R ²
Richness~site	Site: Far	280.65	55.08	171.74	390.29	0.50

Note: "Site: Far" represent the dummy variable for far from road.

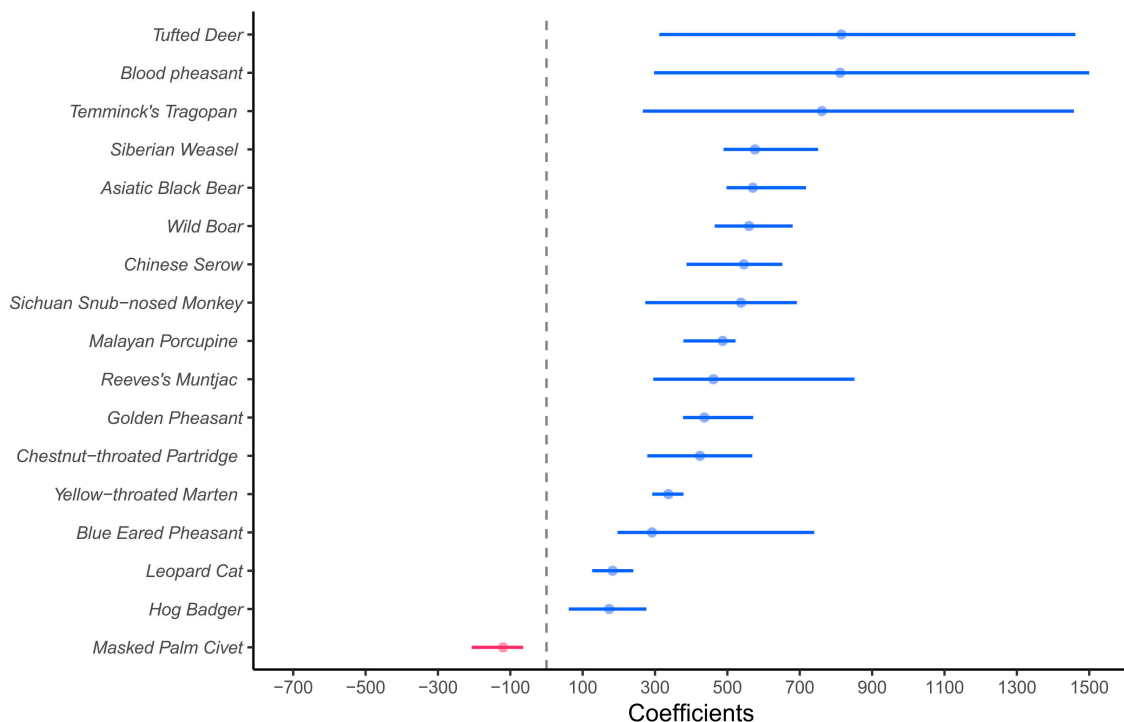


Figure 2. Coefficient plot displaying the regression coefficients of zero-inflated generalized linear mixed models (ZINB) comparing independent events of wildlife at BC and sites far from roads. Solid

circles indicate the estimated coefficients for events in the models, their 95% confidence intervals are presented by the solid line, and the vertical dashed line indicates the value of 0. The color blue means that the count of independent events at sites far from roads was significantly higher than those at BC (the lower limit of confidence interval was greater than 0). The color red indicates that the count of independent events at sites far from roads was significantly less than that at BC (the upper limit of confidence interval was less than 0).

3.2. Factors Affecting Wildlife Visiting

For the GLMMs investigating the factors that affect the wildlife utilization of BC, the reduced-predictor model was chosen for its lower LOOIC and WAIC compared to the global model (Table 2). Human activities and traffic volume significantly negatively affect the counts of independent events of wildlife at BCs. In contrast, domestic animals significantly positively affected independent events of wildlife. Surprisingly, the coefficient for the coverage of woodland and scrub areas within 1 km radius of the camera sites with zero inflation was positive. This indicates that wildlife was more likely to use BCs with sparse woodland and scrub in the surrounding area.

Table 2. The LOOIC and R^2 for zero-inflated Poisson (ZIP) GLMM. WAIC results were consistent with LOOIC. Reduced models include the set of predictors that were considered important in the global models (95% CI did not cross 0). The difference between each model and the best-fit model is shown as Δelpd (expected log predictive density) with standard error (SE).

Model	LOOIC	WAIC	Δelpd (SE)	R^2	Variables						
					Human	Traffic: Low	DA	Openness	Cover50	Cover1 km	Zi-Cover1 km
Global	251.70	248.60	−0.30 (0.70)	0.49	−0.17 (−0.30, −0.04)	0.45 (0.15, 0.75)	0.22 (0.05, 0.39)	−0.56 (−4.29, 3.41)	0.79 (−19.16, 21.22)	−19.60 (−92.98, 39.78)	19.12 (0.50, 37.69)
Reduced	251.10	248.00	0	0.49	−0.17 (−0.31, −0.04)	0.46 (0.17, 0.76)	0.21 (0.05, 0.37)	−	−	−	20.93 (3.89, 38.05)

Note: Variables statistics include the parameter estimates and 95% confidence intervals. Human: Human independent events of visitation. DA: domestic animals. Traffic: the traffic volume levels were divided into low and high. Cover50: the coverage of scrub and woodland within 50 m. Cover1km: the coverage of scrub and woodland within 1 km. Zi-Cover1 km: the zero-inflation probability for the variable of coverage of scrub and woodland within 1 km.

3.3. Daily Pattern of Visiting

Traffic volumes were dense during the day, especially from 07:00 to 22:00, accounting for 92.09% of the total traffic volume. Overlap analysis shows that the visiting patterns of wildlife at the BC sites were significantly different from those at sites far from roads (overlap estimate = 0.47, 95% confidence interval: 0.37–0.56) (Figure 3).

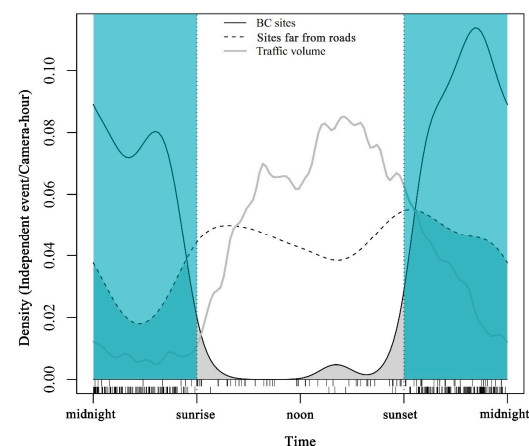


Figure 3. Overlap between daily visiting patterns of medium animals at BC sites (solid line) and the sites far from roads (dotted line). The grey line shows the traffic volume along the road. Time of day is presented on the x-axis. The thin dotted line represents the standardized sunrise time and sunset time respectively. The blue area in the figure represents night time.

4. Discussion

Many studies have highlighted that bridges and culverts could help wildlife cross the road and mitigate road effects of fragmentation [25,27]. A survey at Banff Park, Canada, showed that culverts could mitigate the potentially harmful effects of busy transport corridors by providing a vital habitat linkage for many small- and medium-sized mammals [22]. Braschler also found that set-aside railway bridges were able to serve as corridors for dispersal and population communication among small mammals, amphibians, reptiles, and invertebrates [13]. Our study found that bridges and culverts can serve as wildlife passageways. However, despite this region's rich and abundant wildlife, only a few medium-sized mammals and no large mammals were recorded at the bridge and culvert. It was caused by a combination of at least two negative effects: one was the anthropogenic disturbances introduced by the road, and the second was the unsuitable location or structure of the BC. Many studies have highlighted that bridges and culverts could help wildlife to cross the road and mitigate road effects of fragmentation [25,27]. Nevertheless, it was suggested that bridges and culverts should be modified to address wildlife requirements before they can serve as wildlife crossings [23]. Brunen's research recommends that the construction of drainage culverts in combination with fences will effectively reduce wildlife mortality [23]. Kenneth and Clevenger's also suggested reducing road noise and creating appropriate culvert sizes to promote the use of culverts by mammals [22,53]. A substantial network of roads totaling 1192 km is located within the giant panda habitat in Sichuan Province [35]. This region is also inhabited by abundant wildlife, including giant pandas and other threatened species. Numerous bridges and culverts have been constructed along the roads for drainage, since a mountainous terrain and ample rainfall characterize this region. However, none of these infrastructures have undergone ecological modifications. Our results highlight the urgent need for the ecological retrofitting BCs in the GPNP.

The results show that, at BCs, wildlife visits were more common at night. Meanwhile, the wildlife was recorded more during the day than at night at sites distant from roads. The traffic density was low at night. This implies that the high volume of traffic could hinder wildlife from BCs. However, it is still possible that wildlife visited BC at night because wildlife tend to leave the forest and travel to roads at night. Studies found that noise and light from passing vehicles can reduce wildlife's utilization of road crossing facilities [54]. Nevertheless, for dedicated wildlife crossings, the negative effects of traffic can be mitigated by noise barriers, light shielding, and other traffic mitigation measures [55,56]. Research has shown that traffic levels as high as 17,970 vehicles/day did not significantly impact the utilization of dedicated wildlife underpasses in Banff, Canada [55]. Meanwhile, the traffic volumes in our study were less than 114 vehicles/hour at the peak hour of the day. This highlighted the significance of disturbance mitigation measures for those bridges and culverts [57].

Our results imply facilitation on the part of from domestic animals but interference on the part of human activities in relation to wildlife using bridges and culverts. The negative impact of human activity was not surprising, since most wildlife avoids not only the presence of people, but also places where human activity has just occurred [58–60]. In this study, the effect of domestic animals can be regarded as not associated with human activity. Domestic animals at the bridge and culvert, including cattle, chickens, sheep, horses, etc., were free-range with little human management. The impact of domestic animals varies among studies. Some studies found that wildlife avoids livestock, but many suggested that livestock has little impact on wildlife, and can even attract wildlife [61,62].

Medium mammals showed no significant preference for the openness of bridges and culverts in our study. The effects of passages' openness are still unclear. Most studies suggest that wildlife prefers bridges and culverts with a higher openness for an open field of view [6,25]. Nevertheless, some studies found that wildlife prefers culverts with less openness [63,64].

Surprisingly, wildlife was more likely to cross the roads using bridges and culverts with sparse surrounding forest and scrub compared to those with dense surrounding forest

and scrub. Studies have shown that surrounding vegetation cover facilitates the passage of wildlife [65–67], yet our results found an opposite trend. It is possible that because of this, wildlife will move quickly in areas with little vegetation, and are not willing to get close to the heavily disturbed road sections when they have nearby forests and scrubs as shelters.

The sites where wildlife crosses roads are clustered in space and characterized by attributes associated with the landscape and road [68,69]. Gu's research has shown that roads surrounded by abundant suitable habitat are more likely to experience high levels of road mortality [69]. Possibly, the relatively low use of BC by wildlife is because these structures were built in inappropriate places along the road. The locations of bridges and culverts are selected mostly according to hydrology and topography considerations, not to the needs of wildlife. Surveying along the road, including assessing roadkill and wildlife distribution, can help reveal the spatial distribution patterns of wildlife crossing the road and identify sites where potential wildlife crossing structures need to be built.

Overall, existing bridges and culverts provide means for wildlife to cross roads, yet the number of species using them was only a tiny fraction of species present in this region. Although the mechanism leading to the problem has not been fully investigated in this study, our research suggested that these structures require alterations to accommodate wildlife crossing, as they were not originally designed for wildlife. Wildlife is rich in this region, but roads have caused severe habitat fragmentation [70]. The movement of wildlife across roads is expected to be harder in the future, with the busier traffic brought about by the development of tourism and the economy [71]. A highway in this region is under construction to connect Jiuzhaigou Valley, a renowned tourist resort, to the existing highway network. This highlights the urgency of planning dedicated wildlife crossings in this region. A detailed survey of wildlife distribution and activity rhythms along the roads will help identify future sites for wildlife corridors. Mitigation measures, such as noise and light barriers, will be helpful for wildlife at existing bridges and culverts. Besides this, barrier wall–culvert systems, which have been proven to increase the number of species and counts of individuals using BCs [54,71], should be adopted to reduce road deaths.

Supplementary Materials: The following supporting information is available at <https://www.mdpi.com/article/10.3390/d15040487/s1>. Table S1: Variance inflation factors (VIF) for variables fit in ZIP GLMM. Table S2: Total independent camera detections at sites of bridges and culverts. Table S3: Total independent camera detections at sites far from roads.

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