

# **Impact of Injury Caused by Snare Traps on the Space Use of Endangered Asiatic Black Bears in Taiwan**

by

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A thesis submitted in partial fulfillment of  
the requirements for the degree of  
Master of Science (Environment and Sustainability)  
in the University of Michigan

April 2024

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## **ABSTRACT**

Anthropogenic impacts, such as habitat degradation and overhunting, pose significant threats to wildlife populations globally. In Taiwan, alongside habitat loss due to urban development, the proliferation of snare traps has escalated threats to the locally endangered Formosan black bear (*Ursus thibetanus formosanus*), leading to increased bear mortalities and physical injuries. Despite the severity of these issues, there is limited information that can inform conservation strategies regarding the preferred habitat characteristics of the bears and the long-term behavioral impacts of snare-induced injuries. In this study, I evaluated movement rates, home range sizes, and habitat selection patterns of 15 bears (6 injured, 9 healthy) inhabiting Yushan National Park, Taiwan, to examine the impact of snare-derived injuries on bear space use. Further, I spatially predicted habitat quality across the system and compared quality within home ranges between healthy bears and injured bears. I did not find significant differences in diffusion rates and home range sizes, while I found that injured and healthy bears had different habitat selection patterns. Healthy bears preferred rugged terrain and greener areas, while injured bears exhibited no preferences for vegetation greenness and terrain ruggedness. Injured bears also showed stronger spatial avoidance of areas closer to roads with higher human activities, yet they did not temporally avoid human activities to the same degree that healthy bears did. These results suggest that injuries caused by snare traps could alter bears' space use and possibly change the way bears react to human disturbances like roads. This behavioral impact potentially increases the encounters and risks from humans and impacts their energy gain in the long term. This study highlights that the impacts of snare traps extend beyond mortality and physical injury, possibly

influencing the behavioral and energetic dynamics of bear populations, and necessitates strong regulations on snare trap usage to protect this locally endangered species.

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## 1. INTRODUCTION

Effective conservation plans depend on understanding the impact of anthropogenic disturbances on both animal space use behavior and essential resources to support animal populations (Cross et al., 2021; Salafsky et al., 2002). Animals use the landscape to fulfill their energy demands, avoid dangers, and conduct reproductive activities for survival, including mating and raising their offspring (Burt, 1943; Pyke, 2019). As such, the abundance of resources, the presence of dangers, and inter- and intraspecies interactions are important components that shape animal space use; these factors are also easily affected by human activity (Tuomainen & Candolin, 2011).

Serving as surrogate species, carnivorous species play important roles in biodiversity conservation (Sergio et al., 2008). However, due to their high demand for energy and space, carnivorous species are particularly susceptible to anthropogenic impacts like habitat modification (Woodroffe, 2000). Moreover, the rarity of these charismatic species often increases the monetary values of these animals in illegal trade, making them frequent targets of hunting activities (Hughes et al., 2023; Sung & Fong, 2018).

Additionally, many carnivore species are involved in negative human-wildlife interactions, including livestock depredation and human attacks (Bombieri et al., 2023; Widman & Elofsson, 2018). This highlights the importance of understanding the direct and indirect impacts of human pressure on carnivore movement behavior and habitats to achieve long-term sustainable coexistence goals (König et al., 2020; Trajçe et al., 2019; Treves & Karanth, 2003).



Anthropogenic disturbances, including habitat modification and hunting activities, profoundly influence carnivore-habitat dynamics and population health. This leads to shifts in animal space use patterns, increased mortality rates, and significant physical injuries with potential long-term consequences for carnivore populations. Habitat modification through habitat degradation and the introduction of human presence consequently induces changes in animal space use both temporally and spatially (Hogue & Breon, 2022; Li et al., 2022; Støen et al., 2015; Tucker et al., 2018). This alteration in habitat structure can force animals to relocate to less suitable areas, as observed in Asiatic black bears (*Ursus thibetanus*), which have demonstrated a notable behavioral shift towards highland areas with extreme climatic conditions to avoid anthropogenic impacts (Escobar et al., 2015). Human recreation in natural habitats can also disrupt carnivore habitat use patterns by increasing stress levels (Ladle et al., 2019). Carnivores have shown behavioral responses not only in spatial adjustments but also in temporal activity patterns to minimize human encounters (Carter et al., 2012; Gaynor et al., 2018). These shifts in spatial and temporal space use may cause long-term consequences for carnivore populations, potentially leading to reduced population sizes owing to inadequate forage resources (H. E. Johnson et al., 2020).

Hunting activities, including various harvesting methods such as shooting and trapping, pose significant threats to carnivore populations, resulting in increased mortality rates and direct physical injuries (Benítez-López et al., 2017; Bouley et al., 2018; Liberg et al., 2011; López et al., 2014). These physical injuries caused by trapping can have long-lasting effects on the behavior and overall fitness of carnivores, ranging from decreased mobility to impact on reproductive success (Benhaiem et al., 2023; Bouley et al., 2018).

Among various trapping practices, snare trapping stands out as one of the most widely used methods that inflict severe injuries on wildlife, particularly in biodiversity hotspots (Belecky & Gray, 2020; Figel et al., 2021). Due to their ease of use and difficulty of detection, snare traps are frequently used in poaching. Snare traps, notorious for catching non-target species (so-called by-catch) and causing severe injuries or death, threaten endangered or vulnerable species (Becker et al., 2024; Virgós et al., 2016). The Asiatic black bear, identified as a vulnerable species according to the IUCN Red List, is one of the species most susceptible to snare trapping (Figel et al., 2021). Reports from Japan, Taiwan, South Korea, and Vietnam suggest that these traps impact Asiatic black bears through the entanglement of their limbs or bodies, leading to severe injuries, amputations, or even death (Crudge et al., 2016; Hwang, 2003; Jeong et al., 2021; Nakagawa, 2020). However, little is known about the behavioral impact of snare-induced injuries on their long-term space use pattern.

The Formosan black bear, a locally endangered Asiatic black bear subspecies endemic to Taiwan, has been severely affected by snare traps (Figure 1). The issue of snare trapping has been documented in multiple studies: Hwang, 2003 found that 8 out of 15 (53.3%) bears captured for research purposes had missing paws or digits in Yushan National Park; Yeh, 2020 reported 4 out of 9 (44.4%) bears and Hwang et al., 2022 reported 2 out of 6 (33.3%) bears captured for research purposes had missing digits in Yushan National Park; Hwang et al., 2021 reported that 3 out of 8 (37.5%) captured bears had missing digits in Dasyueshan Forest Recreation Area. In some cases, the injuries from the snares directly lead to bear mortality. Although awareness of this problem has increased, and the use of snare traps has been partially prohibited by the Animal Protection Act since March

2020, by-catch incidents persist. Between 2020 and 2023, 13 bears were by-caught by snare traps, among which two were found with missing digits or paws upon capture, three required amputation due to severe infection, and four died from causes such as dehydration, illegal hunting, or shock during wound cleaning surgery (Taiwan Black Bear Conservation Association, 2023). Given the endangered status of the Formosan black bear and the increasing threat of snare traps, it is urgent to understand the potential long-term threats and behavioral impacts of these traps on the locally endangered species.

In this study, I aim to examine the behavioral impact of the snare-induced injury on space use patterns of Formosan black bears. I evaluated two specific aspects of these patterns: (1) how snare-induced injuries impact Formosan black bear mobility and their space use reflected by diffusion rates and home range sizes, respectively, and (2) how snare-induced injuries impact the habitat selection by bears. I hypothesized that if bears were injured due to snare traps, then their mobility would be impacted, and thus, they would have lower diffusion rates. I also hypothesized that injured bears would have lower energy gain efficiency that impacts their ability to compete for resources with healthy bears. This could lead to their use of less suitable areas, potentially bringing them closer to human activities and increasing the likelihood of negative interactions. Additionally, since animals that are able to acquire higher-quality habitats will have smaller home range sizes according to optimal foraging theory (Mitchell & Powell, 2007), I anticipated that injured bears would have larger home ranges, indicating a deficiency in securing suitable habitats.

To test these hypotheses, I used GPS data of 15 bears (9 healthy and 6 injured by snare traps) collected between 2014 and 2024. These bears inhabit habitats mainly within the

Yushan National Park (YNSNP), which is a protected area surrounded by anthropogenic landscapes. I investigated the topographic, environmental, and anthropogenic factors that affect habitat selection to generate a predictive map of habitat preference and compare the potential impact of snare-induced injuries. This study is the first quantitative report highlighting the behavioral impact of snare traps on endangered bears. By illustrating the effects of snares on bear mobility and habitat selection, this work can motivate concerted efforts to reduce the prevalence of snares, and thus decrease a major threat to Asiatic black bears and other bear species in other areas.

## 2. MATERIALS AND METHODS

### 2.1. Study area

The study was conducted in Yushan National Park (YSNP), which is the largest national park in Taiwan, covering an area of approximately 1,050 km<sup>2</sup>. The park was established in 1985 and is situated in the Central Mountain Range in Taiwan (Figure 2(a)). YSNP encompasses the highest peak in Taiwan, Yushan (Mount Jade; 23° 28' 12" N, 120° 57' 26" E), with elevations ranging from 300 m at Laklak River Valley to 3,952 m at the main peak of Yushan (Figure 2(b)). The climate varies within the park due to the wide elevation range, with an annual average temperature of 5.9 °C for areas above 3,500 m and 11.3°C for areas above 2,500 m. Annual precipitation ranges from 3000 to 4700 mm, with monsoon seasons occurring from May to early June and typhoon seasons from June to September. Vegetation types in YSNP exhibit a wide range, transitioning from subtropical species to subarctic species (Hsu & Lin, 2019). YSNP has an abundant variation of species, particularly mammals like the Formosan black bear, Taiwan serow (*Naemorhedus swinhoei*), and Formosan sambar deer (*Rusa unicolor swinhoei*). YSNP is thought to be the only high-density area of the Formosan black bear; as such, this population is critical to maintaining the viability of the endangered Formosan black bear (Hwang et al., 2010; Tsai, 2011).

### 2.2. GPS data collection

GPS location data of 15 bears were collected by Dr. Mei-Hsiu Hwang and her research team at National Pingtung Technology University (NPUST), Taiwan. The GPS locations of the 15 bears in this study were captured and tracked at two different times ranging from 2014 to 2018 and from 2020 to 2024 (Table 1). Nine bears were tracked between

2014 to 2018 under the project "Analyzing and Constructing the Sustainability of a Core Population of Formosan Black Bears: Satellite Tracking of the Movements and Habitat Utilization Patterns of Formosan Black Bears" sponsored by the National Science and Technology Council, Taiwan. Six bears were tracked between 2020 to 2024 under the project "Formosan Black Bear Satellite Tracking and Ecological Monitoring Program in Yushan National Park" sponsored by the Yushan National Park Headquarters, National Park Service, Ministry of the Interior, Taiwan.

Initially, location data were recorded every 5 hours. However, due to battery issues, the interval was adjusted to every 8.5 hours in 2016. Following the discovery that a collared bear died in a snare trap because of dehydration in 2023, the research team reverted to 5-hour intervals to enhance the temporal resolution of location data, aiming to prevent similar incidents. GPS location data from the first 4 days were excluded to minimize the potential bias from immobilization on bear behavior for both habitat selection analyses.

Bears were captured by either Aldrich spring-activated foot snares in cubby sets or 200×78×78 cm barrel traps (K. G. Johnson & Pelton, 1980). Captured bears were immobilized using an anesthetizing mixture of Zoletil (3 mg/kg) and Dexmedetomidine (0.03 mg/kg) (Coltrane et al., 2015; Teisberg et al., 2014) and were equipped with GPS collars (Vectronic Aerospace GmbH, Berlin, Germany) with a release mechanism to drop off. The research team monitored the barrel traps using trail cameras to ensure the bears were trapped for no longer than 24 hours. Every bear capture was accompanied by veterinarians to monitor the anesthetized bear's vital signs, including body temperature, pulse rate, respiration rate, and oxygen saturation. To shorten the recovery time from immobilization to reduce the side effects of anesthetics, Atipamezole (0.25 mg/kg), an

antagonist of Dexmedetomidine, was injected intramuscularly after the measurement and collar equipment placement (Jalanka & Roeken, 1990). Captured individuals were then released in the same location, and the research team stayed until the bears had recovered and started normal activities. All capture, handling, and immobilization activities were permitted by the NPUST, YSNP, and the Forestry and Nature Conservation Agency, Ministry of Agriculture, Taiwan (YSNP License No. 1031700938 and 1090003474 for the first and second tracking periods, respectively).

### *2.3. Home range and movement analysis*

Each bear's home range was estimated using weighted autocorrelated kernel density estimation (wAKDE; Fleming et al., 2015, 2018). The original kernel density estimator (KDE) is a common method for the estimation of animal home range size. Specifically, this statistical method calculates the density of data points in a neighborhood around a feature with the key assumption that the data are independent and identically distributed (Silverman, 1986). However, since animal movement data such as GPS tracking data are often spatially and temporally autocorrelated, it violates the key assumption of KDE. AKDE is a novel method Fleming et al. (2015) proposed for animal movement data sets and this method increased the accuracy of home range size estimation (Noonan et al., 2019).

Additionally, Fleming et al. (2018) developed wAKDE to deal with the issue of uneven sample intervals and missing points within GPS tracking data using optimal weighting. I selected optimally weighted AKDE as the method of calculating the home range sizes of each bear to incorporate autocorrelation and the difference in tracking intervals within my

data, which were 5 hours and 8.5 hours. wAKDE ranges were estimated by the package “ctmm” (Calabrese et al., 2016) in program R ver. 4.2.2 (R Core Team, 2022). 95% wAKDE home range sizes of all individuals were calculated using the Ornstein-Uhlenbeck with foraging (OUF) model with the perturbative hybrid residual maximum likelihood (pHREML) estimator to deal with small sample size issues (Fleming et al., 2014, 2019; Silva et al., 2022).

Variograms were generated for all bears to assess residency since wAKDE will not be accurate to estimate the home range sizes for non-residents (Fig. S2). The variograms of residents flatten out at certain time lags, while non-residents do not flatten out. Bears are known to display seasonal migrations to patches out of their home ranges for rich seasonal forage resources (Noyce & Garshelis, 2011). In Taiwan, acorn seasons start in October and last until February, and some bears will migrate to oak forests during acorn seasons (Hwang et al., 2010). This kind of seasonal migration is one of the main reasons why their variograms showed non-residency. Home range sizes of individuals showing migration-like movement patterns were estimated by the sum of the acorn season home range and non-acorn season home range, and the variograms for both seasons were generated to check residency.

To compare the movement ability of healthy and injured bears, I estimated the diffusion rates as an assessment of movement ability using “ctmm” package. Diffusion rates represent the daily expected area and animal ranges, which are used for quantifying movement rates in data that are too coarse for speed estimation (Gill et al., 2023). Since the intervals of my data were either 5 hours or 8.5 hours and there were missing data, I selected diffusion rate as a parameter to capture the horizontal movement ability of bears.



I performed Welch Two Sample t-tests to test the difference in both home range sizes and diffusion rates between injured and healthy male bears. Since only two female bears were used in this study, I did not conduct any statistical analyses on female bears.

#### *2.4. Environmental data collection and covariate extraction*

To quantify habitat characteristics as inputs to habitat selection models, I selected 9 environmental covariates that potentially change bears' preference toward the habitat (Table 2; Figure S1). All maps were reprojected to the same projected coordinate system (UTM 51N), cropped to the same extent, and resampled to the same spatial resolution (30 m). All continuous environmental covariates were rescaled to means equal to 0 and standard deviations equal to 1 for habitat selection models.

##### *2.4.1. Forage and water availability*

###### *2.4.1.1. Forest cover*

Forests provide bears with food resources, shelter, and resting sites, and the heterogeneity of natural forests affects the abundance of food resources year-round (Hwang et al., 2002; Mangipane et al., 2018; Mori & Izumiyama, 2024; Takahata et al., 2014; Ullah et al., 2021). Since most Formosan black bears do not hibernate, habitats providing forage resources for all seasons can reduce the energy expended on foraging (Hwang, 2003). Here, I categorized forests within the study area as broadleaf, mixed, and coniferous forests and combined land cover types that do not belong to any categories as “other land cover type”, including open fields, grassland, early successional forests, bamboo-dominated forests, water bodies, and human development. Forest types were extracted from the Fourth National Forest Resource Survey conducted by Taiwan's Forestry Bureau

(Taiwan Forestry Bureau, 2018), and provided as open data by the Public AgriData exchange platform run by the Ministry of Agriculture (MOA), Taiwan.

#### 2.4.1.2. *NDVI*

Normalized Difference Vegetation Index (NDVI) quantifies the greenness of the vegetation, which is one of the main food resources of bear species. NDVI is a widely used remotely sensed index for monitoring the condition of vegetation, including biomass, primary productivity, and habitat quality (Running, 1990; Wiegand et al., 2008). Multiple reports indicate that bear species prefer areas with higher NDVI (Bashir et al., 2018; Lara-Díaz et al., 2018; Sells et al., 2022). This reinforces the importance of incorporating NDVI to capture the habitat quality when analyzing habitat selection by bears.

NDVI is calculated by dividing the difference between the reflectance of the near-infrared (NIR) band and the reflectance of the red band by the sum of NIR band reflectance and red band reflectance extracted from satellite images:

$$NDVI = (NIR - RED) / (NIR + RED)$$

NDVI was calculated from Landsat-8 image courtesy (16-day intervals) of the U.S. Geological Survey (USGS) on Google Earth Engine (Gorelick et al., 2017). The presence of clouds and cloud shadows can lead to an underestimation of NDVI. Although some studies excluded images with more than 30% cloud coverage initially, this practice does not work well with my study area due to frequent high cloud coverage (Haro et al., 2023; Karlsen et al., 2021). To address this issue, I masked the pixels that were identified as

clouds or cloud shadows and maintained other pixels as the NDVI value for that certain date (Foga et al., 2017; Jing et al., 2022).

I generated two sets of NDVI values to provide information at two temporal scales. Firstly, to capture the preference overtime on the landscape, I calculated the average NDVI from March 2014 to February 2024. This time frame captured the tracking periods of all individuals and included the whole year to avoid seasonal variation. Secondly, to reflect bears' decision at each data point, I calculated NDVI values for each pixel at each time point. Since NDVI is a time-dependent index and can only be obtained every 16 days, I calculated the interpolated NDVI value from the closest two-time points as the NDVI value for a specific pixel on a specific date using the “zoo” package in R (Zeileis & Grothendieck, 2005).

#### *2.4.1.3. Water*

In addition to food availability, water resources also influence habitat preference for bear species (Ahmadipari et al., 2021; Sadeghpour & Ginnett, 2011; Sells et al., 2022). I quantified this habitat characteristic by measuring the distance to water resources, including rivers and lakes. River and lake maps were provided by the Taiwan Water Resources Agency, and I calculated the distance to rivers using the distance accumulation function of ArcGIS Pro 3.0.1 (Esri, Redlands, CA, USA), with the digital elevation model (DEM) as the input surface.

#### *2.4.2 Topographic conditions*

Topographic characteristics change the composition of food resources and the accessibility by animals and humans, which also alters bears' habitat selection. As such,

multiple habitat selection models of bear species included topographic factors, including elevation, slope, aspect, and terrain ruggedness index (TRI), as variables (Costello et al., 2013; Scotson et al., 2021; Takahata et al., 2014). I chose to exclude the elevation-only term due to its correlation with other factors and selected TRI to represent topographic characteristics. I used the package “spatialEco” in R to calculate TRI from the DEM of Taiwan with a spatial resolution of 20 meters, provided as open data by the Ministry of the Interior, Taiwan (Evans & Murphy, 2023).

#### *2.4.3 Human Activity*

Anthropogenic disturbance has been observed to shift movement patterns and habitat selection by bear species (Kautz et al., 2021). To quantify the impact of human activities on bear habitat selection around YSNP, I selected two variables: distance to trails and distance to roads. Both the road and trail maps were provided by the Hwang lab at NPUST. The road map was created by integrating data from multiple sources, including the OpenStreet map road layers, the land use map of Taiwan from the National Land Surveying and Mapping Center (MoI, Taiwan), and the forest road map from the Forest Bureau, Taiwan. Similarly, the trail map was compiled using data from various sources, including the OpenStreet map trail layers, official trail maps from YSNP Headquarters, the forest road map, Rudy Map (<https://rudy.outdoors.tw/drops/beta.html>), and Happyman map (<https://twmap.happyman.idv.tw/map/>), an open-source platform where hikers can contribute their tracked paths. Forest roads with restricted car usage were classified as trails. The shortest distances to roads and trails were computed using the same method employed for calculating the distance to water resources in ArcGIS Pro.

## *2.5 Habitat selection analysis*

I used two different approaches to modeling the habitat selection by Formosan black bears to determine preferred and avoided factors: integrated resource selection function (iRSF) and integrated step selection function (iSSF). The scales of both iRSF and iSSF align with third-order habitat selection, which quantifies individual space use within an individual's home range according to the definition of habitat selection by D. H. Johnson, 1980. However, each provides distinct information: iRSF is appropriate for habitat suitability evaluation and making broader inferences on animal decision making, while iSSF can provide information at the level of the individual movement step, a finer temporal scale for modeling animal decision making. (Hemmingmoore et al., 2020; Thorsen et al., 2022).

### *2.5.1 Integrated Step Selection Function (iSSF)*

Resource selection functions (RSFs) are commonly used to analyze animal habitat selection by comparing the characteristics of used spatial units to randomly distributed available spatial units in the environment (Boyce & McDonald, 1999). One of the remaining concerns is that movement ability has not been considered when accounting for the availability of a spatial domain. The step selection function (SSF) is a conditional RSF that chooses available spatial units based on the empirical distribution of observed steps and the movement characteristics, including step length and direction (Fortin et al., 2005). However, the estimation of the movement and habitat selection by SSF is sequential rather than simultaneous, resulting in the assumption that movement and habitat selection are independent while they are not (Avgar et al., 2016). The iSSF

method addresses the concerns of RSFs and SSF by simultaneously considering the movement and habitat selection component of each animal simultaneously to generate the random availability of spatial units in the landscape (Avgar et al., 2016). It combines the selection-free movement kernel, including step length and turn angle, and movement-free selection kernel, i.e., the selection at the end of the step, to account for the animal's actual movement in heterogeneous landscapes. iSSF compares each used movement step with a set of conditioned available steps randomly sampled from an analytical distribution parameterized based on observed steps.

In this study, I used iSSF to model the habitat selection by individual bears and compared the difference between bears injured by snare traps and those that were not. Since the same tracking interval is required for calculating step lengths, I excluded location data that were 5 hours apart from each other and used the remaining 11 individuals with the 8.5-hour intervals for iSSF (Table S1). I excluded locations for iSSF based on dilution of precision (DOP) and the fix type, which was two-dimensional (2-D) and three-dimensional (3-D). Higher DOP values represent lower location accuracy. (Lewis et al., 2007) suggested that 2-D fixes had larger variables at higher DOP values than 3-D fixes, so there should be different screening standards for 2-D and 3-D fixes. Therefore, I eliminated 2-D fixes with  $DOP > 5$  and 3-D fixes with  $DOP > 10$  to minimize the impact of location error.

I separated the GPS location data by individuals and calculated the step lengths and turning angles between each pair of continuous points of each individual. 20 random steps were generated with step lengths sampled from a Gamma distribution and turning angles sampled from von Mises distribution (Avgar et al., 2016). Every observed step and

random step had two locations: start point and end point. Each set of an observed step and 20 random steps had the same start point and different endpoint. I extracted the environmental covariates mentioned in 2.4 of each endpoint and log-transformed all distance variables, including distance to water resources, distance to roads, and distance to trails, to represent the diminishment of behavioral response through the increase in distance. All environmental covariates were rescaled to means equal to 0 and standard deviations equal to 1 after extraction.

I included 6 environmental variables in the model: NDVI, TRI, *log* Distance to trails, *log* Distance to roads, *log* Distance to water, and forest cover type. To account for the influence of animal movements, the step length, the log-step length, and the cosine-transformed turning angle were also integrated. I included the effect of the time of day at the end of the steps on the selection of the proximity to roads to capture the behavioral change during high and low human activity times. I ran one conditional logistic regression model for each individual and grouped the observed steps with their corresponding random steps by including a stratum step ID as a covariate in the model. Covariate extraction, step length and turn angle calculation, random steps generation, and the conditional logistic regression model were all conducted by the “amt” package in R (Signer et al., 2019). I used the nonparametric bootstrapping method to estimate 95% confidence intervals of the coefficient of each covariate of each group: injured bears and non-injured bears. iSSF was not used for population-level habitat selection analysis because of the limitation of data structure.

### 2.5.2 Integrated Resource Selection Function (iRSF)

Although iSSF handles some of the problems with the autocorrelation of GPS tracking data, since the step length and turning angle estimations rely on a fixed sampling interval, accurately modeling comparable habitat selection is challenging (Alston et al., 2022).

iRSF is a method that uses likelihood weighting to mitigate the bias from spatial and temporal autocorrelations of GPS data. This method enables comparable estimations of resource selection coefficients even with uneven tracking intervals. I used iRSF to estimate the coarser scale habitat use within the study area and also compared the difference in habitat selection between injured and non-injured bears.

I performed error calibration by estimating the root-mean-square user equivalent range errors (RMS UEREs) using the “uere.fit” function in the “ctmm” package instead of setting a cutoff DOP value (Fleming et al., 2021). I assigned a gamma distribution with a 10-meter mean and 2-degree-of-freedom as an informative prior as Fleming et al., 2021 suggested.

I rescaled the continuous environmental covariates to means equal to 0 and standard deviations equal to 1 within the combined wAKDE home range of all individuals. I used the “rsf.fit” function in the “ctmm” package to estimate the individual resource selection coefficients of 6 variables: NDVI, TRI, *log* Distance to trails, *log* Distance to roads, *log* Distance to water, and forest cover type. To incorporate different levels of human disturbances, I added an interaction term to evaluate the differences in the selection of *log* Distance to roads at low (< 500 m), medium (500–1,500 m), and high (> 1,500 m) elevations, reflecting varying degrees of human disturbances. Main road systems and



residential areas within my study area are located at elevations lower than 500 m, while the roads that are prohibited at night to mitigate human impacts are mostly at elevations higher than 1,500 m. Therefore, I used elevation to reflect human disturbance in this area, with low elevations associated with high human impact and high elevations associated with low human impact.

The average habitat selection coefficients were also calculated by the bootstrapping method mentioned in 2.5.1. I also calculated the average of all individuals to evaluate the iRSF score of each pixel within the study area. I used quantile classification to categorize the iRSF score as 10 levels (1-10) and generated a map representing the relative probability of use. I combined 2 categories to represent lowest, low, medium, high, and highest quality habitats, and then I calculated the proportion of each habitat level within the home range of 15 individuals to compare the difference in habitat quality usage between injured and healthy bears.

### 3. RESULTS

GPS location data of 15 Formosan black bears from 2014 to 2018 and from 2020 to 2023 were collected: four were non-injured females, two were injured females, five were non-injured males, and four were injured males (Table 1). The start date of the tracking period is 4 days after the captured date. Healthy females were tracked for 507.5 days on average ( $n = 4$ , range = 286–826 days,  $SD = 217.1$  days), injured females were tracked for 161 days on average ( $n = 2$ , range = 97–225 days,  $SD = 64$  days), healthy males were tracked for 482.8 days ( $n = 5$ , range = 243–958 days,  $SD = 260.7$  days), and injured males were tracked for 576.3 days ( $n = 4$ , range = 133–997 days,  $SD = 306.2$  days). After excluding the first 4 days of tracking, I obtained a total of 17,004 fixes (mean = 1,133.6, range = 234–2,127 per individual,  $SD = 612.5$ ), and all of them were used in iRSF. Data used in iSSF were 4,573 (mean = 415.7, range = 30–1,138,  $SD = 357.5$ ) fixes for 11 individuals after data filtering (Table S1).

#### 3.1. Movement rate

I analyzed the average diffusion rates, measured in hectares per day, for both healthy and injured bears by sex. The average diffusion rate of healthy male bears was 88.1 hectares/day ( $n = 5$ , range = 40.9–166.7 hectares/day,  $SD = 48.3$  hectares/day). In comparison, the average diffusion rate of injured male bears was 125.3 hectares/day ( $n = 4$ , range = 84.4–164.4 hectares/day,  $SD = 34.4$  hectares/day). There was no significant difference between injured and healthy male bears ( $t = 1.3478$ ,  $df = 6.952$ ,  $p = 0.22$ ).

For female bears, the average diffusion rates were 59.8 hectares/day ( $n = 4$ , range = 33.9–103.8 hectares/day,  $SD = 30.4$  hectares/day) for healthy female bears and 26.4

hectares/day ( $n = 2$ , range = 17.6–35.2 hectares/day, SD = 12.5 hectares/day) for injured female bears (Figure 3).

### *3.2. Home range analyses*

Twelve individuals were identified as range residents after variogram inspection and three bears (MS39916, FA16698, FS16702) showed non-residency (Figure S2). FA16698 and FS16702 showed migration-like movement patterns and their home range sizes were calculated by calculating the sum of home range sizes in acorn and non-acorn seasons.

Home range sizes throughout the whole tracking period were estimated by wAKDE (Table 3). The average home range size of healthy male bears was 107.4 km<sup>2</sup> ( $n = 5$ , range = 30.5–197.7 km<sup>2</sup>, SD = 89.1 km<sup>2</sup>). In comparison, the average home range size of injured male bears was 334.6 km<sup>2</sup> ( $n = 4$ , range = 122.8–700.2 km<sup>2</sup>, SD = 309.0 km<sup>2</sup>).

The Welch two-sample t-test was performed to compare the home range sizes of injured vs. healthy male bears. There was no significant difference in home range sizes between injured and healthy male bears ( $t = -1.47$ ,  $df = 3.40$ ,  $p = 0.23$ ).

For female bears, the average home range sizes were 54.1 km<sup>2</sup> ( $n = 4$ , range = 16.4–125.0 km<sup>2</sup>, SD = 49.5 km<sup>2</sup>) for healthy female bears and 39.5 km<sup>2</sup> ( $n = 2$ , range = 21.4–57.7 km<sup>2</sup>, SD = 22.2 km<sup>2</sup>) for injured female bears (Figure 4).

### *3.3. Injured vs. Healthy Bear Habitat Selection*

Estimated coefficients of iSSF differed between bears with different injury statuses, as shown in Figure 5 (a). Healthy bears exhibited significantly positive coefficients of continuous variables TRI (median = 0.20, 95% CI: 0.05, 0.37), NDVI (median = 0.07, 95% CI: 0.00, 0.20), and distance to roads during daytime (median = 0.32, 95% CI: 0.05,

0.61), while injured bears did not show a significant effect on any of these continuous variables.

Estimated coefficients of iRSF differed between injury status (Figure 5 (b)). Healthy bears showed significantly positive coefficients of NDVI (median = 0.36, 95% CI: 0.10, 0.74) and TRI (median = 0.24, 95% CI: 0.12, 0.38). Healthy bears showed significantly negative coefficients of  $\log(\text{Distance to roads})$  at high elevations ( $> 1,500$  m) compared to medium elevations (500 m–1,500 m) (median = -1.69, 95% CI: -6.69, -0.02), coniferous forest (median = -1.62, 95% CI: -4.71, -0.38) and other land cover types (median = -0.53, 95% CI: -1.10, -0.30) compared to broadleaf forests. Injured bears showed significantly positive coefficients of  $\log(\text{Distance to roads})$  at low elevation compared to medium elevation (median = 2.28, 95% CI: 0.82, 5.67) and significantly negative coefficients of  $\log(\text{Distance to roads})$  at high elevation compared to medium elevation (median = -1.14, 95% CI: -2.09, -0.63) and coniferous (median = -3.48, 95% CI: -7.77, -1.03) compared to broadleaf forests.

#### *3.4. Habitat quality assessment and comparison*

The population-level results of iRSF (Figure 6) after bootstrapping indicated that bears had significant positive selection coefficients of TRI (median = 0.22, 95% CI: 0.10, 0.33) and significant negative coefficients of  $\log(\text{Distance to roads})$  (median = -1.45, 95% CI: -4.68, -0.46), coniferous forests (median = -2.36, 95% CI: -4.77, -1.06) and other cover type (mean = -0.50, 95% CI: -0.99, -0.15) compared to broadleaf forests.

I generated a predictive map of habitat selection within the study site according to the population-level iRSF results, categorizing from level 1 to level 10 (Figure 7a). The

residential areas on the east side are mostly level 1 habitats, which are not suitable for bears. The coniferous forests located at high elevations also have low habitat quality levels, and thus they are not the most suitable habitats for Formosan black bears.

To compare the habitat quality within each bear's home range, I calculated the percentage of each habitat level within home ranges and compared the results of injured and healthy bears by sex (Figure 7b). Healthy male bears (highest = 30.7%, high = 31.5%, medium = 22%, low = 11.3%, lowest = 4.5%) and healthy female bears (highest = 27.6%, high = 34.0%, medium = 23.4%, low = 8.9%, lowest = 6.1%) showed similar proportion of each habitat quality category, whereas injured males and females showed different composition of the habitat quality categories. Injured females were found more in higher quality categories (highest = 42.5%, high = 49.6%, medium = 6.8%, low = 1.1%, lowest = 0%), while injured males (highest = 24.5%, high = 26.1%, medium = 20.6%, low = 18.6%, lowest = 10.1%) were found more in lower quality categories.

## 4. DISCUSSION

In this study, I compared the movement ability, home range sizes, and habitat selection of 15 Formosan black bears (9 healthy and 6 injured) to investigate the impacts of snare-induced injuries on the spatial behavior of the locally endangered bear species. Based on the comparison of diffusion rates, I found that the injuries on bears did not impact their horizontal mobility. However, snare-induced injuries possibly have a further impact on bears' energy intake efficiency, their ability to explore the landscape, and their avoidance of human activity. Healthy bears tended to select patches with higher productivity on rugged surfaces and show diurnal avoidance of roads, while injured bears showed no preference for rugged terrains and greener areas but showed a strong spatial avoidance of roads in areas with frequent human activity.

### *4.1. Movement rate, home range size, and home range quality*

I used the home range sizes and diffusion rates of injured and healthy bears as proxies for area use and mobility. Due to the sex difference in space demand and movement, I compared male bears and female bears separately (Dahle et al., 2006; Lewis & Rachlow, 2011; Schoen, 1990). I found three bears showed non-residency according to the variograms (Fig. S2). Among those who were not range residents, two female bears showed migration-like movement to a known area of high acorn abundance during acorn seasons, usually from October to early February. The male subadult (MS39916) did not show residency possibly because it is in its dispersal stage without a formed home range (Takayama et al., 2023).

#### 4.1.1. Movement behavior

Contrary to my hypothesis, there was no significant difference in diffusion rates between injured and healthy male bears ( $p = 0.22$ ). This contradicts previous research which has shown that lions injured by steel-jaw traps exhibited decreased mobility immediately after the injuries (Bouley et al., 2018). The lack of observed decrease in mobility in my study may be attributed to the fact that the injury did not affect bears' entire paws or limbs but rather resulted in partial injuries of one to three digits, which was not significant enough to impact their mobility. Similarly, Lamb et al., 2022 also discovered that snare-induced injuries did not affect grizzly bears' locomotion, possibly because the injury was confined to their digits. Given the variance in movement rates among individuals, influenced by intrinsic factors such as sex and reproductive status, an analysis that pools all individuals together may fail to adequately capture changes in mobility within a specific individual (Lewis & Rachlow, 2011; Zeller et al., 2019).

Injuries might also have an impact on vertical movement like climbing trees and accessing rugged terrain, which is not captured by daily diffusion rates. Although the injured bears in my study did not have their whole paws or limbs removed, there is a possibility that the energy costs for accessing forage resources on the tree or rugged terrains increased. Asiatic black bears forage on the trees to get fruits or hard masts (Hwang et al. 2002). Previous reports conducted *ex-situ* suggested that although the amputation did not affect the ability of an Asiatic black bear to climb up and down a tree, the energy costs of conducting those activities might have changed and led to a weaker internal drive to obtain higher quality forage on the tree (Dallaire et al., 2012; Jeong et al., 2021).

#### *4.1.2. Home range size and quality*

Although there was not a significant difference in home range sizes between injured and healthy male bears ( $p = 0.23$ ), I found that injured male bears tended to have larger home range sizes (mean = 334.6 km<sup>2</sup>,  $n = 4$ , range = 122.8–700.2 km<sup>2</sup>, SD = 309.0 km<sup>2</sup>) than healthy male bears (mean = 107.4 km<sup>2</sup>,  $n = 5$ , range = 30.5–197.7 km<sup>2</sup>, SD = 89.1 km<sup>2</sup>). The observed difference in home range sizes may stem from the need for injured bears to occupy larger areas to meet their energy demands. This could be attributed to their reduced ability to efficiently obtain high-quality resources, evidenced by lower selection for green vegetation than healthy bears. As suggested by the optimal foraging theory, animals select patches to maximize resource acquisition while minimizing the area of their home range needed to fulfill energy requirements (Mitchell & Powell, 2007). As such, larger home range sizes may imply lower energy intake efficiency due to the limitations of foraging.

On the other hand, I did not observe similar patterns between injured and healthy female bears. This could be attributed to the limitation of data and biological differences between males and females. As mentioned, my dataset only included two injured female bears and one had a short tracking period (97 days), resulting in insufficient data to reveal any differences. Reproductive status of female bears also affects their home range sizes and seasonal habitat use (Jones et al., 2015; Moyer et al., 2007). As such, it might not be appropriate to compare home range sizes among female bears without information about their reproduction status.

In general, Female bears have smaller home range sizes compared to male bears due to lower energy demands and the different nature of reproductive activities. Lower energy



demand might result in less obvious differences between injured and healthy female bears, compared to male bears. Bears have a polygynandrous mating system, where one male can mate with multiple females and one female can mate with multiple males to reduce the risk of sexually selected infanticide (Garshelis, 2009; Morehouse et al., 2021; Naganuma et al., 2021; Steyaert et al., 2011). Therefore, males tend to increase their movements to consort with several females to enhance reproductive success (Sandell, 1989). Since Asiatic black bears are also known to have males that fight for the opportunity to mate with the same female, snare-induced injuries potentially make bears less dominant in mating, forcing injured bears to travel further to find mating partners (Naganuma et al., 2021).

The sex difference also appears in the overall habitat quality level within home ranges. Healthy male bears and healthy female bears showed similar proportions of habitats in each quality level within their home ranges, while injured female bears and injured male bears have different compositions of each habitat quality level. Injured female bears showed larger proportions of the highest and high quality habitats, compared to healthy bears. This serves as a possible reason why injured females did not show larger home range sizes than healthy female bears. On the other hand, injured male bears' home ranges are composed of more low and lowest quality habitats. This is likely why they acquired larger home ranges to fulfill their energy demands.

Considering that home range sizes can be influenced by various environmental, topographical, and anthropogenic factors, it is necessary to incorporate the effect of each factor on home range sizes to further understand the difference in home range sizes

between injured and healthy bears (Ferguson et al., 1999; Mangipane et al., 2018; Powell & Mitchell, 1998).

#### *4.2. Habitat selection patterns*

##### *4.2.1. Population-level habitat selection*

My study indicated that Formosan black bears selected patches with higher TRI, preferred broadleaf forests, and showed a selection of proximity to roads at high elevations and avoidance at low elevations. For multiple bear species, including brown bears and Asiatic black bears, rugged terrains provide abundant forage resources and shelter from humans, and thus bears tend to select these areas, which aligns with my results of bears selecting high TRI patches (Nellemann et al., 2007; Suel, 2019; Takahata et al., 2013). The population-level habitat selection results also reflected the importance of broadleaf forests, providing food resources like acorns and fruits, to Formosan black bears, similar to previous studies (Hwang et al., 2002; Takahata et al., 2017). NDVI, as a criterion for forest productivity, is also a crucial factor bears prefer since high NDVI forests tend to have higher supplies of food resources (Gantchoff et al., 2018; Kuchali et al., 2019; Lara-Díaz et al., 2018; Sells et al., 2022; Yeh, 2020). However, I did not find significant selection toward high NDVI areas in population-level habitat selection, potentially due to the lack of selection of NDVI for injured bears, leading to the non-significant overall results (see section 4.2.2. Injured vs. no-injured bear habitat selection for further discussion).

The selection patterns regarding distance to roads at high, medium, and low elevations reflect bears' responses to varying levels of human activity in the study area. The main

human residential area within the study site is on the east side (Figure S1 (f)), where the road density is high with higher traffic volumes compared to other areas within the study site. Frequent human activities can impact the space use of wildlife, and roads with high traffic volumes often cause higher anthropogenic mortalities, resulting in the avoidance of using areas close to roads (Simek et al., 2015; Skuban et al., 2017). Formosan black bears showed higher selection to the areas closer to roads at high elevations (> 1,500 m) compared to medium elevations (500–1,500 m). Roads on the west side of my study area are at high and medium elevations, and there are only two main roads entering the national park: one on the northwest and the other on the southwest. These roads are partially regulated within the national park, with restrictions imposed from 5:30 pm to 7 am for the northwest one and 5 pm to 7 am for the southwest one. These regulations limit the impact of traffic, particularly during nighttime. Many studies on bear species revealed that it is not uncommon for bears to spatially select the proximity to roads with lower traffic volume (Manville, 1982; Roever et al., 2008; Stewart et al., 2013; Thorsen et al., 2022; Young & Beecham, 1986). Although roads can pose severe threats to wildlife populations, roads with lower traffic volume may serve as travel corridors and benefit the movement between suitable habitat patches (Reynolds-Hogland & Mitchell, 2007).

#### *4.2.2. Injured vs. non-injured bear habitat selection*

The results indicated that healthy bears select patches with higher TRI and NDVI, while injured bears did not show as strong a preference as healthy bears. Injured bears showed stronger avoidance of frequent human activities, through selection of distance to roads at low elevations on the east side of my study area, whereas healthy bears showed temporal avoidance of proximity to roads, regardless of traffic levels.

Different patterns of selection are likely due to the impact of snare-induced injuries on bears' ability to acquire high-quality habitats and fully explore the landscapes. Injured bears showed preferences for neither high NDVI habitats, associated with high productivity forests, nor high TRI habitats, which potentially provide food resources and safeguard areas from humans. As discussed in 4.1., injured bears' ability to climb trees or move on rugged terrains can be impacted, which also leads to the restriction of getting high-quality forage resources. Although I did not find significant avoidance of the proximity to trails and roads at high elevations, the inability to access rugged terrain could affect injured bears' ability to promptly escape from humans.

These patterns could also be the trade-offs between energy gain efficiency and avoidance of dangers. In this study, I found that injured bears showed a significant effect of avoiding roads at lower elevations, while healthy bears did not show any significant effect. This avoidance likely resulted from the stronger human-induced fear on bears that were trapped and injured before, compared to the bears that have not been exposed to the negative event (Moleón & Sánchez-Zapata, 2023; Støen et al., 2015). Although trapping might not have the same impact as other armed hunting practices like shooting using firearms, the memory of being trapped may sensitize the animal to its environment. This could result in increased wariness and decreased motivation to explore the landscape to secure higher-quality forage (Conover, 2001). Additionally, due to the lack of direct interactions with humans, they are more likely to avoid habitat characteristics associated with past trapping events instead of human presence. These habitat traits, which are often in proximity to areas with heightened human accessibility such as roads, could serve as

deterrents for wildlife presence. This aligns with the result indicating that injured bears showed spatial avoidance of areas with frequent human activities.

In recent years, snare traps have typically been set close to villages, often within a one-day hike distance. These areas might symbolize high risks for bears, where subadult or less dominant individuals tend to use. As such, it is also possible that injured bears were initially less dominant individuals, making them more susceptible to being caught by snare traps.

On the other hand, healthy bears did not show distinctive spatial avoidance of human-dominant areas; rather, they showed a temporal avoidance of roads, which is associated with human activities. Shifting temporal activity patterns is a common reaction of bears to avoid human encounters, and this strategy enables bears to obtain areas with high-quality forage while minimizing the risks (Hertel et al., 2016; Hilderbrand et al., 2019; Kautz et al., 2021). Injured bears, however, might lack the plasticity to adjust their temporal activities, leading to increased encounters in areas with relatively low human pressure and can trigger negative human-bear interactions in those areas. Lamb et al., 2022 reported that grizzly bears that had toes injured due to foot-hold traps were possibly more likely to engage in human-bear conflicts, which might have resulted from the lack of behavioral plasticity to avoid humans. Another possible reason why injured bears showed spatial avoidance but not temporal avoidance is the limitation of injured bears' access to rugged terrains. Injured bears prefer areas closer to roads at high elevations (> 1,500 m), and these areas usually have more rugged terrains compared to areas at low elevations (< 500 m). As such, injured bears possibly rely more on areas closer to roads to access patches that provide forage opportunities since roads can serve as travel

corridors as mentioned in 4.2.1. *Population-level habitat selection*, leading to the lack of avoidance during daytime.

This study demonstrated the long-term behavioral impacts of snare-induced injuries on Formosan black bears' space use patterns and behavior, including mobility, home range formation, and habitat selection. Injured bears, overall, needed more space to fulfill their energy demand due to the restriction of access to high-quality habitats. However, several limitations must be acknowledged, including the bias of tracking data and the lack of consideration of the severity of injuries. It is known that individual differences in habitat selection can be influenced by intrinsic factors like fitness and reproductive status; therefore, it might be hard to elucidate the overall trend of the impact of injuries with only 15 bears (Leclerc et al., 2016). It was also challenging to categorize the severity of injuries (i.e. the number of digits lost) with 15 bears, so there might be differences depending on the severity of injuries that were not reflected in this research. To further explore the impact of snare trapping on bears' space use, it is necessary to understand the distributions of snare traps in the landscape and how bears react to them. However, since hunting-related data are often sensitive and challenging to obtain, this study did not reveal the direct alteration of snare traps on bears' space use.

My research focuses on the bears inhabiting within or close to YSNP, a protected area, which might not be the most ideal site to explore the effect of anthropogenic activities due to the overall low human impact. Bears are highly adaptive animals and are sensitive to human activities, so the impact of injuries might change in a landscape that is more disturbed by humans (Kautz et al., 2021). However, it is worth noticing that the Formosan black bear is endangered in Taiwan; therefore, obtaining data from 15 GPS-

collared individuals undoubtedly contributes to enhancing our understanding of the species and habitat traits bears prefer to inform future conservation plans for YSNP and surrounding areas.

To better understand how snare-induced injuries impact bears' fitness, it is also important to compare bears' reproductive activities such as litter sizes and intraspecies interactions like competition between injured and healthy bears. Data with shorter tracking periods can also advance understanding of the strategies of bears selecting their habitats and their movement ability, providing insights into bears' forage strategy at a finer temporal scale.

#### *4.3. Conservation and Management Implications*

Formosan black bears are endangered, and the recent escalation of snare trapping issues has been threatening this species. The findings of this study underscore the urgent need for stronger enforcement of regulations of snare traps. Addressing the escalating threat of snare trapping to Formosan black bears requires strategic conservation approaches tailored to different contexts, aimed at 1) mitigating the impact of traps on bears and 2) prohibiting trapping activities using snare traps. Frequent checking of traps, ideally every 24 hours, is considered an effective way to mitigate the impact of each trap and prevent animals from being trapped for extended periods, which can reduce their suffering and injuries (Proulx & Rodtka, 2019). Additionally, innovative trap designs tailored for specific wildlife can help reduce by-catch issues: in Japan, snare traps are required to have tightening prevention metal fittings which ensure the target species would not be severely injured due to the trap and there are novel snare traps designed only for wild boars and deer. In Taiwan, the government currently encourages hunters to use snare

traps with diameters smaller than 12 cm to replace commercial snare traps, aiming to decrease the chance of catching Formosan black bears. Such snares may decrease the by-catch of bears but continue to cause injured bears based on the report of Japanese black bears. Therefore, the management plan should include regulating the areas where hunters can place traps, such as avoiding areas of hot spots of bear distribution.

In addition to mitigating the impacts of snare traps on bears, increased public awareness about the harmful impacts of snare traps on wildlife populations is crucial for fostering conservation action. Research priorities should include understanding the full extent of the impacts of snare traps on bear populations and investigating long-term population dynamics and non-lethal impacts to inform evidence-based conservation strategies.



## 5. CONCLUSION

This study quantified the behavioral impacts of snare-induced injuries on Formosan black bears. The findings suggest that while snare-induced injuries did not significantly affect bears' horizontal mobility or home range formation, they may impact bears' ability to efficiently obtain high-quality resources and alter their behavior in response to human presence. While injured bears exhibited spatial avoidance of human-dominant areas, they may lack the plasticity to adjust their temporal activities, potentially leading to increased encounters in areas with relatively low human pressure and triggering negative human-bear interactions. Moving forward, it is crucial to address the escalating threat of snare trapping to Formosan black bears through strategic conservation approaches. This includes stronger enforcement of regulations, such as frequent checking of traps and innovative trap designs tailored for specific wildlife. Community involvement and increased public awareness are also essential for reducing the usage of snare traps and fostering conservation action. Further research should prioritize understanding the full extent of the impacts of snare traps on bear populations and investigating long-term population dynamics to inform evidence-based conservation strategies.

## ACKNOWLEDGEMENT

I would like to express my sincere gratitude to Tsai Ron-Tsan Funding, the University of Michigan, and the National Ping-tung University of Science and Technology for providing funding for this research and facilitating my fieldwork. I am indebted to Dr. Neil Carter for his valuable feedback and innovative ideas that enhanced the quality of my analyses and refined my research questions. Special thanks to Dr. Kirby Mills, Dr. Martin Leclerc, Amy Zuckerwise, and Madi Standen for their invaluable assistance with GPS data processing, home range size analyses, habitat selection, and remote sensing data extraction. Their guidance greatly contributed to the improvement of my research methods and my confidence in using R. I am also grateful to the members of the CoCo lab for their unwavering support and the nurturing environment they provided during my time at the University of Michigan. I would also like to thank the ESA lab for providing the necessary resources, particularly computers, which facilitated the completion of complex analyses.

Furthermore, I am deeply thankful to Dr. Mei-Hsiu Hwang for her invaluable feedback and expertise regarding the Formosan black bear. Additionally, I extend my appreciation to the students at NPUST, especially Riva Lu, He-Jie Shu, and Yu-Chia Chen, for their selfless assistance during the progression of my thesis. I am also grateful to the research group for their diligent fieldwork, which enabled the collection of crucial data on this mysterious endangered bear species in Taiwan. Without Dr. Hwang and her group's guidance, I would not have been able to discern inappropriate factors for bears or identify potential inaccuracies in geospatial data layers.

I also thank my friends from all over the world and my family for emotionally and financially supporting me to finish my master's degree. Without them, I would not have been able to accomplish all of my thesis work. Thank you again to everyone who has helped me throughout my research journey.

Last but not least, I thank the bears that were collared in this research. Although collaring was suggested to have low impacts on individuals, it could still be uncomfortable wearing a collar for as long as 2~3 years. Without their help, it would have been impossible to understand the impact of snare-induced injuries and further inform the decision-making process to regulate the usage of snare traps. I sincerely thank my research animals and their contribution to this research.

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## TABLES

Table 1. Status and tracking information of fifteen Formosan black bears. The 'Tracking Period' column indicates the start and end date of the data used in the analyses, beginning 4 days post-capture to reduce the potential impact of immobilization stress. Sex and age classifications are denoted by the initial two letters: 'F' for female, 'M' for male, 'A' for adult, and 'S' for subadult (bears under 1.5 years at the time of capture).

MS: Male subadult, MA: Male adult, FS: Female subadult, FA: Female adult

ID	Injury Status	Tracking Period	Day	Interval	Fixes	Fix Rate	Ave. Fix Rate
FA16698	Y	2014/11/15 - 2015/06/29	225	5 hr	796	73.43%	
FA16703	N	2014/11/16 - 2015/10/12	330	5 hr	1342	84.62%	
MA16708	N	2014/11/24 - 2015/09/06	286	5 hr	842	61.28%	
FS16702	N	2014/12/19 - 2015/10/01	286	5 hr	1154	83.81%	
MA16709	Y	2014/12/31 - 2016/07/22	570	5 hr	1638	59.89%	60.87%
		2016/07/23 - 2016/09/05	43	8.5 hr	101	82.79%	
MA16704	Y	2015/07/15 - 2016/07/08	359	5 hr	688	39.86%	34.09%
		2016/07/13 - 2017/01/27	203	8.5 hr	91	16.28%	
FA16707	N	2015/12/25-2016/01/08	15	5 hr	47	68.12%	79.58%
		2016/01/08 - 2018/03/29	811	8.5 hr	1831	79.92%	
FA16699	Y	2016/05/04 - 2016/08/09	97	8.5 hr	234	84.78%	
FA16706	N	2016/07/05 - 2018/02/13	588	8.5 hr	1371	82.59%	
MS39916	N	2020/11/17 - 2021/05/05	371	8.5 hr	794	76.45%	
		2021/05/11 - 2021/11/23					
MA39919	Y	2021/03/26 - 2021/08/06	133	8.5 hr	168	44.44%	
MA39915	N	2021/04/30 - 2021/12/29	243	8.5 hr	386	56.25%	
MA39917	N	2021/05/07 - 2022/11/14	556	8.5 hr	1348	85.94%	
MA39920	Y	2021/06/06 - 2023/06/29	753	8.5 hr	1319	61.99%	62.04%
		2023/06/30 - 2024/02/29	244	5hr	727	62.14%	
MA39918	N	2021/07/16 - 2023/06/17	701	8.5 hr	1375	69.51%	66.22%
		2023/06/18 - 2024/02/29	257	5hr	752	60.95%	

Table 2. Environmental variables, variable type, range, and sources of the covariates used to parameterize Formosan black bear habitat selection.

Variable	Variable Type	Range	Source
Elevation	Continuous	4-3945 m	20-m resolution DEM (Ministry of the Interior (MoI), Taiwan)
Distance to Road	Continuous	0-21299 m	OpenStreetMap National Land Surveying and Mapping center, MoI, Taiwan* Forest Road Layer, Forest Bureau
Distance to Water	Continuous	0-2507 m	Water Resource Databases Integration and System Platform, Taiwan
Distance to Trail	Continuous	0-22819 m	YSNP Headquarters OpenStreetMap Happyman Map Rudy Map
Normalized Difference Vegetation Index (NDVI)	Continuous	-0.19-0.81	Landsat 8 Imagery (United States Geological Survey)
Terrain Ruggedness Index (TRI)	Continuous	0-462.56	Calculated from DEM
Land Cover Type	Categorical	Other land cover type Broadleaf Forest Mixed Forest Coniferous Forest	4th Forest Resources Survey (Forest Bureau, Taiwan)

\* provided by the Forestry/GIS Lab at NPUST

Table 3. Diffusion rates and 95% home range sizes calculated by optimally weighted Autocorrelated Kernel Density Estimation (wAKDE) of the 15 Formosan black bears in Yushan National Park.

ID	Diffusion Rate (hectares/day) (95% CI)	95% wAKDE (km <sup>2</sup> ) (95% CI)
FA16698	35.21 (32.68–37.82)	21.39 (13.06 - 31.78)
FA16703	103.82 (95.17–112.85)	28.83 (22.93 - 35.39)
MA16708	87.15 (78.22–96.54)	32.79 (23.79 - 43.21)
FS16702	51.15 (46.25–56.29)	16.27 (12.40 - 20.66)
MA16709	84.45 (78.35–90.77)	342.33 (170.66 - 572.74)
MA16704	113.16 (100.44–126.62)	792.96 (319.90 - 1477.02)
FA16707	50.42 (46.86–54.10)	126.16 (74.56 - 191.10)
FA16699	17.60 (13.94–21.67)	52.80 (16.30 - 110.37)
FA16706	33.93 (31.07–36.92)	45.48 (31.61 - 61.83)
MS39916	57.79 (53.15–62.62)	64.38 (40.99 - 92.98)
MA39919	164.39 (137.97–193.09)	180.27 (77.21 - 326.26)
MA39915	40.87 (33.98–48.39)	72.85 (33.19 - 127.85)
MA39917	166.74 (152.72–181.35)	196.86 (135.49 - 269.50)
MA39920	139.36 (130.54–148.45)	102.18 (82.79 - 123.57)
MA39918	88.14 (83.71–92.67)	233.68 (153.29 - 330.74)

## FIGURES

(a)



(b)



Figure 1. Photos of bears injured by snare traps and a snare trap. (a) Bear paws that were injured by snare traps (b) Commercial snare trap (Photos are provided by Dr. Mei-Hsiu Hwang).



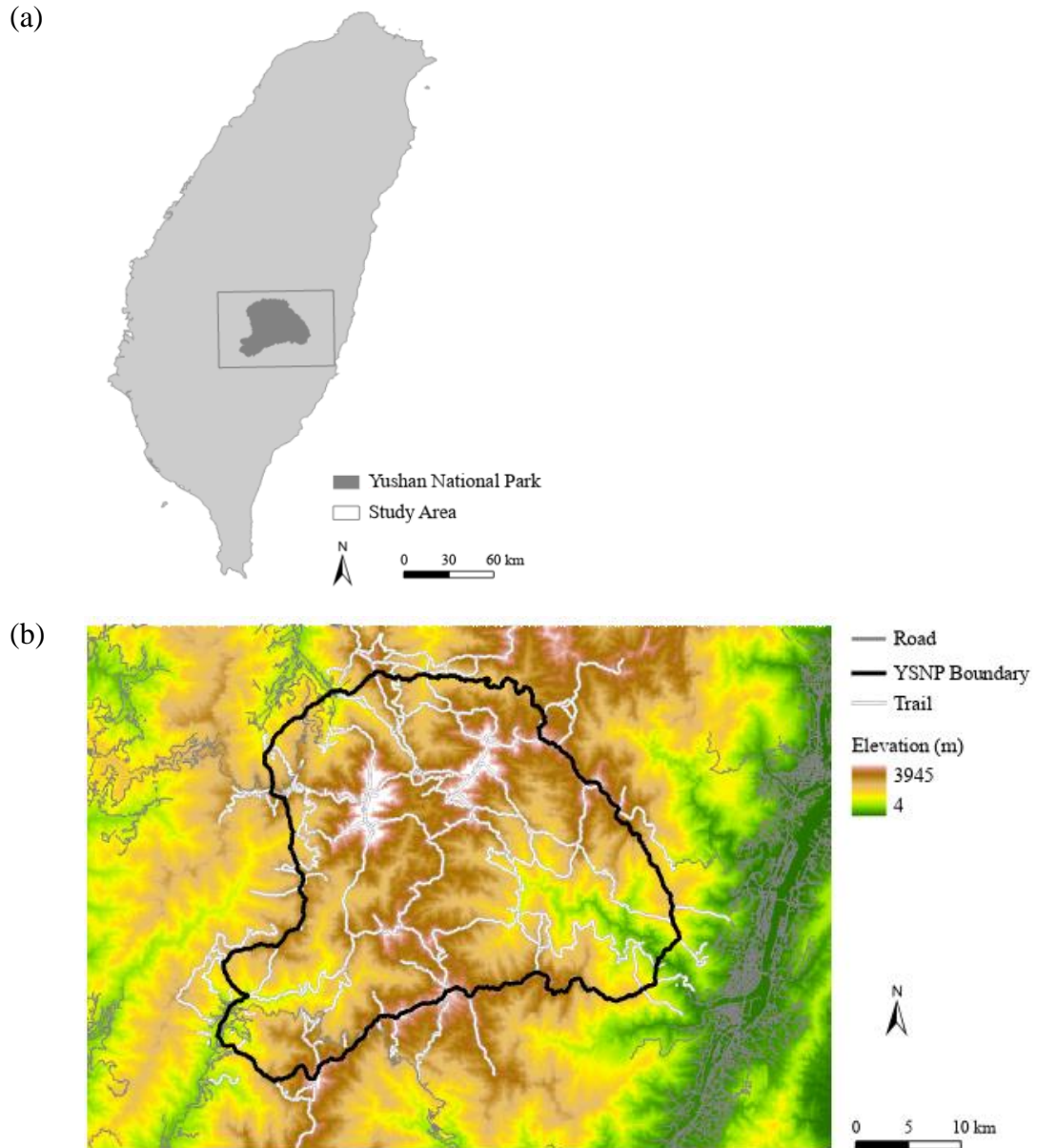


Figure 2. Study site. (a) Map illustrating the study site around Yushan National Park (YSNP), depicted in dark gray. The square indicates the specific area investigated in this research. (b) Surrounding environment of YSNP, showing roads (gray lines), trails (white lines), and the park boundary (black line). The base layer shows the elevation of the area, ranging from 4 to 3945 m (spatial resolution = 30 m).

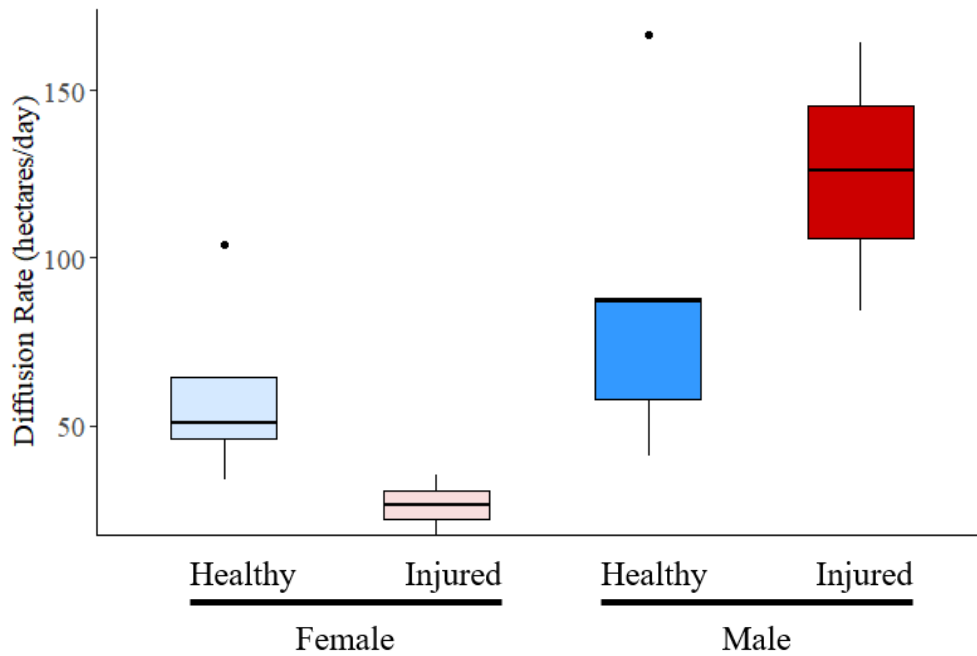


Figure 3. Boxplots of diffusion rates of injured and healthy Formosan black bears by sex. The diffusion rate reflects the daily area occupation potential in hectares per day, among injured and healthy bears separated by sex. Healthy females are represented in light blue, injured females in pink, healthy males in blue, and injured males in red. Group sample sizes are as follows: 4 healthy females, 2 injured females, 5 healthy males, and 4 injured males.

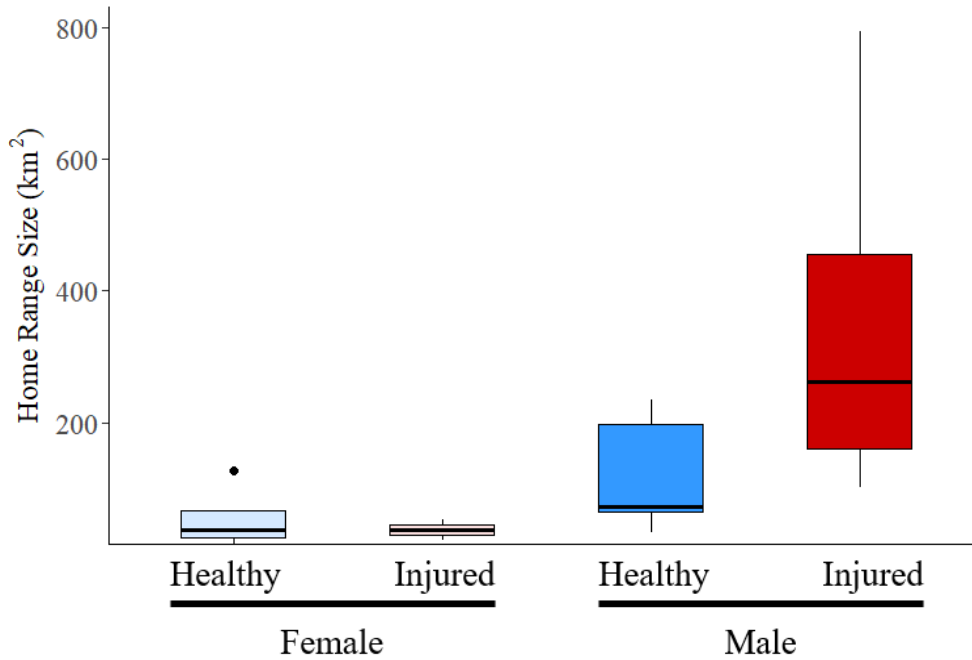
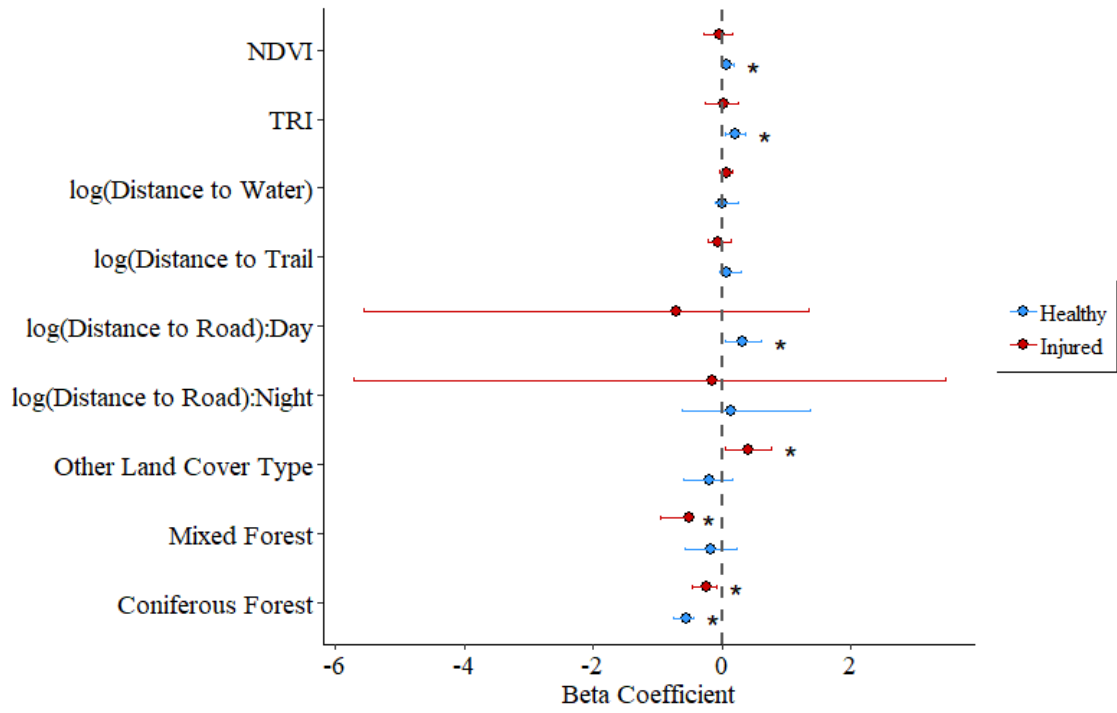


Figure 4. Boxplots of home range sizes of injured and healthy Formosan black bears by sex. Home range sizes in square kilometers (km<sup>2</sup>) are depicted for injured and healthy bears separated by sexes. Healthy females are represented in light blue, injured females in pink, healthy males in blue, and injured males in red. Home range estimates were derived using the 95% optimally weighted Autocorrelated Kernel Density Estimation (wAKDE) method. Group sample sizes are as follows: 4 healthy females, 2 injured females, 5 healthy males, and 4 injured males.

(a)



(b)

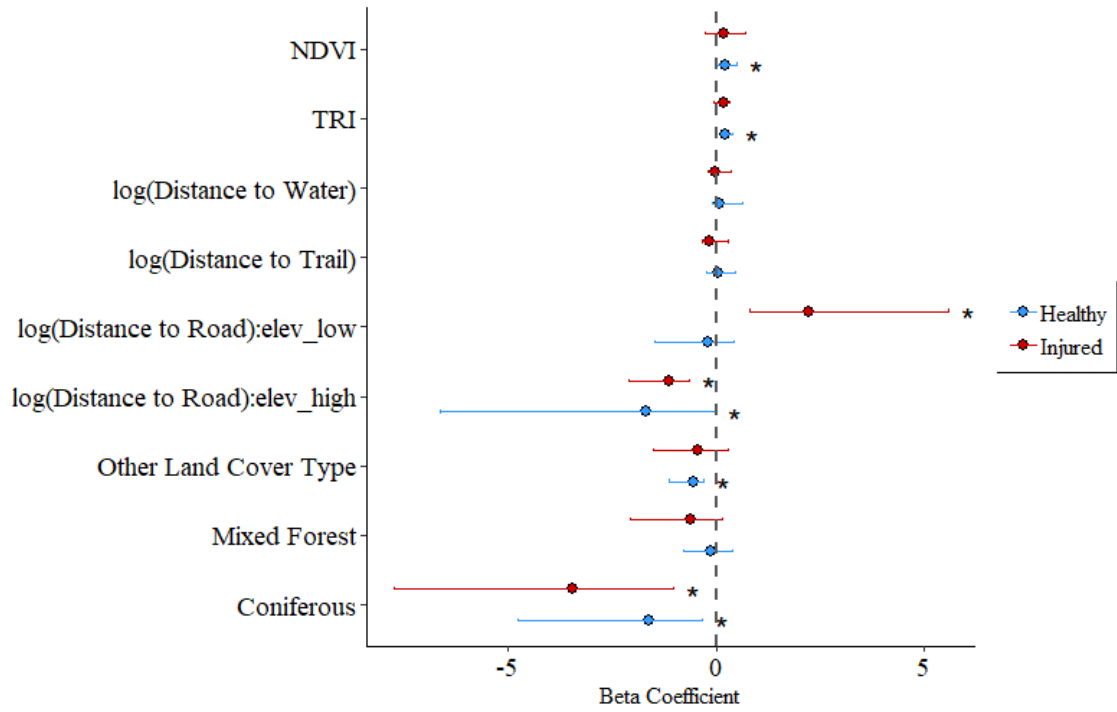


Figure 5. Habitat selection results of injured (red) and healthy (blue) bears. The Y axis shows the environmental covariates that I used in the habitat selection models, including Normalized Difference Vegetation Index (NDVI), Terrain Ruggedness Index (TRI), log-transformed distance to water bodies, log-transformed distance to trails, log-transformed distance to road, and land cover types. Land cover types include coniferous forests, mixed forests, broadleaf forests, and other land cover types, with the reference category set as broadleaf forests. (a) Results of integrated step selection function (iSSF) where interaction terms of time of day with log-transformed distances to roads were employed to compare different temporal human avoidance patterns, (b) Results of integrated resource selection function (iRSF), where interaction terms of three elevation categories (low (<500 m), medium (500-1,500 m; reference category), and high (> 1,500 m)) with log-transformed distance were used to differentiate the intensity of road usage at different elevations.

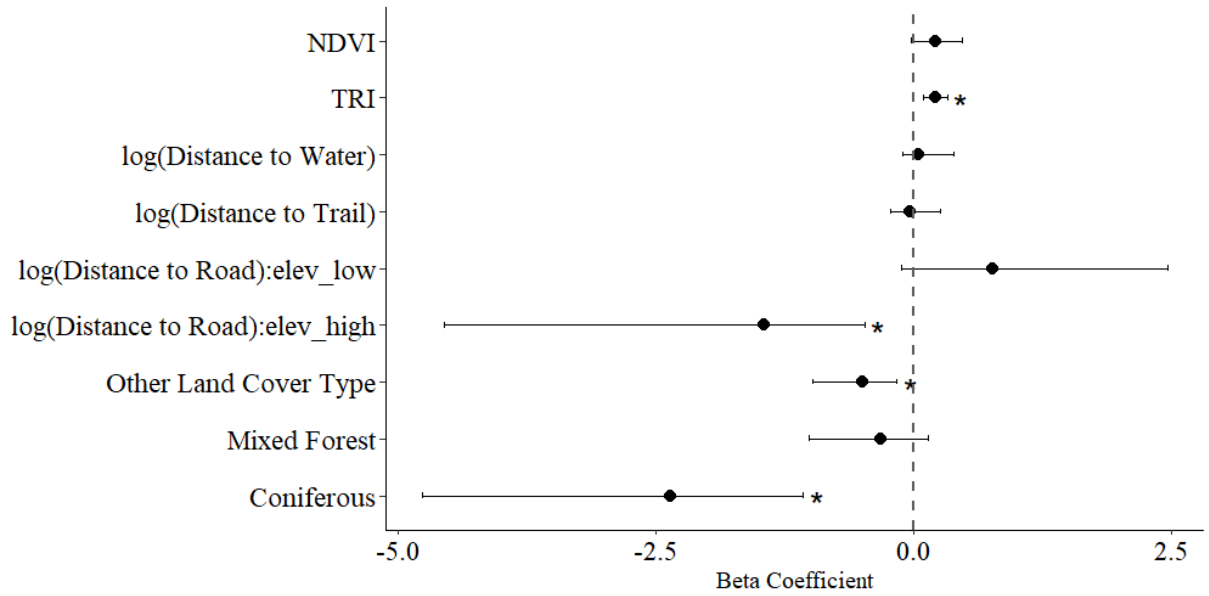


Figure 6. Population-level integrated resource selection function (iRSF) results. The Y axis shows the environmental covariates that I used in iRSF, including Normalized Difference Vegetation Index (NDVI), Terrain Ruggedness Index (TRI), log-transformed distance to water bodies, log-transformed distance to trails, log-transformed distance to road interacting with different elevation categories (low (< 500 m), medium (500-1,500 m), and high (> 1,500 m)), and land cover types. Land cover types include coniferous forests, mixed forests, broadleaf forests, and other land cover types, with the reference category set as broadleaf forests.

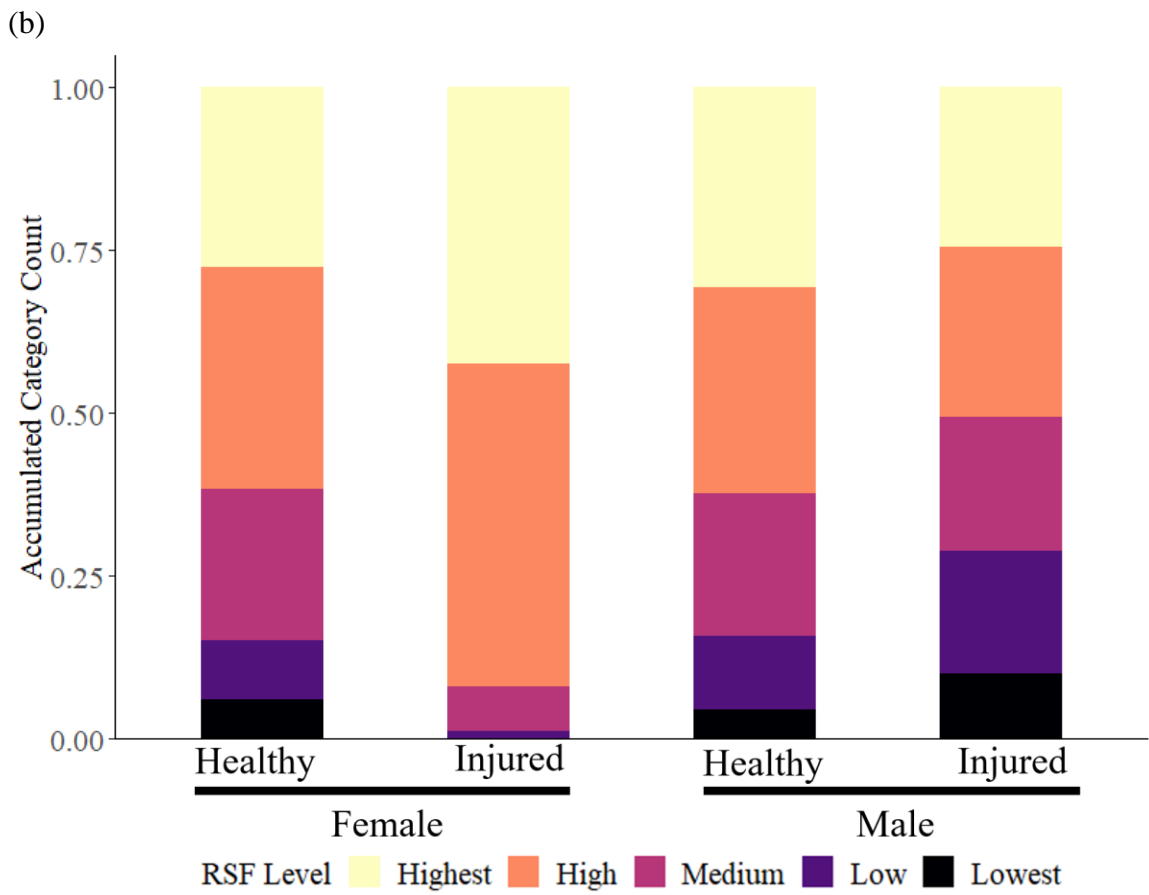
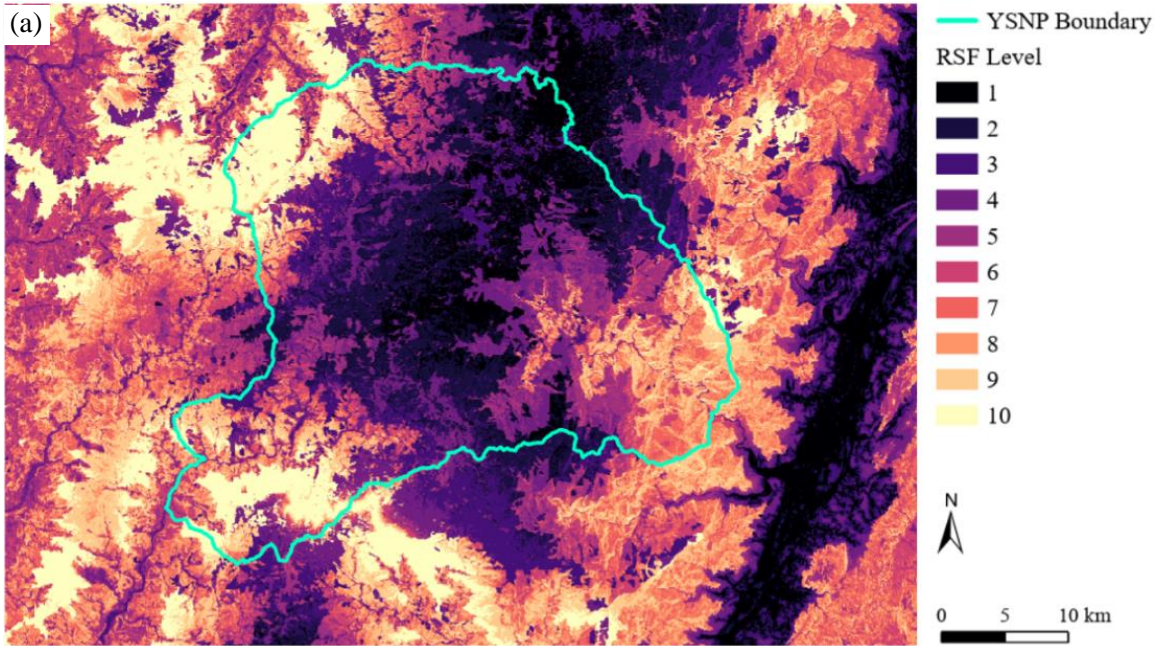


Figure 7. Predictive habitat quality map and average habitat quality within home ranges of injured and healthy bears by sex. (a) Predictive habitat map for 15 bears around Yushan National Park (YSNP). Values represent the quantile-binned relative habitat use values calculated from the iRSF results. RSF level 1 (dark purple) shows the lowest quality habitats and level 10 (yellow) shows the highest quality habitats, (b) Bar chart illustrating the proportion of habitat quality within injured and healthy bears' home ranges by sex. I combined two levels in (a) as one habitat quality level here: levels 9 and 10 were as highest, levels 7 and 8 as high, levels 5 and 6 as medium, levels 3 and 4 as low quality habitats, and levels 1 and 2 as lowest quality habitats.



## SUPPLEMENTARY TABLES AND FIGURES

Table S1. GPS fixes of Formosan black bears in Yushan National Park that were used in my study for integrated Resource Selection Function (iRSF) and integrated Step Selection Function (iSSF). Only fixes with 8.5 hour intervals were used in iSSF, leading to the fewer fixes compared to fixes used for iRSF.

ID	Injury Status	Fixes used for iRSF	Fixes used for iSSF
FA16698	Y	796	
FA16703	N	1342	
MA16708	N	842	
FS16702	N	1154	
MA16709	Y	1739	43
MA16704	Y	779	49
FA16707	N	1878	1138
FA16699	Y	234	144
FA16706	N	1371	935
MS39916	N	794	451
MA39919	Y	168	30
MA39915	N	386	180
MA39917	N	1348	610
MA39920	Y	1143	422
MA39918	N	1468	571

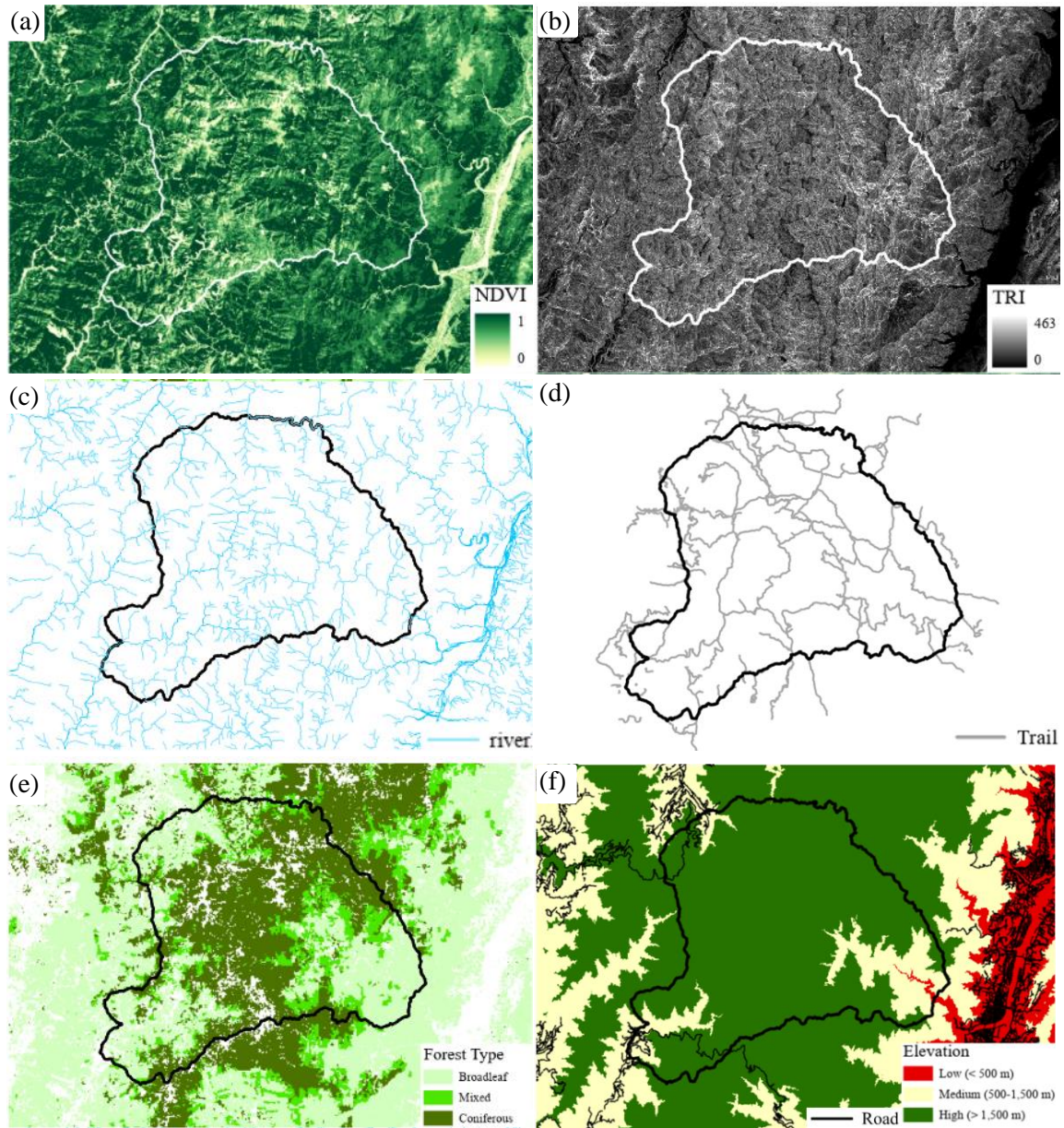


Figure S1. Environmental Covariates Used for Habitat Selection Models. The boundary of Yushan National Park was shown on each map. (a) Normalized Difference Vegetation Index (NDVI) Roads (b) Terrain Ruggedness Index (TRI) (c) Rivers and other water bodies (d) Trails (e) Land cover types (f) Elevation with road map.

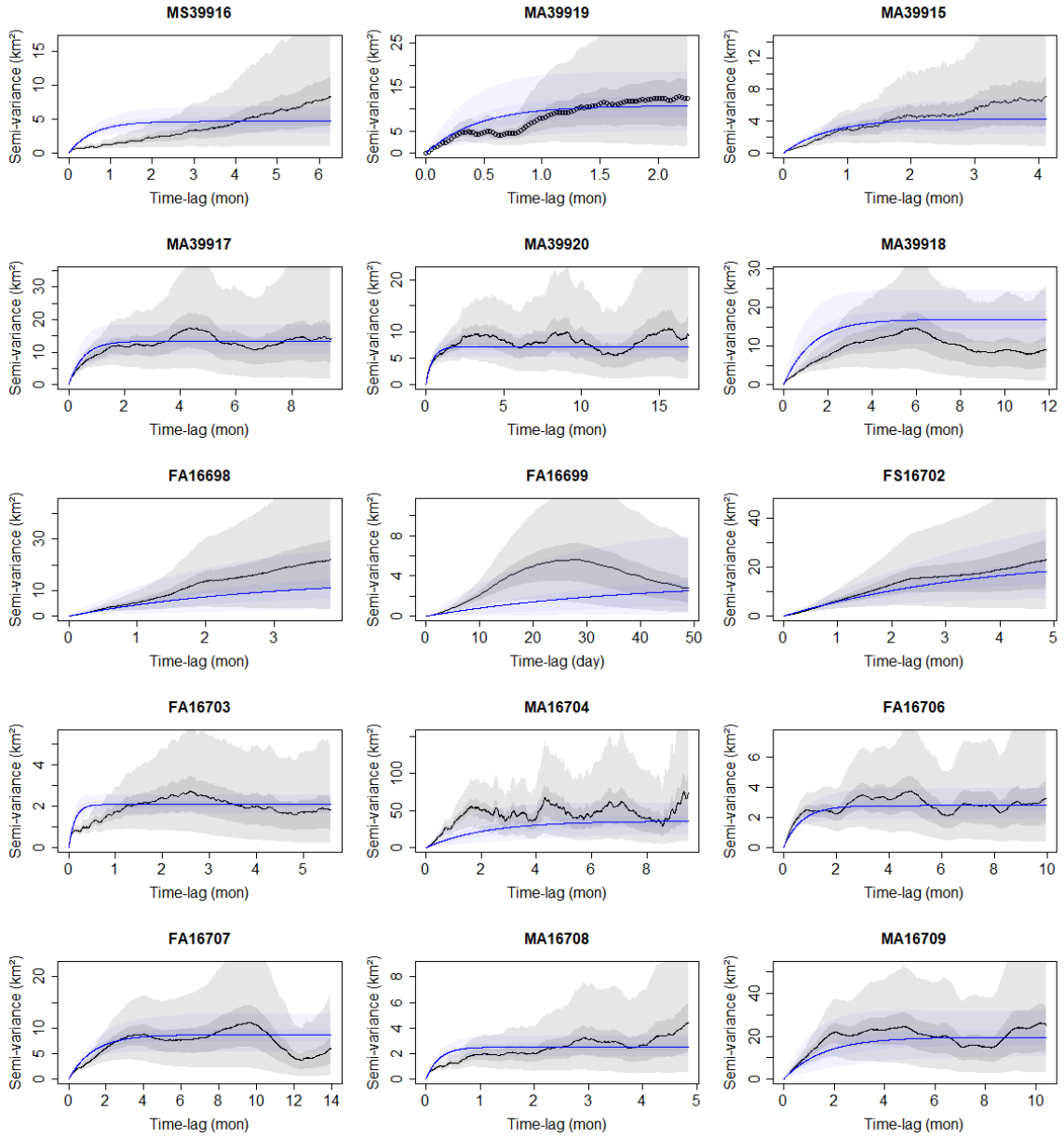


Figure S2. Variograms of 15 Formosan black bears captured in Yushan National Park. The variogram shows the average square distance an individual travels (y axis) within certain time lag (x axis). A flattened variogram represents residents, indicating that Autocorrelated Kernel Density Estimation is appropriate for calculating the home range size of the individual. The blue line and the shade in each graph represent the estimated values and 95% confidence intervals of the best fit movement model identified by maximum likelihood. MS39916, FA16698, and FS16702 did not show residency according to the variograms.