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Animal occurrence and space use change in the landscape of anthropogenic noise

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ABSTRACT

Habitat fragmentation, destruction, and disturbance are major threats to biodiversity. Global road networks represent one of the most significant human impacts on ecosystems, and a spatially extensive source of anthropogenic disturbance and noise. We developed a novel approach by combining traffic monitoring with noise mapping on the basis of a standardized traffic-noise stimulus generated by controlled vehicle operation to investigate temporal and spatial heterogeneity of traffic noise. We used animal presence or absence, radio-telemetric monitoring of space use, and remotely sensed habitat characteristics with occupancy modeling and spatial analysis to assess influences of distance from roads, habitat characteristics, and traffic noise level on site occupancy and space use of Mt. Graham red squirrels (*Tamiasciurus hudsonicus grahamensis*). Traffic noise had spatially extensive and negative effects on site occupancy. Animal occurrence decreased as traffic noise increased after accounting for distance from roads. Traffic noise levels in animal core home ranges were lower than noise levels within total home ranges. Our study disentangled effects of traffic noise from confounding environmental characteristics and demonstrated the chronic impacts of traffic noise on animal distribution. We highlight the importance of incorporating spatial and temporal heterogeneity of traffic noise at a local scale when investigating effects of anthropogenic noise on wildlife.

1. Introduction

Habitat fragmentation, destruction, and disturbance are major threats to biodiversity (Millennium Ecosystem Assessment, 2005). Impact of anthropogenic noise is of concern due to an increasing human population, expanding infrastructure and energy development, and growth in air travel as well as motorized recreation in natural areas (Miller, 2008; United Nations, 2011). Noise that arises from infrastructure such as oil compressors can affect animal communication and behavior, reduce reproductive success and further influence habitat quality and animal distribution (Barber et al., 2010; Bayne et al., 2008; Francis and Barber, 2013).

Measuring nearly 65 million km in length, road networks across the world represent one of the most significant human impacts on nature and wildlife, and a spatially extensive source of anthropogenic disturbance and noise (Central Intelligence Agency, 2014; Forman and Alexander, 1998). Animal abundance and richness are reduced near roads and impacts of roads on population density and community structure can extend to several kilometers from the road (Benítez-López et al., 2010; Fuentes-Montemayor et al., 2009). Vehicles cause wildlife mortality and introduce disturbance including vehicular noise, movement, vibration, exhaust fumes, dust, headlight illumination and human presence (Trombulak and Frissell, 2000). Traffic noise is often related to animal avoidance of areas adjacent to roads (Barber et al., 2010). However, few studies separate effects of traffic noise from other confounding environmental factors or forces related to distance from roads. Environmental changes associated with edges created by roads may affect habitat quality and further influence animal populations and distribution (Murcia, 1995). Coincidence between increase in richness or abundance with increasing distance from roads, and the negative relationship between traffic noise and distance from roads, have been taken as evidence that traffic noise affects diversity (Barber et al., 2010; Fahrig and Rytwinski, 2009; Summers et al., 2011). Recently, acute effects of traffic noise on species richness of migratory birds were demonstrated by introducing traffic noise to roadless areas through playback experiments (McClure et al., 2013). Nevertheless, studies and evidence of chronic impacts of traffic noise on habitat quality and animal occurrence are scarce. To better understand how habitat fragmentation and human disturbance affect animal populations and to inform management and mitigation for expanding anthropogenic disturbance, it is important to disentangle effects of traffic noise from distance to roads and environmental characteristics.

In this study, we used an endangered forest dependent species, the Mount Graham red squirrel (*Tamiasciurus hudsonicus grahamensis*), as our study organism to test hypotheses to explain negative effects of roads on animal occurrence. We developed a novel approach to investigate temporal and spatial heterogeneity of traffic noise by combining

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traffic monitoring with noise mapping on the basis of a standardized traffic-noise stimulus generated by controlled vehicle operation. We used animal presence or absence, radio-telemetric monitoring of movement, and three-dimensional remote sensing (LiDAR, Light detection and ranging) to quantify environmental characteristics in combination with site occupancy models and spatial analysis to assess influences of distance to roads, environmental characteristics, and traffic noise level on animal occurrence and space use.

2. Material and methods

2.1. Study area and study species

The southwestern United States represents one of the most important regions for biodiversity in North America (Stein, 2002) and the isolated montane forests known as sky islands are refugia for many species. However, continued expansion of the human population and associated infrastructure development (Arizona Department of Transportation, 2006) along with long term projections of significant redistribution and fragmentation of forests due to climate change (Opdam and Wascher, 2004; Weiss and Overpeck, 2005) threaten survival of endemic species and exacerbate levels of isolation in the region. Our study was conducted in 149.5 ha of mixed-conifer forest >3000 m elevation atop Mt. Graham, an isolated, 3267-m peak located in the Pinaleño Mountains, Graham County, Arizona, USA (32° 42′ 06″ N, 109° 52′ 17″ W), and home to critically endangered Mt. Graham red squirrels. The North American red squirrel is a small (<300 g), diurnal tree squirrel with a wide-ranging distribution in Canada and the United States (Steele, 1998). The Mt. Graham red squirrel is a subspecies that is isolated and endemic to high elevation forests (>2000 m) of the Pinaleño Mountains, and represents the southernmost population of red squirrels (Brown, 1984; Steele, 1998). Red squirrels relies on cone scale piles known as middens to store food for winter survival (Hurly and Lourie, 1997; Steele, 1998). Middens are typically located in forests with dense canopy and understory cover and provide a cool and moist microclimate that prevents cones from opening and releasing seeds (Merrick et al., 2007; Smith and Mannan, 1994; Zugmeyer and Koprowski, 2009). Because of geographic isolation, low population numbers (~300 individuals, Sanderson and Koprowski, 2009), and habitat destruction, Mt. Graham red squirrels were listed as federally endangered in 1987 (U.S. Fish and Wildlife Service, 1987). In addition to habitat loss, severe fire, and insect damage, a potential threat to Mt. Graham red squirrels is human disturbance from recreation, road traffic, and habitat modification associated with road improvement (Buenau and Gerber, 2004; U.S. Fish and Wildlife Service, 2011; Zugmeyer and Koprowski, 2009).

We focused our work on 3.7 km of 3 graded dirt roads: Arizona State Highway 366 also known as Swift Trail (6- to 13-m wide, annual average daily traffic [AADT]: 50 vehicles, hereafter, high traffic), the Bible Camp Road (4- to 9-m wide, AADT: 25 vehicles, hereafter, medium traffic), and Soldier Trail (3- to 24-m wide, AADT: 7 vehicles, hereafter, low traffic). Speed limit was 40 km/h. Roads were closed to the public from 15 November to 15 April annually due to snow. The forest was dominated by Douglas-fir (*Pseudotsuga menziesii*), southwestern white pine (*Pinus strobiformis*), and corkbark fir (*Abies lasiocarpa* var. *arizonica*) interspersed with Engelmann spruce (*Picea engelmanii*), aspen (*Populus tremuloides*) and ponderosa pine (*Pinus ponderosa*, Sanderson and Koprowski, 2009).

2.2. Quantification of traffic noise and background sound level

Acoustic landscape of noise, defined as the spatial extent of noise exposure, is complicated by spatial and temporal variation. Transmission of traffic noise is affected by road condition, vegetation, vehicle types, traffic load and traffic speed (Garg and Maji, 2014). Noise playback experiments have been used to control these factors, but the full frequency spectrum of traffic noise and temporal aspects of noise source cannot be generated by this approach (Pater et al., 2009). We controlled these factors while maintaining the sound profile of traffic noise and obtained information of spatial variation of noise transmission by using controlled vehicle operation as a standardized traffic-noise stimulus. We explored temporal variation of traffic noise by monitoring traffic intensity through a year.

2.2.1. Measurement and mapping of traffic noise level

To generate a standardized traffic-noise stimulus, we drove a sport utility vehicle (SUV, 2009 Escape Hybrid, Ford Motor Company, Dearborn, Michigan, USA) at 32 km/h on high and medium traffic roads and at 24 km/h on the low traffic road. The driving speed was determined on the basis of speed limit and road condition. We used an extension for ArcGIS (Environmental Systems Research Institute), XTool Pro (Data East LLC, Novosibirsk, Russia), to create a sampling grid with 50 m × 50 m grid size and randomly selected 50% of grid cells to measure sound pressure levels (dB) of the standardized traffic-noise stimulus in a random order. Most vehicle noise events last for 20 s (Brown et al., 2013). Therefore, we measured traffic noise for 20 s beginning when the SUV was 100 m from the sampling locations with a handheld CEL-244 integrating basic sound-level meter (Casella CEL, Buffalo, New York) equipped with a small foam windscreen, set to A weighting, 30–100 dB range, and impulse response. Sound level meters were calibrated with a CEL-120/2 calibrator (Casella CEL, Buffalo, New York) before use. We recorded equivalent continuous sound level (L_{eq}) and maximum power (L_{max}) with a 5 dB exchange rate and recorded ≥4 measurements at each location from 8:00 to 17:00, during which red squirrels are active and when most traffic occurs. We used polynomial regression models to assess how traffic noise attenuates with increased distance from roads. We used the Ordinary Kriging geostatistical interpolation method under GeoStatistical Analyst extension in ArcMap 10.1 (Environmental Systems Research Institute) to create the surfaces (25-m resolution) of L_{eq} and L_{max} of the standardized traffic-noise stimulus for the entire study area (Fig. 1). We evaluated performance of created surfaces by comparing measured values with the predicted values and assessing standard errors of observation and prediction. If our prediction is unbiased, the mean standardized prediction error should be near zero. We combined estimated traffic noise levels and recorded traffic volume to create traffic noise indices for occupancy modeling.

2.2.2. Traffic monitoring

We used bi-directional traffic counters (TRAFx Vehicle Counter Model G3, TRAFx Research Ltd., Canmore, Alberta, Canada) to record traffic on the 3 roads in 2013. Traffic counters were placed at the roadside for each road and set to a slow rate, 3 s delay, 014 threshold of sensitivity with time stamp mode that records time when vehicles are detected. Additionally, we placed 1 traffic counter (slow rate, 0.5 s delay, 008 threshold of sensitivity) at a paved section of Swift Trail, which was at lower elevation on Mt. Graham. Many sources of anthropogenic noise show daily, weekday versus weekend, and seasonal variation (Halfwerk et al., 2011). To understand the temporal pattern of traffic noise, we used one-way analysis of variance (ANOVA) to compare hourly traffic volume among 24 h, daily traffic volume among 12 months, and daily traffic volume between weekdays and weekends.

2.2.3. Influences of driving speed, vehicle type, and road surface

To better anticipate how noise level changes with different traffic and road conditions, we investigated effects of driving speed and type of vehicle on traffic noise level. We drove the SUV (mass = 1737 kg) and a truck (mass = 2418 kg, 2011 Silverado Pickup 4 × 4, Chevrolet, Detroit, USA) at 24 km/h, 32 km/h and 40 km/h on Swift Trail and measured L_{eq} and L_{max} at 6 locations (0–175 m from roads) with the same methods stated above. We tested effects of road pavement on traffic noise level by driving the SUV on paved sections of Swift Trail at 32 km/h and recorded L_{eq} and L_{max} at 18 locations (0–100 m from