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SHORT NOTE

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Mass displacement of Korean clawed salamanders (*Onychodactylus koreanus*) and the threat of road-kill

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ABSTRACT - Little is known about the ecology of the Korean clawed salamander (*Onychodactylus koreanus*) but populations are declining due to human activities. We surveyed a mountainside road in the Republic of Korea and recorded the sex and life history stage of the salamanders crossing the road. Our results present the first evidence of mass movement in this species. We also show that road-kill is greater than estimated in previous studies. The males observed had fleshy hind-limb extensions and all females except one were gravid, indicating they were in reproductive condition and that mass movement of this species is probably linked to seasonal conditions and reproduction. Consequently, we argue that road-kill may have a large impact on this species by eliminating reproductive adults. We call for road-kill mitigation measures on mountainside roads and further research into the migration patterns of this species.

INTRODUCTION

Amphibians are particularly prone to being killed on roads because they are slow-moving and many species migrate long distances seasonally to breed (Mazerolle, 2004; Brzeziński et al., 2012). Consequently, roads cutting through habitats can become significant threats to migrating populations (Jackson, 1996; Marsh et al., 2005).

In several amphibian species, mass movements associated with reproduction have been documented (Bovbjerg & Bovbjerg, 1964; Holland et al., 1990; Woolbright & Martin, 2014). Mass movements are associated with annual migration of adults to and from breeding sites and the dispersal of juveniles (Bovbjerg & Bovbjerg, 1964; Woolbright & Martin, 2014). When amphibians cross roads en masse, road traffic may kill a large number of individuals which may impact populations through genetic isolation, unequal sex-ratio, and result in extirpation (Puky, 2005). However, despite such negative consequences, the effects of roads have not been evaluated in detail for many amphibian species (van der Ree et al., 2015). This is partly due to the lack of background ecological information to make assessments as is the case with the Korean clawed salamander (*Onychodactylus koreanus*). This species is endemic to the Korean Peninsula and has a patchy distribution along the main mountain ranges (Poyarkov et al., 2012; Lee & Park, 2016). This pattern of patchy distribution is due to the species being lungless, requiring cool and humid forests and unpolluted, low-temperature mountain creeks to survive and breed (Lee et al., 2012; Lee & Park, 2016).

Due to anthropogenic causes, populations of *O. koreanus* are already shrinking (Suk et al., 2017; Maslova et al., 2018) and the risk of population decline is increased as subpopulations are already likely to be isolated. However, the effects of known threats on populations have not been properly evaluated and other potential threats are yet to be investigated (Hong, 2017). Herein, we report the first evidence of mass movement and associated high road-kill of *O. koreanus*.

MATERIALS AND METHODS

Field observations

Observations were made by driving a car along a 2.6 km stretch of a two-lane mountainside road in Wangsan-ri, Gangneung, Republic of Korea (37.6357°N, 128.7782°E). The altitude of the roads ranged between 532 m a.s.l. at the first point of observation to 418 m a.s.l. northward to the last point of observation (Fig. 1). Alongside this road, and separated from it by a wall of granite boulders approximately two meters high, was a closed maintenance road. To the east, the roads were flanked by deciduous and conifer forests and to the west by a creek. The distance from the forest edge to the creek was approximately 150 m (Fig. 2).

We collected data during the nights of 11 and 12 October 2019. The air temperature was 12 °C on both nights and the weather was windy with light drizzle. We drove the car slowly (< 12 km/h) on the two-lane road and searched visually for salamanders by their movement and shape against the headlights. We recorded the sex and life history stage of all the identifiable road-kills and any live individuals, and photographed each of them for future reference. Detailed ecological information such as snout-to-vent length, accurate ground temperature, and humidity were not recorded. For the live individuals, we moved them across the two-lane road in the direction of the creek where they were heading. For all but seven individuals, we uploaded pictures to a citizen science network iNaturalist (GBIF Occurrence Download https://doi.org/10.15468/dl.kavt2n).

Statistical analysis

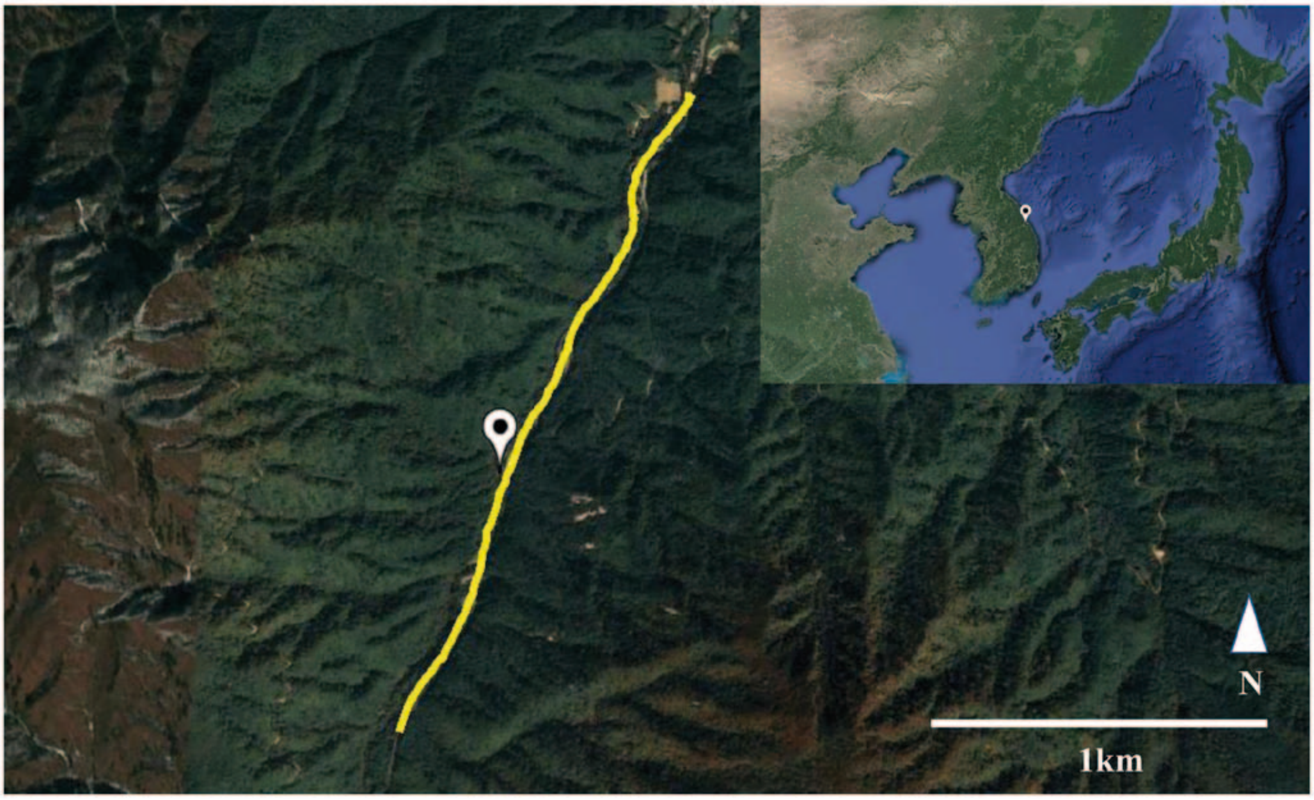

Figure 1. The stretch of two-lane road in Wangsan-ri, Gangneung, Republic of Korea, where mass movement of *O. koreanus* was observed on 11 and 12 October 2019. Map was generated using Google Earth Pro (Google Inc., California, USA), with data credits to SIO, NOAA, U.S. Navy, NGA, GEBCC. Image Landsat/Copernicus.

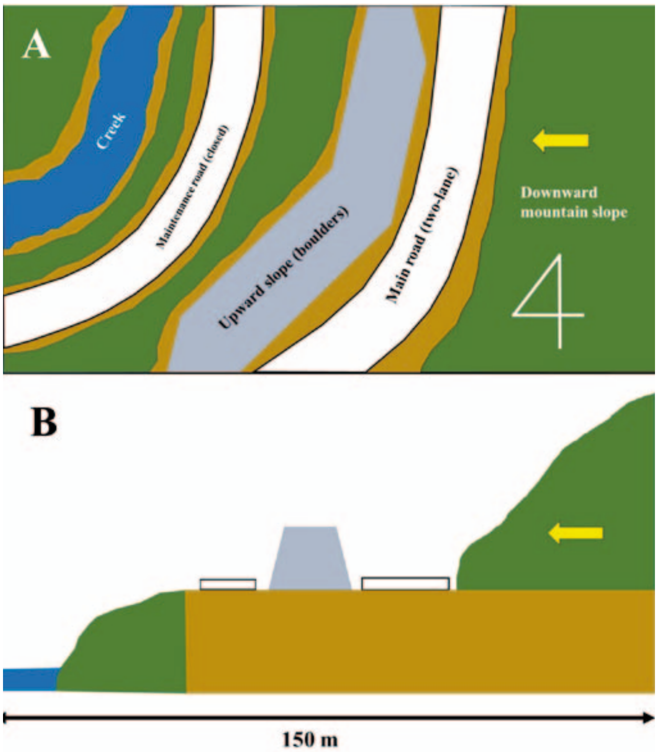

Figure 2. Structure of the roads where the observations of *O. koreanus* were made, seen from above **A.** and in cross section **B.**, the yellow arrows denote the general movement direction of observed salamanders

We analyzed a total of 43 observations of adult salamanders to test for sex ratio imbalance and for difference in road-kill between sexes in moving salamanders. As the data were not normally distributed our analysis was confined to a chi-square test (RStudio, RStudio Inc.; Boston, USA). We excluded five juveniles and individuals of unknown sex from the analysis.

RESULTS

Over two nights, we observed a total of 48 individual *O. koreanus* on the road (25 males, 18 females, two juveniles, and three damaged specimens of indeterminate sex; Fig. 3). On 11 October 2019 between 00:13 h and 00:46 h, we observed 15 males, 12 females, two juveniles and two individuals of indeterminate sex on the two-lane road. On 12 October between 20:20 h and 21:10 h, we observed 10 males, 6 females and one specimen of indeterminate sex on the same stretch of two-lane road. The total survey time over the two nights was about 85 minutes. Sex ratio was not significantly different within the migrating *O. koreanus* (χ^2 = 1.13, df = 1, p = 0.285). All females except one were gravid (n = 17) and contained well developed ova in their bodies (Fig. 3).

Among the 48 individuals observed, 18 were road-kills (three females, 12 males, three indeterminate) and 30 individuals were found alive (15 females, 13 males, two juveniles). Thus, the total road mortality rate over two nights was 37.5 %. Road-kill was significantly higher in males (25 %) than in females (6.25 %; χ^2 = 5.40, df = 1, p = 0.020).

DISCUSSION

Figure 3. Some of the *O. koreanus* individuals observed on 11 and 12 October 2019 in Wangsan-ri, Gangneung, Republic of Korea- **A.** Two *O. koreanus* found sitting on the middle of the two-lane road (white arrows), **B.** Gravid female killed by a car, with developing eggs visible (yellow arrows), **C.** Gravid female found alive on the road with eggs visible through the transparent skin

Our observations are the first evidence of mass movement in *O. koreanus*, a salamander species endemic to the Korean peninsula. We also highlight the risk of road-kill associated with this event. We found that *O. koreanus* were coming down the mountain slope and crossing the road westward, towards the creek. In this process, the salamanders were forced to cross a two-lane road. As a result, many individuals were victims of road-kill. For safety reasons, the traffic on the road during our surveys prevented us from a thorough examination of the opposite lane (uphill / southward direction). It is likely that the salamanders we observed were not the only ones moving during those two nights and thus our figures for salamanders on the road and mortality are probably underestimated.

During a three year study of ten Korean national parks (Song et al., 2009), a total of four *O. koreanus* road-kills were recorded among 24 stretches of roads each 188.9 km long. The authors considered that road-kill risk of *O. koreanus* was low. In another study of vertebrate road-kill, 14 *O. koreanus* were recorded among 368 amphibian road-kills over five years on a 18 km stretch of road in Odaesan National Park, Gangwon province (Min et al., 2012). This area is in the same general region as our study site where we recorded a significantly higher number of *O. koreanus* road-kill on a significantly shorter distance and time span. Consequently, our results show that the road mortality of the species can be greater than previously estimated during mass movement.

We could not identify the causes of this mass movement. However, the area was under the indirect effects of typhoon Hagibis during the time of observation (SBS News, 2019). Rainfall brought on by the typhoon could be one of the causes of this event (Gleeson et al., 2018). Another possible reason for this mass movement is reproduction, which is known as a major factor of amphibian migration (Semlitsch, 2008). Although the known breeding season of *O. koreanus* is between April and July, the species may breed once or twice a year depending on the region and populations (Lee et al., 2008; Lee & Park, 2016). Therefore, the individuals observed may have been migrating to the creek to breed since most females were gravid and the males still retained fleshy hind leg extensions (Park, 2005; Lee & Park, 2016).

Amphibians are usually active after sunset and night time when traffic volumes on rural mountainside roads are unlikely to be high (Gibbs & Shriver, 2005). However, the particular road in this study is the only one leading to a highland plateau, a popular area where many people visit to photograph stars and night sky, giving higher than normal traffic volumes. In such situations where roads cutting through habitats have high traffic volumes, road-kill can have a significant impact on migrating populations by eliminating large numbers of individuals in a short time. Considering the patchy distribution and occurrence of mass movements in the species, we argue that the effects of road mortality present an additional potential threat to the species.

Habitat modifications in general and edge effects associated with road constructions have clear detrimental effects on amphibian populations (Jochimsen et al., 2004; Marsh & Beck, 2004; Rytwinski & Fahrig, 2015; Bae et al., 2019). In our observations, the roads themselves, the wall of granite boulders and the maintenance road all present obstacles for migrating salamanders and expose them to greater risk of mortality due to desiccation and predation. Despite this, we could not find any devices or installations on this road to mitigate road-kill.

In conclusion, we suggest that road mortality is an additional threat to *O. koreanus*. However, detailed information on movement patterns is needed to properly evaluate the extent of this threat. Also, further investigations on the frequency and duration of mass movements are needed to better understand the associated threats. Meanwhile, we call for mitigation measures to decrease the risk of road mortality.

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