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Species traits explaining sensitivity of snakes to human land use estimated from citizen science data

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ABSTRACT

Understanding how traits affect species responses to threats like habitat loss may help prevent extinctions. This may be especially true for understudied taxa for which we have little data to identify declines before it is too late to intervene. We used a metric derived from citizen science data on snake occurrences to determine which traits were most correlated with species' sensitivity to human land use. We found that snake species that feed primarily on vertebrates, that use a high proportion of aquatic habitats, and that have small geographic ranges occurred in more natural and less human-dominated landscapes. In contrast, body size, clutch (or litter) size, the degree of exposure to human-dominated landscapes, reproductive mode, habitat specialization, and whether a species was venomous or not had less effect on their sensitivity to human land use. Our results extend previous findings that higher trophic position is correlated with extinction risk in many vertebrates by showing that snake species that feed primarily on vertebrates are more sensitive to human land use – a primary driver of extinction. It is likely that conversion of natural landscapes for human land use alters biotic communities, causing losses of important trophic groups, especially in aquatic and riparian communities. Practitioners should therefore prioritize preserving aquatic habitat and natural landscapes with intact biotic communities that can support species at higher trophic levels, as well as focus monitoring on populations of range-restricted species.

1. Introduction

Understanding how extinction risk is affected by species traits can guide conservation and monitoring of vulnerable species where it is needed most (Ribeiro et al., 2016). Linking traits to extinction risk may be especially important for preventing extinctions in understudied taxa for which we have little data to identify declines before it is too late. To date, several traits have been linked to increased extinction vulnerability in commonly studied vertebrates. For instance, extinction risk often increases with increasing habitat specialization, body size, and trophic level, but decreases with increasing range size and fecundity (Gaston and Blackburn, 1995; Purvis et al., 2000; Jones et al., 2003; Cardillo et al., 2005; Cardillo et al., 2008; Davidson et al., 2012; Tingley et al., 2013; Böhm et al., 2016). Ultimately, however, different suites of traits may underlie how species respond to a given threat (e.g., habitat loss, disease, overharvesting; Murray et al., 2014). Thus, understanding which traits directly link species responses to specific threats will provide clearer information with which to target conservation effort (Murray et al., 2011; Murray et al., 2014).

For most taxa, habitat loss is the primary threat driving their imperilment (Sala et al., 2000). However, the degree to which species are imperiled by habitat loss varies depending on their life histories and other traits. For example, species with small ranges, narrow niche breadths, and those at higher trophic levels are often among the first to disappear when habitat is lost (Laurance et al., 2002; Swihart et al., 2003; Barbaro and Van Halder, 2009). But research on which traits affect species responses to habitat loss have mostly focused on relatively visible and well-studied groups, such as birds, mammals, and butterflies (Swihart et al., 2003; Barbaro and Van Halder, 2009; Öckinger et al., 2010). Identifying traits linked to species declines from habitat loss may be especially valuable for preventing extinctions of understudied or hard-to-study taxa whose declines may go largely unnoticed.

Reptiles are perhaps one of the least studied vertebrate groups. For example, 65% of reptiles have not been evaluated in IUCN Red List assessments (Böhm et al., 2013). Additionally, of those species that have been evaluated, 20% of them have been deemed data deficient (Böhm et al., 2013). This is troubling given recent concerns that reptiles may be experiencing global declines on par with those in other taxa (Gibbons et al., 2000; Böhm et al., 2016). Among reptiles, snakes perhaps best epitomize the problem of both a considerable lack of data and recent enigmatic declines across several continents (Winne et al., 2007; Reading et al., 2010; Todd et al., 2010). Thus, identifying which

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traits in snakes are associated with sensitivity to human land use – defined here as the absence of a species from human-dominated landscapes, either because of habitat selection or because of local extirpations – may provide timely information to prevent declines of these often unnoticed or understudied species.

A major challenge to predicting how understudied taxa will respond to habitat loss or which traits affect their sensitivity to human land use is scarcity of data. One method scientists have used to address this lack of data in recent years has been to include volunteers from the public – citizen scientists – to increase the quantity of data that can be collected (Devictor et al., 2010; Dickinson et al., 2010). Citizen scientists can provide information for many understudied taxa that might otherwise escape research or management attention (Losey et al., 2007; Braschler, 2009; Barlow et al., 2015). Information obtained by citizen scientists for understudied taxa can in turn be used in species assessments or to direct management intervention and habitat preservation. For example, citizen science data were recently used to rank the sensitivity of reptile and amphibian species to human land use while accounting for inherent biases associated with these types of data (Todd et al., 2016); citizen science data can provide much-needed information for taxa that are difficult to study because of their cryptic behavior. One advantage of large data sets gathered from citizen scientists is that it is increasingly possible to examine how traits in understudied species are linked to their responses to habitat loss.

Our goal in this study was to determine which traits are linked with sensitivity of snakes to human land use, the primary driver of habitat loss globally. We used a quantitative measure of species sensitivity to land use recently developed from citizen science data collected in North and South Carolina (USA) to identify intrinsic factors of snakes that may help explain variation in their sensitivity to this major threat. Given earlier findings from other taxa discussed above, we predicted that snake species that feed primarily on vertebrates (i.e., at a higher trophic level than those feeding primarily on invertebrates), that have small ranges, produce small clutches (or litters for live-bearers), have large body sizes, and have narrow diet and habitat breadths would be more sensitive to human land use than other species. We also expected species that are highly aquatic and depend on streams and wetlands to be more sensitive to human land use than others because these habitats are often highly affected by human land use (Dahl, 2001; Allan, 2004). Several live-bearing snake species have longer generational times and we thus expected them to be sensitive to human land use because their populations may be slow to recover from disturbances. Finally, we expected that venomous snake species would be more sensitive to human land use because they are prone to human persecution and thus may disappear from areas where human land use dominates.

2. Methods

2.1. Data collection

We obtained data on the sensitivity of snake species to human land use from Todd et al. (2016). These data provide a quantitative ranking of the degree to which 33 snake species in North and South Carolina (USA) were associated with natural or human-dominated landscapes – defined as urban or built areas, agricultural areas, and roads. The 7684 snake occurrences were originally reported by citizen scientists to the Carolina Herp Atlas (www.carolinaherpatlas.org; Price and Dorcas, 2011) and included observations from every county across the two states. At each occurrence for each species, Todd et al. (2016) used the GIS layer of Theobald (2010) to extract a natural landscape value. Natural landscape values range from 1, representing an entirely natural 270-m cell with only natural landscapes neighboring it, to 0, representing an entirely human-dominated cell with only human-dominated landscapes neighboring it (Theobald, 2010). Todd et al. (2016) then calculated an effect size representing the sensitivity of snake species to human land use. The effect size was the difference between the mean natural landscape value across all observations of a given species and 1000 bootstrapped means of an equal number of observations for all other snake species within the range of the focal species. This method addressed possible spatial biases in how users find and report observations to determine whether a snake species was observed in more or less natural landscapes than were all others given known sampling locations. Positive effect sizes indicate a species was found in more natural landscapes than was the average snake (i.e. more sensitive to human land use), and negative effect sizes indicate a species was found in more human-dominated areas (i.e., less sensitive to human land use). Although both agricultural and urban lands are treated as human-dominated (i.e., a score of 0), in practice, most agricultural areas include natural landscapes nearby whereas urban areas do not. Thus, the weighting schema of Theobald (2010) results in typically higher values for agricultural areas compared to urban areas, in line with the expectation that agricultural lands may be of higher quality for wildlife than urban lands would be. For complete details of how effect sizes were calculated, see Todd et al. (2016). Here, we use their effect size as the response variable in our analyses.

We obtained data on mean clutch or litter size (hereafter “clutch size”) and minimum snout-to-vent length (SVL; “body size”) of females at reproductive maturity for each species from Ernst and Ernst (2003), except for *Tantilla coronata*, for which we obtained mean clutch size from Todd et al. (2008). We categorized each species as live-bearing or not (hereafter “reproductive mode”), venomous or not (“venomous”), and either feeding primarily on vertebrates or invertebrates (“primary prey”) following species accounts in Ernst and Ernst (2003). As a measure of “diet breadth”, we included a count of the number of all taxonomic Classes reported as prey in species accounts in Ernst and Ernst (2003). As an index of habitat specialization/breadth (“habitat breadth”), we followed Böhm et al. (2016) and used a count of the number of habitat types inhabited by each species reported in IUCN species accounts (www.iucnredlist.org accessed 15 January 2016). We calculated the proportion of these habitats that were aquatic for each species as an index of the degree to which each species uses aquatic habitats (“aquatic index”), the results of which agreed well with life history accounts in Ernst and Ernst (2003) and the authors' personal observations. We downloaded geographic range shapefiles from IUCN and used ArcGIS 10.0 to calculate the total expanse of each species' geographic range (“range size”). Finally, we included as a covariate, thereby controlling for, each species' exposure to human land use (“exposure”). For this measure of exposure, we used ArcGIS 10.0 to calculate the mean natural landscape value of each species' range in the Carolinas from the Natural Landscape GIS layer of Theobald (2010). A lower value for exposure thus indicates less natural landscape within a species' range, whereas a higher value for exposure indicates more natural landscape within a species' range. Ultimately, because each species' occurrences were compared only to other snake occurrences within its range, its sensitivity response metric is not confounded by the mean exposure value of its range. In other words, a species whose range is predominantly natural landscape can still be found in more human-dominated areas compared with other snakes in its range.

2.2. Statistical analyses

We examined correlations among continuous predictor variables and variable inflation factors (VIF) for all variables, finding only weak-moderate correlations among variables, which did not meet thresholds for high multicollinearity (e.g., $r > 0.7$; Fig. S1; Zuur et al., 2009), and further supported by examination of VIF (≤4 for all variables). All continuous predictor variables were centered and scaled prior to analyses. We used generalized least squares (GLS) and phylogenetic GLS (PGLS) models to analyze variation in species sensitivity to human land use. First, we fit a global GLS model with clutch size, body size, reproductive mode, venomous, primary prey, diet breadth, habitat breadth, aquatic index, range size, and exposure as explanatory variables. We then fit