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Proceedings of the Vertebrate Pest Conference

Title

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Journal

Proceedings of the Vertebrate Pest Conference, 25(25)

ISSN

0507-6773

Authors

Maestas, Jesse M.
Theimer, Tad C.
Hausig, Krista M.
et al.

Publication Date

2012

DOI

10.5070/V425110586

Striped Skunk Relative Abundance in Flagstaff, Arizona: Implications for Rabies Spread and the Current TVR Program

Jesse M. Maestas and Tad C. Theimer

Biological Sciences, Northern Arizona University, Flagstaff, Arizona

Krista M. Hausig and David L. Bergman

USDA APHIS Wildlife Services, Phoenix, Arizona

ABSTRACT: Potentially fatal wildlife diseases like rabies are of increasing concern, due to human effects on the environment that could alter wildlife behavior and population dynamics in ways that increase disease prevalence. Wildlife population abundance is a key factor, affecting both disease outbreak and rate of disease spread, and understanding how population abundance changes across landscapes is crucial for developing predictive models to control and manage wildlife diseases. We investigated how urbanization in Flagstaff, AZ influenced skunk population abundance by simultaneously trapping 6 pairs of suburban and wildland study sites for 200 trap-nights between June and September 2011. The number of unique skunks captured at the 6 suburban locations ranged from 3-14 (mean = 6.5) while the number trapped at the 6 wildland sites ranged from 0-2 (mean = 0.5). We also reviewed data gathered as part of the trap-vaccinate-release (TVR) program carried out from 2004-2010 by USDA APHIS Wildlife Services to estimate population sizes and the percentage of the population vaccinated. Our estimates of the percentage of the population vaccinated in any one year ranged from 11%-23%, below percentages reported in the literature as necessary to prevent disease spread. Overall, these data indicate that the potential for disease spread was greatest within the suburban matrix and relatively low in surrounding wildlands and that intensified annual TVR programs would be necessary to maintain high enough percentages of immunized animals to achieve effective herd immunity.

KEY WORDS: abundance, Arizona, disease, herd immunity, *Mephitis mephitis*, rabies, skunks, suburban, trapping, trap-vaccinate-release, urban, wildland

Proc. 25th Vertebr. Pest Conf. (R. M. Timm, Ed.)
Published at Univ. of Calif., Davis. 2012. Pp. 267-270.

INTRODUCTION

Wildlife population abundance is a key factor affecting both disease outbreak and rate of disease spread (Anderson and May 1986, Scott 1988). The abundance of wildlife that harbor disease can often be artificially high in cities and towns when wildlife benefit from human-provided food or shelter (e.g., Rosatte et al. 1992a, Smith and Engeman 2002). Whether disease will spread beyond those urban and suburban areas of high abundance then depends upon the quality of the surrounding habitat (Prange et al. 2003, Randa and Yunker 2006). Although wildland habitats generally are viewed as more natural, and therefore capable of sustaining high populations of wildlife, wildland types vary considerably in their productivity and carrying capacity and could thereby limit or alter the rate of disease spread through their effects on population density.

Understanding how population density changes across landscapes is also crucial for developing effective management strategies to control wildlife diseases (Barlow 1996, Keeling 2005, Lloyd-Smith et al. 2005, Bansal et al. 2007). The goal of trap-vaccinate-release programs (TVR) is to vaccinate a sufficient proportion of the population so that probability of disease transmission drops below the level necessary to sustain the disease (Rosatte et al. 1992b). Although the specific proportion of the population needed to achieve this "herd immunity" is difficult to estimate in the absence of detailed information about the rate of contact and probability of disease transmission among individuals (Anderson and May 1986), at least some idea of the target population abundance is needed to assess the potential for

TVR to be effective.

In this study, we investigated the relative abundance of striped skunks (*Mephitis mephitis*) in and around Flagstaff, AZ to assess the potential for rabies spread from urban/suburban areas into and through the surrounding wildlands. Rabies is an acute encephalitis caused by single-stranded negative sense RNA lyssaviruses directly transmitted by bite, and has a case fatality ratio approaching 100%, the highest of any infectious disease (CDC 2008). Rabies persists in the form of several unique viral variants within a diverse assemblage of bat and carnivore reservoir species in North America, including gray foxes (*Urocyon cinereoargenteus*), coyotes (*Canis latrans*), raccoons (*Procyon lotor*), skunks (*Mephitis mephitis*), and bats (Chiroptera) (Rupprecht and Smith 1994, Blanton et al. 2010). In central and southern Arizona, two carnivore rabies variants have been identified: a variant associated with striped skunks in the southern and central U.S., and a variant associated with gray fox (Blanton et al. 2010). In 2001, northern Arizona in and around Flagstaff experienced a unique emergence of rabies in carnivores with a big brown bat (*Eptesicus fuscus*) rabies variant apparently establishing in striped skunks, with recurring outbreaks in skunks 2004 and 2009 (Leslie et al. 2006). In response to these outbreaks, USDA APHIS Wildlife Services (WS) conducted annual TVR activities in an attempt to mitigate the possibility of recurring outbreaks and limit disease spread. In this paper, we use data collected during those TVR activities to estimate population abundances in 3 areas of Flagstaff to obtain estimates of the percentage of the

skunk population immunized in those years. Our goals were to develop preliminary assessments of the potential for rabies to be carried beyond the urban/suburban areas of Flagstaff through the surrounding wildlands to other urban areas and to assess the potential efficacy of current levels of TVR activities in immunizing an adequate proportion of the skunk population.

METHODS

We studied skunks in and around Flagstaff, AZ (35° 11'N, 111° 39'W). Flagstaff is the largest city in northern Arizona, covering approximately 1,600 ha, with a human population circa 60,000. Located at 6,900 ft (2,100 m), it has a seasonal climate with a mean annual rainfall of 22 inches (55 cm). The city lies amid the largest continuous stand of ponderosa pine (*Pinus ponderosa*) forest in the U.S. and is separated from several nearby communities by forest.

To test whether skunk abundance differed between urban/suburban and surrounding wildland areas, we trapped skunks at 6 pairs of study sites, with each pair consisting of an urban/suburban trapping grid and a wildland trapping grid. Trapping for all 6 pairs was conducted from June-September 2011 during the post-breeding and rearing period for skunks. Each pair of grids was trapped simultaneously. Live traps (Tomahawk Live Trap, Models 106 and 108, Tomahawk, WI) were placed in urban/suburban areas opportunistically by USDA APHIS personnel as part of their TVR activities. For each urban/suburban location, we then placed the same number of live traps in wildland areas in a similar spatial arrangement. Traps were baited with peanut butter and set each night before sunset and checked early the following morning and then closed for the remainder of the day. Trapped skunks were marked with a uniquely numbered, self-piercing 1×3-mm nickel-copper ear tag (#1005-1, National Band and Tag Company, Newport, KY). Skunk abundance at each trapping grid was estimated as the total number of uniquely marked skunks. We tested each pair of trapping grids for differences in total number of skunks present using chi-square, with the expectation that the total number of unique skunks captured should be the same in suburban/urban and wildland areas.

To estimate skunk population sizes and the percentage of the population vaccinated, we analyzed USDA APHIS Wildlife Services data collected as part of their TVR program between 2004-2010. The Flagstaff TVR program focuses on 3 areas of the city, so our analysis was limited to skunks captured within those areas. We used a standard Lincoln-Peterson mark-recapture approach (Seber 1982) by assuming all skunks ear-tagged and vaccinated in one year represented the marked population, while the total number of adult skunks captured the following year represented the resample and the number of adult skunks in the resample that bore ear-tags from the previous year represented the recaptured sample. Thus for the standard equation $N = [(M + C)(C + 1) / (R + 1)] - 1$ in our study, M = skunks vaccinated and ear-tagged in Year 1, C = all adult

Table 1. Total number of uniquely marked striped skunks captured at paired suburban/urban and wildland trapping grids in and around Flagstaff, AZ, June-September 2011. Limited trapping was undertaken in 2008, so that year was not included.

Paired Site Name	# Unique Skunks		Chi-square	P Value
	Urban/Suburban	Wildland		
University Heights	6	0	6.0	0.014
Foxglenn	14	0	14.0	0.002
Continental	4	2	0.7	0.417
Cheshire 1	3	0	3.0	0.083
Cheshire 2	11	0	11.0	0.003
Mount Elden	3	0	3.0	0.083
Total	41	2		

Table 2. Mark-recapture population estimates and 95% CI for striped skunk populations combined across 3 areas of Flagstaff, AZ, based on TVR trapping data collected by USDA APHIS from 2004-2010.

Years	Population Estimate	Lower 95% CI	Upper 95% CI
2004-2005	194	48	340
2005-2006	405	79	731
2006-2007	418	122	714
2009-2010	367	213	521

skunks recaptured in Year 2, R = all adult animals recaptured in Year 2 with ear tags from Year 1, and N = estimated population size. We then determined the 95% CI for each population estimate. To estimate the percentage of the population vaccinated against rabies from our skunk abundance, we simply divided the number of skunks vaccinated in that year by the total population estimate for that year. To estimate the potential range in the percentage of the population vaccinated, we also divided the number of animals vaccinated in that year by the lower and upper population estimate of that year based on the 95% CI.

RESULTS

Across the 6 pairs of urban/suburban-wildland trapping grids, we captured a total of 3-14 skunks (mean = 6.8) in urban/suburban areas and 0-2 skunks (mean = 0.3) in wildland areas. The number of skunks captured was significantly higher in urban/suburban areas at 5 of the 6 trapping sites (Table 1).

Our estimates of skunk population sizes based on data collected by USDA APHIS from 2004-2011 ranged from 194-418 with 95% CI ranging from the lowest population estimate at 48 and the largest at 731 (Table 2). As a result, our estimates of the percentage of the population vaccinated in any one year also varied considerably, from a low of 6% to a high of 92% (Table 3).

DISCUSSION

Although we expected skunk abundance to be lower in the wildland areas than in suburban/urban areas, given the numerous studies that have shown higher abundances in human-dominated areas (Rosatte et al. 1992a, Smith and Engeman 2002), we were surprised by the 20-fold lower

Table 3. Estimated percentage of the skunk population vaccinated against rabies and 95% CI based on the number of animals immunized in a year and the mark-recapture population estimate for that year, as reported in Table 2, for striped skunk populations combined across 3 areas of Flagstaff, AZ.

Years	% of Population Vaccinated	lower pop estimate %	higher pop estimate %
2004-2005	22%	91%	12%
2005-2006	18%	92%	10%
2006-2007	11%	38%	6%
2009-2010	23%	40%	16%

capture success in wildland areas in our study. Even the two skunks captured in wildland may have been dependent on human altered environments, as one of the two ran for several kilometers after release to a den under an isolated ranch house, suggesting den sites in the ponderosa pine forests may be limiting. Similarly, radio-collared skunks that spent most of their time in the urban/suburban areas of Flagstaff often ventured into surrounding wildlands for short periods of a few days or weeks (Weissinger et al. 2009). The terrain throughout much of the extensive ponderosa pine forests surrounding Flagstaff is relatively flat, and rocky outcrops that could provide den sites are relatively rare. We were also conservative in placing 2 of the 6 wildland trapping grids in relatively rare habitats that should have been more attractive to skunks. These two trapping grids included areas near drainages where rock outcrops provided what appeared to be suitable denning sites and where plant diversity was much higher than the surrounding forest, including stands of live oak that produce acorn crops. These riparian corridors presumably would provide greater food resources for skunks and should have been areas with highest abundances, yet we caught no skunks. At one of these sites, we provided canned dog food as bait, and we monitored the area with automatic cameras for an additional 2 weeks after trapping and still recorded no visits by skunks. Overall, these results suggest that ponderosa pine habitat around Flagstaff supports very low skunk densities, and that the probability of disease transmission through this habitat is therefore likewise very low.

We believe our population estimates based on data collected by USDAAPHIS from 2004-2011 are indicative of skunk population sizes in Flagstaff, even though our approach violated several of the assumptions of the mark-recapture approach. The populations were not closed, mortality and immigration/emigration undoubtedly occurred, and sampling effort was not standardized across years. We assumed that mortality was equally likely for marked and unmarked subsets of the population, which seems reasonable in absence of a rabies outbreak, and that immigration and emigration were relatively low. Large amounts of emigration out of the study areas would have led to an underestimate of marked animals in subsequent years, but we documented relatively few long-distance movements between years based on recaptures of marked animals. Our estimates of the percentage of the population vaccinated in any one year all fell below 25% but

ranged from 6%-92% depending upon whether upper or lower bounds of the 95% CI for population size was used. Although this suggests that in the best-case scenario (assuming populations are biased toward the lower end of the 95% CI) levels of vaccination may meet or exceed those necessary to prevent spread of disease, this is unlikely in most, if not all, years. Mark-recapture approaches for estimating skunk population size generally underestimates the true population size (Greenwood et al. 1985). As a result, our population estimates are likely underestimates, rather than overestimates, and therefore the percentage of the population immunized is more likely lower rather than higher than higher. Previous studies suggested that vaccination of 40%-80% of the population successfully prevented skunk rabies outbreaks in Toronto (Rosatte et al. 1992a), while raccoon rabies apparently re-emerged when percentages fell from roughly 50% to 38% (Rosatte et al. 2007). The highest of our estimates were roughly half of the minimum level required to prevent outbreaks as suggested by these studies.

Overall, our findings indicate that the continuous ponderosa pine-dominated habitat surrounding Flagstaff, AZ supports low densities of skunks and therefore represents an ecological barrier to rabies transmission by skunks across the wildland landscape. In this sense, Flagstaff may be similar to many other urbanized areas in the intermountain western United States that are surrounded by arid, low-productivity conifer forests. We note that other rabies vectors, such as gray fox, coyote, and bobcat may not show similar patterns and may transmit the disease beyond the urban/suburban landscape. In addition, our estimates of the percentage of skunks currently vaccinated as part of the ongoing TVR program suggest the number vaccinated may be too low to create the level of herd immunity necessary to forestall rabies outbreaks. We therefore recommend that TVR efforts in Flagstaff be increased to increase the percentage of animals vaccinated.

ACKNOWLEDGEMENTS

We would like to thank S. Johnston for her trapping advice and help. This research was part of J. Maestas' work as a fellow in the Undergraduate Research Mentoring Program at NAU, funded by the National Science Foundation. Additional funding was provided through a grant from the Arizona Biomedical Research Commission. Animal handling protocols were approved by the NAU IACUC.

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