Short Communication

Winter Home Range and Habitat Selection of a Rhesus Macaque Group (*Macaca mulatta*) at Silver Springs State Park

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Introduction

Native to southern and eastern Asia, rhesus macaques (*Macaca mulatta*) have the largest geographic range of any non-human primate (Southwick et al. 1996). They can adapt to a diversity of environmental conditions including subtropical, temperate and subalpine habitats (Fooden 2000), as well as urban and other human-modified environments (Richard et al. 1989). Primarily herbivorous, they supplement their diet with invertebrates, small vertebrates, honeycombs, and bird eggs (Fooden 2000).

Their adaptable nature has allowed this species to thrive when introduced into novel habitats. Impacts in novel landscapes include crop destruction (Engeman et al. 2010), bacterial contamination of water bodies (Klopchin et al. 2008), destruction of mangroves leading to shoreline erosion (Kruer 1996), and decreased island bird populations due to egg and chick predation (Evans 1989). Three populations of rhesus macaques have been introduced in Florida since the 1930s (Anderson et al. 2017). The oldest and only remaining is within Silver Springs State Park (SSSP) and surrounding forests.

Prior to our study, there were no records of home range or habitat selection of introduced rhesus macaques in Florida. Understanding habitat use of introduced species is important for evaluating potential impacts on natural resources and developing management strategies (Adams et al. 2014). In this study, we determined winter home range and habitat selection of a group of rhesus macaques in SSSP. Although feeding wildlife is prohibited, the macaques are provisionally fed by boaters along the Silver River (Riley and Wade 2016). Because provisional feeding from humans can alter rhesus macaque behavior and population dynamics (Jaman and Huffman 2013, Sengupta et al. 2015), we also evaluated whether this may be influencing winter home range and habitat use.

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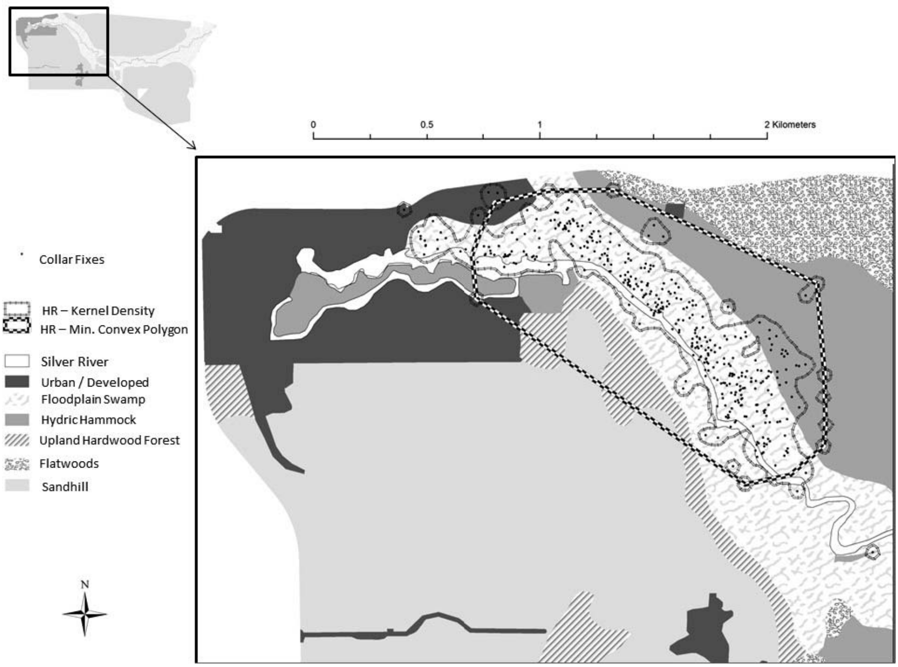

Figure 1. Winter home range estimates of a group of rhesus macaques in Silver Springs State Park, Florida, U.S.A., using minimum convex polygon and kernel density methods.

Materials and Methods

Study site. SSSP was purchased by the state of Florida in 1985 (Florida Department of Environmental Protection 2014). The park spans 4,685 aces and is situated around the Silver River, a spring-fed river which flows east into the Ocklawaha River (Figure 1). Approximately 12 rhesus macaques were introduced along the Silver River in the mid-1930s and 1940s into what is now SSSP (Wolfe and Peters 1987). The 1968 population was estimated to include 78 individuals (Maples et al. 1976). By the late 1970s, the population spread to forests adjacent to SSSP (Montague et al. 1994), and by the mid-1980s, the population within SSSP reached nearly 400 individuals (Wolfe and Peters 1987, Wolfe 2002). From 1984 to 2012, approximately 1,000 rhesus macaques from SSSP and approximately 130 additional macaques from adjacent lands were trapped and removed. The population was estimated to include 118 animals in Spring 2013 (Riley and Wade 2016) and over 175 animals in Fall 2015 (Anderson et al. 2017).

Animal capture and collar placement. We selected a site within SSSP where our target macaque group had been previously observed (Anderson et al. 2016). To habituate the macaques to the trap site, we pre-baited the site daily with corn and fresh produce. Once the macaques began traveling to the site more than four days per week in early December 2014, we placed eight 48-inch box live traps (Tomahawk Live Trap Company, Hazelhurst, WI) around the site; traps were initially wired open to habituate the animals to traps while preventing unintentional capture.

Our aim was to collar an adult female. Female rhesus macaques remain with their natal groups their entire lives (Fooden 2000). The movements of a single female, therefore, act as a proxy for the entire group (González-Martínez 2004). We modified traps so they could be triggered by a line, rather than a treadle, to prevent capture of non-target animals. We operated traps from inside camouflaged blinds (developed by W. Hyde, USGS, 2014).

On December 18, 2014, we captured an adult female macaque. We immobilized the animal with an intramuscular injection of ketamine (4 mg/kg) and dexmedetomidine (40 ug/kg) using a blow dart to allow us to safely fit it with a GPS radio collar (Followit, Lindesberg, Sweden). The collar weighed 210 g, 3.23% of the weight of the animal (6.5 kg), congruent with the Guidelines of the American Society of Mammalogists (Sikes 2016). The collar was equipped with an automatic release mechanism to prevent the need to recapture the animal for collar removal. Rhesus macaques are diurnal and roost in trees at night (Fooden 2000). We scheduled the collar to record coordinates every two hours from 06:30 to 20:30 to evaluate daily movement. An additional point was taken at 23:30 to determine roosting locations.

A one-year study duration was intended. However, on February 2nd the collar was observed to be causing neck abrasions on the animal. We sent repeated release signals February 3rd -8th for the collar to drop off. Because the collar did not immediately fall off, we attempted to re-trap the animal from February 5th - 8th in order to manually remove the collar. The collar dropped off on February 9th. The animal recovered rapidly from the neck abrasions following collar removal. The abrasions caused by the collar led to negative publicity on social media, and consequently we were targeted by animal rights activists and chose to discontinue the study.

Data analysis. The collar was on the animal from December 18 – February 9th, however only data from December 20th - February 4th were included in our analyses; the dates before and after these were excluded because we were providing bait for the animals, potentially biasing group movements (Fooden 2000, Jaman and Huffman 2013). We estimated home range size using the fixed kernel density (KD) method using a 95% probability distribution and a least squares cross validation smoothing parameter (Worton 1989) and using the minimum convex polygon (MCP) method including 95% of observed locations (Harris et al. 1990). We used the adehabitatHR package in R Version 3.3.1 (Calenge 2006) to conduct home range analyses. Habitat types were defined following the Florida Natural Areas Inventory guidelines (1990) and consolidated using Hubbard and Judd (2013). Habitat selection was determined as the proportion of time spent in each habitat type within the home range (McDonald et al. 2005).

Boater use of the Silver River is higher on weekends than weekdays (Florida Department of Environmental Protection 2014, Riley and Wade 2016), suggesting the macaques are more likely to receive provisional feeding from boaters on weekends than weekdays. To determine if the macaques remained in closer proximity to the Silver River on weekends than weekdays, we calculated distance of each recorded point within the home range to the Silver River using ArcGIS and conducted a means comparison (t-test; $\alpha = 0.05$) to evaluate if this distance was greater on weekdays than weekends.

Results and Discussion

Home range was estimated to include 0.65 km^2 using the 95% KD estimate and 1.26 km^2 using the MCP estimate. The KD estimate of home range appears to be a better representation of their true home range (Figure 1). The Silver River likely influenced the shape of the home range and consequently the MCP method artificially inflates the home range estimate. Rhesus macaque home range and habitat selection can vary seasonally (Lindburg 1977, Fooden 2000). Thus, it is possible the results of this study do not represent the full extent of this group's annual home range.

Of 381 fixes included within the home range, 83% were within floodplain swamp, 16.5% were in hydric hammock, and a single point was in an urban area (Figure 1). The selection of floodplain swamp suggests this habitat is beneficial in winter months. Proximity to fresh water (Lindburg 1977, Dong-Ming et al. 2012) and increased canopy cover (Dong-Ming et al. 2012) are among natural resources selected by rhesus macaques in their native range. The floodplain swamp offers constant access to freshwater, as well as greater foraging diversity and canopy cover than the unused habitats (e.g., sandhill, scrub, flatwoods; FNAI 1990). Further, floodplain swamp may offer preferred foods or important fallback food resources during winter (Marshall et al. 2009). Ash (*Fraxinus sp*.), sedges (*Carex spp*., *Rhyncospera sp*.), and cabbage palm (*Sabal palmetto*) are consistently consumed by this population (Wolfe and Peters 1987, Riley and Wade 2016) and are more available in floodplain swamp than in hydric hammock or the unused habitats (FNAI 1990).

Our results suggest native species in the floodplain swamp are at a greater risk of impact from introduced macaques in SSSP during winter than those in other habitats. Winter food resources are likely limited in floodplain swamp for herbivores, as this habitat type includes primarily deciduous tree species (FNAI 1990) and demonstrates decreased seed abundance in winter (Titus 1991). Foraging of vegetation by the rhesus macaques may alter forest composition or reduce already-limited winter food resources (Charles and Dukes 2007). Native species may also be vulnerable to interference competition (e.g., aggressive interactions) from rhesus macaques, such as those reported by Peters (1983).

The rhesus macaques spent a greater proportion of time in the floodplain swamp on weekends (91%) than weekdays (80%) and average distance of coordinates to the Silver River was shorter on weekends (75.68 m; $n=113$) than weekdays (92.29 m; $n=268$; t-statistic = -1.6279; $p = .05$). Closer proximity to the Silver River on weekends may indicate increased boater traffic – and related food opportunities – influence macaque movement. The environmental consequences of this feeding are unknown. Provisional feeding may decrease rhesus macaque consumption of natural resources, thereby potentially reducing resource competition with native species. Conversely, it may cause the rhesus macaque population to grow faster or to a larger density than it would without supplemental feeding (Fooden 2000, Jaman and Huffman 2013, Sengupta et al. 2015).

Management of invasive species is difficult and controversial, particularly when the species is charismatic (Verbrugge et al. 2013). Although limited temporally, our study provides inference to the potential environmental impacts of rhesus macaques in SSSP and provides evidence human provisioning is potentially influencing rhesus macaque behavior in SSSP. These findings, paired with the consistent growth in this population (Anderson et al. 2017) and the negative impacts demonstrated by other introduced rhesus macaque populations, highlight the importance of continued research and management of this population.

Acknowledgements This study was conducted with permission from the Florida Department of Environmental Protection (Permit Number 01281413), the Florida Fish and Wildlife Conservation Commission (Permit EXOT-13-249), and the University of Florida Institutional Animal Care and Use Committee (IACUC Protocol Number 201308022). Research funding was provided by The Felburn Foundation and student support funding was provided by a USDA National Needs Fellowship. We thank Michael "Mickey" Summers for guidance in the field, Brittany Bankovich for research assistance, William "Buddy" Hyde for building our blinds, and Dr. Mathieu Basille, Dr. Catherine Haase, and Ke Zhang for guidance with data analysis.

References

Adams AL, Recio MR, Robertson BC, Dickinson KJM, van Heezik Y. 2014. Understanding home range behaviour and resource selection of invasive common brushtail possums (*Trichosurus vulpecula*) in urban environments. Biological Invasions 16:1791–1804.

Anderson CJ, Hostetler ME, Sieving KE, Johnson SA. 2016. Predation of artificial nests by introduced rhesus macaques (*Macaca mulatta*) in central Florida, USA. Biological Invasions 18:2783 – 2789.

Anderson CJ, Hostetler ME, Johnson SA. 2017. History and status of introduced non-human primate populations in Florida. Southeastern Naturalist 16:19 – 36.Calenge C. 2006. The package "adehabitat" for the R software: a tool for the analysis of space and habitat use by animals. Ecological Modelling 197:516–519.

Charles H, Dukes JS. 2007. 13 impacts of invasive species on ecosystem services. Pp. 217–237 *in* Caldwell M, Heldmaier G, Jackson R, Lange OL, Mooney HA, Schulze E-D, Sommer U, eds. Biological Invasions. Springer-Verlag, Berlin.

Dong-Ming X, Lu J-Q, Sichilima AM, Wang B-S. 2012. Patterns of habitat selection and use by *Macaca mulatta tcheliensis* in winter and early spring in temperate forest, Jiyuan, China. Biologia 67:234–239.

Engeman RM, Laborde JE, Constantin BU, Schwiff SA, Hall P, Duffiney A, Luciano F. 2010. The economic impacts to commercial farms from invasive monkeys in Puerto Rico. Crop Protection 29:401–405.

Evans MA. 1989. Ecology and removal of introduced rhesus monkeys: Desecheo Island National Wildlife Refuge, Puerto Rico. Puerto Rico Health Sciences Journal 8:139–156.

Florida Department of Environmental Protection. 2014. Silver Springs State Park Draft Unit Management Plan Amendment. http://www.dep.state.fl.us/parks/planning/ssag/Silver_Springs_draft_management_plan_amend.pdf. Accessed: 28 August 2016.

Florida Natural Areas Inventory (FNAI) and Florida Department of Natural Resources. 1990. Guide to the Natural Communities of Florida. http://fnai.org/PDF/Natural_Communities_Guide_1990.pdf. Accessed: 28 August 2016.

Fooden J. 2000. Systematic review of the rhesus macaque, *Macaca mulatta* (Zimmermann, 1780). Fieldiana 1509:1-180.

González-Martínez J. 2004. The introduced free-ranging rhesus and patas monkey populations of Southwestern Puerto Rico. Puerto Rico Health Sciences Journal 23:39 – 46.

Harris S, Cresswell WJ, Forde PG, Trewhella WJ, Woollard T, Wray S. 1990. Home-range analysis using radio-tracking data: a review of problems and techniques particularly as applied to the study of mammals. Mammal Review 20:97–123.

Hubbard JR, Judd WS. 2013. Floristics of Silver River State Park, Marion County, Florida. Rhodora 115:250–280.

Jaman MF, Huffman MA. 2013. The effect of urban and rural habitats and resource type on activity budgets of commensal rhesus macaques (*Macaca mulatta*) in Bangladesh. Primates 54:49–59.

Klopchin JL, Stewart JR, Webster LF, Sandifer P. 2008. Assessment of environmental impacts of a colony of free-ranging rhesus monkeys (*Macca mulatta*) on Morgan Island, South Carolina. Environmental Monitoring and Assessment 137:301–313.

Kruer C. 1996. The inside story on the monkey islands of the Florida Keys. Florida Naturalist 69:10-11.

Lindburg DG. 1977. Feeding behaviour and diet of rhesus monkeys (*Macaca mulatta*) in a Siwalik Forest in North India. Pp 223–249 *in* Clutton-Brock TH, ed. Primate Ecology: Studies of Feeding and Ranging Behaviour in Lemurs, Monkeys, and Apes. Academic Press, London.

Maples WR, Brown AB, Hutchens PM. 1976. Introduced monkey populations at Silver Springs, Florida. Florida Anthropologist 29:133–136.

Marshall AJ, Boyko CM, Feilen KL, Boyko RH, Leighton M. 2009. Defining fallback foods and assessing their importance in primate ecology and evolution. American Journal of Physical Anthropology 140:603–614.

McDonald L, Alldredge JR, Boyce MS, Erickson WP. 2005. Measuring availability and vertebrate use of terrestrial habitats and foods. Pp 465–488 *in* Braun CE, ed. Techniques for Wildlife Investigations and Management. The Wildlife Society, Bethesda.

Montague CL, Colwell SV, Percival HF, Gottgens JF. 1994. Issues and options related to management of Silver Springs rhesus macaques: Technical Report #49. Florida Cooperative Fish and Wildlife Research Unit, Gainesville.
Peters EH. 1983. Vocal communication in an introduced colony of feral rhesus monkeys (*Macaca mulatta*). Ph.D. dissertation. University of Florida. Gainesville.
Richard AF, Goldstein SJ, Dewar RE. 1989. Weed macaques: the evolutionary implications of macaque feeding ecology. International Journal of Primatoly 10:569–594.
Riley EP, Wade TW. 2016. Adapting to Florida's riverine woodlands: the population status and feeding ecology of the Silver River rhesus macaques and their interface with humans. Primates 57:195-210.
Sengupta A, McConkey KR, Radhakrishna S. 2015. Primates, provisioning and plants: impacts of human cultural behaviours on primateecological functions. PLoS One 10:1–13.
Sikes RS, The Animal Care and Use Committee of the American Society of Mammalogists. 2016. Guidelines of the American Society of Mammalogists for the use of wild mammals in research and education. Journal of Mammalogy 97:663–688.
Southwick CH, Yongzu Z, Haisheng J, Zhene L, Wenyuan Q. 1996. Population ecology of rhesus macaques in tropical and temperate habitats in China. Pp 95–105 *in* Fa JE, Lindburg DG, eds. Evolution and ecology of macaque societies. Cambridge University Press, Cambridge.
Titus JH. 1991. Seed bank of a hardwood floodplain swamp in Florida. Castanea 56:117–127.
Verbrugge LNH, Van Den Born RJG, Lenders HJR. 2013. Exploring public perception of non-native species from a visions of nature perspective. Environmental Management 52:1562–1573.
Wolfe LD. 2002. Rhesus macaques: a comparative study of two sites, Jaipur, India, and Silver Springs, Florida. Pp 310–330 *in* Fuentes A, Wolfe LD, eds. Primates Face to Face: the Conservation Implications of Human-Nonhuman Primate Interconnections. Cambridge University Press, Cambridge.
Wolfe LD, Peters EH. 1987. History of The freeranging rhesus monkeys (*Macaca mulatta*) of Silver Springs. Florida Scientist 50:234–245.Worton BJ. 1989. Kernel methods for estimating the utilization distribution in home-range Studies. Ecology 70:164–168.

Submitted: April 24, 2017
Accepted: July 17, 2017