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.
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 acres 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 km² using the 95% KD estimate and 1.26 km² 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.

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