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A Population Characterization of Allegheny Woodrats (Neotoma magister) In the Hudson River Palisades of New Jersey

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Abstract:

Allegheny woodrats (*Neotoma magister*) are an endangered species within New Jersey, with a limited number of individuals found within one small area of suitable habitat along the Hudson River Palisades. There are very little detailed datum on the number of woodrats living at this location, however new conservation measures are being instituted to sustain this last remaining population in New Jersey. To gather additional data on the extent of the population of woodrats at this location, wildlife camera monitoring was conducted in two-week intervals at 10 separate locations that appeared to have satisfactory habitat for the woodrats but had not been previously surveyed. Camera monitoring showed that woodrats were present on six of the ten sites surveyed, indicating that the population is more extensive than previously thought. In addition to camera-trap surveys, an analysis of live trapping data from 1987-2017 indicates that the population has fluctuated widely over those years, but has increased in recent years, presumably due to several conservation measures recently initiated. Conservation efforts during this study included the translocation of individuals from Pennsylvania, a raccoon baiting program to rid the area of a deadly woodrat parasite, and supplemental feeding. The results from this research indicate that these conservation measures have stabilized the population, and that the population has expanded into adjacent suitable habitat within the Palisades.

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A Population Characterization of Allegheny woodrats (*Neotoma magister*) in the Hudson River Palisades of New Jersey

By

Amanda Menasion

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All methods and protocols used in this study are approved by Montclair State University's Institutional Animal Care and Use Committee (IACUC) – protocols 043-2017 and 044-2017 – and Institutional Biosafety Committee (IBC) – protocol 2017-IBC_0009.

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Introduction

Biodiversity is the variety of different organisms found interacting with one another throughout ecosystems. Increased diversity, within an area, is correlated with increased community stability due to a larger species pool, which is evenly distributed with members providing different functions to the ecosystem. A larger species pool contains a greater range of adaptive traits, which stabilizes the performance of an ecosystem through resilience and production under varying environmental conditions (Worm and Duffy 2003). Biodiversity is divided into two main components with respect to species: richness and composition (Worm and Duffy 2003). While species richness has a large impact on ecosystem functions, community structure is important in that it affects the entire flow of energy throughout the ecosystem (Worm and Duffy 2003).

An ecosystem functions more efficiently if depending on the total number of species and trophic links to determine community structure, function, and stability (Worm and Duffy 2003). For example, ecosystems often have a single, or few, keystone or dominant species within the community, without which the ecosystems are significantly altered because changes in productivity. Keystone species are an essential part of the ecosystem influencing the productivity of the environment they are apart of. Other species with less direct impacts on community structure play important roles in maintaining the complexity of the food web and species diversity, but the impact is not as significant as that of the keystone species (Worm and Duffy 2003). Loss of biodiversity within communities can destabilize food webs, changing species composition and diminishing species richness. Ecosystem processes and functions depend on the number of interacting species, and as populations vanish, important ecosystem services are lost, further affecting biodiversity (Loreau et al. 2001). Loss of important ecosystem functions results in large-scale changes in the quality of the environment and has an impact on human health and well being (Novacek and Cleland 2001).

Humans are highly efficient manipulators of the environment and have dominated the vast majority of landscapes on the planet. Humans affect the values and benefits received from the environment, causing changes to both the ecosystems around them and the biodiversity (Loreau et al. 2001). These changes have occurred on a variety of spatial scales, ranging from regional to global (Loreau et al. 2001). Generally, humans find it difficult to understand, and therefore care about, biodiversity since the effects are often only felt indirectly (Mace et al. 2012). This becomes a concern when considering specific species that are affected by humans, but do not carry enough charisma to concern humans, creating high extinction rates.

A precursor to the extinction of species is the disappearance of entire populations from habitat (Caeballos and Ehrlich 2002). Extinction risk depends on the characteristics of organisms, such as rarity, population sizes, geographic range, recruitment, and specialized ecological habits (Duffy 2003). The loss of species can have severe consequences in dramatically reorganizing ecosystems through a variety of processes including trophic cascades, cascading extinctions, and rapid shifts to unfavorable stable states (Worm and Duffy 2003). Extinctions tend to be concentrated in areas with high human densities or in areas experiencing human induced impacts, including agriculture, urbanization, and hunting (Caeballos and Ehrlich 2002). With the encroachment of human activities throughout most areas, historic ranges of species have been dramatically reduced, thereby decreasing the geographic distributions for a number of species (Caeballos and Ehrlich 2002). Human induced changes do not equally impact all species; endangered and threatened species are more at risk to changes within their environment.

Discovery of the Allegheny Woodrat

Numerous fossil remains of Allegheny woodrats (*Neotoma magister*) have been located throughout their historic range. Most fossil artifacts have been located within cave deposits dating back to the Pleistocene Epoch (Castleberry et al. 2006). The Pleistocene Epoch began 2.6 million years ago and lasted until about 11,700 years ago. The most recent Ice Age took place during the Pleistocene Epoch and is known for the evolution of humans (*Homo sapiens*), and the movement of the continents to current positions (Zimmermann 2017). The oldest deposits of woodrat remains date to the middle of the Pleistocene Epoch and were discovered in two caves located in Maryland and West Virginia (Castleberry et al. 2006). The southern Appalachians served as a refuge for the woodrat because the mountain range remained ice free unlike most of the historical northern range (Castleberry et al. 2016).

The range of the Allegheny woodrat overlaps with that of the Eastern woodrat (*N. floridana*) (Feldhamer and Poole 2010). The Allegheny and Eastern woodrats have a long and mottled history; Allegheny woodrats were first classified as *N. magister* in the 1850s using a portion of the jawbone and were thought to be extinct (Wright 2010). In 1893, woodrat specimens were found in Pennsylvania where an ornithologist declared them a new species, *N. pennsylvanica* (Wright 2010). The *N. pennsylvanica* was later discarded in 1940 by Poole, and the Allegheny woodrat was resurrected from extinction and classified as *N. magister* once again (Wright 2010). During the 1950s, *N. magister* was thought to be a subspecies of the Eastern woodrat, and was classified as *N. f. magister* (Wright 2010; Monty and Feldhamer 2002). In the 1990s, researchers completed a comprehensive molecular study, supported by morphological analyses, claiming *N. f. magister* was a completely separate species, returning the Allegheny woodrat to its original classification of *N. magister* (Monty and Feldhamer 2002). Visual observation is not recommended for differentiating between the two species because of their likeness; generally, the Allegheny woodrat is larger than the Eastern woodrat (Monty and

Feldhamer 2002). The one defining difference is a maxillovomerine notch found on the skull (Wright 2010). The Allegheny woodrat is considered a sister species to the Eastern woodrat (Castleberry et al. 2006). The two species ranges intersect in North Carolina where there is insufficient evidence of hybrids (Castleberry et al. 2006).

Life History

The Allegheny woodrat is a medium sized, nocturnal rodent. Woodrats range in body length from 300-450 millimeters with a tail length of 150-210 millimeters (Castleberry et al. 2006). Woodrats resemble the much smaller white-footed mice (*Peromyscus leucopus*), because of their large naked ears and long whiskers (Monty and Feldhamer 2002). Allegheny woodrats have bicolored fur, with gray dorsal pelage and white ventral pelage from the throat to the tip of the tail (Castleberry et al 2006). The tail is long and covered with moderate fur growth. The winter coat (November to January) is a darker gray, while the coat turns brown in the summer (March to September) (Monty and Feldhamer 2002).

The breeding season is variable depending on the geographic location, availability of den sites, mast crop production, and severity of winter (Wood 2010). Woodrats generally breed in early spring to mid fall, though they are opportunistic reproducers, and if conditions allow, will breed throughout the year (Castleberry et al. 2006; Wood 2010). Woodrats tend to live for two to five years, an average of three years. Sexual maturity occurs at 3-4 months, though woodrats typically will not reproduce their first year (Castleberry et al. 2006; LoGiudice 2010). The gestation period is 30-36 days, with litter sizes ranging from one to four, with an average of two (Monty and Feldhamer 2002). Woodrat young are born pink, naked and weigh about 15-17 grams (Castleberry et al. 2006). Within five days, offspring are lightly furred, and by two weeks, completely covered in fur (Castleberry et al. 2006). At three weeks of age offspring are weaned, have their eyes fully open, and tails characteristically covered in fur (Castleberry et al 2006; Stanesa 2012). By three months, juveniles will lose their juvenile gray colored fur for adult pelage (Beans and Niles 2003). Once the young receive their adult pelage it is difficult to differentiate ages based on anything other than observational size differences, because sub-adults are recognized as being smaller than adult woodrats. Woodrats are indistinguishable from one another, though males tend to be somewhat larger than females, consistent with polygynous species (Monty and Feldhamer 2002).

This species is philopatric, due to the nature of their patchy habitat. Like most rodents, females tend to be more philopatric than males, and juveniles sometimes remain with their mother for 28-60 days after being weaned, depending on environmental conditions and available resources (Peles and Wright 2010a; Wood 2010; Stanesa 2012). Remaining close to the maternal den sites provides advantages for sub-adults: access to parental resources, increased familiarity with food resources, refuge and den sites, as well as tolerant relatives at neighboring dens. These advantages increase the expected survivorship of individuals that disperse short distances from the natal site (Wood 2010). Female juveniles will take over the maternal den if the parent disappears due to relocation or predation (Wood 2010).

The Allegheny woodrat ranges throughout the eastern central part of the United States (Feldhamer and Poole 2010). The historic distribution of the Allegheny woodrat follows the Appalachian Mountains and Interior Highlands, ranging from western Connecticut to northern Alabama (Castleberry et al. 2006). However, the current range of the Allegheny woodrats has significantly decreased from that of its historic range, with drastic declines occurring along the northern and western borders (Castleberry et al. 2006). Populations have been extirpated from the most northern parts of their range, including all of New York and Connecticut, and the status varies in other states (Castleberry et al. 2006). Both New Jersey and Ohio support only one known population each (Monty and Feldhamer 2002). Indiana and Maryland have both listed the woodrat as endangered, while Pennsylvania’s populations are state-threatened (Wright 2010). The central and southern ranges boast stable woodrat populations within appropriate habitat areas (Castleberry et al. 2006). West Virginia and Virginia have stated their populations are stable, though West Virginia considers the woodrat a species of concern (Wright 2010). Kentucky and North Carolina have woodrats listed as a priority species, with no evidence of decline; while Tennessee and Alabama both have woodrats listed as the highest conservation priority (Wright 2010). Some states do not have the resources to regularly trap locations, well-represented declines may be noted in the northern states because monitoring techniques are more vigilant (Wright 2010).

Allegheny woodrats are habitat specialists but do show variation among habitat characteristics depending on the population’s geographic locale. Woodrats inhabit protected crevices in rocky bluffs, talus slopes, boulder fields, and caves (Monty and Feldhamer 2002). The physical characteristics of their preferred habitat include large rock outcrops with many crevices. The crevices between the boulders afford woodrats pathways for foraging, the microhabitat necessary for establishing dens, and allows them to avoid and escape predators (Castleberry 2010b). The occurrence of woodrats depends heavily on the presence of rocky habitat and is somewhat independent of the abundance of dominant vegetation type (Castleberry et al. 2006).

Metapopulations are characterized by populations of the same species that are spatially separated, but interact through individuals dispersing from one population to another. As mentioned previously, woodrats tend to reside in patchy specialized habitat, with small subpopulations living within these patchy habitats (Wood 2010). The size of suitable woodrat habitat patches, and therefore the number of individuals occupying any given patch, varies. The smaller the habitat "island" the greater the chance that a subpopulation will go extinct, leaving suitable habitat available for future dispersers throughout their landscape. Woodrats move away from their protected den sites to forage for food and find mates. Males have been observed as the sex more likely to disperse long distances between rock sites throughout their life span in the search of mates (Wood 2010).

Typical of polygynous rodent species, male woodrats tend to have larger home ranges, overlapping several female woodrat ranges (Wood 2010). Home ranges vary with the season due to the changes in food availability. For example, in the summer the average home range for males is 6.5 hectares and for females, 2.2 hectares; while in the fall and winter home ranges reduce to .65 and .49 hectares, respectively (Castleberry 2010b). In the summer, woodrats move farther from den sites to forage for green vegetation, fruits, and fungi, while in the winter outside of breeding season woodrats stay closer to their dens, relying on cached foodstuffs and venturing less than 50 meters from the den location (Castleberry 2010b).

The availability of suitable den sites and woodrat territorial behavior are both considered limiting factors for population size (Peles and Wright 2010a). Den quality is based on different biological and physical factors that affect the suitability and length of time a woodrat will reside within a specific den (Peles and Wright 2010a). Den characteristics that are of higher quality have deeper crevices with less tree cover over the boulders. In confined locations, woodrats have been observed forming dominance hierarchies (Peles and Wright 2010a). In high-density captive woodrat populations, a positive correlation was discovered between body mass and occupancy of den sites with social ranking (Castleberry et al. 2006). Allegheny woodrats show a high level of aggression towards one another and live solitary (Castleberry et al. 2006). In the fall and winter male woodrats become more aggressive and territorial as competition for overwintering den sites increases, while females are most aggressive in the spring and summer, when den sites are needed for offspring (Castleberry et al. 2006: Monty and Feldhamer 2000).

Den sites are located on ledges in caves or deep rock crevices that are inaccessible to casual observers and predators (Peles and Wright 2010a). Dens are used for multiple functions including shelter, protection from predators, rearing young, and caching foodstuffs (Peles and Wright 2010a). Nests are constructed using bark, grasses, roots, and shredded wood fibers. The interior is lined with fine materials while the outside of the den is constructed using coarse materials (Castleberry et al. 2006). Nest diameter, on average, is 460 millimeters and the nest cavity has a diameter of 120 millimeters (Castleberry et al. 2006). The nests and den sites are kept free of woodrat excretion;

communal latrines are found throughout the habitat in open areas usually beneath an overhanging rock on a flat surface (Monty and Feldhamer 2002).

Both genders have a mid-ventral abdominal gland used to mark locations with a unique scent (Castleberry et al. 2006). The gland is a longitudinal strip, with sparse hair, that runs ventrally along the stomach of a woodrat (Stanesa 2012). The males' gland becomes especially active during the breeding season as a way to communicate their location to potential mates (Castleberry et al. 2006; Stanesa 2012). Males will scent mark by pressing their body against objects and dragging themselves across, the release of oily liquid discoloring fur (Castleberry et al. 2006).

Woodrats have been documented in various forest communities, including northern hardwoods, mixed mesophytic, mixed oak and pine (Castleberry et al. 2006). Overall, woodrats tolerate a variety of forest age and structure conditions, but preferentially select areas with diverse understory vegetation for foraging (Castleberry et al. 2006). Woodrats are generalist herbivores, which rely on a variety of hard and soft masts, green vegetation, fungi, and ferns as important diet components, however they will also take advantage of seasonally available foods (Castleberry and Castleberry 2010a). The fall and winter diet is composed mainly of fungi, leaves, acorns, and ferns, and in winter, occasionally woody foods (Castleberry and Castleberry 2010a). The summer and fall diet incorporates seasonally available items, including fruits, buds, lichen, and insects (Castleberry and Castleberry 2010a). Acorns play an important role in the woodrats' diet and are cached away for later use. The availability of acorns is a significant factor for many rodents and affects the growth and survival of young, adult body weight, and reproductive success (Castleberry and Castleberry 2010a). Fungi are another staple in the woodrat diet and are believed to be a top choice because of the ability to be cached without degradation (Castleberry and Castleberry 2010a).

This caching behavior has led to the Allegheny woodrat receiving the nickname "packrat." Woodrats cache food resources with high priority beginning in September or October and lasting until the onset of winter, however, they will continue to collect and store items year round (Castleberry and Castleberry 2010a). Food caches are stored close to the den site in large stick piles known as middens, which are usually built underneath overhanging rock ledges generally at the beginning of crevices (Castleberry et al. 2006; Monty and Feldhamer 2002). Most of the contents will be consumed over winter, while limited foraging prevents the complete depletion of food before the spring bloom (Castleberry and Castleberry 2010a). When available, woodrats store away more food than necessary, with leftover materials still present in the midden when restocking begins for the next season (Castleberry and Castleberry 2010a). Food is not the only items stored away in middens, non-edible items are also cached, including human refuse, bones, feathers, and scat from other animals (Castleberry and Castleberry 2010a).

Woodrats exhibit unique physiological and behavioral attributes making it difficult to fully implement conservation strategies. Difficulty in monitoring woodrat den sites impacts data availability. As previously mentioned, woodrats are one of the few mammals that naturally exist in metapopulations (Peles and Wright 2010a). The subpopulations remain small, most with fewer than 20 individuals; these populations have to survive environmental and stochastic events, high mortality rates, and low reproductive rates (Peles and Wright 2010a). The small population characteristics create conservation concerns when considering the different factors affecting the species on a local or regional scale, such as genetic drift, inbreeding, and high homozygosity. The original source of decline for the Allegheny woodrat is unknown but with fewer individuals in populations, genetic concerns have coalesced with environmental and anthropogenic factors resulting in species decline, that may not affect the entire distribution of woodrats (LoGiudice 2010). The different factors of small population dynamics and environmental conditions need to be monitored together to ensure the survival of woodrats, as a whole, not the original precipice that led to major declines of populations.

Causes of Allegheny Woodrat Declines

Allegheny woodrat populations dramatically declined in abundance over the past 30 years. Woodrats are state-listed or on a watch list in 10 of the 11 states in which the species is found (Monty and Feldhamer 2002). Because woodrats reside in isolated locations within a metapopulation model, generally containing one to five individuals per rock patch (Wood 2010). The small population sizes are more susceptible to stochastic events causing local extinctions (Wood 2010). Dispersal is important for metapopulations, by connecting subpopulations between suitable habitats and repopulating areas that may have become available due to local extinction events (Wood 2010).

The Allegheny woodrat decline was first noted in the 1970s in Pennsylvania and New York (LoGiudice 2010). The cause for the decline cannot be traced to one source, but instead seems to be associated with the interaction of multiple stressors, which led to dramatic losses. Most populations are impacted by human induced influences, such as habitat fragmentation, while one cause may not drastically affect a population; multiple causes working together can be devastating (Manjerovic et al. 2009). Metapopulation models have subpopulations that are made up of a small number of individuals, which causes genetic diversity concerns; other hypotheses include the loss of food resources, habitat fragmentation, loss of genetic heterogeneity, and the prevalence of raccoon roundworm (*Baylisascaris procyonis*). These factors interact to cause range wide decline. The main hypotheses for the decline of New Jersey woodrat populations are food decline, habitat fragmentation, and parasites (LioGiudice 2010).

Population Decline Hypotheses

The "food decline" hypothesis posits woodrat populations decrease with the reduction of hard mast availability (LoGiudice 2010). Woodrats are forest obligates, relying on forests surrounding rocky outcrops to forage for food resources. Over the years, environmental and human impact on food resources has reduced the quality and quantity of food available to sustain woodrats (Manjerovic et al. 2009). Nutritional resources are important for survival, fecundity, and population dynamics (Smyser et al. 2012). The dominant tree throughout Appalachian forests was the American chestnut (*Castanea dentata*) (LoGiudice 2010). American chestnuts were a dependable mast species that began receding in forests between 1910 and the 1930s due to a parasitic fungus known as the chestnut blight (*Cryphonectria parasitica*) (Smyser et al. 2012; LoGiudice 2010).

Oak (*Quercus sp.*) became the dominant tree within forests after the decline of the American chestnut. Oak tree species do not synchronize mast production; acorn production varies from year to year (Smyser et al. 2012). Acorns and other hard masts provide high-energy resources for woodrats, and are present in the diet year round (Castleberry et al. 2002). It has been shown that acorn crop and population fluctuations are linked, with increased acorn production leading to increases in recruitment (Castleberry et al. 2002). The invasive gypsy moth (*Lymantria dispar*) defoliates deciduous trees, primarily oaks, since its introduction in the late 1800s, and has slowly spread throughout most of the hardwood forests in the eastern United States (Elkinton and Leibhold 1990). With repeated defoliations, mast failure and oak mortality occur (LoGiudice 2010).

In addition to the impact gypsy moths inflict on oak trees, human activities such as timber harvesting and fire suppression play a role in reducing the number of mast producing trees in the forest (Manjerovic et al. 2009). These activities allow for competitor growth into newly available areas, and most are species such as maple (*Acer sp.*) and birch (*Betula sp.*) that grow faster than oaks (Manjerovic et al. 2009; LoGiudice 2010). With a changing forest composition, fewer mast-producing trees reside in forest communities creating increased consumer competition. These threats may be intensified, especially in the northern distribution of woodrats, by harsh winters (Manjerovic et al. 2009). Under harsh conditions, woodrats are forced to increase foraging distances, thereby increasing predation risk and exposure to winter weather, and thus reducing reproductive output because individuals are entering the breeding season with depleted fat reserves (LoGiudice 2010). Compared to other rodents, woodrats are not prolific breeders, which is further compromised without the availability of high-energy food resources for reproduction and maintenance of offspring.

The "habitat fragmentation" hypothesis suggests an interruption in the ability of woodrats to move freely between rock sites to another, which restricts gene flow and suppresses metapopulation dynamics (Wood 2010). Highways, urbanization, and agriculture create dispersal barriers (LoGiudice 2010). Small populations are vulnerable to deleterious genetic effects, which are amplified in isolated subpopulations because of dispersal barriers (Smyser and Rhodes 2010). Genetic drift is the stochastic fluctuation in allele frequencies from one generation to the next as a consequence of random sampling of gametes during fertilization (Smyser and Rhodes 2010). The restriction of gene flow and repeated random sampling can cause a loss in the diversity of alleles, and results in a population being unable to evolve by natural selection in response to environmental changes (Smyser and Rhodes 2010). With the loss of genetic diversity through genetic drift, inbreeding depression can occur resulting in an increase in the homozygosity of harmful alleles (Smyser and Rhodes 2010). Inbreeding depression varies throughout taxa, but are generally substantial enough to affect both the individual and population performance (Keller and Waller 2002). Inbreeding depression can cause negative impacts on birth weight, survival, reproduction, resistance to diseases, exposure to predation, and greater susceptibility to environmental stressors (Keller and Waller 2002). When subpopulations are numerous, overall genetic diversity is retained within the metapopulation, but as the number of subpopulations decline, genetic diversity can be lowered at the metapopulation level (Smyser and Rhodes 2010).

Woodrats tend to be more sensitive to anthropogenic pressures that cause habitat fragmentation between subpopulations (Smyser et al. 2012). The probability of occupied den sites decreases with distance from the forest edge. LoGiudice (2010) reported abandoned sites when the forest edge receded to two kilometers. As the forest edge recedes, increased contact with predators associated with human disturbance occurs (LoGiudice 2010). Documented woodrat predators include black rat snakes (*Elaphe obsoleta*), great horned owls (*Bubo virginianus*), feral cats (*Felis catus*), raccoons (*Procyon lotor*), skunks (*Mephitis* and *Spilogale putorius*), foxes (*Vulpes* and *Urocyon cinereoargenteus*), and long tailed weasels (*Mustela frenata*) (Hassinger et al. 2010). Many of the predators listed are mesopredators which reside close to human populations, as habitat is built upon these species are able to infiltrate the rocky habitat, increasing competition and predation among woodrat populations.

The "parasite" hypothesis is tied to the fragmentation of forests surrounding woodrat habitat. Habitat fragmentation increases access to the rock outcrops where woodrats live, increasing the number of woodrat predators and competitors (Hassinger et al. 2010).

Additionally, raccoon populations have dramatically increased with the loss of top predators and decreased hunting and trapping efforts; there is evidence that the increased prevalence of raccoon roundworm occurs in human-dominated landscapes with increased densities of raccoons and the loss of top predators (LoGiudice 2010; Page 2013). Top predators limit mesopredators by interference competition, creating a cascade of ecosystem effects, with the potential to indirectly benefit birds and rodents (Gompper 2002).

Raccoon feces can contain 35% or more seeds by volume creating an ideal food resource that can be easily collected by small rodents and birds (LoGiudice 2006). Raccoons are the definitive hosts to the parasitic *B. procyonis*, which is believed to cause increased mortality to the Allegheny woodrat, with no effects on raccoon populations (LoGiudice 2010). Raccoon and woodrat habitats naturally overlap, but increasing raccoon densities create the possibility of *B. procyonis* remaining in raccoon latrines for extended periods of time, reinfecting the host and granivores visiting the latrine (Page 2013). The intestinal nematode has a complex life history, and can invade a multitude of species to use as intermediate hosts (LoGiudice 2010). Mature worms live within the raccoon's intestines and the eggs are passed through the raccoon's feces (LoGiudice 2010). Infected raccoon feces can contain anywhere from 20,000-26,000 eggs per gram (Page 2013). The eggs are picked up by granivorous birds and mammals foraging in raccoon latrines or passively in feathers or fur. Once ingested the nematode migrates through the intermediate host's tissues towards the central nervous system (LoGiudice 2010). This migration culminates in death of the individual directly or results in behavioral changes allowing for easier predation; the cycle completes when raccoons consume the intermediate hosts (LoGiudice 2010).

It is thought that Allegheny woodrats suffer declines more dramatically than other small mammals because of their caching behavior. Foraging woodrats tend to cache the whole raccoon feces instead of removing the seeds; this risks contaminating the whole midden even if the feces are not directly consumed (LoGiudice 2006). Observational studies have shown woodrats prefer to collect older scat, on average waiting 21 days before caching the scat; this allows *B. procyonis* eggs the opportunity to embryonate, which takes anywhere from two to four weeks. Before embryonation the eggs are harmless (LoGiudice 2006). The cool, moist conditions within rock crevices allow for eggs to remain infective for years (LoGiudice 2006). Woodrats tend to reuse dens for multiple generations, which can cause residents to become infected by *B. procyonis* from the original infected scat years later (LoGiudice 2010).

With the loss of food resources, competition increases for the resources that do become available. Woodrats have to compete for acorn masts with an array of other species, such as white tailed deer (*Odocoileus virginianus*), white-footed mice, and black bears (*Ursus americanus)* (Mengak et al. 2002). White tailed deer are generalist herbivores, and overpopulation of these ungulates creates overgrazing of plant species, which changes the composition of desired plants within an area (Mengak et al. 2002). In the southern range, woodrat habitat undergoes disturbance because of coal mining, but within the northern region destruction of habitat is infrequent and undocumented (LoGiudice 2010).

Status of Allegheny Woodrats in New Jersey

Allegheny woodrats have declined in numbers and range throughout most of their northern habitat. As stated above, the woodrat has been extirpated from Connecticut and New York, with declines throughout New Jersey. New Jersey had several locations in the four northernmost counties that boasted woodrat populations, prior to the 1960s (Wright 2010). During the 1980s, growing concern from New York's extirpation of woodrats led to a survey of past historic sites, which resulted in no captures or recent signs of woodrats within New Jersey (Wright 2010). Subsequent searching of suitable habitat led to the discovery of two previously unknown populations in New Jersey (Wright 2010). One of the two new locations (Picatinny Arsenal) became extirpated of woodrats, and in 1991 New Jersey listed the Allegheny woodrat as endangered (Wright 2010). The last known population resides within Bergen County along the Hudson River Palisades.

Conservation strategies have been put into place to help protect and stabilize this population. The Endangered and Nongame Species Program (ENSP) of the New Jersey Fish and Wildlife works closely with other agencies and biologists to create a management plan that addresses the variety of stressors that can lead to population declines for Allegheny woodrats. Current management strategies include boosting genetic variation within the population through translocation events, monitoring population levels, and creating mitigation strategies for *B. procyonis* throughout the Palisades. The decision was made to boost the genetic variability within the population after low heterozygosity was detected; this was to be accomplished through translocation of individuals. Concern was expressed about the survivability of individuals especially because of the increased rates of *B. procyonis* within New Jersey (Page 2013). In fall 2015, bait dispensers were placed throughout the Palisades containing anthelmintic baits, in the hopes of deworming infected raccoons. Woodrat translocations tend to be more successful when baiting occurs regularly (Page 2013). That summer, the Palisades population received its first two translocated individuals in the hopes of increasing genetic diversity and population size.

The Allegheny woodrat is listed as threatened, endangered, extirpated, or a species of concern in more states than any other rodent (Peles and Wright 2010b). This investigation was designed to answer fundamental questions relating to baseline data on distribution and abundance of the Hudson River Palisades woodrat population, in order to better understand the woodrat population dynamics. Four questions will be explored by this study: 1) what does the current number and age structure of the population of woodrats in the Palisades look like, 2) How has the population changed in abundance over time, 3) What has results from the study conducted by Doyle et al. show of genetic diversity within the population and how has results changed with the introduction of new individuals, and 4) How extensive is the geographic range of the population along the Palisades boulder fields?

Methods

Site Selection

The Palisades cliffs range approximately 40 miles along the Hudson River from southern New York to central New Jersey. The Palisades Interstate Park protects 2,500 acres, an approximate 12-mile stretch of the cliffs. The Palisades receives its name from the vertical formation of rocks resembling a fence post also known as a palisade (PIPC 2017).

The Palisades rock formation is composed of diabase, an igneous rock, containing two minerals: light feldspar and dark augite (PIPC 2017). The Palisades formed 200 million years ago when Pangaea broke apart, and molten diabase escaped from the depths of the Earth, spreading throughout the sedimentary rock layers creating a sill of hard rock beneath layers of softer rocks (PIPC 2017). Throughout the millions of years since the sill formed, the softer rocks have eroded away, leaving behind the distinctive vertical columns of the Palisades cliffs (PIPC 2017). Throughout the years, natural weathering processes have taken a toll on the Palisades, with portions of the cliffs flaking and breaking off, causing major rock falls, resulting in piles of debris and boulders, known as talus, which collect at the foot of the cliffs (PIPC 2017).

During the nineteenth century, quarries populated the cliffs to mine the talus for building materials; by the 1890s, quarries began creating their own talus material by blasting the cliffs with dynamite (PIPC 2017). In 1900, supported by the New Jersey State Federation of Women's Clubs and other citizens, New Jersey and New York, created the Interstate Palisades Park Commission to preserve the cliffs (PIPC 2017). In 1998, the Palisades Interstate Parkway was designated a National Landmark by the National Park Service, preserving the land for its scenic value (PIPC 2017).

Throughout millions of years, rich soils have collected, allowing for forests to flourish between the talus fields, while in other areas exposed bedrock is still observed (PIPC 2017). The Palisades are inhabited by mature oak and maple dominated forests, though birch and other species can be found (PIPC 2017). Throughout the open areas of the Palisades, shrubs and vine communities thrive, including large amounts of grape vines (*Vitis sp.*) and poison ivy (*Toxicodendron radicans*). The Palisades also have a plethora of invasive plant species growing throughout, which entered the ecosystem through the Hudson River tides, and by humans for aesthetic purposes. Some species do not cause too much harm to the natural plant species community such as the *paulownia* tree (*Paulownia tomentosa*), while others such as Mile-A-Minute (*Persicaria perfoliata*) are more aggressive, displacing natural plant species within the community (PIPC 2017).

The ENSP first searched the Palisades in the 1980s for Allegheny woodrat signs. During this time, woodrat populations were declining throughout New Jersey. The viable habitat was protected within the park and a working relationship between ENSP and the Palisades Interstate Park Commission allowed for the establishment of a permit system to monitor the woodrat population. ENSP officials created five trapping locations (DE, AB, F, C, and G) distributed throughout approximately one mile of the park (G. Fowles, per. com., 2015) (Figure 1). For the past three years the five sites have been used as release locations for the six translocated individuals from Pennsylvania.

Live Trapping – Population Analysis

In the fall, between September and November, ENSP and academic institutions undertake a large scale trapping effort in the Palisades. The trapping event has occurred intermittently throughout 1987-1996, and annually since 1999 (G. Fowles, per. com., 2016). Prior to the 2007 established standard protocol there was variability between the traps.

The trapping protocol, established by the ENSP, occurs for a period of three days and two nights, with 40 Tomahawk TM Model 201 (5”x5”x16”) collapsible, standard single-door, live traps divided among the five sites (G. Fowles, per. com., 2016). Two trapping nights have proven to be a sufficient amount of time to capture virtually all woodrats present in an area (Peles and Wright 2010a). Each trap is baited with peanut butter and an apple slice to ensure all animals caught are fed and hydrated. The traps are checked every morning to ensure that the woodrats spend less than 24 hours in the traps. When a woodrat is first captured, body mass, sex, reproductive condition, and overall health are determined, visually. Unique 5mm ear tags are placed on either or both ears. Additionally, a 3mm ear punch is taken as a genetic sample and if possible a scat sample as well. If a woodrat is a recapture, ear tag identification, body mass, reproductive condition, and overall health are noted. Field notes document all information and at the end of trapping, data are entered into a database for future reference, and tissue samples are sent out for testing.

During the ENSP’s annual trapping, ear punches are taken from each woodrat and placed in a vial filled with alcohol and labeled with the newly acquired ear tag identification number. At the end of the trapping event, genetic samples are sent to Dr. Jacqueline Doyle, an assistant professor at Towson University, for analysis. Using an SNP panel, individual woodrats are identified using genetic markers to gain a unique “fingerprint” (Doyle and Muller-Girard 2018).

The trapping data is analyzed to evaluate the sex of individuals, age class structure, and genetic makeup. Genetic data was obtained through single nucleotide polymorphisms

(SNPs), and incorporated over a hundred gene-associated and neutral markers (Doyle and Muller-Girard 2018). This information allows for individuals to be recognized within the population, gaining a better idea of genetic diversity throughout the entire population. Gaining data on the composition of the sex and age classes allows for a better understanding of the changes occurring for competition for mates, resources, and mating costs within the population (Dreiss et al. 2010).

The trapping data was analyzed in this investigation by calculating trap success throughout all trapping events to understand the effectiveness of trapping individuals within the population. The Jolly-Seber Mark and Recapture Model was utilized in order to estimate yearly population abundance (Ryan 2011). This model takes into account four assumptions: 1) Every individual has the same probability of being captured, whether marked or not 2) Every marked individual has the same probability of surviving from one sampling period to the next 3) Individuals do not lose their marks and marks are not overlooked 4) Sampling is negligible in relation to the intervals between samples (Ryan 2011). This model was chosen because it accounts for the temporal variations that occurred in past trapping events of the Palisades, before a standard protocol was established and trapping occurred annually.

Wildlife Camera Sampling

Using the trapping area as a starting point, three survey regions were generated (northern, central, and southern) in order to gain a better understanding of the population within the Palisades (Figure 2). The central section, based on current trapping sites, was approximately 1.96 kilometers long. The goal of the survey was to cover the length of uninterrupted habitat surrounding the current woodrat trapping locations (1.49 kilometers) (Figure 1). In order to do so, the northern region measured .79 kilometers, but stopped because of the New York state border, while the southern region went as far south as a parking lot, and covered 1.17 kilometers. The overall distance that was surveyed from the northern to southern regions was 5.25 kilometers. The three survey sections were divided into three to four sub-sites. Using the protocol of Ford et al. (2006), sub-sites consisted of a 1-kilometer radius of forested area. Each sub-site was chosen based on the quality of talus fields, such as large boulders that created deep crevices, translocated woodrat movements and settlement areas, and proximity to the current population range.

Using a modified version of an absence/presence survey created by the Pennsylvania Game Commission (PGC), the ten sub-sites were visually surveyed for signs of woodrats, such as latrines, middens, or sightings. If a latrine location was found it was marked using a GPS, and a random sample of ten fresh scat samples were collected and sent for genetic testing. Classification of fresh and old scat samples followed Mengak et al.'s (2010) classifications: fresh scats had a soft moist texture or black shiny exterior, old scats looked dry with dull and deteriorated exteriors. Each site's perimeter was traced using the Trimble GeoExplorer 6000 series, and the positions of cameras were recorded.

Depending on the size of the potential habitat four to six Covert Scouting Cameras (Black Maverick 2015 and 2016 models) were used (Turner 2017b). Cameras were deployed and baited with Peanut Blend Suet Plus and unsalted peanuts, to attract Allegheny woodrats. The bait was replaced every three days as suggested by the PGC protocol, unless extenuating circumstances occurred to make it unfeasible to get to a location (G. Turner, per. com., 2017a). The cameras were placed with a deliberate-bias, usually being positioned facing active and inactive woodrat latrines, placement on flat rock surfaces for ease, and in discrete locations to hinder human disturbance (Meek et al. 2014). Cameras were placed at ground level stabilized with rocks found around the site. To ensure plant movement did not activate the cameras, plants in direct line of sight were removed and surfaces covered with forest debris were cleared (Meek et al. 2014). The cameras were motion activated and set at high sensitivity for 10-second videos. Cameras were in place for two weeks and powered on 24 hours a day (Turner 2017b). After the first week, memory cards and batteries were swapped and cameras were examined and any malfunctions rectified.

One observer viewed all videos from the cameras and documented videos containing vertebrates, the main focus being woodrats, while disregarding videos with invertebrates, plants, weather conditions, or human activity. Videos containing woodrats were evaluated for individual identification based on, gender, presence of ear-tag, and a visual age estimate. Woodrats were marked as unknown if the individual's characteristics were unidentifiable. Videos containing vertebrate species other than woodrats were documented by species. It is difficult to identify individual organisms on camera, so videos were deemed unique sightings after five minutes had passed with inactivity on the camera for all species observed. After five minutes of inactivity on camera, it was assumed a new event. The five-minute interval is a common practice for ENSP camera data analysis (G. Fowles, per. com., 2017).

During this investigation live trapping did not occur during the camera monitoring period determining absence and presence. Wildlife cameras were chosen because they are a less invasive way to monitor wildlife (Meek et al. 2014).

Translocations

In order to address the low heterozygosity observed by collected genetic samples, the ENSP decided to introduce new individuals into the current population. Translocation allows for an organism to be released within parts of its historic range, where remnant members still exist to provide genetic or numeric support to an isolated population (Serfass 2010). Since the Palisades population is the last extant woodrat population, within New Jersey, supplementation had to occur from another state's population. The ENSP collaborated with the PGC, where Allegheny woodrats are listed as a state threatened species. It was determined that Pennsylvania would be the best choice because it would allow the ENSP to mimic the natural process of gene flow, by translocating individuals from closer proximities rather than from distant populations (Smyser and Rhodes 2010). Starting in July of 2015, the two agencies coordinated to create a three-year agreement, which allowed two sub-adult woodrats per year, one male and one female, to be trapped and transferred to the Palisades. The sub-adult age class was chosen for translocation because the transition from sub-adult to adult is the natural timeframe for natal dispersal; woodrat dens have a high adult turnover rate, affording sub-adults with opportunities to establish themselves in prime den locations (Monty and Feldhamer 2002; Wood 2010).

Captured woodrats were taken back to New Jersey to the Mercer County Wildlife Center to undergo a vet check, by veterinarian Erica Miller, DVM. The woodrats were anesthetized, x-rayed, ATS telemetry collar attached, ear tags inserted, ear marked, dewormed and flea powder applied. The woodrats were given a minimum of 12 hours to recover from anesthesia and were temporarily housed in a secure ENSP location. To create less stress and to mimic natural activities, woodrats were released in late afternoon/early evening.

The woodrats were tracked daily with radio telemetry during the first two weeks immediately following the release. Once located, two wildlife cameras were placed around the area for visual confirmation and were marked using GPS coordinates. The cameras allowed for continued monitoring of health, and if needed the woodrat was recaptured for veterinarian care. After two weeks, or when the new woodrats began to settle into an area tracking was reduced to every other day. After approximately a month, active monitoring with telemetry was further reduced to once or twice a week.

Collars were removed within three months of release to ensure the woodrats were not harmed by the collar's inability to grow with the woodrat. Traps were set within the settled area and researchers remained close by to remove the translocated individual's collar immediately after capture. Once collars were removed, two wildlife cameras were left in the area to continue monitoring.

Results

Live Trapping - Population Analysis

There is insufficient data collection from 1987-2000 to incorporate a complete analysis of the population. Data collected through 26 years of live trapping include 2,212 trap nights, and 735 total captures of 489 individual woodrats (246 recaptures) (Figure 3). Out of the 489 individual woodrats captured, 146 were sub-adults and 343 were adults. The sub-adult to adult ratio throughout the 26 years is 0.42 per adult.

A more extensive analysis of the population is possible for data collected between 2001-2017. The ENSP has detailed capture data available on the woodrats caught, including sex ratio for both age classes, allowing for a comprehensive look at the population. During this time period, 236 adults were captured, 120 of which were males and 116 females. Additionally, there were 95 sub-adults captured, 44 males and 51 females. The sub-adult to adult ratio was determined to be 0.40, while the female to male ratio was 0.96.

Trapping success (the number of traps set divided by the number of individuals captured) ranged from 8%-50% with the highest trap success occurring in 2005 and the lowest in 1989 (Figure 4). Trap success has increased over the past two years, 2016-2017. Additionally, 2016-2017's total capture numbers have been the highest, since 2006 with 25 individuals. Adult captures reached their highest numbers since 2004. However, sub-adult captures remained low, although there was a noticeable increase between 2012 (0 sub-adults) to 2017 (4 sub-adults). Overall the populations show increases in abundance over the past several years.

The estimated population, using mark and recapture data, ranged from 6-241 individuals (Figure 5). The highest recorded number of individuals occurred in 2001 and the lowest in 2008. Likewise, the number of marked individuals within the population ranged from 2 (in 2001) to 70 (in 2008).

Wildlife Camera Sampling

The absence/presence surveys were not conducted within the same two-week interval because of the limited number of wildlife cameras available and time feasibility. Cameras were specifically baited for Allegheny woodrats, however other organisms seen on cameras were also recorded (Table 1).

Though cameras were concealed during placement, there was the opportunity for a hiker to locate cameras and change the position. Additionally, large animals sometimes shifted cameras during the surveying period. Both of these issues were not accounted for in the data, because it occurred infrequently and cameras were still actively recording and baited regularly, allowing issues to be rectified during maintenance. Camera 524 at site N1 malfunctioned during the second week, and no data was retrieved for that week. Camera 523, at S2, and camera 502 at S4 malfunctioned during the first week of the study and no data was collected.

North Region

The northern region begins at the New Jersey/New York border and extends to the central region and contains three survey sites: N1, N2, N3 (Figure 6, Table 2). Two of three sub-sites within the northern region contained woodrats on camera. Other species located in the northern region include: mice, raccoons, birds (Aves sp.), Sciuridae, foxes, and five lined skinks (*Plestiodon fasciatus*) (Figure 7, Table 1).

The northern region had 223 adult and two sub-adult sightings on camera. Of the 225 woodrats sighted on camera, 147 were males and five were females; the other 73 sightings could not be identified by gender and were labeled “unknown” (Table 3).

Central Region

The central region includes the ENSP’s five trapping sites that are used to analyze the population. The central region contains three sites: C1, C2, and C3 (Figure 8, Table 2). All three of the sub-sites, within the central region recorded woodrats on cameras. Other species located in the central region: included mice, raccoons, birds, and five-lined skinks (Figure 7, Table 1).

The central region’s three sites had a total of 508 adult and 64 sub-adult sightings. The woodrats observed were 175 male and 202 female sightings, and an additional 187 sightings were marked “unknown” for gender (Table 3).

Southern Region

The southern region ends shortly before a public picnic area and large boating dock. The southern regions have four sites: S1 (northernmost site), S2, S3, and S4 (southernmost site) (Figure 9, Table 2). One of the four sites, S1, had woodrats observed on camera (Table 3). Other species located in the southern region included: mice, raccoons, birds, sciuridae, opossums (*Didelphis virginiana*), long tailed shrews (*Sorex dispar*), and deer (Figure 7, Table 1).

The southern region count was comprised of 26 adult and 12 sub-adult sightings. The site had no observed males, 15 confirmed female sightings, and 23 “unknown” (Table 3).

Translocations

A total of six sub-adult woodrats, three females and three males, were translocated to the Palisades over three years (Table 4). In 2015 the two woodrats released survived to reproductive age, and are believed to still be alive and residing throughout the Palisades. In 2016, one of the translocated individuals was confirmed deceased, M352, believed to be caused by raccoon roundworm, however the female is currently alive and monitored on wildlife cameras. In 2017, one of the individuals, M151, was confirmed deceased by predation, but the female, F191, is still alive and currently monitored on wildlife cameras.

Three of the six translocated woodrats are still monitored and observed on wildlife cameras (M301 from 2015, F551 from 2016, and F191 from 2017). The last individual, F501 (2015) was not observed on camera at this time because of relocation to a new den site. The activity of the translocated woodrats was used to designate the three regions of this investigation. The grand mean for distance travelled by the six translocated woodrats was 0.655 kilometers from their release site to their present location (Table 4). In 2016, genetic testing was completed on individuals captured after the trapping event, results showed M301 had an offspring with a New Jersey native woodrat. In 2017, genetic testing that was completed after that trapping event indicated that F501 had three offspring captured, as well as recapturing M301's offspring from the previous year (Doyle and Muller-Girard 2018).

There is circumstantial evidence that the female (F551) from 2016 has reproduced and contributed two offspring to the populations, although this female is not located within the five original trapping locations and it is not a feasible option to bring trapping equipment to her location (C3) (Figure 8) (Table 4). Camera data observes F551 on camera with two juvenile woodrats, though there is no genetic data to support this claim. The female from 2017 has most likely not reproduced yet; it is hopeful that she will reproduce in 2018.

Sixty tissue samples were collected during live trapping events and 35 high quality scat samples were collected and genotyped from 2009, 2011, and 2015-2017 by Dr. Doyle and her associates to gain a better understanding of the heterozygosity of the population (Doyle and Muller-Girard 2018). Genetic testing has shown that increases have been made in observed heterozygosity from 2009 to 2017, while using 139 SNP panels to genotype tissue samples (Doyle and Muller-Girard 2018). The observed heterozygosity went from its lowest point in 2015 (0.094) to almost tripling in 2016 (0.263), and reaching its highest point so far this past year in 2017 (0.288) (Doyle and Muller-Girard 2018).

Discussion

This investigation studied the only known extant population of Allegheny woodrats in New Jersey to better understand the population characteristics, distribution, and the effects of translocations on the population. To gain information about the characteristics of this population, 26 years of live trapping datum from five different woodrat sites in the Palisades of New Jersey were analyzed. During this investigation, an additional 10 potential sites were surveyed for absence or presence of woodrats to ascertain the extent of the population. Finally, the study evaluated the effect of translocating six individuals from Pennsylvania on the genetic diversity of the Palisades population. The most recent datum collected during this study indicate that the Palisades population is increasing, woodrats are present in an additional six sites north and south of the existing five sites, and the addition of translocated individuals from Pennsylvania, genetic reports have confirmed an increase in genetic variability.

Population Characteristics

Analysis of the Allegheny woodrat population data generated through 26 years of live trapping, shows fluctuation of abundance throughout most of the past, but within recent years the population has stabilized. More detailed data have been gathered throughout 2001-2017, allowing for a more in depth look at the composition of the population. Throughout this time, the ratio of adult females to males is 0.97 females per male; roughly the number of males and females are equal (Table 5). The population is believed to exhibit a polygynous mating system, though promiscuity between adults occurs in some *Neotoma* species, suggesting not all males within the breeding population have the opportunity to reproduce (Conditt and Ribble 1997).

Trapping success has been consistent within the past few years, especially with a standard trapping protocol in place where traps are placed in the same location annually, allowing for consistent data collection. Trapping success within the past two years (2016-2017) has increased and the capture of the number of different individual woodrats up, leading to the conclusion that the overall woodrat population has increased within recent years.

Utilizing the Jolly Seber Mark and Recapture method has required that assumptions be made about population sizes within the Palisades. The model analyzes past trapping data to make assumptions. The highest estimate of woodrat individuals within the population was 241 individuals in (2001). Though a population of 241 individuals is not necessarily high, it seems to be an outlier when considering other factors such as trapping success, and trapping protocol. Most of the other estimates appear to be more realistic in the range of about 100 individuals (G. Fowles, per.com.). This estimate is consistent with the average obtained from the mark and recapture model of 70 individuals.

To prevent frequent inbreeding and the deleterious effects it has on populations, it has been proposed that the absolute minimum effective population size should be around 50 individuals (Shaffer 1981). However, over a long period of time genetic drift and inbreeding could still occur within a population of this size. A more effective population size to ensure sufficient genetic variability within the population over time has been estimated to contain 500 individuals, with systemic pressures and stochastic events, such as disease, playing an important role in ensuring the persistence of a metapopulation (Shaffer 1981). The difficulty in preserving population diversity is spreading conservation efforts over wider ranges to preserve "hot spots" for species richness, where human populations have already settled and created barriers for natural dispersal (Ceballos and Ehrlich 2002).

In 2015, a major decline occurred within the population, before the numbers increased in 2016 and 2017. A combination of factors is believed to have caused the declines, but the same can be true about population increases. Beginning in 2015, a full scale-baiting program was created to ameliorate the raccoon roundworm problem. This program is believed to have played a large role in reducing the prevalence of the deadly parasite within the Palisades and thus, has led to the increase in the woodrat population recorded in 2016 and 2017. Other factors that could have led to the population increase but were not monitored during this investigation include favorable weather conditions, and/or an increase in food resources.

Raccoon Baiting

Raccoons are habitat generalists that tend to live in close proximity to humans carry *B. procyonis*, a parasite that is lethal to woodrats within hours of ingesting. In 1992, raccoon rabies became prevalent throughout New Jersey, and led to a large decline in raccoon populations. During the next trapping event, in 1995, woodrat captures had increased to their highest totals, indicating the dramatic effect raccoons have on woodrats as competitors, predators, and disease vectors. Throughout the years of 2008-2012, the ENSP supplemented trapping sites with food for woodrats and medicated anthelmintic baits for raccoons (G. Fowles, per.com.). The effect of the food supplementation and raccoon roundworm baits on the woodrat population can be observed in the results of the 2008-2010 trapping seasons. Capture rates rose from nine individuals, the lowest since 1989, to 16 individuals in 2010. Starting in 2015, the systematic wide spread application of anthelmintic baits commenced year-round with six bait dispensers placed within ENSP's trapping locations (Figure 1). Presumably as a result of this, individual captures increased in the sampled population the following year in 2016 (27 individuals) (Figure 3) and individual capture rates have remained high in 2017 (25 individuals) trapping season (Figure 3).

The year-round raccoon roundworm baiting is believed to have successfully lowered the presence of *B. procyonis* within the Palisades, as indicated by the low incidence of raccoon roundworm found in raccoon scat and the increased number of individuals captured following the start of the program in 2015 (Figure 3). Following the apparent success of raccoon roundworm mitigation, an additional 10 bait dispensers were placed throughout the Palisades. Unfortunately, the baiting program cannot be definitively evaluated because scat surveys were not consistently collected and analyzed prior to the beginning of the systematic deworming program. However, beginning in 2016, raccoon scat was systematically collected, and out of 100 samples from 2016-2017, only three samples were positive for *B. procyonis* (3%). The 16 bait dispensers currently distributed throughout the Palisades, including ones below and above the cliffs as well as along the border between New Jersey and New York, appear to be effective in reducing the prevalence of raccoon roundworm in the Palisades.

Distribution of Population

Trapping efforts require a large time commitment, available hands in the field, and favorable weather conditions. Camera monitoring is a less invasive, more economical, and an ethical alternative (Meek et al. 2014), especially considering the number of sites that were surveyed during this investigation. With the data collected from camera surveys, the total range of Allegheny woodrats along the Palisade ridge equals 3.64 kilometers, approximately doubling the length of known woodrat habitat that is currently monitored with live trapping.

Woodrats live within metapopulations composed of small numbers of individuals living in spatially separated subpopulations utilizing patchy suitable habitat. Interactions occur between the subpopulations when movements of individuals occur from one viable habitat to the next. The smaller the subpopulation, the more susceptible they are to local extinction events (Shaffer 1981). The metapopulation model indicates that extinctions within the subpopulation level are normal and will be repopulated by dispersing individuals. The distribution of Allegheny woodrats fit a metapopulation model, but as barriers are created between subpopulations, woodrats may be unable to follow natural dispersal routes to allow immigration and emigration.

Using the camera data in ten sites outside of the five live trapping areas, six sites were confirmed to have woodrat occupancy. Across all six sites, there was a ratio of 0.40 sub-adults per female. A woodrat study in West Virginia, found a ratio of 0.68 sub-adults per female, indicative of population decline because replacement levels were below the norm (Wood 2010). Woodrats tend to have high turnover rates, which opens up den sites for dispersing individuals, but if there are not enough offspring being reared and surviving to their first year, woodrat populations will continue to decline (Wood 2010).

The woodrat occurrences captured on camera had only one tagged adult female. The rest of the occurrences were untagged woodrats, suggesting that the woodrats on camera are not spending time in any of the five live trapping sites. This data support the metapopulation model proposed earlier, where subpopulations exist in patchy suitable habitat, with individuals only moving between subpopulations when necessary. These newly discovered subpopulations indicate a more extensive and viable population in the Palisades and should be included in the annual live trapping event. This new discovery will drive expanded conservation efforts in the region.

Four of the 10 sites surveyed were devoid of woodrat presence, with one of the four having old latrines within the rock outcrop. This site, N1, is the northernmost site within the surveyed area, close to the New York border. If this site could be recolonized, after a raccoon-baiting program is instituted, there is the potential for future subpopulations to colonize into New York, depending on the management of barriers. If dispersal routes are found and maintained, this could become a natural pathway for individuals to disperse and gene flow to occur. Conservation resources from New York could be used to support the reintroduction of woodrats into New York, expanding and further stabilizing the population in the Palisades along the Hudson River.

Castleberry et al. (2002) studied West Virginia woodrat populations and found substantial differentiation of subpopulations separated by approximately three kilometers. Future work needs be done to gain a better understanding of the genetic makeup of the northern and southern regions of the Palisades population, to identify how natural gene flow occurs throughout this metapopulation. Gaining a better understanding of how individuals move within the Palisades metapopulation will help to shape future management plans that maintain heterozygosity in the gene pool.

Translocation Initiative

Genetic rescue is a management tool that has been used for a number of species. The integration of a limited number of new individuals into a population can improve the genetic diversity f that population (Smyser and Rhodes 2010). Monitoring the genetic diversity of the Palisade population has been an integral part of the management plan initiated by the ENSP. There has been concern in recent years from the results of genetic markers indicating inbreeding depression within the Palisades population (Doyle and Muller-Girard 2018). Contributing to this view, in 2014, the capture of an adult male woodrat with two deformed front feet was observed (Fowles 2015b). Inbreeding depression does not always manifest in physical deformities to individuals, though they can occur during environmental stresses (Smyser and Rhodes 2010). The less obvious indicators of inbreeding depression in the population occur through decreases in survival rate, reproductive success, and population persistence (Smyser and Rhodes 2010). To combat farther loss of genetic diversity and to increase heterozygosity within the Palisades population, translocations began in 2015.

The success of the translocations became apparent in the first year, with both woodrats surviving, and successfully reproducing in the population (Table 4). Translocations are more successful with the presence of high-quality habitat and areas that have historic or current populations (Gerber et al. 2003). The translocation success within the Palisades over a three-year period has been promising (66.7%), based on survivability of the individuals throughout monitoring. A study completed by Blythe et al. (2015) on translocated woodrats in Indiana released 32 individuals, with 18 surviving throughout radio collar monitoring, giving a success rate of 56.3% (2015). The percentages on survival are comparable, especially when considering the difference in the number of individuals translocated between the two events. Reproductive success of the translocated woodrats in the Palisades is 75%, using only the 2015-2016 pairs, because sufficient time has passed for them to reach sexual maturity and reproduce. The translocations have and will continue to add to the genetic viability of the population. Particularly now that all three sets of woodrats have been released into the Palisades, an increase in genetic variability is expected.

One must keep in mind that translocation results will vary because of different environmental factors including but not limited to habitat quality, food availability, predation risk, and intraspecific and interspecific competition (LoGiudice 2003). There is evidence that the two males from 2016 and 2017 are deceased, this was confirmed through radio tracking One male stayed near the release site for approximately one month before being tracked two kilometers away near the New Jersey/New York border (Site N1). Within a week of observing this male on camera at the N1 site, an attempt was made to trap and remove his collar. Observations on cameras stopped abruptly and the frequency from his collar remained in the same location without movement over multiple weeks of tracking. Body retrieval for further testing was attempted, but was unable to locate within the rock crevices. Upon further inspection of videos, it was noted that he appeared to display poor motor control, a usual sign of infection of *B. procyonis* (LoGiudice 2003).

The other translocated male did not survive long after release into the Palisades. Within the first two days, he had moved 0.189 kilometers from his release site, moving towards the cliff tops. It is believed that within the first week he was preyed upon; the radio collar was located with some fur on the collar and a few bones. The cameras monitoring the area noted other woodrats present, especially a large untagged male. It is unsurprising that the two translocated males traveled long distances, since males are more likely to disperse in search of females and open den sites, and during dispersal, woodrats are especially susceptible to predation.

Successful introduction of new genes from the Pennsylvania translocated woodrats are helpful in curbing the effects that occur due to genetic drift and inbreeding depression, with deleterious mutations accumulating in small populations (Keller and Weller 2002). Conservation efforts in New Jersey are combatting low heterozygosity in the Palisades by introducing new genes and increasing efforts to encourage natural gene flow throughout the population. The effects of the translocations are already being documented with increases in heterozygosity indices reported in genetic testing that has been done in 2016 and 2017.

Summary

This investigation has shown that the trajectory of the current population of Allegheny woodrats in the New Jersey Palisades in promising. Furthermore, the investigation has shown that the woodrat sub-populations are present at locations further north and south from the sub-populations that are currently monitored with annual live trapping. Since the Palisades escarpment ranges much farther than the portion of habitat that has been surveyed with live trapping and camera trapping, the range of the Palisades woodrat population could be significantly more extensive. Results from the translocations are promising with a 19.4% increase of heterozygosity within the population after the first translocation of one pair of woodrats in 2015. With continued monitoring of translocated individuals and genetic sampling, the genetic variability may continue to increase with the recruitment of additional individuals into the population.

Study Limitations

As with any study, there were a number of limitations. Raccoon roundworm and inbreeding depression are believed to have played a large role in the decline of woodrat populations throughout their range and particularly within the study area. Both of these negative effects on populations are currently being managed for, with positive responses from the population. During this investigation, suitable habitat was surveyed to gain a better idea of woodrat presence within the Palisades, but with time and equipment constraints, there is still potential habitat that has not been monitored. Most of the camera surveys occurred only during the summer of 2017, although the southern area was surveyed in fall 2017 (Table 1). With temporal difference between the surveys, there is the chance of metapopulation dynamics occurring and some of the sub-sites surveyed becoming extirpated before population analyses could be completed. Woodrat populations change throughout the season, which could have led to a bias among activity captured on camera. During the summer camera surveys, woodrats had larger home ranges for foraging and females were possibly nursing offspring. In the fall, caching was underway and sub-adults born over the past breeding season could have been more active around the mother's den site.

Camera analysis, as stated before, is an easier alternative to live trapping, but without live trapping of individuals, population numbers and genetic results cannot be substantiated. Though live trapping was not a part of this specific investigation on the distribution of individuals in the Palisades, the results from past trapping events were analyzed for a better understanding of the population composition. Live trapping occurs only once a year, in early fall, when the weather is not too cold or too warm for woodrats, to reduce the stress placed upon them being captured. A more frequent trapping regime could gather more information on survivorship, mortality, and recruitment within the population.

Other variables that effect woodrat populations but were not measured include the abundance of mast crops over time and the correlation of weather conditions to body condition and reproductive efforts. Many mast eating mammals are known to have a close relationship to the acorn mast crop. Small mammals are known to increase reproductive output during mast years, and white tailed deer will shift movements towards oak dominated stands (Mengak and Castleberry 2008). Mengak and Castleberry studied Virginia woodrat population densities and the relation to acorn mast years to gain a better understanding of the reliance that woodrats have on acorns (2008). The study revealed woodrats are not under the same constraints with oak masts as other rodents, poor acorn productions do not fully account for woodrat declines (Mengak and Castleberry 2008). However, woodrats are opportunistic mast consumers, and episodic abundance of acorn production can have a positive impact on woodrat populations (Mengak and Castleberry 2008).

Manjerovic et al.'s study (2009) observed a correlation between female capture rates and the previous year's hard mast production and the current year's soft mast production. Since female woodrats are more philopatric in nature, their numbers can be used to predict declines in the population (Manjerovic et al. 2009). Females may be more dependent upon mast events because of their smaller home ranges as well as the increased demand placed upon them during breeding season. New Jersey's trapping data shows females trapped within the past few years have increased from three captures (2015) to 13 captures in both 2016 and 2017. The increases in females being captured could be indicative of favorable environmental conditions, such as the food resources available within the different trapping locations. Unfortunately, the scope of this study did not lend itself to the collection and analysis of mast crop abundance.

Juvenile woodrat captures seemed to correlate with temperatures, with less offspring observed after cooler temperatures (Manjerovic et al. 2009). With cooler temperatures, female body conditions are potentially not as productive as they are during warmer temperatures, producing reduced litter sizes and a reduction in the production of milk for offspring (Manjerovic et al. 2009). Sub-adults reared with adequate resources during lactation provided from their mother have better survivability and body condition to deal with future demands (Manjerovic et al. 2009). Once again, weather conditions and microclimate data was not collected during this investigation.

Current Management Plans

The results from this study indicate that the current management plan in the Palisades has been highly effective. This management plan is relatively new, only being implemented since 2015, but the increasing number of individuals over this time period indicates that we are on the right track. The future goals of the current plan include continuing to monitor the five trapping locations, raccoon roundworm mitigation through the deworming regiment, and continued monitoring of translocated woodrats that appear on camera (G Fowles per.com. 2017). The outcomes of this plan indicate that the population will continue to grow in the future. Though this is a positive indicator for the population, a realistic goal needs to be put into place to ensure this population does not solely rely on constant intervention by humans.

Future Management Goals

Future investigations into the distribution of subpopulations within the Palisades' woodrat metapopulation should continue. There are confirmed woodrat sightings (by wildlife cameras) of individuals residing near the top of the cliffs within different gullies. The slope of rock outcrops and woodrat presence are positively correlated, especially with the accumulation of rock debris (Castleberry 2010b). These areas seem unlikely for breeding woodrats but should still be surveyed, since they may provide temporary areas for subordinates and transients to take refuge, and there is always a possibility for the presence of breeding residents.

A more in-depth survey of raccoon scat should be done throughout the Palisades to gain a better idea on the prevalence of raccoon roundworm at the site. A sampling survey outside of the raccoon baiting area should be instituted to help determine the effectiveness of the baiting program inside the core habitat area, especially with the potential of undiscovered subpopulations in and around the core habitat.

Again, trapping events take a lot of time and planning, but live trapping the six new sites that revealed woodrats on camera would be beneficial in gaining a more accurate baseline population estimate, as well as compiling accurate genetic information. Full trapping events seem unlikely to be incorporated into the current annual event, due to the lack of equipment, labor, and funds. However, spot live trapping of sites where camera data indicated the presence of woodrats would help to gain some knowledge about these other subpopulations. The feasibility of these additional goals could be carried out with some additional planning and assistance from ENSP officials, academic institutions, and dedicated volunteers.

Allegheny woodrat conservation efforts did not begin until populations started to significantly decline throughout the populations' geographic range distribution. Multiple states have started conservation efforts to save their populations over this time period. Communication and coordination efforts need to occur throughout state agencies so researchers working with the Allegheny woodrat can collaborate and evaluate best practices. The sharing of information will help guide future conservation efforts throughout the geographic range of this species. New Jersey and Pennsylvania have worked together with the translocation of woodrats, and Indiana had their own agreement with Kentucky and Tennessee for the translocation of woodrats. The data gained from one population may not translate over to other states fully, but information on raccoon roundworm mitigation or translocation events will allow researchers to gain knowledge on what may work within their populations. After communicating with the New Jersey ENSP, Ohio has started a raccoon roundworm mitigation program as well (G. Fowles per. com. 2017). This coordination and sharing of information between states will hopefully help to stabilize woodrats populations throughout their current geographic range.

As the conservation effort gains momentum, it's important not to understate the role this species plays within their ecosystems. These "packrats" have been around for thousands of years, and within the past thirty years humans have pushed them to the precipice of extinction. Like many of the species represented on threatened and endangered species lists, their environments have changed in drastic ways because of human impacts. As a species declines, it can cause a chain of invisible events until finally they attract attention, and unfortunately by that point it may be too late (LoGiudice 2010). There is rising acknowledgement of the imperiled predicament of woodrats by state officials and researchers. Perhaps more educational outreach programs need to be initiated to educate the general public about the importance of woodrats and the conservation efforts being implemented. Conservation efforts need to increase not only for woodrats but also for multiple species that live in the same habitat, including the state endangered small-footed bat (*Myotis leibii*) and the copperhead (*Agkistrodon controtrix mokasen*), a species of concern in New Jersey. Woodrats, surprisingly, are not considered as charismatic as the mega fauna of the world, but their role as seed and spore dispersers are invaluable to the environments where they reside. Conservation efforts can only be enhanced as the public becomes more informed of the inner workings of how ecosystems work. The most common mammals to go extinct in recent years have been rodents and bats (Peles and Wright 2010). Let's hope that the Allegheny woodrat do not join that list

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Figures:

Figure 1: Map of five trapping sites used for monitoring the Allegheny woodrat (*Neotoma magister)* population in the Hudson River Palisades of New Jersey by the NJ Endangered and Non-Game Species Program. Sites have been monitored since 1987, annually since 1999. (ESRI 2011).

Figure 2: Map of the five trapping locations used by NJ Endangered and Non-Game Species Program (ENSP), along with 10 sub-sites, which were surveyed for absence/presence of the Allegheny woodrat (*Neotoma magister*). The black lines divide the sub-sites into three regions, North (N1, N2, and N3), Central (C1, C2, and C3), and South (S1, S2, S3, and S4). The central region includes the ENSP trapping locations that are trapped annually to monitor the woodrat population within the Palisades. (ESRI 2011).

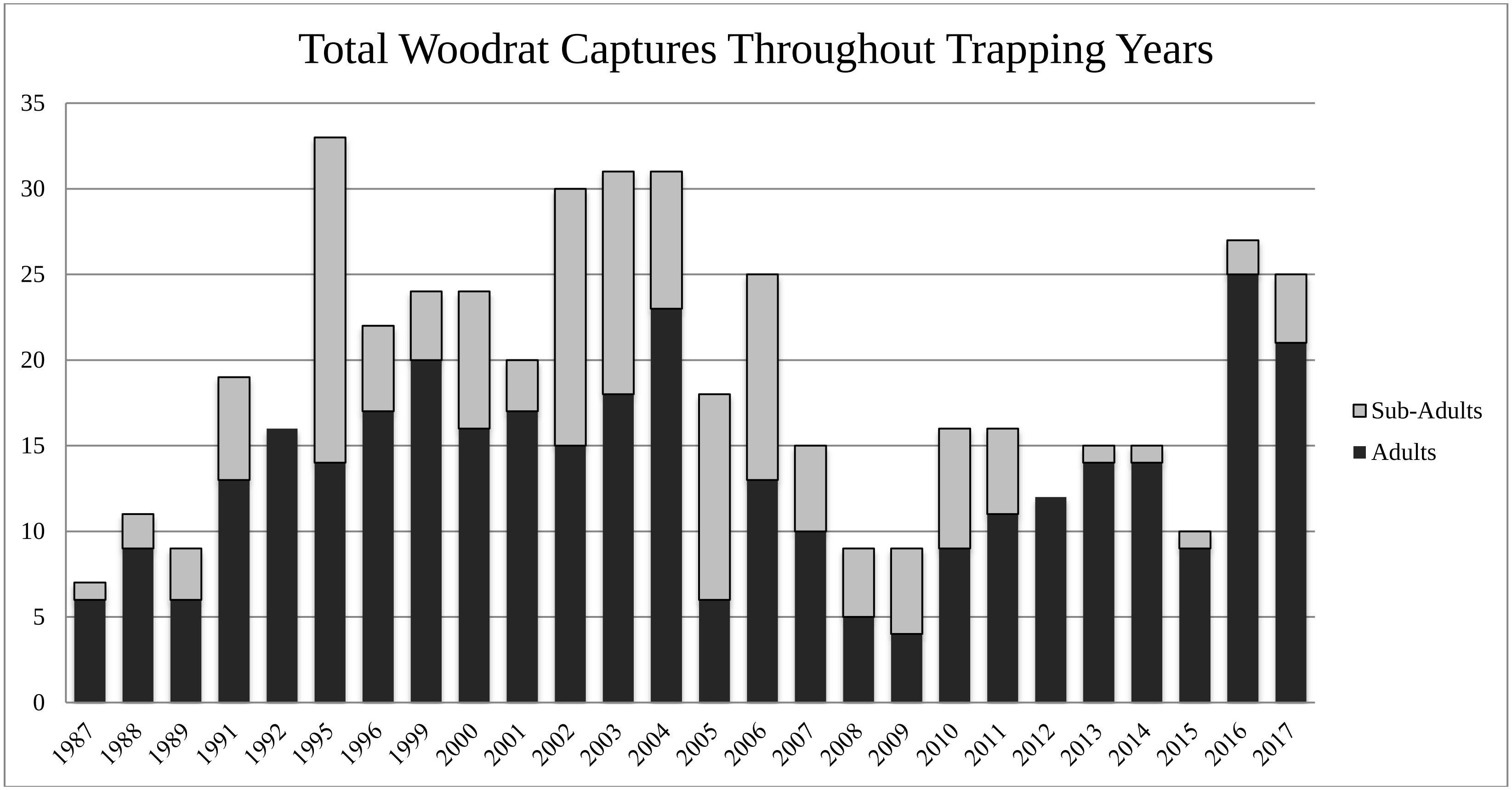

Figure 3: Data collected by NJ Endangered and Non-Game Species Program throughout 1987-2017 on Allegheny woodrats (*Neotoma magister)* captured at five designated trapping locations found in the Palisades. Data represented is individuals captured each year, divided by sub-adults (<225 grams) and adults (>226 grams) (G. Fowles per. com., 2017).

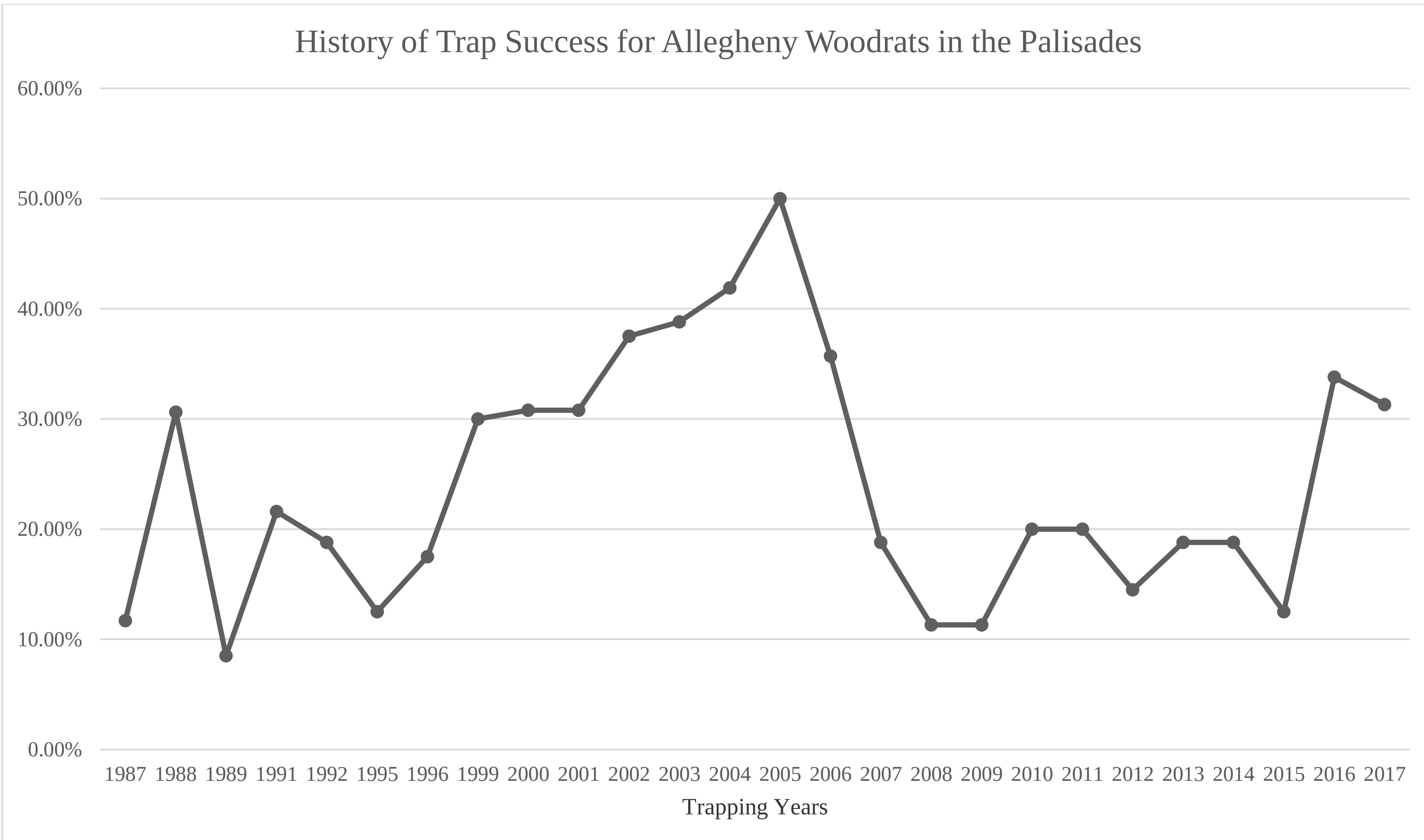

Figure 4: Trapping success (individual woodrats captured/total number of trap nights) of Allegheny woodrats (*Neotoma magister*) throughout 26 years of trapping. New Jersey Endangered and Non-Game Species Program collected data from the Palisades from 1987 to 2017, trap locations are five designated areas that have been trapped annually since 1999.

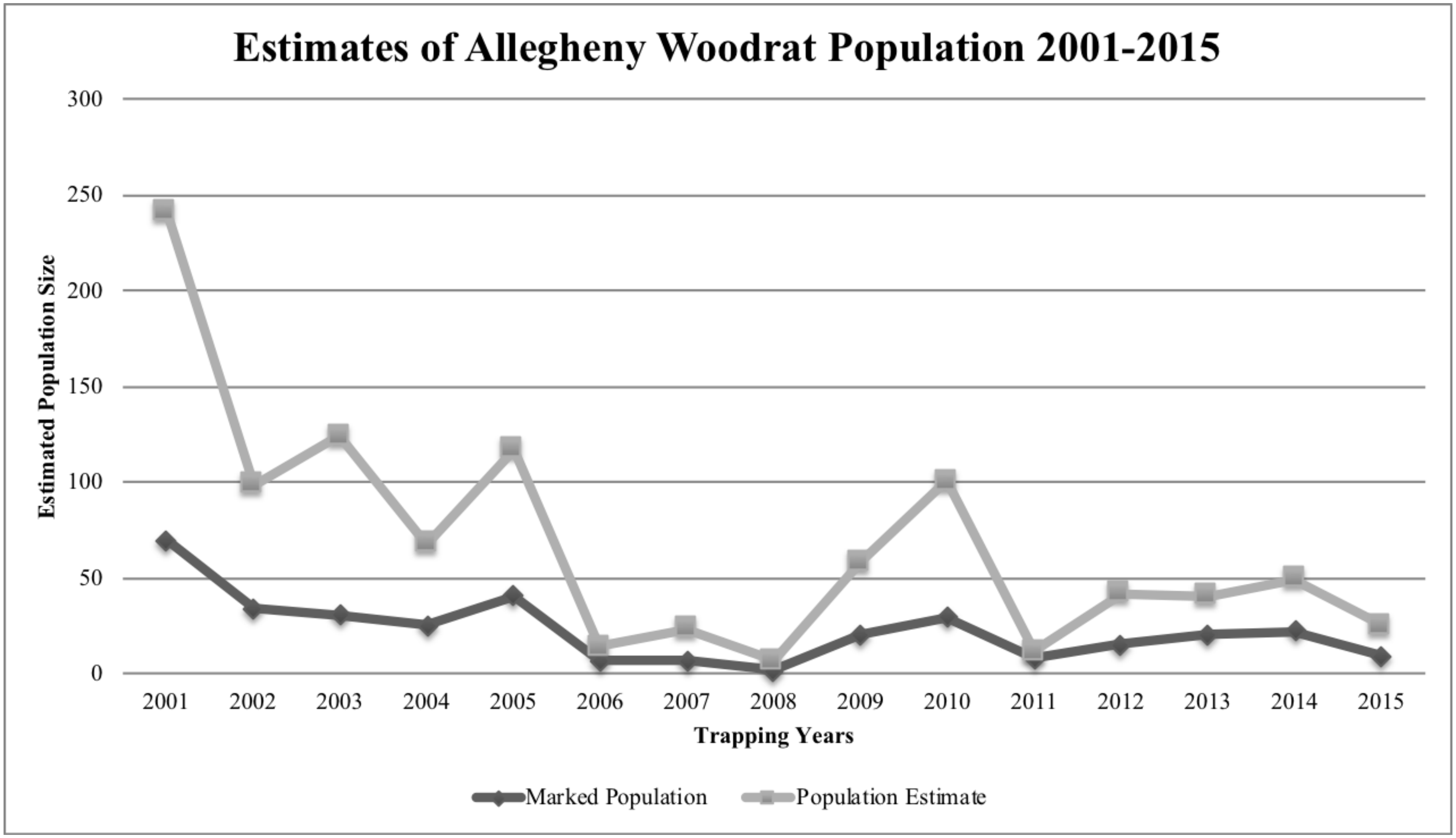

Figure 5: Using the Jolly Seber Mark and Recapture Model, estimates for the Allegheny woodrat (*Neotoma magister*) population and the estimated marked portion of the population, which were calculated using trapping data from 2001-2015. This population is the last known population in New Jersey, trapping data was gathered by NJ Endangered and Non-Game Species Program staff to allow for estimates to be calculated (G. Fowles per. com. 2017).

Figure 6: The northern region, which ranged from the New York and New Jersey border to the central region. The three regions contained 10 sub-sites throughout and were surveyed for absence/presence of the Allegheny woodrat (*Neotoma magister*), sites for the northern region are labeled: N1, N2, and N3. Out of the three sites, two sites, N2 and N3, had woodrat presence. (ESRI 2011).

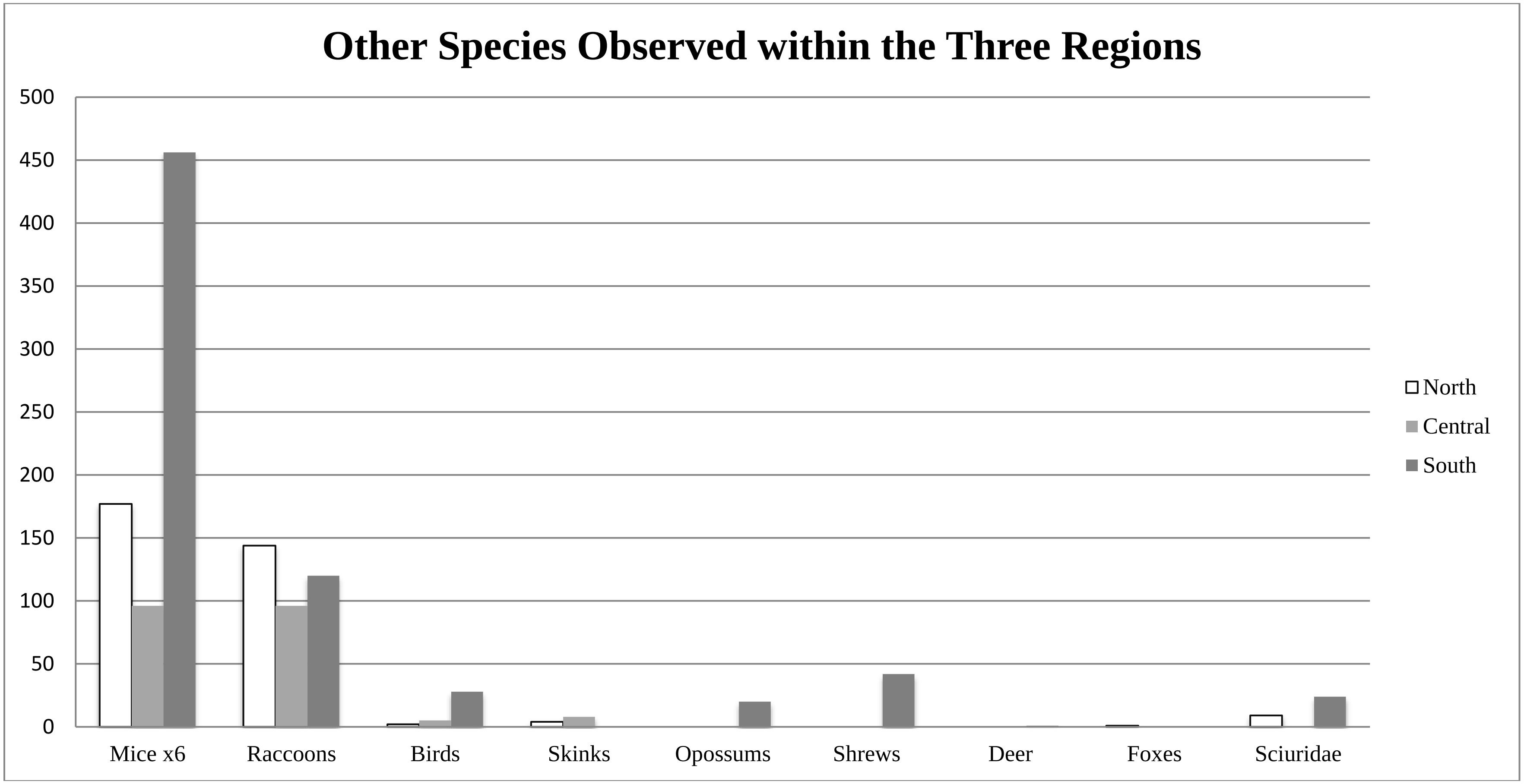

Figure 7: Wildlife cameras were placed and baited throughout three regions for absence/presence surveys of the Allegheny woodrat (*Neotoma magister*) in the Palisades, NJ. Other species were observed on camera and were noted, the animals were deemed a new observation after five minutes of inactivity on the camera.

Figure 8: The central region, which ranged between the northern and southern regions within the Palisades, when NJ Endangered and Non-Game Species Program monitors the Allegheny woodrat (*Neotoma magister*) population. The three regions have 10 sub-sites throughout which were surveyed for absence/presence of woodrats, three of which are in the central region: C1, C2, and C3. All three sites had woodrats observed on wildlife cameras. (ESRI 2011).

Figure 9: The southern region, which ranged from the end of the central region to the Alpine Boat Basin within the Palisades. The three regions contained 10 sub-sites and were surveyed for the absence/presence of the Allegheny woodrat (*Neotoma magister*). The southern sites were labeled: S1, S2, S3, and S4, only site S1 had woodrats observed on wildlife cameras. (ESRI 2011).

Tables:

Sub-sites with Woodrat and Other Species Presence

Region	Sub-Site	Woodrat Presence	Other Species
Northern	N1	No	Mice, Raccoons, Foxes, Birds, Sciuridae
Northern	N2	Yes (96)	Mice, Raccoons, Skinks, Bird, Sciuridae
Northern	N3	Yes (129)	Mice, Raccoons, Sciuridae, Skinks
Central	C1	Yes (211)	Mice, Raccoons, Birds, Skinks
Central	C2	Yes (164)	Mice, Raccoons, Skinks, Sciuridae
Central	C3	Yes (282)	Mice, Raccoons, Skinks, Birds
Southern	S1	Yes (37)	Mice, Raccoons, Birds, Sciuridae
Southern	S2	No	Mice, Raccoons, Birds, Sciuridae, Shrews, Opossums
Southern	S3	No	Mice, Raccoons, Sciuridae, Opossums, Birds, Shrews
Southern	S4	No	Mice, Raccoons, Opossums, Shrews, Sciuridae, Deer

Table 1: Three regions were created throughout the Palisades for absent/present surveys of Allegheny woodrats (*Neotoma magister*). The regions had ten sub-sites divided among them; the table above shows the region, sub-site, woodrat absence or presence, and other species that were observed on wildlife cameras. Woodrat presence also states the number of observations on camera of woodrats throughout the sub-sites; a new observation was counted after five minutes of inactivity. Woodrats were specifically baited for, though other species were observed passing by cameras or were also attracted to bait.

Wildlife Camera Survey Details by Sub-site

Survey Site	Camera Deployment	Number of Cameras	Woodrat Signs
N1	July 27-Aug. 10, 2017	5	Old woodrat latrines
N2	July 13-27, 2017	4	Collected fresh woodrat scat
N3	July 13-27, 2017	4	Collected fresh woodrat scat
C1	July 27-Aug. 10, 2017	6	Woodrat scat observed
C2	July 27-Aug. 10, 2017	4	Woodrat scat observed
C3	July 13-27, 2017	5	Collected fresh woodrat scat
S1	Oct. 28-Nov. 11, 2017	5	No signs observed
S2	Oct. 28-Nov. 11, 2017	5	No signs observed
S3	Oct. 28-Nov. 11, 2017	5	No signs observed
S4	Oct. 28-Nov. 11, 2017	5	No signs observed

Table 2: Absent/present surveys for Allegheny woodrats (*Neotoma magister*) were conducted at the Hudson River Palisades in NJ, other signs of woodrat presence was also observed at some of the sub-sites. Ten sub-sites were broken into three regions: Northern (N), Central (C), and Southern (S). The three regions had cameras deployed throughout the summer and fall of 2017, with 4-6 cameras placed within each site.

The Three Regions Woodrat Observations

	Sub-Site	Adult	Sub-adult	Male (A/S)	Female (A/S)	Unknown (A/S)
Northern Region	N1	0	0	0/0	0/0	0/0
	N2	96	0	65/0	0/0	31/0
	N3	127	2	82/0	4/0	41/1
Central Region	C1	190	21	64/1	67/11	59/9
	C2	79	0	60/0	0/0	19/0
	C3	239	43	32/18	117/13	90/12
Southern Region	S1	26	12	0/0	7/8	19/4
	S2	0/0	0/0	0/0	0/0	0/0
	S3	0/0	0/0	0/0	0/0	0/0
	S4	0/0	0/0	0/0	0/0	0/0
	Totals:	757	78	303/19	195/32	259/26

Table 3: Three regions were surveyed for the absence/presence of Allegheny woodrats (*Neotoma magister*), ten sub-sites were divided among the three regions. Out of the ten sub-sites six had woodrat presence observed on wildlife cameras. Information includes total number of adults and sub-adults, which was determined by size difference. Gender is broken into adults (A), sub-adults (S), and unknown (unable to identify sex from camera angle). The numbers reflected above do not represent individuals but the number of observations captured on camera. A new observation was noted after five minutes of inactivity on the wildlife cameras.

Translocated Allegheny Woodrats

Year	Woodrat ID	Release Site	Distance Travelled	End Location	Result
2015	M301	AB	.0402 km	Site L	Reproduced –Genetic
2015	F501	G	.0198 km	Site G	Reproduced - Genetic
2016	M352	F	2.204 km	Site K	Deceased
2016	F551	C	.805 km	Site H	Reproduced - Visual
2017	M151	F	.189 km	Cliff Tops	Deceased
2017	F191	DE	.3091 km	Near Site L	Unknown

Table 4: The Allegheny woodrat (*Neotoma magister*) population in the Palisades suffers from low heterozygosity, translocations were conducted from 2015-2017 to help diversity in the genetics. Each of the three years, one male and one female sub-adult were released into the Palisades and monitored until settlement occurred. Results from the three years are determined by genetic data and collected during trapping efforts that were conducted by NJ Endangered and Non-Game Species Program. Visual results were collected by wildlife cameras that monitor the translocated woodrats.

ENSP Trapping Data 1987-2017

Year	Total Captures	Trap Nights	Individual Captures	Adult Captures	Sub-adult Captures
1987	9	60	7	6	1
1988	12	36	11	9	2
1989	10	106	9	6	3
1991	26	88	19	13	6
1992	21	85	16	16	0
1995	93	263	33	14	19
1996	37	126	22	17	5
1999	38	80	24	20	4
2000	32	78	24	16	8
2001	30	65	20	17	3
2002	36	80	30	15	15
2003	46	80	31	18	13
2004	39	74	31	23	8
2005	18	36	18	6	12
2006	37	72	25	13	12
2007	24	80	15	10	5
2008	13	80	9	5	4
2009	10	80	9	4	5
2010	23	80	16	9	7
2011	21	80	16	11	5
2012	19	80	12	12	0
2013	23	80	15	14	1
2014	21	80	15	14	1
2015	17	80	10	9	1
2016	40	80	27	25	2
2017	40	80	25	21	4

Table 5: The NJ Endangered and Non-Game Species Program have trapped the Palisades to monitor the Allegheny woodrat (*Neotoma magister*) population. Trapping data includes the years trapping occurred, total captures, the number of trapping nights, individual captures, adult captures, and sub-adult captures (G. Fowles, per. com., 2017).