Population estimates of the Allegheny woodrat (*Neotoma magister*) in Maryland based on long-term capture-recapture data

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Abstract

Allegheny woodrats (*Neotoma magister*) are experiencing population declines in the northeastern portion of their range, and are ranked as S1 and listed as Endangered in Maryland. As a response to reported declines in these states, woodrats have been the focus of ongoing population monitoring in Maryland since 1990. Annual live trapping has occurred at 3 sites, including Savage River State Forest's High Rock Area in Garrett County, Dan's Mountain Wildlife Management Area and Fort Hill Nature Conservancy Preserve in Allegany County. Biennial live trapping has occurred at 2 additional sites, including Indian Springs Wildlife Management Area in Washington County and Frederick City Watershed in Frederick County. Between 10-35 ($\bar{x}$ = 24) Tomahawk live traps baited with oats and peanut butter were placed (10-20m apart) near known, or likely, woodrat middens or latrines, including near overhangs, and talus areas for 2 trap-nights. To date, 5033 trap-nights ($\bar{x}$ = 838.8 ± 612.5 trap-nights) has yielded 908 woodrats (new and recaptured), including 410 individuals captured and uniquely tattooed. Population estimates were calculated using the Lincoln-Petersen Index for all 6 sites and the spatially explicitly recapture program (SECR) program in R for 3 sites with adequate number of re-captures. The results suggest that woodrat populations exist at low densities, are continuing to decline in western Maryland, and that certain sites represent critical habitat.

Key words Allegheny woodrats, density estimation, Lincoln-Petersen, *Neotoma magister*, population estimate

Introduction

The ability of management agencies and ecologists to accurately estimate population density is a critical parameter for many conservation plans. Conventionally, estimating the number of animals in a population is conducted by capture – recapture in a closed population without modelling the spatial relationship between animals and detectors. Because individual animals differ in their exposure to traps, using non-spatial estimators can be problematic. Conventional approaches, such as the Lincoln-Petersen Index estimate abundance as opposed to density, which can lead to over or under estimation of animals with only part of their home range within the sampling area (Parmenter et al. 2003). To overcome the "edge-effect" (i.e., higher probability of captures in traps around the edge [Gurnell and Flowerdew 1990]) and these other concerns, Efford (2004) developed a spatially explicit capture–recapture (SECR) method to estimate population density. Spatially explicit methods do not assume geographic closure, which has been demonstrated to increase the precision of population estimates (Efford & Fewster 2013).

The SECR approach assumes that every individual occupies an unknown home-range center, and the probability of detecting an individual is a decreasing function of the distance between its home-range center and a live trap (Efford 2004). This probability follows a 2-parameter spatial detection function that correspond to a measure of home-range size (sigma [σ]), and the probability of capture at the center of the home range (g_o). The most simple detection function estimates these 2 parameters based on the distance between recaptures of uniquely marked individuals and the frequency of the capture. Additional detection parameters can also be modeled, including learned response (b), which can account for "trap-happy" or "trap-shy" animals. Population density (D) is estimated concurrently with the spatial scale of detection (σ) using maximum-likelihood methods (Borchers and Efford 2008).

Allegheny woodrats (*Neotoma magister*) were once distributed from southern Connecticut, westward to Indiana and southward to northern Alabama, but are now extirpated or in decline throughout this range (Wright 2008). In Maryland, Allegheny woodrats currently only remain in scattered segments of the four westernmost counties (Garrett, Allegany, Washington, and Frederick) and are state ranked S1 (highly state rare) and state listed as Endangered (Maryland State Wildlife Action Plan 2015). Allegheny woodrats are habitat specialists, inhabiting discrete rock outcroppings and talus slopes surrounded by mast-bearing, mature to old growth forests (Ford et al. 2006). In Maryland, this habitat has a patchy distribution across the landscape and so Allegheny woodrats exist in small semi-isolated subpopulations within larger metapopulations (Wood 2008).

As a response to reported population declines in the northeast, Allegheny woodrats have been the focus of ongoing population monitoring in Maryland since 1990. Annual live trapping has occurred at 4 sites, in Garrett and Allegany County and biennial live trapping has occurred at 2 sites in Washington County and Frederick County. The goal of this study is to estimate population density of the Allegheny woodrat using capture-recapture data obtained by live-trapping of 6 long-term sites in western Maryland. We estimate population density using both non-spatial (classical) methods (i.e., Lincoln-Petersen Index) and SECR methods in an attempt to accurately estimate the population of Allegheny woodrats in western Maryland.

Methods

Field Data Collection

Maryland Department of Natural Resources (DNR) Natural Heritage Program personnel conducted annual live trapping between 1990 – 2017 at 4 sites in western Maryland (Savage River State Forest's High Rock Area in Garrett County [1990 – 2017, except 1995], Dans Mountain Wildlife Management Area [1991-2017] and Fort Hill North [Fort Hill N] [1991–1992, 1996 – 2017], and Fort Hill The Nature Conservancy Preserve [Fort Hill TNC] [1992, 1994 – 2017] in Allegany County, Figure 1). Live trapping occurred at 2 additional sites (Indian Springs Wildlife Management Area [1991 – 1992, 1993 – 2017 biennially] in Washington County and Frederick City Watershed [1991 – 1992, 1995, 1996-2016 biennially] in Frederick County, Figure 1). Trapping was conducted for two consecutive nights between July and September to correspond with the weaning of the young of the year and before night time temperatures became too cold. At each site 5-35 ($\bar{X} = 24$) Tomahawk live traps (Model 202 [15.24 cm x 15.24 cm x 48.26 cm] Tomahawk Live Trap, Tomahawk, Wisconsin, USA) were baited with peanut butter and oats and set 10-20 m apart at the same marked location each survey year. Live traps were placed near known, or likely, woodrat middens or latrines, including in overhangs, and talus areas. The number of traps at each site, and the locations of each trap at each site remained consistent throughout the 27-year period, although there were some instances when a trap was left closed to prevent the recapture of young, or a lactating female. DNR personnel checked traps before 1100h the following morning and recorded sex (male/female/unknown), reproductive condition, reproductive status (yes/no), weight, (grams), age (juvenile, subadult, adult), recapture status, and if unmarked, each woodrat was given a unique ear tattoo.

Data Analysis

We summarized total trap-days (TD) (defined as a 24 hour period in which the live trap was operational), total captures, and total captures by sex across all sites. If a trap was closed to prevent recapture of a young, or lactating female, it was not included in the total TD. Lincoln-Petersen index was used to estimate woodrat population size at all 6 sites from 1990-2017. We used the naïve density estimator to convert population size to density. Thus, we took the average over the 27-year period and divided it by effective trapping area (hectares). We considered that the area covered by traps represented the effective trapping area, a method used in estimating other rodent species (e.g., Juškaitis 2014). Effective trapping area was estimated using the polygon measurement feature in Google Earth Pro (v 7.3.0) for each site.

We further analyzed the capture histories to estimate population density using the SECR program in R (R Development Core Team 2007) at 3 sites (Abe Mills, Dans Rock, High Rock). Because of the small recapture sample size at Fort Hill N, Fort Hill TNC and Fishing Creek, we excluded those sites from the SECR analysis. SECR models capture-recapture data collected with an array of 'detectors' (e.g., live-traps) and models were fitted with a half-normal detection function by numerically maximizing the full likelihood (Borchers & Efford 2008). We varied the spatial buffer by site, and assumed that all home-range centers had a Poisson distribution (Efford 2004).

Each trapping session was treated as an independent sample for estimation. We applied two multiple models to each of the 3 sites: the null model with all model parameters (D, λ_0, and σ) constant (i.e., capture and recapture probabilities equal), and a behavioral model with different capture and recapture probabilities (i.e., trap happy or trap shy). We selected the best model based on Akaike Informational Criteria weights corrected for small sample size (AIC_c) (Burnham & Anderson 2002). We ranked all models by AIC_c values and considered the best models as those with the smallest AIC_c values and largest Akaike weights (w_i) (Burnham & Anderson 2002). Based on the AIC criterion, models with Δ AIC_c values <2 were also considered useful (Burnham & Anderson 2002).

Results

At the six long-term monitoring sites, 4833 TD ($\bar{x}$ = 805.5 ± 643.26 TD) yielded 908 woodrats (new and recaptured), including 410 individuals captured and uniquely tattooed over the 27-year period (Figure 2). Additionally, 129 (31%) individuals were recaptured during another trapping session (i.e., year). Between 2007-2017 live trapping yielded 201 woodrats captured, including 99 individuals captured and uniquely tattooed (Figure 2)

The capture rate varied by sites, with the highest capture rate at Fort Hill N (28.75 captures/100 TD, Table 2) and lowest at Fort Hill TNC (10.90 captures/100 TD, Table 2). Of the 410 unique individuals, 189 (46%) were females, 212 (52%) were males and 9 (2%) were unknown. The mean weight was 272.7 (± 98.7 SD) grams.

We estimated the population for each site every year live trapping occurred using the Lincoln-Petersen Index (Figure 3). Lincoln-Petersen density estimates ranged from 0-35.7 ($\bar{x}$ = 4.5 ± 3.15 SD) woodrats per site, with the highest estimate at High Rock ($\bar{x}$ = 9.37 ± 9.41 SD) and lowest at Fort Hill TNC ($\bar{x}$ = 0.46 ± 0.72 SD) (Table 3). Current (2017) population estimates range from 0-6 ($\bar{x}$ = 1.8 ± 2.56) woodrats/site.

Effords spatial models assume no competition for traps, and there was no trapping session during the study period where trap saturation was reached. Density varied among sites, with the highest density occurring at High Rock (3.28/ha) (Table 4). For Abe Mills, the null model was more supported ($\Delta AIC_c < 2$, AIC_c weight 0.53) compared to the behavioral model ($\Delta AIC_c = 0.27$, AIC_c weight = 0.46, Table 5) which was also supported. For Dans rock, the null model was supported $\Delta AIC_c < 2$, AIC_c weight 0.73, Table 6). Finally, for High Rock the null model was supported ($\Delta AIC_c < 2$, AIC_c weight 0.83, Table 7).

Discussion

Accurately estimating population abundance and density is a critical aspect of any conservation management plan. Allegheny woodrats, are habitat specialists that exists in small, isolated populations and have been in decline throughout their northeastern range since 1970s (LoGiudice 2008). In Maryland, Allegheny woodrats have been the focus of long-term population monitoring since 1990, through the use of annual, and biennial live-trapping. There is a general decreasing population trend at all 6 long-term monitoring sites since 1990. However, Dans Rock reached a peak in 2013, and both Fort Hill N and High Rock have experienced an increase in the Lincoln-Petersen estimate since 2012 and 2010, respectively (Figure 4).

Spatially explicit methods for estimating population size offers an advantage over more conventional estimates such as the Lincoln-Petersen index which does not consider the geographic extent of the target population, nor account for behavioral impacts that live-trapping can induce (Royle et al. 2014). By combining user-specified geographic region of interest with a fitted model of density, spatially explicit methods are generally less biased then estimates from non-spatial methods (Efford & Fewster 2013). However, SECR also requires a minimum number of recaptures, which prevented us from applying this method to all 6 long-term sites.

Using the naïve density estimate, our results at Abe Mills (1.68 ± 1.64 SE), Dans Rock (35.38 ± 0.61 SE) and High Rock (25.34 ± 1.81 SE) were much higher than the SECR density estimates (Figure 3). The naïve density estimate is likely to be overestimated (Burt and Grossenheider 1976).

The traditional non-spatial methods based on translating population size into density does not appear to be a robust estimate because it eliminates the spatial component of capture data (royle et al. 2014). The SECR maximum likelihood density estimate obtained at Abe Mills (0.22 individuals/ha), Dans Rock (3.84 individuals/ha), and High Rock (3.28 individuals/ha) is lower than our non-spatial density results and suggests that Allegheny woodrats exist in low densities in western Maryland, and is similar to other reported densities (Burt and Grossenheider 1976). However, Allegheny woodrat densities are not frequently reported in hectares, so the ability to compare our results were limited. The ideal number of recaptures is 20, so with additional trap nights or sessions at Fishing Creek, Fort Hill N, and Fort Hill TNC those sites may also be able to be included in the analysis.

Our results suggest that Allegheny woodrat populations are continuing to decline, especially considering that the only 22% of all captures have occurred in the past 10 years (Figure 2). The population at many of these sites has been reduced to 1 or 0 individuals at least one time since trapping efforts have started. These sites likely experienced immigration from nearby sites (Mengak et al. 2008). Additionally, current (2017) population estimates 0-6 ($\bar{x}$ = 1.8 ± 2.56) woodrats/site indicate the small number of woodrats at each site. These long-term monitoring sites are considered some of the best strongholds for Allegheny woodrat populations in western Maryland, but low population densities, continued declines, and possibility of genetic consequences put into question the species long-term viability in the state.

Acknowledgments

"Identifying and Targeting Intervention Strategies for Allegheny Woodrat (*Neotoma magister*) Recovery" was supported by State Wildlife Grant funding awarded through the Northeast Regional Conservation Needs (RCN) Program. The RCN Program joins thirteen northeast states, the District of Columbia, and the U.S. Fish and Wildlife Service in a partnership to address landscape-scale, regional wildlife conservation issues. Progress on these regional issues is achieved through combining resources, leveraging funds, and prioritizing conservation actions identified in the State Wildlife Action Plans. See RCNGrants.org for more information.

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Figures and Tables

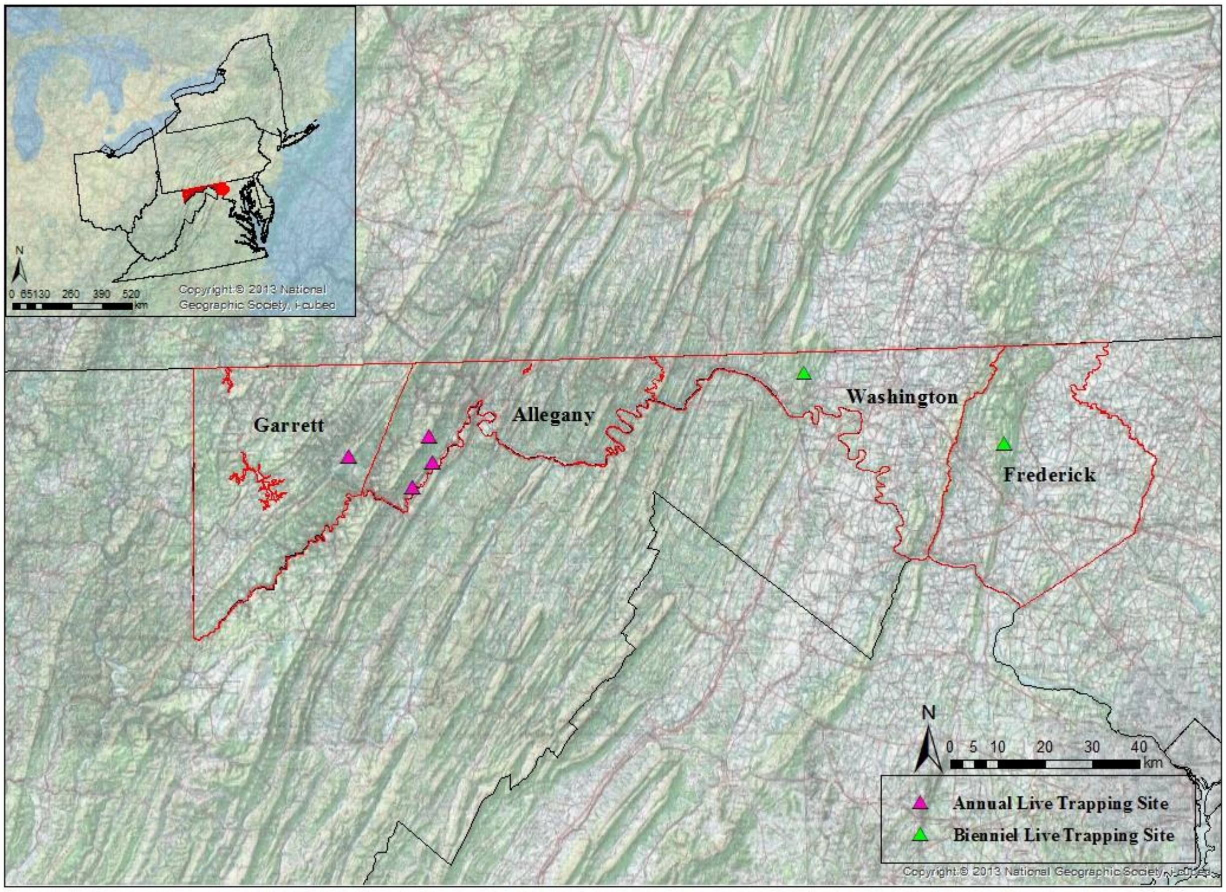

Figure 1. Six live trapping sites are distributed across western Maryland. Four sites (Dan’s Rock, Fort Hill North, Fort Hill The Nature Conservancy, and High Rock are trapped annually; Abe Mills and Fishing Creek are trapped biennially.

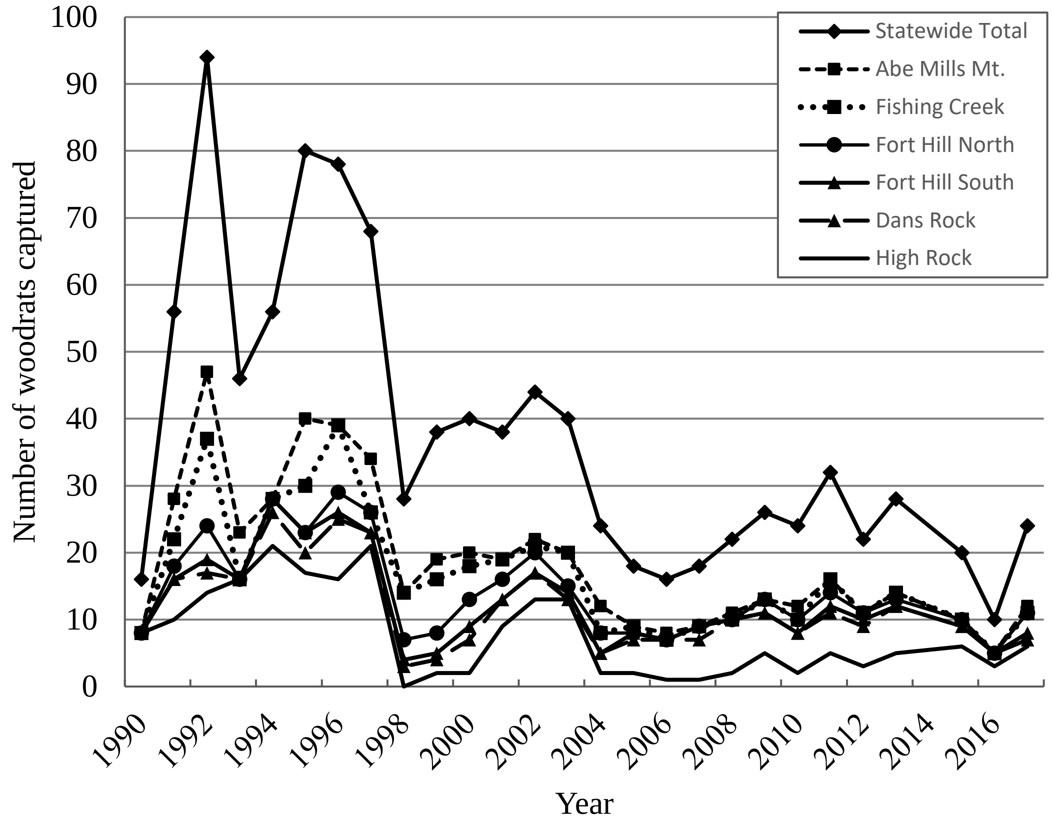

Figure 2. Combined live-trapping results (1990-2017) at Allegheny woodrat (*Neotoma magister*) long-term monitoring sites in Garrett, Allegany, Washington and Frederick County, Maryland.

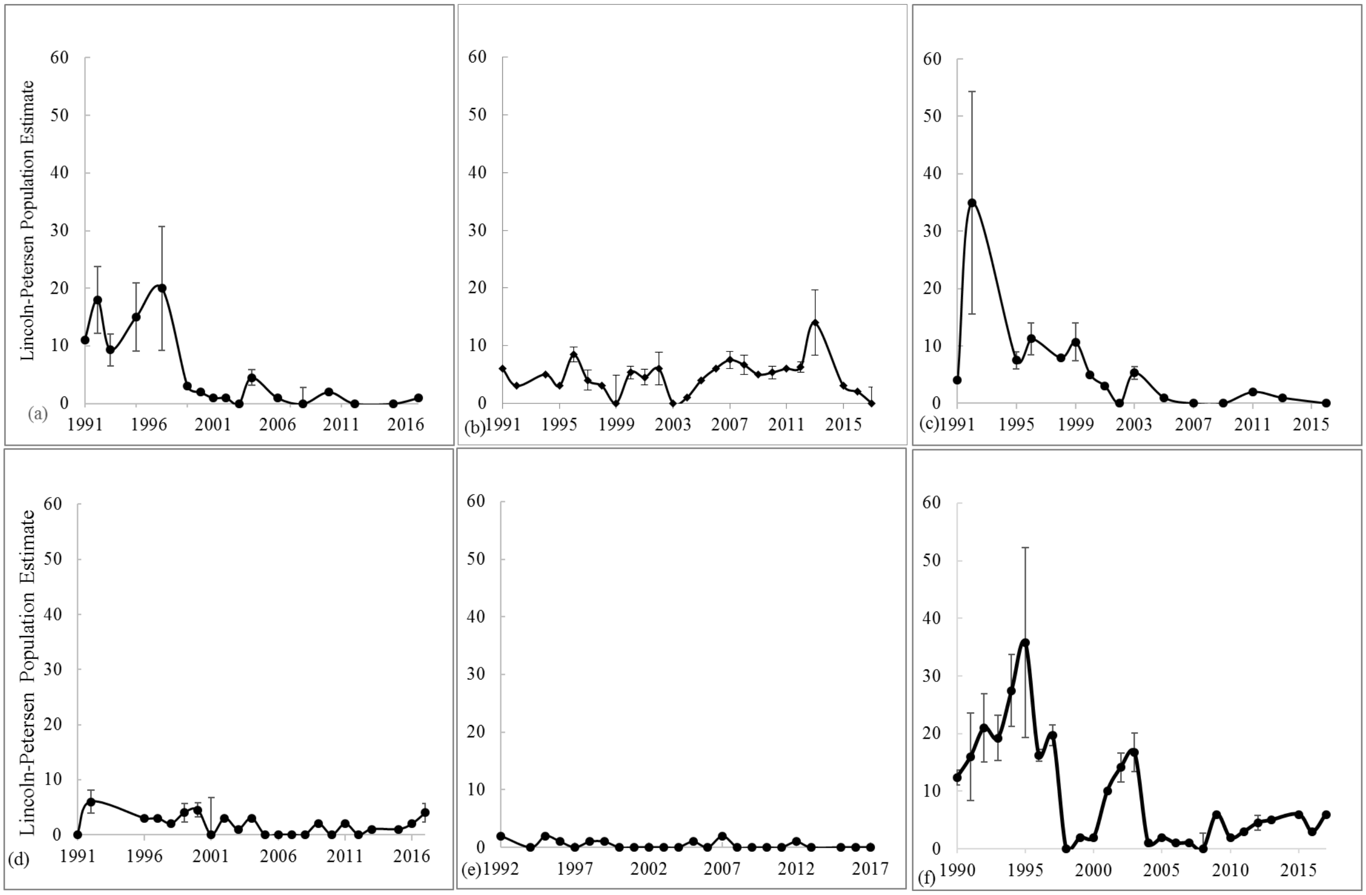

Figure 3. Lincoln-Petersen population estimates of Allegheny woodrat (*Neotoma magister*) between 1990-2017 at six long-term monitoring sites in Garrett, Allegany, Washington and Frederick County, Maryland. (a) Abe Mills (b) Dan's Rock (c) Fishing Creek (d) Fort Hill North (e) Fort Hill The Nature Conservancy (f) High Rock. Error bars represent the 95% confidence interval.

Table 1. Capture rate of the Allegheny woodrat (*Neotoma magister)* at 6 long-term monitoring sites in western Maryland surveyed from 1990-2017.

	Abe Mills	Dans Rock	Fishing Creek	High Rock	Fort Hill TNC	Fort Hill N
No. Trap Nights	746	770	800	2011	266	240
Total Woodrats Captured	104	202	114	390	29	69
Capture Rate ([trap events/ trap nights] x 100))	13.94	26.23	14.25	19.39	10.90	28.75

Table 2. Descriptive data for the Allegheny woodrat (*Neotoma magister*) Lincoln-Petersen Index population estimates based on long-term data at 6 sites in western Maryland surveyed from 1990-2017.

	Abe Mills	Dans Rock	Fishing Creek	Fort Hill N	Fort Hill TNC	High Rock
Range	0-18	0-8.4	0-10.66	0-6	0-2	0-35.75
Average ± SD	5.23 ± 6.77	4.60 ± 3.04	5.86 ± 8.46	1.80 ± 1.76	0.46 ± 0 .72	9.37 ± 9.41
Size (ha)	3.1	0.13	1.23	0.45	0.10	0.37
Density (indiv/ha) ± SE	1.685 ± 1.64	35.38 ± 0.61	4.76 ± 2.16	4.00 ± 0.37	4.58 ± 1.47	25.38 ± 4.71

Table 3. Descriptive data for the Allegheny woodrats (*Neotoma magister*) included in the analysis for density estimates. High Rock and Dans Rock were trapped annually from 1990-2017 except for 2014. Abe Mills was trapped biennially from 1990-2017. Each trapping session lasted 2 consecutive days. All estimates ± *SE* from point estimates

Site	No. trapping sessions	No. woodrats captured	Mean density/ha	Range of densities/ha	Mean g(0)[a]	Mean σ[b]
Abe Mills	16	68	0.22	0.15 – 0.33	0.24 ± 0.05	79.16 ± 12.3
Dans Rock	23	112	3.84	2.63 – 5.63	0.5 ± 0.10	18.63 ± 2.16
High Rock	30	253	3.28	2.76 – 3.89	0.16 ± 0.02	27.8 ± 2.10

[a] Detection probability of an animal at its home-range center (Efford 2004)

[b] Measure of the spatial scale over which probability declines and is related to home range size and trap spacing

Table 4. Comparison of SECR models for variation in the density of Allegheny woodrats (*Neotoma magister*) at Abe Mills Mountain, Indian Springs Wildlife Management Area, Maryland. The buffer width was set at 50m because it was rare to get an individual movement above these distances at this site.

Model	Formula	K[a]	LL[b]	ΔAIC_c[c]	AIC_c weight[d]
Null	D~1 g0~1 sigma~1	3	-1256.4	0	0.53
Behavior	D~1 g0~b sigma~1	3	-1255.5	0.269	0.46

[a] Number of fitted parameters

[b] Maximized log likelihood

[c] Difference in the small-sample adjusted AIC between the current model and the best model

[d] Probability that a model best approximates the data in comparison to other models being considered

Table 5. Comparison of SECR models for variation in the density of Allegheny woodrats (*Neotoma magister*) at Dans Rock, Maryland. The buffer width was set at 100m because it was rare to get an individual movement above these distances at this site.

Model	Formula	K[a]	LL[b]	ΔAIC_c[c]	AIC_c weight[d]
Null	D~1 g0~1 sigma~1	3	-502.97	0	0.73
Behavior	D~1 g0~b sigma~1	3	-502.91	2.2	0.26

[a] Number of fitted parameters

[b] Maximized log likelihood

[c] Difference in the small-sample adjusted AIC between the current model and the best model

[d] Probability that a model best approximates the data in comparison to other models being considered

Table 6. Comparison of SECR models for variation in the density of Allegheny woodrats (*Neotoma magister*) at High Rock, Savage River State Forest, Maryland. The buffer width was set at 50m because it was rare to get an individual movement above these distances at this site.

Model	Formula	K[a]	LL[b]	ΔAIC_c[c]	AIC_c weight[d]
Null	D~1 g0~1 sigma~1	3	-1382.8	0	0.83
Behavior	D~1 g0~b sigma~1	3	-1385.1	4.17	0.09

[a] Number of fitted parameters

[b] Maximized log likelihood

[c] Difference in the small-sample adjusted AIC between the current model and the best model

[d] Probability that a model best approximates the data in comparison to other models being considered