Long-term Population Monitoring of Northern Idaho Ground Squirrel: 2019 Implementation and Population Estimates

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Photo by Carly Baker

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EXECUTIVE SUMMARY

We implemented the sixth full year of the new northern Idaho ground squirrel (NIDGS) long-term population monitoring strategy in 2019. The sampling frame consisted of the original 1,757 100-m x 100-m grid cells across occupied habitat, plus an additional 833 grid cells from a newly created stratum of cells. We conducted line-transect distance surveys in 1,120 cells and recorded 1,720 NIDGS at 635 cells (57%). From these data program DISTANCE estimated a density of 0.85 squirrels/ha and a total population size of 2,193 squirrels (95% CI: 1,990–2,429). We post-stratified data based on relative density (higher, lower, or unknown), with resulting densities of 0.97 squirrels/ha in stratum 1, 0.60 squirrels/ha in stratum 2, and 0.72 squirrels/ha in the newly created stratum 3. Corresponding unadjusted population sizes were 1,326, 233, and 602, respectively. Our adjusted index to overall abundance was 2,960 NIDGS. We compared the 1-year change in population estimates between 2019 and 2018 in 3 ways: from the DISTANCE analyses of survey data from all 3 strata, from DISTANCE analysis of 500 core grid cells intended to be surveyed every year, and from a pair-wise comparison of the 500 core cells. The population estimates were essentially the same for the 2-year period. We explored several environmental variables, including tree canopy cover, aspect, heat load index, soil properties, and proximity to nearest squirrel, as site covariates in occupancy modeling with program PRESENCE. The most parsimonious model included proximity to nearest squirrel, tree canopy cover, and southerly aspect, with constant probability of detection across visits. We applied this model to the full 2,590-cell sampling frame to generate estimates of occupancy across occupied habitat. Almost half of cells in our expanded sampling frame had >75% probability of being occupied, a similar number of cells had <50% probability of being occupied, and only 4% of cells had 0 probability. We conducted presence surveys at 2 sites where no grid cells were selected for surveys and 6 sites discovered in 2018. We conducted exploratory surveys across 1,540 ha outside of known sites to determine if sites were still extant and to document dispersal into new or treated areas. We detected 246 squirrels at 12 locations between or adjacent to known occupied areas.

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INTRODUCTION

The northern Idaho ground squirrel (*Urocitellus brunneus*) is a rare, endemic mammal whose currently known distribution is limited to a 29 km x 37 km area in Adams County and a single disjunct population within a 3 km x 4 km area of Valley County in west-central Idaho. Within this range northern Idaho ground squirrels (NIDGS) occur at ~60 locations within an elevational range of 1,050–2,300 m. Occupied sites are quite variable in size (1 to >100 ha) and density of squirrels (Wagner and Evans Mack 2012). Typical habitat includes dry montane meadows or open scablands surrounded by ponderosa pine (*Pinus ponderosa*) or Douglas-fir (*Pseudotsuga menziesii*) forest (Yensen 1991).

Decline of NIDGS through the 1980s and 1990s was attributed primarily to changes in habitat that subsequently isolated populations. Fire suppression allowed forests to encroach into meadows, reducing the amount of habitat available to ground squirrels and closing off dispersal corridors (Sherman and Runge 2002). It also was hypothesized that fire suppression and land conversions resulted in poorer quality food plants that lacked the nutritional value squirrels needed to sustain prolonged hibernation (Sherman and Runge 2002, Yensen et al. 2018). More recently, fleas carrying sylvatic plague have been recognized as a possible threat to NIDGS populations if low levels of enzootic plague are preventing NIDGS populations from reaching higher densities (Goldberg et al. 2017, Goldberg 2018). This study found that reduced flea loads on NIDGS and other small mammals result in higher survival rates. Other threats to NIDGS populations include competition with the larger Columbian ground squirrel (*Urocitellus columbianus*), loss of habitat to development, and shooting (USDI Fish and Wildlife Service 2003). Natural predators include badger (*Taxidea taxus*), red fox (*Vulpes fulva*), coyote (*Canis latrans*), and diurnal raptors.

The NIDGS was federally listed as Threatened in 2000 and a recovery plan completed in 2003 (USDI Fish and Wildlife Service 2003). Recovery criteria incorporate numerical and geographic goals, including overall effective population size >5,000, a stable or increasing population trend over 5 years, and sufficient distribution across the range to maintain secure, self-sustaining metapopulations. Thus, in addition to monitoring changes in overall population size, there is a need to track population size and trend at several scales, including over the entire range, within recovery areas, and at the metapopulation level.

In 2014 we implemented a new long-term monitoring approach that combined grid-based line-transect distance sampling with patch occupancy theory (Evans Mack et al. 2013). The distance-based sampling component of the design yields estimates of density and abundance (Buckland et al. 1993), providing a statistically valid, repeatable approach for estimating population size and trend each year for a time frame of 20–30 years. The patch occupancy component tracks spatial occurrence (MacKenzie et al. 2006). Together these 2 tools allow managers and regulatory agencies to assess the status of NIDGS relative to population recovery goals. The 2014 sampling frame is intended to form the baseline for monitoring through the life of the long-term monitoring plan. This report summarizes the 2019 field season, which was the 6th year of implementing the current long-term monitoring design. Objectives were to:

1) conduct systematic distance sampling on transects from a sample of units selected from the grid-based sampling frame
2) conduct presence/absence surveys at sites that were not selected for surveys under the grid-based sampling design
3) calculate population and occupancy estimates
4) compare results across years

STUDY AREA

The known NIDGS distribution extends across Adams County from northwest of Council north to Smith Mountain and east to New Meadows in the Bear Creek, Lick Creek, Lost Creek, Weiser River, and Mud Creek drainages. A disjunct population occurs in Valley County in Round Valley (Figure 1). The study area encompasses all identified NIDGS sites except for those known to be 'extinct' (e.g., Van Wyck inundated by Cascade Reservoir).

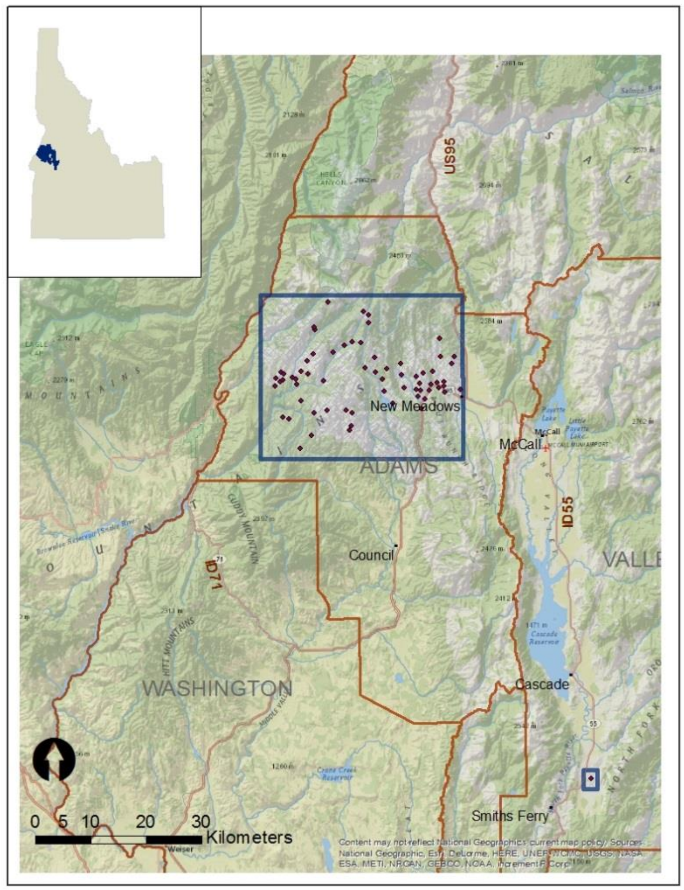

Figure 1. Known occupied range (blue squares) and locations (dots) of northern Idaho ground squirrel survey sites in 2019.

METHODS

Sampling Frame

The basis for NIDGS long-term population monitoring is a sampling frame that consists of 100-m x 100-m grid cells corresponding to known or predicted NIDGS occurrence. The original sampling frame included 1,757 grid cells that contained at least 40% of modeled NIDGS habitat (Evans Mack et al. 2013). In 2018 we added 833 new cells that included: (1) cells that did not meet the 40% overlap rule but occurred along the outer perimeters of currently occupied sites, (2) cells that encompassed previously occupied sites whose current status was unknown, (3) cells that encompassed areas where NIDGS had been discovered since 2013, (4) cells encompassing modeled suitable habitat (Crist and Nutt 2008) which had never been surveyed, and/or (5) cells encompassing areas that will be treated (thinned and burned) to create new habitat. Of the 2,590 grid cells currently surveyed for long-term monitoring, 61% occur on private land, 33% on land managed by the U.S. Forest Service, and 6% on state land.

Built into the sampling frame was stratification initially based on NIDGS abundance. The original 1,757 grid cells were assigned to either stratum 1 or stratum 2 according to the NIDGS site in which

the cell occurred. The term 'site' refers to a localized geographic area of occupied habitat. Sites are variable in size and typically defined by an open meadow surrounded by unsuitable habitat (e.g., forest). Sites were the framework for monitoring changes in NIDGS abundance and distribution prior to 2013. In general we defined stratum 1 as those sites where >10 squirrels had been detected in any year during 2010–2013. Stratum 2 encompassed sites known to be occupied but where ≤10 squirrels had been observed. Stratum 3 was not based on abundance; it was designed to allow for expansion of the sampling frame over time as new areas are identified to be surveyed.

Annual Surveys

Each year's survey is based on a rotating panel of randomly selected grid cells that was established in 2014 for the original strata 1 and 2, and modified in 2018 for the newly created stratum 3. Across the 3 strata approximately 1,197 cells are surveyed each year. This includes a core sample of 500 cells from strata 1 and 2 that are surveyed every year, and a rotating group of ~700 cells that changes each year (Figure 2). All 2,590 cells are visited within 3 years. This approach is a compromise between sampling the same grid cells every year, which should give the earliest indications of trends in abundance, and wanting to ensure that all sites are represented in the long-term assessment of trends. We assigned grid cells to a panel according to their 'rank' from the spatially-balanced equal-probability sampling procedure Balanced Acceptance Sampling (BAS; Robertson et al. 2013). We retained the original BAS ranking for strata 1 and 2, and conducted a separate BAS ranking for the new stratum 3.

2019 Sample	BAS rank
Stratum 1 & 2	
Panel 1 (n=500; core sample)	1-500
Panel 2 (n=419)	501-919
Panel 3 (n=419)	920-1338
Panel 4 (n=419)	1339-1757
Stratum 3	
Panel 1 (n=278)	1 - 278
Panel 2 (n=277)	279 - 555
Panel 3 (n=278)	556 - 833
2020 Sample	**BAS rank**
Stratum 1 & 2	
Panel 1 (n=500; core sample)	1-500
Panel 2 (n=419)	501-919
Panel 3 (n=419)	920-1338
Panel 4 (n=419)	1339-1757
Stratum 3	
Panel 1 (n=278)	1 - 278
Panel 2 (n=277)	279 – 555
Panel 3 (n=278)	556 - 833
2021 Sample	**BAS rank**
Stratum 1 & 2	
Panel 1 (n=500; core sample)	1 - 500
Panel 2 (n=419)	501 - 919
Panel 3 (n=419)	920 - 1338
Panel 4 (n=419)	1339 - 1757
Stratum 3	
Panel 1 (n=278)	1 - 278
Panel 2 (n=277)	279 – 555
Panel 3 (n=278)	556 - 833

Figure 2. Rotating panel design for determining grid cells to be surveyed in successive years (blue highlighted rows) as part of northern Idaho ground squirrel long-term population monitoring.

Line-Transect Distance-Based Surveys

Each grid cell contained 2 parallel, north–south, 100-m transect lines positioned 50 m apart and 25 m from the edge of the cell (Figure 3). To keep line-transect sampling aligned with the overarching patch occupancy framework and to increase survey independence with regard to variables such as weather conditions and time of day, we made ≥2 independent visits to each cell (MacKenzie et al. 2006). We walked 1 line on the 1st visit and the other line on the 2nd visit. In cases where a line was not walkable (private property, water, dense vegetation), the 1st line was surveyed twice.

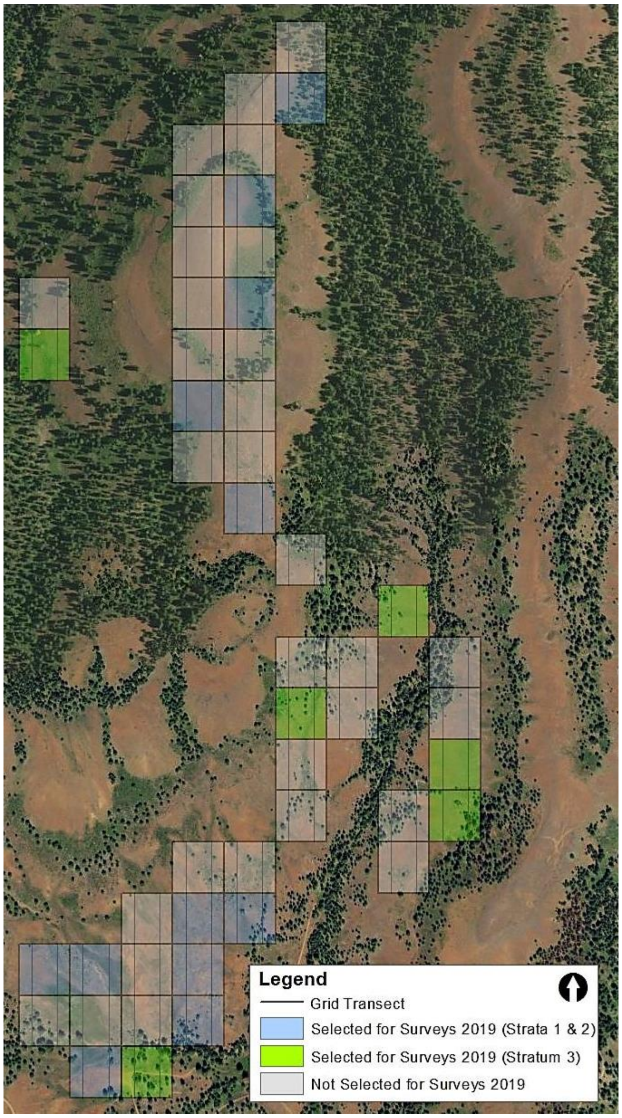

Figure 3. Portion of 2019 sampling frame with 100-m x 100-m grid cells, cells selected for surveys, and 2 parallel 100-m long transect lines per cell.

Cells within the same geographic area generally were surveyed on the same day. We surveyed all selected cells the same way regardless of stratum.

In 2019 we added a 3rd visit to a subset of grid cells. We prioritized cells that occurred in sites or subsites where no NIDGS detections had been made on either visits 1 or 2. We also included "control" cells in which occupancy had been confirmed in either visit 1 or 2. We selected 1 of the 100-m transects within each grid cell to survey and in most cases conducted the survey after pups had emerged to increase opportunity to document the cell as occupied. Squirrels observed on this 3rd survey were included in analyses for occupancy but not for population estimates.

Coordinates for start and end points of transect lines in all selected cells were uploaded from ArcMap™ v10.3 (ESRI® 2014) to hand-held Global Positioning System (GPS) units for navigation in the field. For each initial NIDGS detection (visual or aural), we recorded perpendicular distance from the line, group size, and marked the point on the line with a hand-held GPS. Prior to the first survey all crew members practiced distance estimations along a mock transect line with stakes at various distances.

Surveys followed existing protocols for optimizing detections (e.g., time of season, time of day, and weather; Evans Mack 2016) and site visits were scheduled to coincide with spring emergence when squirrels were particularly active and before vegetation had grown to obscure them. The majority of surveys were conducted before pup emergence to standardize all surveys for the adult/yearling portion of the population. A survey was canceled, discounted, and repeated in full at another time if interrupted by weather, predator presence, or other factors that created sub-optimal survey conditions. Columbian ground squirrels were recorded on surveys in the same way as NIDGS.

Presence/Exploratory Visits

Adding new grid cells to create stratum 3 greatly reduced the number of known sites that had no grid cells selected for surveys in this year's sample. However, some areas were still "missed" in the 2019 selection process, so we conducted informal surveys to document presence. We also included areas where NIDGS had been detected during 2018 exploratory surveys. The IDFG crew attempted

to visit each site 1 or 2 times to establish their status. Observers walked through a site or observed from a stationary point for approximately 15–30 minutes. Squirrels detected visually and aurally were marked with GPS and the site was considered occupied. None of the individuals detected on these visits were included in analyses of population size. We also conducted exploratory surveys to gain a better understanding of NIDGS occurrence and dispersal corridors within the known distribution. We targeted habitat between or adjacent to known occupied locations where we thought squirrels could have expanded into.

Analyses

Abundance

We analyzed line-transect survey data with program DISTANCE v7.2 (Thomas et al. 2010). We defined the area of inference as 2,590 ha, corresponding to the adjusted sampling frame from which our survey sample was drawn (1,757 cells in strata 1 and 2 plus 833 cells in the newly created stratum 3). We used a 5% truncation (i.e., the distance corresponding to the last 5% of the observations, ordered from smallest to greatest distance from the line) to reduce outlier effects on model estimates (Buckland et al. 1993). Observations were truncated at 60 m. We defined a model to estimate density using a global detection probability and encounter rate, and global density based on clustered observations. We examined half normal, hazard rate, and uniform estimators, all using the cosine series expansion. Model selection was based on Akaike's Information Criterion (AIC). Measures of precision and confidence intervals were obtained by bootstrapping the original sample of units (Manly 1997) using the bootstrap procedure within program DISTANCE and specifying 999 replicates.

We subsequently ran a second, separate analysis of the data using stratum as a layer. We estimated encounter rate and density by stratum, detection probability and cluster size for all data combined, and a pooled estimate of density from area-weighted stratum estimates. All other model specifications were the same as described above for the entire data set.

Estimates of population size from program DISTANCE provide an index to abundance. Distance-based line-transect sampling takes into account that some animals will be missed on surveys, but it also assumes that all individuals are 'available' for detection or non-detection. Some unknown number of squirrels will be underground during NIDGS line-transect surveys and not available to be counted. We adjusted estimates of population size from program DISTANCE upward by a factor of 1.35 to obtain an approximate abundance. This adjustment factor was calculated from a comparison of abundance estimates from line-transect surveys and mark-recapture at 10 sites in 2016 (Wagner and Evans Mack 2016). The comparison showed that 1.35 squirrels were present for every squirrel detected on a survey.

Population Change

We compared the 1-year change in population estimates (2018 to 2019) in several ways. First, we looked at population estimates from program DISTANCE for all 3 strata each year. Even though the collection of strata 1, 2, and 3 cells we surveyed differed between years, each group of cells had been selected with a sampling procedure that incorporated spatial balance and thus should be a

representative sample of the target population. For a tighter comparison we ran DISTANCE analyses on just the 500 core grid cells that are surveyed every year (ranks 1–500 from the BAS sampling procedure, strata 1 and 2 only). Lastly, we conducted a cell-to-cell analysis (paired *t*-test) with the core 462 grid cells surveyed in both years (32 of the 500 cells were not surveyed in 2019 due to limited access and a separate 6 cells were not surveyed in 2018). For a longer-term look at population trajectory, we plotted the annual abundance estimates from program DISTANCE for strata 1 and 2 only for the past 6 years.

<u>NIDGS Distribution (Occupancy)</u>
We analyzed line-transect survey data with program PRESENCE v2.12.37 (Hines 2006) to predict occupancy across our baseline grid of NIDGS habitat. The occupancy analysis was based on the same dataset (grid cells) analyzed with program DISTANCE, but also included any third visits to transect lines. Some detections made from within a grid cell were of NIDGS groups beyond the cell boundary. We removed these detections from the occupancy analysis rather than re-assign the detection to the appropriate cell. Our rationale was that the sampling design was intended to estimate occupancy based on detections within each cell following line-transect sampling, not to use any available data to claim a cell as occupied (L. McDonald, pers. comm.).

We continued to explore environmental variables to use as covariates in our occupancy analyses and methods to aggregate those variables within each grid cell. We examined a measure of tree canopy cover, preponderance of south-facing aspects, heat load index, bulk density of soil, soil depth to restrictive layer, and proximity to other squirrels. Data sources are summarized in Appendix A. For soil covariates and proximity, we measured values at known squirrel locations from the past 3 years (2017–2019) within each cell. For heat load, tree canopy cover, and southerly aspects, we averaged values within a 100-m neighborhood of squirrel locations. We took the average covariate value from each sample point within a grid cell to generate a mean covariate value for each cell. For cells with no detections, we used the center point of each of the 2 survey transects in each grid cell to extract covariate values. We standardized most covariate values with a Z transformation (Donovan and Hines 2007).

We used the ‘single season’ group of models in PRESENCE and compared 10 models based on our covariates. The base model was a simple model assuming single probabilities of occupancy and detection across all sites. A second reference model assumed a single probability of occupancy but varying detection probability across visits. We examined 8 models using combinations of environmental site covariates with a single probability of detection across visits. Model selection was based on Akaike’s Information Criterion (AIC). Measures of precision and confidence intervals were obtained by bootstrapping the original sample of units (Manly 1997) using the bootstrap procedure within program PRESENCE. We applied the ‘best’ model to all 2,590 grid cells in our expanded sampling frame, using covariate values to predict probability of occupancy for the cells we did not survey this year.

Although our covariate data was extracted from a different suite of points in 2019 compared with 2018, the variables themselves and the methods we used to summarize each covariate at the grid

cell level were the same. Thus, we explored how well the 2018 modeled probability of occupancy estimates (Wagner and Evans Mack 2018) aligned with our survey results in 2019. In other words, we used 2019 survey results to informally validate the 2018 model. We used all NIDGS detections for this analysis (distance-based surveys, presence–absence surveys, incidental observations, and exploratory surveys) and assigned detections to the appropriate grid cell. This analysis was limited to the 1,120 cells (of the 2,590-cell sampling frame) surveyed in 2019.

With the 2019 surveys, we completed 2 full rounds of the 3-year rotating sampling scheme, allowing us to compare occurrence and distribution of NIDGS across strata 1 and 2 during 2014–2016 with 2017–2019. This overview was intended to satisfy our curiosity about changes in the distribution of NIDGS during the last 6 years. As above, we included all actual locations of NIDGS from line-transect surveys, detections from presence–absence surveys, or other incidentals if we had identified the grid cell in the field. We did not use PRESENCE to analyze these data. We calculated naïve occupancy rates from all years combined for all 1,757 cells in strata 1 and 2 and for the core 500 cells surveyed every year. Using only the core 500, we determined if there were any cells that had detections at the beginning of the new study design in 2014, but nothing since. We also looked at possible new areas where we had detections in 2019, but not in the years prior.

RESULTS

Distance Sampling and Analysis

Of the 1,196 cells selected for surveys in 2019 across all strata, 76 were not surveyed because of access issues (lack of landowner permission). The majority of surveys were completed between 22 April and 2 July 2019. The 1,120 cells analyzed represented 223.40 km of effort. We recorded 1,678 groups of NIDGS (representing 1,720 individuals) at 635 of these 1,120 cells (57%).

From these data program DISTANCE estimated a detection probability of 0.73, a density of 0.85 squirrels/ha, and a total population size of 2,193 squirrels (Table 1). Based on AICc, model 1 from the hazard rate set of models was significantly better than the next best models in the half-normal and uniform sets. We used that single hazard rate to estimate density and population size. We detected up to 3 squirrels together, but most detections were of single animals. Average group size was 1.02 squirrels. Detection probability accounted for 22% of the variation in the density estimate, whereas encounter rate accounted for 77% and cluster size accounted for 1%. Applying a correction factor of 1.35 to the DISTANCE-estimated population size yielded an adjusted index to abundance of 2,960 NIDGS (Table 1).

In our stratified data set there were substantially more grid cells in stratum 1 (59%), fewest in stratum 2 (17%), and 24% in stratum 3 (Table 2). Correspondingly, most (67%) of the NIDGS detections occurred in stratum 1. The separate DISTANCE analysis using strata as a data layer resulted in density estimates of 0.97 squirrels/ha in stratum 1, 0.60 in stratum 2, and 0.72 in stratum 3, with unadjusted population sizes of 1,326, 233, and 602, respectively (Table 2).

Table 1. Modeled global population parameters from program DISTANCE for grid-based line transect distance sampling across occupied northern Idaho ground squirrel habitat in west-central Idaho, 2019.

	Estimate	Confidence Interval
Effort (km)	223.40	
# Grid cells surveyed	1,120	
# Groups detected	1,678	
Truncation distance (m)	60	
Detection probability (*p*)	0.73	0.70 – 0.76
Avg. group size (*E(S)*)	1.02	1.02 – 1.03[a]
Density (*D*)	0.85	0.77 – 0.94[a]
Population estimate (*N*)	2,193	1,990 – 2,429[a]
Adjusted index to abundance[b]	2,960	

[a] 2.5% and 97.5% quantiles of bootstrap estimate
[b] Population estimate adjusted upwards by a factor of 1.35 based on comparison of line-transect distance-based survey to mark-recapture in 2016 (Wagner and Evans Mack 2016).

Table 2. Modeled population parameters from program DISTANCE for stratified grid-based line transect distance sampling across occupied northern Idaho ground squirrel habitat in west-central Idaho, 2019**.**

	Stratum 1	Stratum 2	Stratum 3	Pooled
Effort (km)	131.40	38.75	53.25	
# Groups detected	1,122	205	351	
# Grid cells surveyed	658	195	267	
Truncation distance (m)	60	60	60	
Detection probability (*p*)				0.73 (0.70 – 0.76)
Avg. group size (*E(S)*)				1.02 (1.02 – 1.03)
Density (*D*)	0.97 (0.86 – 1.09)	0.60 (0.44 – 0.76)	0.72 (0.60 – 0.87)	
% Coefficient of variation of *D*	5.94	14.92	9.54	
Population estimate (*N*)	1,326 (1,180 – 1,484)	233 (172 – 303)	602 (497 – 725)	2,161 (1,953 – 2,389)

Population Abundance Trajectory

NIDGS population size remained static in 2019 compared with 2018 (Table 3). Based on analysis of distance-based survey data common to both years, the population estimates were essentially the same for the 2-year period. Likewise, the direct cell-to-cell comparison of the 462 core cells surveyed both years was similar to DISTANCE results in that average detections per cell were not significantly higher in 2019 compared with 2018 ($t = 0.99$, $p > 0.05$).

Table 3. Comparison of northern Idaho ground squirrel population metrics for years 2019 and 2018 across occupied habitat in west-central Idaho.

Method and Metrics	2019	2018[a]
All Strata[b]		
# Grid cells surveyed	1,120	1,107
# Groups detected	1,678	1,641
Avg # detections/grid cell	1.50	1.48
% Grid cells with ≥1 detection	52%	48%
Density (*D*)	0.85 (0.77 – 0.94)	0.84 (0.74 – 0.94)
Population estimate (*N*)	2,193 (1,990 – 2,429)	2,173 (1,923 – 2,434)
Core grid cells (Ranks 1-500)[c]		
# Grid cells	468	462
# Groups detected	765	685
Avg # detections/grid cell	1.63	1.48
Density (*D*)	0.93 (0.80 – 1.09)	0.95 (0.80 – 1.13)
Population estimate (*N*)	1,630 (1,410 – 1,919)	1,667 (1,401 – 1,987)
Paired sample *t*-test[d]		
# Core grid cells	462	462
Avg # detections/grid cell	1.64	1.54
t-statistic	0.99	
p-value	$p > 0.05$	

[a] Source data: Wagner and Evans Mack 2018

[b] Results from program DISTANCE based on each year's sample of grid cells (3 strata) selected for surveys across a common area of inference.

[c] Results from program DISTANCE for core grid cells in strata 1 and 2 (BAS ranks 1–500) surveyed every year.

[d] Pair-wise comparison of core cells (BAS ranks 1–500) surveyed every year. (Only 462 of the core cells were surveyed in both 2018 & 2019.)

Looking back 6 years, NIDGS abundance in strata 1 and 2 has been on a downward trend since the peak observed in 2016 (Figure 4). However, the addition of stratum 3 in 2018 shows a plateau in estimated overall population size. Stratum 3 encompasses areas where squirrels have more recently been documented, in part as a result of squirrels moving on the landscape.

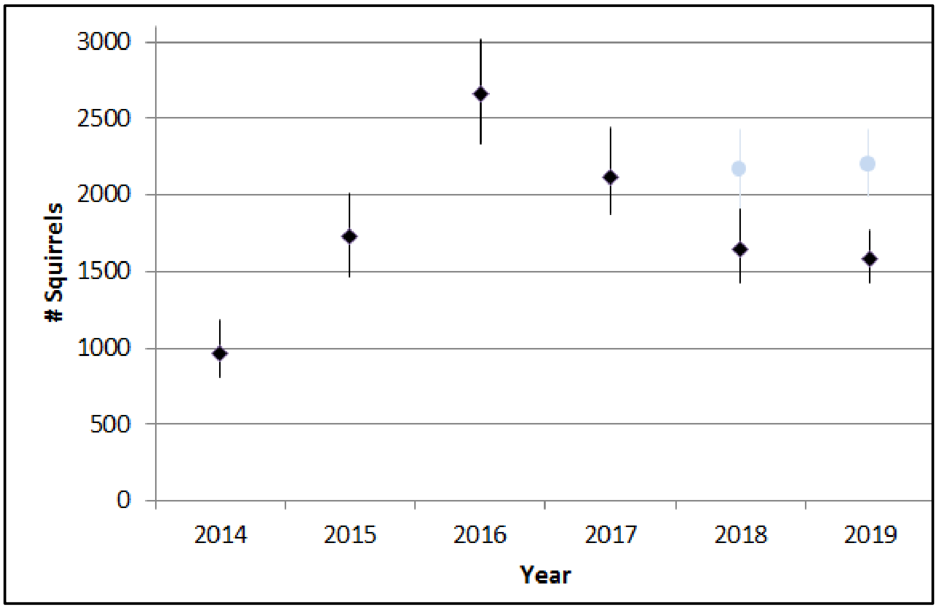

Figure 4. Unadjusted population estimates and 95% confidence intervals from program DISTANCE for strata 1 and 2 only (black); strata 1, 2, and 3 shown in blue for 2018 and 2019.

NIDGS Distribution (Occupancy)

After adjusting for detections made from grid cells that fell beyond the cell boundary, we detected NIDGS in 584 of the 1120 cells surveyed with line-transect distance-based surveys, giving a naive occupancy of 0.52 (i.e., 52% of grid cells were occupied, without correcting for detection probability). This was a slight increase over 2018 (48%). We conducted 3rd surveys at 158 grid cells, 111 target grid cells that had not had a detection in either visit 1 or 2, and 47 control cells. We gained 22 cells as occupied over visits 1 and 2.

Of the 10 models compared with program PRESENCE, models with a constant detection probability across visits performed better than models with a different detection probability each visit (Table 4). Three models were roughly equivalent (<2 units difference in AIC value with substantial AIC wt) in predicting whether a cell was occupied (Table 4). Proximity to recent known squirrel locations, tree canopy cover, and proportion of a grid cell with southerly aspects contributed to the 3 most supported models. The other 3 site covariates we considered (heat load index, soil bulk density, soil depth) had little explanatory power.

Probability of detection, given a cell was occupied, was estimated at 0.58 (95% CI 0.55–0.62) for each of 3 visits. The probability of missing a squirrel on an occupied site was ≤0.07. Thus, we could have missed detecting presence on fewer than 7% of occupied sites and we detected presence on at least 93% of occupied sites. Probability of occupancy ranged from 1.0 at cells where we detected squirrels to 0. We applied the ‘best’ model (Table 4) to all 2,590 cells in our expanded sampling frame, using covariate values to predict probability of occupancy for the cells we did not survey this year. With this model, almost half (45%) of cells in our expanded sampling frame had >75%

probability of being occupied, a similar number of cells had <50% probability of being occupied, and only 4% of cells had 0 probability. These proportions are slightly better than 2018.

Table 4. Comparison of models from program PRESENCE for grid-based line transect distance sampling across occupied northern Idaho ground squirrel habitat in west-central Idaho, 2019**.**

Model	AIC	deltaAIC	AIC wt
psi(canopy, proximity, aspect), p(.)	2601.46	0.00	0.3838
psi(proximity), p(.)	2602.16	0.70	0.2705
psi(canopy, proximity), p(.)	2602.32	0.86	0.2497
psi(canopy, proximity, soildepth), p(.)	2604.23	2.77	0.0961
psi(canopy), p(.)	2929.80	328.34	0.0000
psi(.), p(.)[a]	2963.69	362.23	0.0000
psi(soildepth), p(.)	2963.96	362.50	0.0000
psi(bulkdensity), p(.)	2965.45	363.99	0.0000
psi(heatload), p(.)	2965.51	364.05	0.0000
psi(.), p(visit)[b]	2967.65	366.19	0.0000

[a] Reference model using constant probabilities of occupancy and detection.
[b] Reference model using constant probability of occupancy and probability of detection varying across visits.

The 2018 modeled probability of occupancy estimates, which were based on a model incorporating tree canopy cover, proximity to other squirrels, and variable detection probability across visits (Wagner and Evans Mack 2018) aligned well with 2019 surveys. We detected at least 1 NIDGS in 70% of the grid cells with higher (>0.50) probability of being occupied (based on the 2018 model), and NIDGS were detected in only 2 cells that had been estimated to have 0 probability of being occupied. Likewise, 71% of cells with a lower probability of being occupied (<0.50) had no detections in 2019.

Occupancy within our original sampling frame (1,797 grid cells in Stratum 1 and 2) has increased modestly from when we initiated grid-based surveys in 2014 (Table 5). Comparing the most recent 3-year period to the previous 3 years, numbers of cells gaining detections exceeds those losing detections. Several annual metrics support this conclusion as well. For example, in 2019 we detected NIDGS in 103 grid cells that had no detections the 5 previous years. Comparatively, there were only 30 cells that had been occupied in 2014 and not subsequently. Nevertheless, there also is evidence of instability over time. Of the core 500 grid cells which are surveyed every year, only 10% were occupied in each of the past 6 years.

Table 5. Changes in occupancy after 2 rounds of a 3-year rotating panel of surveys across occupied northern Idaho ground squirrel habitat in west-central Idaho.

	2014–2016	2017–2019
% of cells w/ ≥1 detection in at least 1 of the 3 years	52% [a]	57% [b]
% of cells with ≥1 detection in all 3 years	6% [a]	8% [b]
% of core 500 cells occupied all 3 years	18% [c]	28% [c]
# of cells in which we gained occupancy in 2017–19 over 2014–16		332
# of cells in which we lost occupancy in 2017–19 over 2014–16		245

[a] Based on 1,757 S1S2 grid cells surveyed
[b] Based on 1,742 S1S2 grid cells surveyed
[c] Based on 500 core S1S2 grid cells surveyed

Presence/Exploratory Surveys

We visited 2 known sites in 2019 that did not contain selected grid cells for surveys (both in stratum 2) and revisited 6 new sites (75 ha covered) that had detections in 2018 to determine if NIDGS were still present. We detected NIDGS at 6 of these (RCF West, Lost Valley Reservoir NW, Grouse Creek Rock Pit, East x West Branch Weiser River, Price Valley Private, and Tamarack Southeast). Data from presence-absence surveys was used to determine if sites were still extant, not for annual abundance or occupancy analyses.

We covered 1,540 ha of habitat during exploratory surveys. We detected 221 NIDGS at several locations between existing sites on and around the OX Ranch and in the vicinity of Fawn Creek (Figure 5), Price Valley, Tamarack View Estates, Tamarack East, Lower Butter, Rocky Top, and Round Valley. A renewed interest in the status of NIDGS sites managed by the Bureau of Land Management prompted us to join BLM Biologist Noel Copenhaver to survey 60 ha at North Hornet Creek, a site that had been considered extirpated and had not been surveyed since the late 1990's. We detected approximately 25 NIDGS. We confirmed that the location was the same as reported decades ago (E. Yensen, pers. comm), despite the fact that the original site polygon was off by several hundred meters in our spatial database. We found NIDGS across a broader area than the original site delineation. North Hornet occurs at the lowest elevation and farthest south (except Round Valley) in the NIDGS range and is approximately 11 km from the nearest known NIDGS at Halfway and Cottonwood. We also assisted the Payette NF with clearance surveys for NIDGS in the Weasel Gulch Prescribed Fire treatment area in preparation for prescribed burning. We surveyed 635 ha with 0 NIDGS detections.

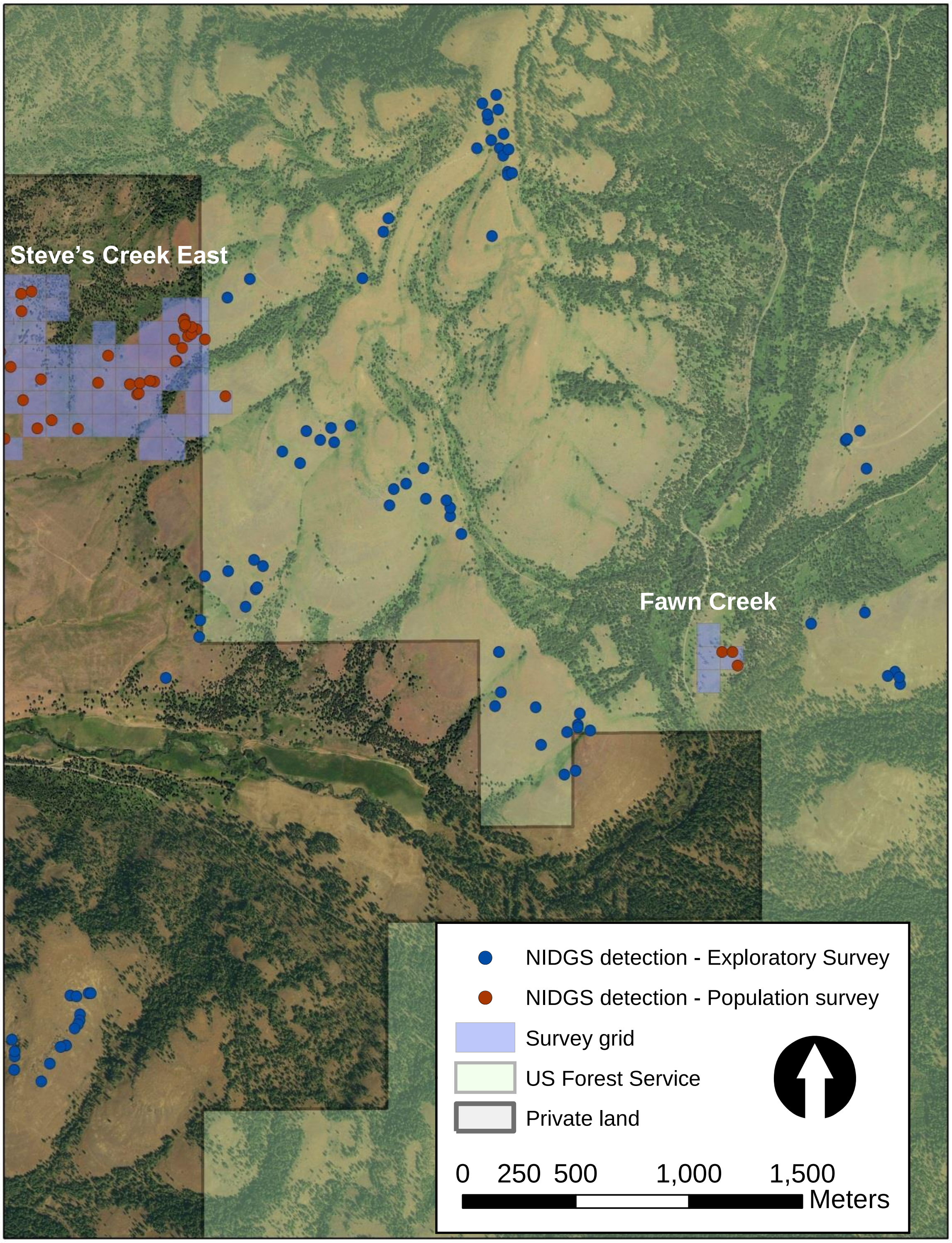

Figure 5. A portion of new occupied habitat documented between and adjacent to known northern Idaho ground squirrel sites as a result of exploratory surveys in 2019.

Columbian Ground Squirrels and Badger Activity
A total of 351 Columbian ground squirrels were detected at 59 sites in 2019. This was about half the number of detections made in 2018 (600) and the lowest number of detections since 2015. Lost Valley Reservoir had the highest number of any single location (65 squirrels), but still substantially less than in 2018 (175). Despite the apparent overall decline in Columbian ground squirrels across all sites, we saw a noticeable increase in abundance at Tamarack East and Price Valley Main.

Recent badger activity was noted at 18 locations. Most of the activity we recorded was fresh digs, but we observed badgers out foraging at Lost Valley Reservoir and 3 sites on the OX Ranch: Bear Meadow North, Rocky Comfort Flat, and Lick Creek Feedlot. Our crew was unsuccessful at live-capturing and relocating these badgers. Wildlife Services, under contract with the USFWS, targeted these and other locations for lethal trapping and removed 5 badgers from Steve's Creek and 1 badger from Fawn Creek. Trapping was unsuccessful at Lower Butter and Lost Valley. Nobuto blood samples were taken from all 6 badgers removed as part of disease surveillance, particularly for rabies. The FS employee at Lick Creek Lookout reported a badger working in the area, but we did not observe fresh sign during our surveys there. Given our grid cell selection, it is possible the badger activity occurred in grid cells we did not survey in 2019.

DISCUSSION

Based on our standardized surveys, the NIDGS population remained stable in 2019, with no significant increase or decrease in abundance compared with 2018. Because the 2019 field season completed the second round of our 3-year rotating survey scheme, we could explore changes in population size and distribution based on the full suite of grid cells in our original sampling frame (strata 1 and 2, 2014–2016 to 2017–2019). On the surface, the most current 3 years showed a downward trajectory compared with increases during 2014–2016. However, this is confounded somewhat by the shifting distribution of NIDGS on the landscape and the loss of access to key private lands. We developed the survey design with another stratum in mind, one that could be added to the sampling frame and expanded over time specifically to account for changes in NIDGS distribution. We created a new stratum after the 2017 field season, and its inclusion in 2018 and 2019 increased population estimates for those 2 years. While this made the downward trajectory less pronounced, the extent to which squirrels detected in stratum 3 represented animals that moved from strata 1 and 2 is unknown. The dynamic nature of NIDGS occurrence on the landscape will always present a challenge to defining population trajectory.

With that dynamic nature in mind, in 2019 we prioritized surveying "gaps" between known occupied areas, focusing on the OX Ranch, Price Valley, the Lost Creek drainage, and the complex around the junction of Price Valley Road and Hwy 95. These exploratory surveys were very productive. In addition to generating ~200 new 'dots on the map', they demonstrated the importance of actively looking for an expanding footprint.

As designed in the monitoring strategy, we used occupancy modeling to estimate the proportion of cells occupied and each grid cell's probability of being occupied as metrics for NIDGS distribution.

Naïve occupancy was slightly higher in 2019 compared with 2018, and there were more cells with a higher probability of being occupied in 2019. Site covariates, derived primarily from spatial (GIS) data, allowed us to predict the probability of occupancy for cells we did not survey based on how similar the site conditions were to those we did survey and had detections. After 2 years of exploring relationships with the same suite of covariates, the combination of proximity to other squirrels and tree canopy cover has the greatest influence on whether squirrels are present. Given that NIDGS are loosely colonial, it makes sense that locations near other squirrels have higher probability of being occupied. Other environmental variables we think should be important for a ground-dwelling mammal, such as soil characteristics and aspect, had limited predictive power within the suite of covariates we modeled, but in models limited strictly to environmental conditions (without squirrel occurrence) they rank high and therefore are powerful in predicting suitable habitat.

The best models in our 2019 occupancy analysis included constant detection across visits rather than different probabilities of detection each visit. This seemed counterintuitive, as visits occurred during different phases of above-ground activity. Visit 1 optimized adult squirrel visibility, visit 2 occurred after the heightened activity associated with emergence and breeding, and visit 3 occurred after pups were above ground, suggesting that detection could differ across visits. In fact, we found that to be the case in 2018 (Wagner and Evans Mack 2018). The purpose of a 3rd visit was to target grid cells where we had 0 detections during visit 1 and 2 to increase our measure of occupancy. However, this year we included an equal number of control sites in visit 3 (sites where we knew squirrels were present from visit 1 or 2). We wanted to ensure that if we did not detect squirrels on visit 3 at sites where we had not detected them on visit 1 or 2, it was reflective of squirrel presence/absence and not due to conditions affecting the survey. Because detection on visit 3 was similar between control and target grid cells, the overall effect was diminished differences in detection probability across visits.

Our long-term sampling design moves away from the old site-based method of tracking populations. However, there still is interest in following the status and history of specific locations on the landscape, particularly those that have supported robust numbers of NIDGS in the past but now appear to be in decline, or sites that rebound after decline. Riley Ranch, Cottonwood, Cold Springs, Halfway, Huckleberry, Squirrel Manor, Summit Gulch, East Fork Lost Creek, and Slaughter Gulch are sites that have undergone noticeable changes. We did not observe any substantial changes in distribution as a result of recent thinning or burning. However, forest restoration work is in the early phases of implementation.

RECOMMENDATIONS

- Continue to implement long-term monitoring as designed in 2014.
- Validate survey results with mark-recapture live-trapping in 2020. Validation should be based on a minimum of 10 well-distributed and well-defined geographic areas wherein distance sampling occurs on transects completely covering the area and 3–4 trapping occasions occur within the same area. For efficiency, a validation effort should be

coordinated with other ongoing studies to minimize multiple trapping sessions or surveys at sites. Repeat this validation every 3–5 years.

- Advise the Forest Service to continue to conduct clearance surveys for small projects as presence/absence surveys. If NIDGS are detected, these locations will be added to the stratum 3 layer and incorporated into systematic sampling in a following year. If a target area is very large and there is a desire to estimate NIDGS density rather than presence, we recommend surveys be conducted within the grid-based framework established for long-term monitoring such that data can be compared. Specifically, surveys will tier to the range-wide 100 m x 100 m grid. If not all grid cells within the defined geographic area of interest can be surveyed, cells should be selected following the same equal-probability sampling procedure (e.g., BAS) and surveys conducted following the same standard operating procedures as the long-term monitoring design.
- Pursue long-term protection for key privately-owned sites by outright acquisition (Recovery Land Acquisition grants), conservation easements, or long-term Safe Harbor agreements. A comprehensive conservation strategy for NIDGS on private land in Round Valley, Price Valley, and the Mud/Little Mud Creek drainages should be developed.

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APPENDIX A. Description and source data for environmental covariates used in NIDGS occupancy modeling, 2019.

Covariate	Description	Data Source
southerly aspect <asppcSOUTH>	proportion (%) of a 100m circular neighborhood with a southerly aspect (SE, S, SW; 113–248 degrees)	10-meter digital elevation model (USGS 2017)[a]
soil bulk density <bulkdens30>	bulk density (g/cm3), averaged in first 1m of soil; weight of soil in a given volume.	30-meter resolution POLARIS soils data (Chaney et al. 2016)[b]
heat load index <heatMEAN>	average heat load index within 100m circular neighborhood; a temperature index that ranges from 0 (coolest) to 1 (hottest) accounting for aspect and steepness of slope.	derived from 10-meter digital elevation model (USGS 2017) using the Geomorphometry and Gradient Metrics v2.0 toolbox (Evans et al. 2014)[c]
soil depth <resdep30>	depth to restrictive layer (cm)	30-meter resolution POLARIS soils data (Chaney et al. 2016)
tree canopy cover <treeMEAN>	mean tree canopy cover (%) within a 100m circular neighborhood	30-meter resolution NLCD 2016 USFS Percent Tree Canopy (Analytical Version) (USGS 2019)[d]
proximity NEAR_DIST	distance to nearest known NIDGS observation within the last 3 years (measured planar distance)	IDFG unpublished data using the Generate Near Table tool in ArcGIS

[a] USGS. 2017. 1/3rd arc-second Digital Elevation Models (DEMs) - USGS National Map 3DEP Downloadable Data Collection. Raster Digital Data Set. Available at: https://www.usgs.gov/core-science-systems/ngp/3dep

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