



Acoustic Inventory of Breeding Birds in Denali National Park and Preserve

NPS / NSNSD / [Technical Assistance Request #2252](#)



ON THE COVER

Hauke Creek sound station in Denali National Park, a location with high bird diversity.
NPS Photo/Davyd Halyn Betchkal

Acoustic Inventory of Breeding Birds in Denali National Park and Preserve

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February 24th, 2022

U.S. Department of the Interior
National Park Service
Natural Resource Stewardship and Science
Fort Collins, Colorado

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Executive Summary



Photo 1. Hot Slough sound station, located in Denali National Preserve. NPS Photo.

Measurements of the occurrence and diversity of avian species at landscape scales are crucial in light of Alaska’s rapidly changing climate. Traditionally, the National Park Service conducts avian inventories by sending research teams into the field where they use a variety of survey methods to collect data on species presence. Such data can be time consuming and costly to collect. To extend this type of work, we demonstrate a toolkit of acoustic methods that can be used to conduct avian inventories in parks (especially large or remote ones.)

Our acoustic methods use data collected by autonomous recording systems at a 20 x 20 km resolution throughout the park. These systems are beneficial because they can provide both calibrated numeric measurements of sound pressure level and continuous digital audio recordings for over a month. In this study, we used 25 acoustic records that were collected as part of the Denali Soundscape Inventory between 2010 – 2014. These span the full range of elevations in the park, ranging from 168 to 3327 meters above sea level. For that reason, they span a wide variety of habitats as well. The entire set of recordings totaled to 19,705 hours of MP3 audio. After removing data outside the breeding season, subsampling further focused analysis to the period around sunrise when birds are usually most active. This whittled the entire record down to about 100 hours of audio.

To analyze the subsampled acoustic records:

- **We developed a computer-aided detection technique to facilitate species annotation, then,**
- **We trained ornithologists to use visual, auditory, and analytical tools to annotate the bird species present – if any – in each automated detection.**

Using the expert’s resulting species annotations:

- **We provide estimates of presence/absence and relative abundance of birds at each site.** Our results compliment and extend traditional roadside Breeding Bird Surveys (BBS) as well as large-scale bird inventories in Lake Clark, Katmai, and Aniakchak.

- **We compare species lists across sites to identify regions with similar species presence.** We observe at least three distinct biogeographic regions of avifauna in Denali with mutually-overlapping species presence: (1) the Minchumina/Kuskokwim basin, (2) East sub-alpine Denali, and (3) South-West sub-alpine Denali. We also highlight an alpine site (Sushana Ridge) for being highly *dissimilar* to any other site.
- **We estimate species richness within the detection area of the microphone.** The range of species detected across acoustic sites ranged from 0 (Upper Kahiltna Glacier) to 27 species (Hauke Creek). We observed at least two factors, elevation and natural ambience, which appear to be predictive of avian species richness.
- **We provide a robust analysis of potential error sources for the techniques listed above.** We find that categorization errors were negligible, and that instead most annotation errors were due to the unavoidable constraints of detection in the presence of (masking) noise. We emphasize that changes in masking due to changing waterways represent a serious source of potential error in *all auditory studies of birds*, automated or in-person. This is especially true in light of climate change, the fundamental impetus of this project.

Acknowledgments

Without the impetus from Dr. Carol McIntyre, this project would never have advanced as far as it did. We are very grateful for her biological insights and overall support. Dr. Josh Schmidt provided helpful suggestions on subsampling and use of the Jaccard Index. We thank Dr. Kurt Fristrup (now retired) and Dr. Megan McKenna from the Natural Sounds and Night Skies Division office for help with avian detector development.

Many of the difficulties with soundscape fieldwork are related to moving heavy, awkward, or fragile components over the landscape. In particular, Denali Backcountry and Mountaineering Ranger staff were extremely generous with their time and energy in making our data collection efforts successful.

This study is funded and made possible by support from Denali National Park and Preserve and the National Park Service.

Introduction

The potential impacts of a rapidly changing climate on Denali National Park and Preserve's ecosystems and the cascading effects on its wildlife cannot be overstated. Results of a warming climate are already evident across much of Denali and these effects and impacts will continue in the future. The effects of a warming climate are predicted to be most pronounced at the high latitudes including the ecosystems in Denali (Maxwell 1992, Mitchell et al. 1995, Houghton et al. 2001). Further, boreal forest wetlands and mountainous regions, both very common in Denali, were identified as the high latitude ecosystems most affected by a warming climate (Ostercamp et al. 2000). Birds respond rapidly to environmental changes and have a very active metabolism; therefore, they are highly sensitive to climatic changes. Furthermore, birds are very mobile and can react immediately to environmental changes. As a result, birds can be viewed as pioneer indicators for changes related to a warming climate (Møller et al. 2004, Lemoine et al. 2007). The cascading effects of climate change could result in substantial loss of breeding habitat and food supplies, and ensuing population declines for many birds in Denali. For instance, species now common in Denali may become locally extinct due to changes in habitat (i.e., drying of lakes and wetlands or loss of alpine habitat). In contrast, species that have not historically occurred in Denali may start moving northward due to environmental change.

Measurements of the occurrence and diversity of avian species at landscape scales are crucial in light of Alaska's rapidly changing climate. Before the present study, no formal bird inventory has been conducted on a park-wide scale. Little is known about the abundance and distribution of most birds across most of Denali. A park-wide bird inventory is necessary to fill in many information gaps. Large-scale bird inventories have been completed in several other National Park Service units in Alaska (Tibbetts et al. 2005, Ruthrauff et al. 2007) and provided critical information, including documenting new or rare species and refining the distribution of species. Inventory on a similar scale is equally important for Denali – this report documents such an effort. As such, it also serves to demonstrate a set of new analytical tools appropriate for avian research via acoustic methods over large areas of land. As *new* tools, they are *necessarily unfamiliar*, and so the thrifty reader is encouraged to advance with an exploratory mindset.

Our project uses legacy acoustic data to document the presence of breeding birds across Denali. This project was timely for several reasons. First, the project enhances the Vital Signs monitoring program in Denali. Second, it provides essential information for the Climate Change Response Focus Area of the Alaska Natural Resource Program (NPS 2014) because of the potential for habitat and behavioral changes resulting from a changing climate. Third, it explores the application of remotely sensed data (automated acoustic records) to measure change in presence and distribution of Denali's avifauna. The inventory results provide a benchmark to measure future changes, including those associated with climate change. Such information complements passerine monitoring programs in the Central Alaska Monitoring Network (Schmidt et al. 2013) and beyond.

Methods

Acoustic Data Collection

We collected acoustic data using audio recording systems at a 20 x 20 km resolution as part of a larger natural acoustics inventory of Denali National Park and Preserve. (For specific details on site locations and attributes, see published metadata in Withers and Betchkal 2013, Betchkal 2013a, Betchkal 2013b, Betchkal 2015.) The recording systems used a PCB Pizeotronics microphone type 377B02 paired with a Larson Davis sound level meter model 831-A. From there, the signal was logged continuously using a Roland R-05 digital audio recorder (Figure 1). The input setting on the R-05 was usually 16 or 17. At most sites (n=23) we recorded to 64 kbps MP3. At a few (n=4), we recorded 96 kbps MP3.

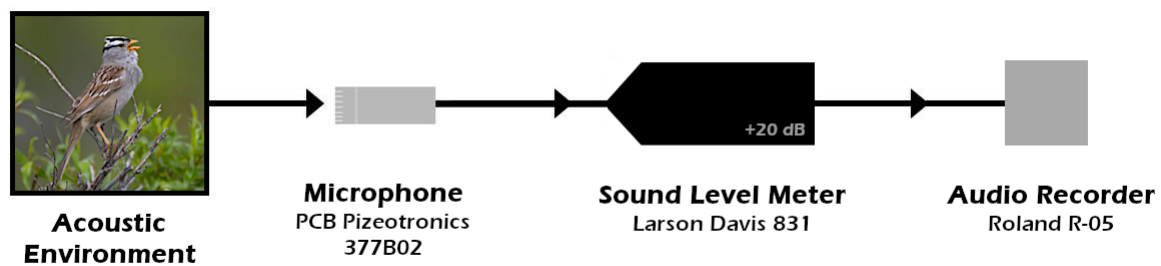


Figure 1. Schematic of the audio recording system used to collect acoustic data. Note that the sound level meter was necessary for the original purposes of the measurement, and though helpful for this study would not be necessary for studying avian ecology in the general case.

To focus our analysis effort, we only include sites that had data on the bounded interval [April 20th, July 1st), the typical extent of breeding season in Denali. For each site-day we determined sunrise time using an online service (U.S. Naval Observatory 2016). To align with Breeding Bird Survey protocol (NPS 2011) we limited our analysis effort on each day to within a half-hour before sunrise to six hours after sunrise. Within this period, we analyzed only the first 15 minutes of each hour (examples of subsample indicated by green blocks in Figure 2).

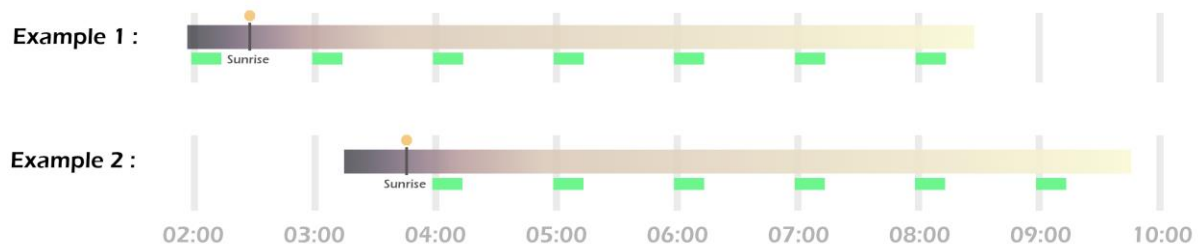


Figure 2. Audio subsampling method. For each day, we limited analysis to within a half-hour before sunrise to six hours after sunrise. Within this period, the first 15-minutes of each hour was analyzed.

Subsampled data from 25 sites (Figure 3) total to nearly 100 hours of analysis effort for the entire project. Site locations span the area of the park and represent at least 11 different landcover categories (Boggs et al. 2001). Site elevations range from 168 to 3327 meters above sea level.

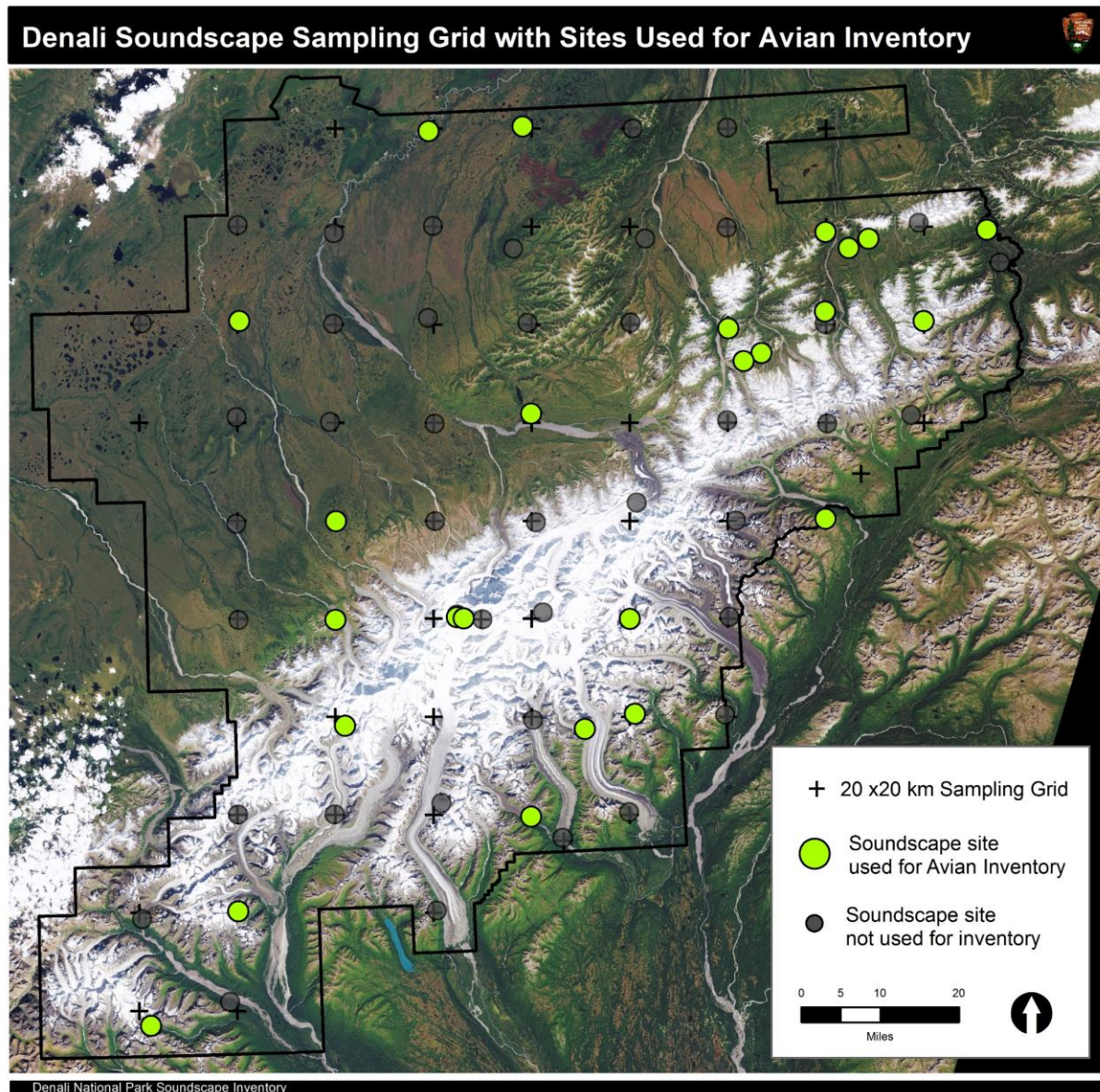


Figure 3. Location of soundscape sites 2010 - 2014 (in green) used for the inventory of breeding birds in Denali National Park and Preserve.

Detection and Annotation of Avian Calls

We first devised an *automated detection method* (hereafter “detector” / “detections”) to concentrate analysis on portions of the full acoustic record (hereafter “record”) that contained avian sound. The detector was developed using the band-limited energy detection algorithm in Raven Pro 1.5 (Cornell Lab of Ornithology 2014). The goal was to create a single, generalized detector capable of isolating a

wide variety of avian sounds present in the record (“true positives”). Our detector tends to reject portions of the record that contain no avian sound (“true negatives”). The choice is deliberate: having staff review detections with no avian sound (“false positives”) is wasteful. An additional consequence of this choice is that our detector also tends to reject portions of the record that contain faint avian sounds (“false negatives”). Thankfully this helps reduce staff time spent scrutinizing sounds on the threshold of perception. We can tolerate leaving some avian sounds out of the analysis if we assume that given our large sampling effort, the majority of species present at a site will appear in at least one true positive detection. We also assume that the majority of false negatives represent abundant species and dismissing them from consideration will not change species richness estimates significantly, *if at all*.

For each resulting detection, an ornithologist used visual, auditory, and analytical tools to annotate the audible species (hereafter “analyst” / “annotations”). The annotation contained two parts: a four-letter species code and a sound category – call, song, drum, or winnow. Because the record is permanent, detections could be listened to multiple times and compared to reference recordings as time allowed. Some detections contained no avian sound (= 0 annotations), some contained the sound of a single species (= 1 annotation), and some contained the sound of multiple species (>1 annotation). Figure 4 visualizes the detection and annotation steps of the analysis.

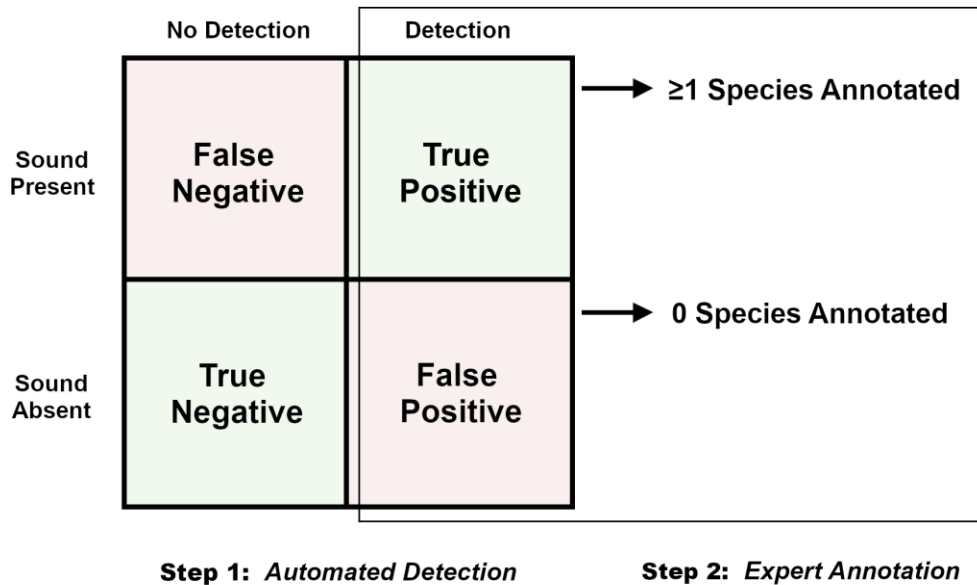


Figure 4. Diagram of detection – annotation process. The detection step was conducted automatically using Raven software. Then ornithologists annotated each detection with the species present, if any.

We validated our results by having a different set of ornithologists review 5% of the detections for each site at random, flagging both false positives and false negatives. A detection was considered erroneous if *any* annotation associated with it was incorrect. Validators tabulated the percentage of incorrect detections in the sample, p . This allowed us to use the standard error of a proportion to estimate the overall percentage with error:

$$SE_p = \sqrt{\frac{p(1-p)}{n}}$$

Validators also reviewed every annotation for species making up less than 2% of the total annotations at a given site location. This was used to look for systematic misidentification that might have resulted due to unfamiliarity.

Calculation of Species Richness and Diversity

Annotations were used to calculate an estimate of species richness at each site. If we assume the total species richness, S of an area has a finite limit, we can utilize a convenient asymptotic curve to fit our empirical observations (Clench 1979.) It takes the form:

$$S = \frac{a t}{1 + b t}$$

Where t is the time sampled and a and b are shape parameters of the curve. The asymptote of the curve is the limit as time goes to infinity:

$$\lim_{t \rightarrow \infty} S = \frac{a}{b}$$

We used a non-linear least squares curve fitting method implemented in {SciPy}(Jones et al 2014) to calculate the estimated values of a and b as well as their variance. The resulting parameter estimates were divided to provide an estimate of the species richness within the listening area of the microphone. The result is a non-integer value which would need to be quantized to make sense in the physical world. However, for the purposes of error analysis we report the richness to a precision of one decimal place.

Because we are estimating species richness (S) at it's limit, we chose to estimate the upper and lower bounds on species richness using a conservative approach. For the upper bound on S we use our estimate of a plus one standard deviation of a divided by our estimate of b minus one standard deviation of b :

$$S_{upper} = \frac{a_{max}}{b_{min}} = \frac{a_{est} + \sqrt{\sigma_a^2}}{b_{est} - \sqrt{\sigma_b^2}}, \quad S_{lower} = \frac{a_{min}}{b_{max}} = \frac{a_{est} - \sqrt{\sigma_a^2}}{b_{est} + \sqrt{\sigma_b^2}}$$

Which gives the usual 95% confidence band for the curve fit, and thus also for the richness estimate. An example of this approach is illustrated in Figure 5.

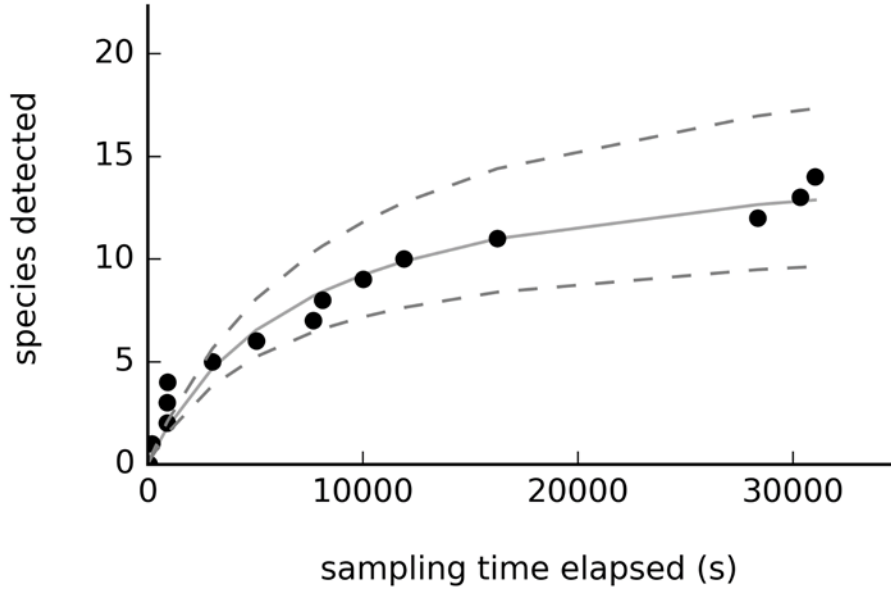


Figure 5. An example Species Accumulation Plot. The rate at which new species are annotated decreases as sampling time increases. The solid grey line is a least-squares fit to the Clench Curve. The dashed grey lines indicate the 95% confidence interval.

Calculation of Species Similiarity Between Sites

In addition to general estimates of species richness, we were also interested in a spatial comparison of the species present at different sites. The Jaccard Index measures the probability that, “*an element of at least one of two sets is an element of both*” (Levandowsky and Winter 1971). Thus, the probability a species is shared by two sites A and B is given by:

$$J = \frac{|A \cap B|}{|A \cup B|}$$

Where $\cap$ is the logical intersection, $\cup$ is the logical union, and the vertical bar symbols indicate the number of elements in the resulting set (it’s *cardinality*). From these measures, we created maps which visualize the similarity of a focal site to all other inventory sites in the park.

Calculation of Relative Species Abundance

We calculated relative abundance by species for each site location. This was done by counting the number of times a species was annotated at each site and dividing by the total duration of audio the detector processed (as presented above, Figure 2). This resulted in detection rates for each species. From these we ordered each species by detection rate to create rank-abundance plots.

Results

Species Detected

We analyzed about 100 hours of audio across 25 sites, amounting to 78,402 avian detections. The range of species detected across acoustic sites ranged from 0 (Upper Kahiltna Glacier) to 27 species (Hauke Creek). Compared with the long-term passerine monitoring data (see ‘*Methods*’, Phillips et al. 2017), there were fewer species detected overall (61 total species compared to 90+ species detected on the roadside surveys in a given year).

The effort identified 61 species across the four years of the study. Redpoll spp. were the most commonly detected bird species across sites (present at 18 of 25 sites; Figure 6; Table APP 1), followed closely by White-crowned Sparrow (15 sites) and Wilson’s Warbler (13 sites). Conversely, a third of the species were only detected at a single site (species=19). These were primarily birds that either vocalize uncommonly (e.g., Golden Eagle), at lower frequencies (e.g., Ruffed Grouse, Scaup sp.), or are restricted to rare landcover types that may not represent enough of the park’s habitat composition to have been included more than once in the acoustic inventory’s spatial sample (e.g., American Golden-Plover, Long-tailed Jaeger, Gray-Crowned Rosy Finch.) Finally, it is possible that some species may have only been detected during migration through the region (e.g., Lapland Longspur, Common Goldeneye). Elevation distributions for species detected more than once during the inventory are shown in Figure 7, fashioned after similar plots for avian inventory work in Katmai, Lake Clark, and Aniakchak (Ruthrauff et al. 2007, Ruthrauff and Tibbitts 2009).

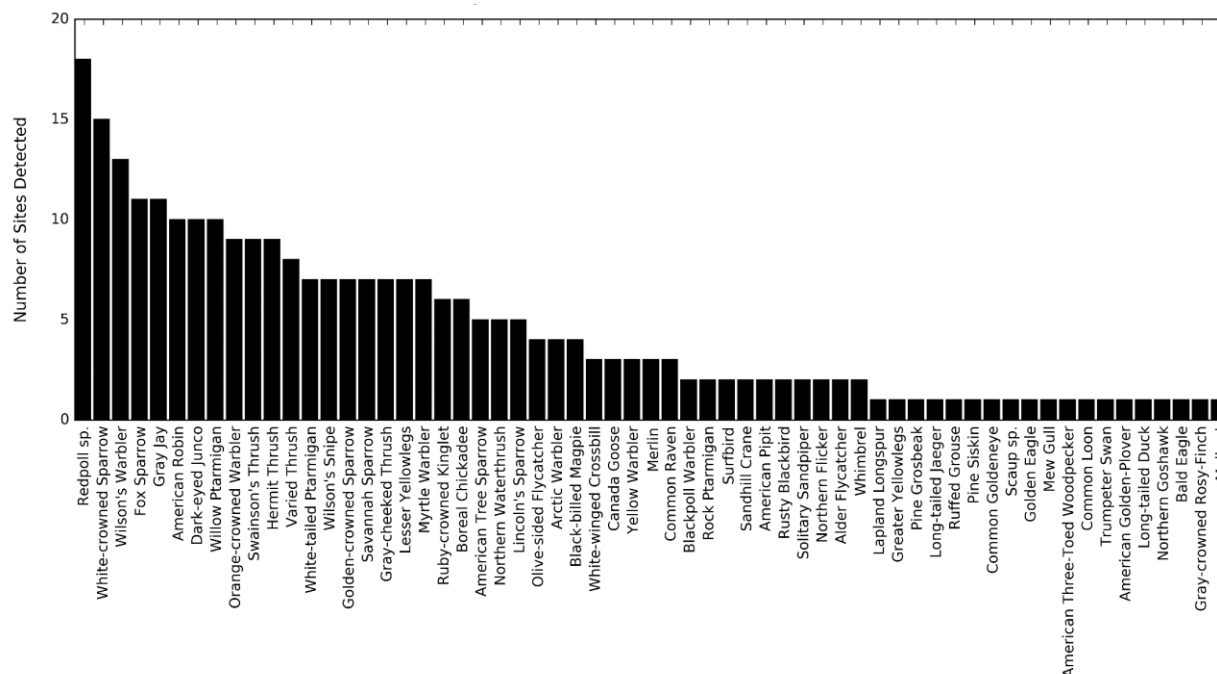


Figure 6. Incidence of 61 avian species at 25 sites in Denali National Park and Preserve, 2010 – 2014. Data are sorted based on the number of sites a species occupied.

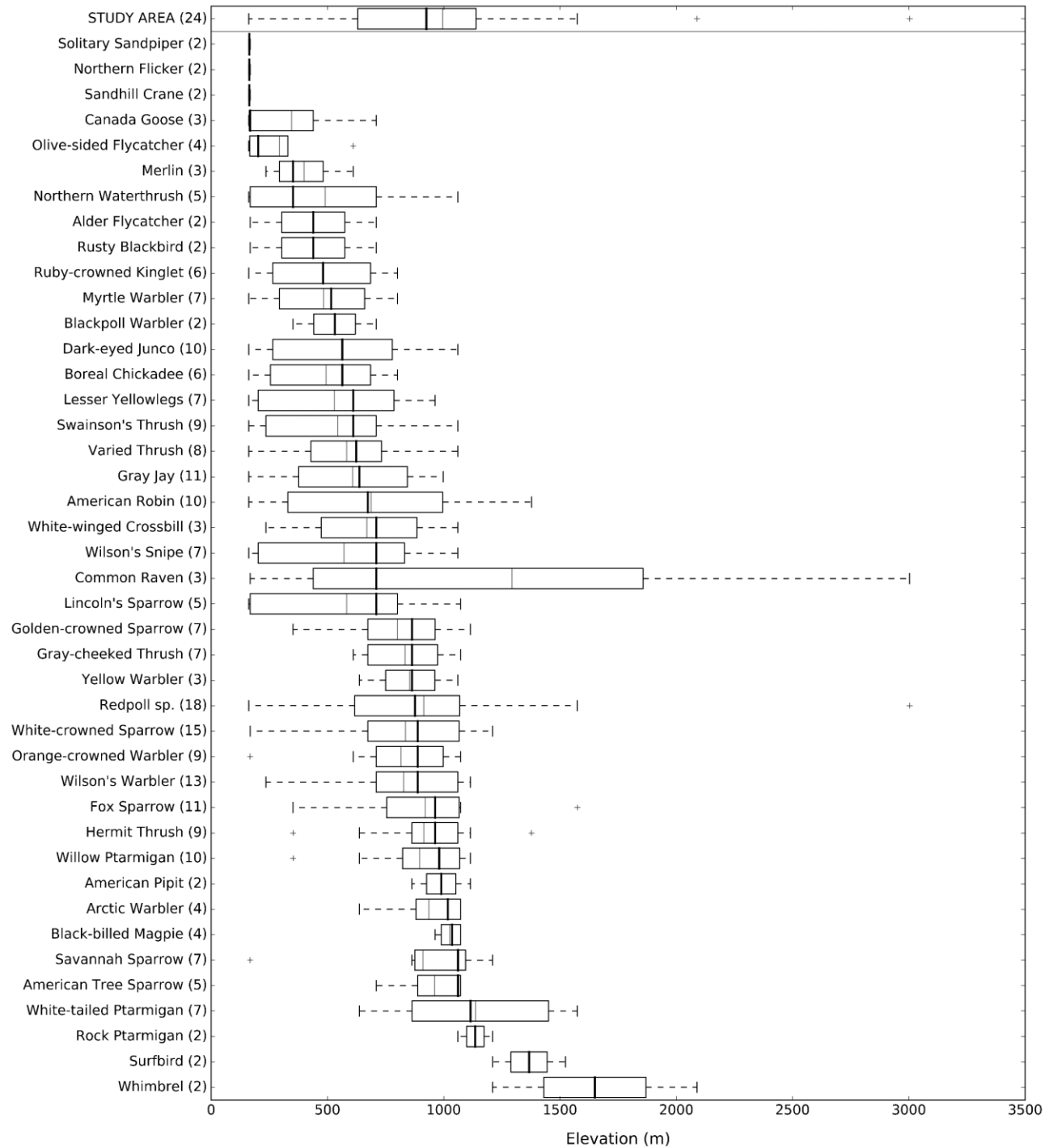


Figure 7. Elevation distribution of species detected more than once during the inventory of breeding birds in Denali National Park and Preserve, 2010 - 2014. Box plots show median (thick vertical line), mean (thin vertical line), quartiles (open box), and 10th / 90th percentiles of values (whiskers). The number of sites occupied by the species is shown in parentheses.

Species Richness

For a majority of the sites ($n=21$) we generated an estimate of species richness. It ranged from 3.5 species at Mount Lee to 33.5 species at Hauke Creek (Table 1). The median richness was 15.5 species, with a median absolute deviation of 6.8 species. A simple histogram of richness is shown in Figure 8, indicating a non-uniform distribution of richness across the park's landscape.

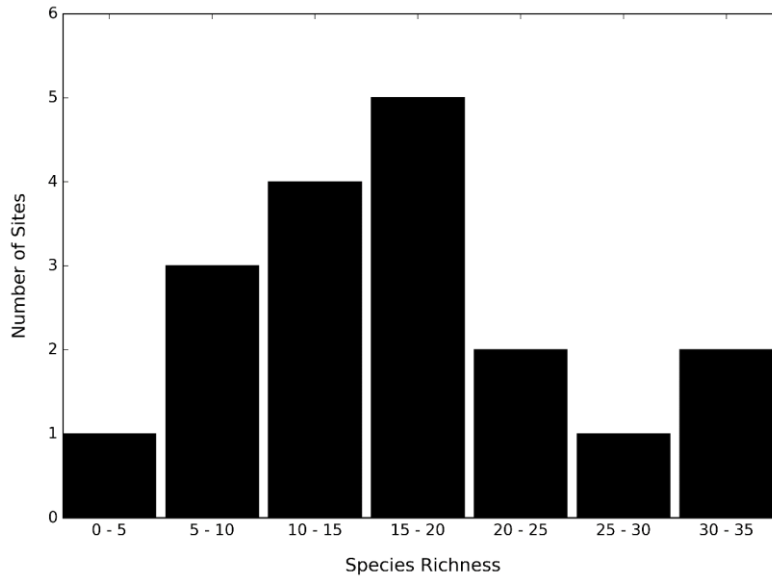


Figure 8. A histogram of species richness for all sites where a curve fit was successful. Bin size of 5 species.

For some sites ($n=4$), curve-fitting could not be used to estimate species richness because of the small number of species detected overall (Kahiltna Pass, Fang Mountain, Upper Eldridge Glacier, Lower Dall Glacier). Additionally, curve fitting failed to return parameters for two sites where waves of migrants introduced distortions to the temporal axis of the species accumulation plot (Sanctuary River 3, Backside Lake). This also caused computerized fitting of the theoretical model to fail. We do not report detailed measures of richness at sites without curve-fit estimates. When plotted, such sites are shown using a naïve species count.

A plot of richness versus elevation (Figure 9) shows a strong negative correlation ($r = -0.41$) up to about 1900 meters where richness essentially drops to zero. Two sites – Hauke Creek and Blind Creek – defy the otherwise monotonic decrease in richness with elevation. We also mention North Triple Lakes Trail and Mount Lee for have the lowest richness at their elevation.

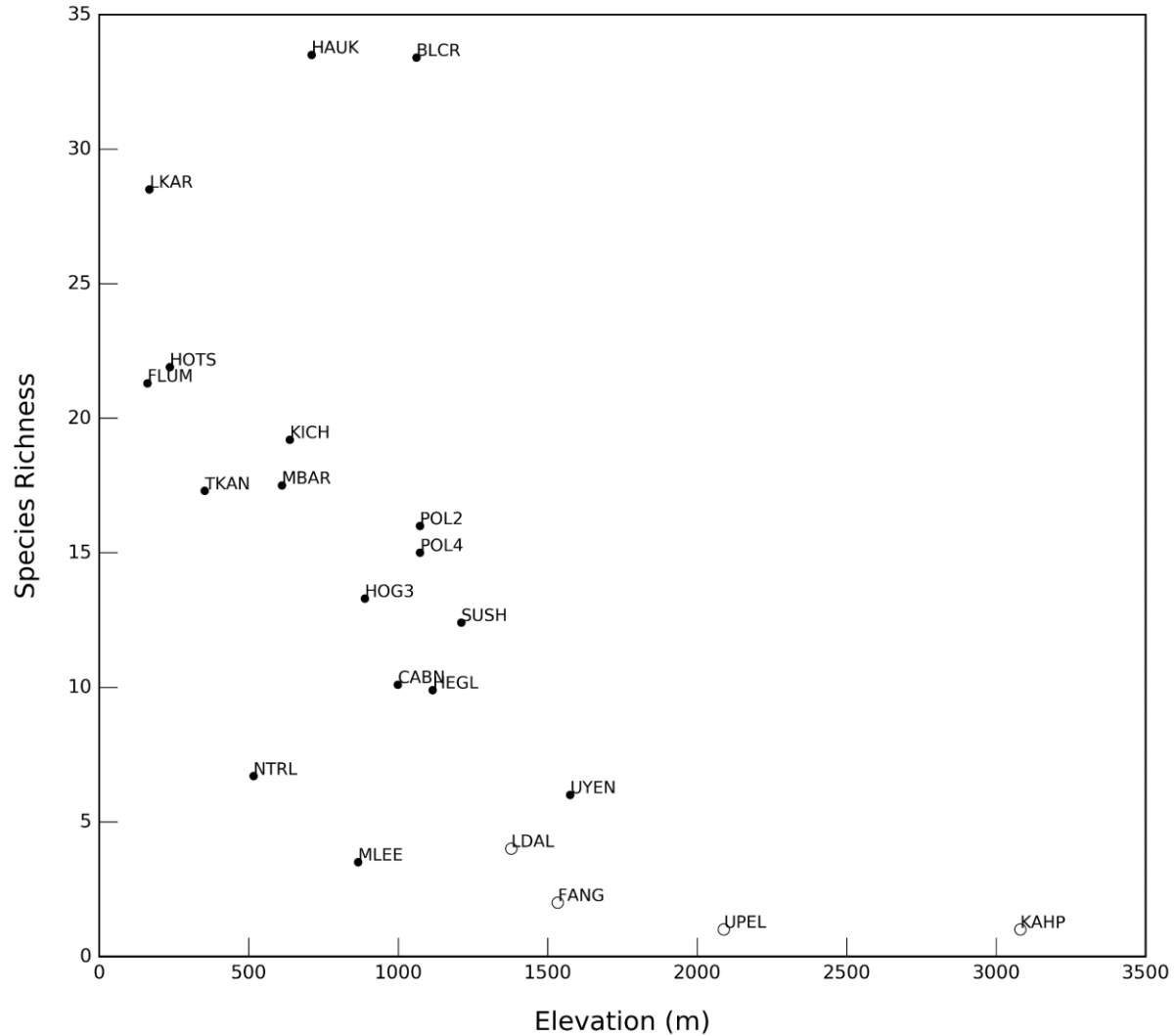


Figure 9. Species richness versus elevation for avian inventory sites. Sites where richness was estimated by curve-fit shown with filled circles. Sites where curve fit was not possible due to too few species observed are shown as hollow circles (the number of species observed is plotted instead.)

These latter two sites were especially loud (both sampled near energetic flowing water) and prompted an analysis of the effect of natural ambient acoustic energy on species richness. Because the audio data were originally collected with simultaneous sound pressure level measurements (see Figure 1, above) this could easily be realized.

We theoretically expect ambient acoustic energy to limit the spatial area around the microphone in which birds can be detected (Barber et al. 2010). From the species-area relationship (Preston 1962), it follows that if the sampled area decreases, so should the number of species detected. Figure 10 shows a plot of the 10th percentile sound pressure level (L_{90}) within the 2000 to 8000 Hertz (Hz) 1/3rd octave bands (i.e., background energy between 1778 to 8913 Hz) against richness. Because of the strong correlation of elevation with richness, the relationship between richness and sound pressure level

appears as an inequality in the plot. The anticipated relationship is more easily visualized when elevation is controlled for. (For example, consider the sites below 750 meters in Figure 10, shown in red.)

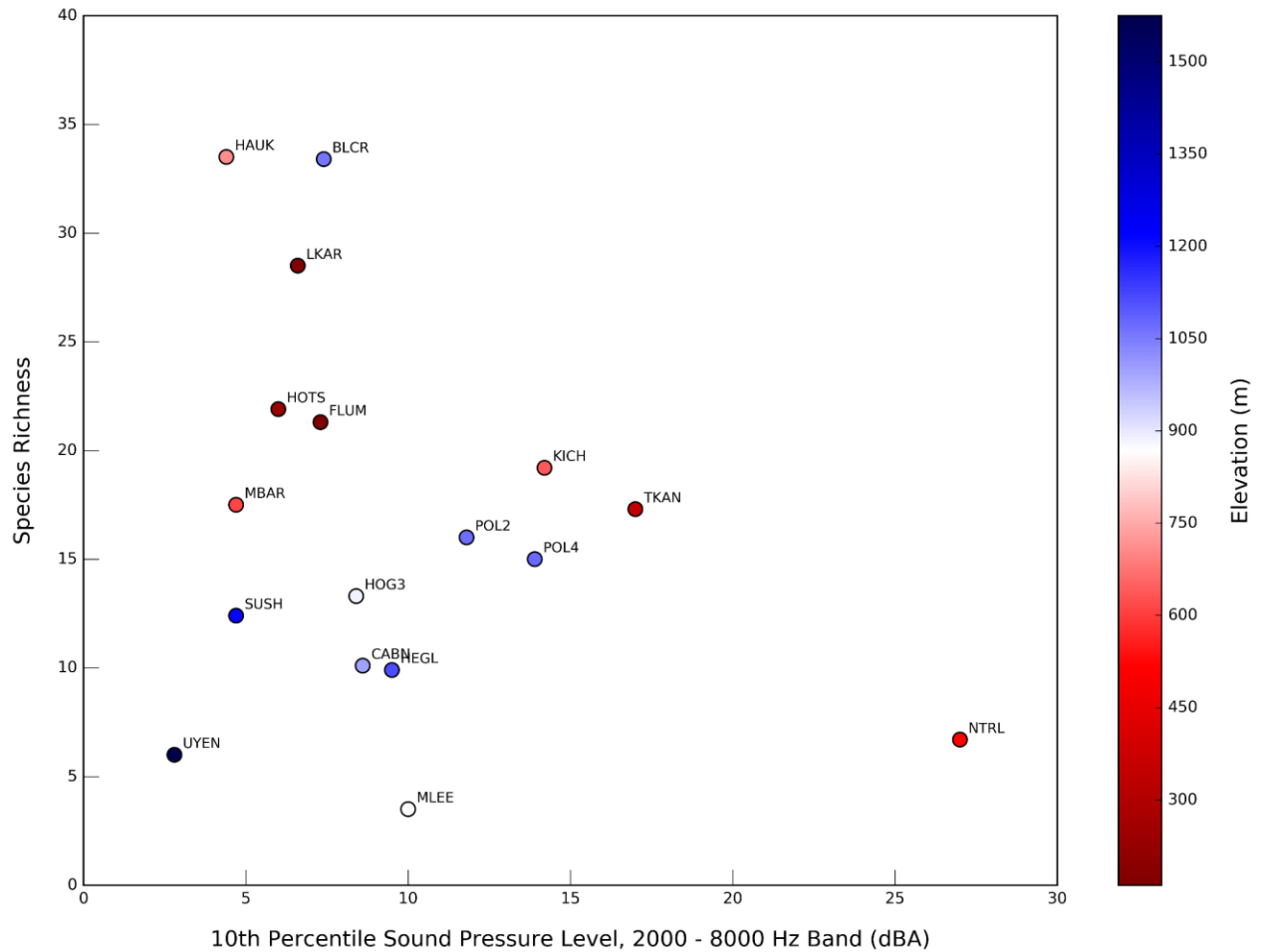


Figure 10. Species Richness (S) versus the 10th percentile sound pressure level within the 2000 - 8000 Hz band, where avian vocalizations were primarily detected. With greater background energy we expect distant individuals to be masked, decreasing the effective sampling area – and thus diversity – at these sites. To help visualize the confounding effects of elevation a third color axis is included.

Table 1. The percent (Correct) and standard error (SE) of detections for each of the acoustic records collected in Denali. ($S_{\text{annotated}}$) refers to species richness estimated using original annotations, and ($S_{\text{validated}}$) refers to species richness estimated with any annotation errors omitted. (S_{min}) and (S_{max}) associated with each refer to the absolute maximum limits associated with the estimate. (Fitting Error) refers to the percent difference in species richness between annotated and validated steps of the identification process.

Site	Correct	SE	$S_{\text{annotated}}$	$S_{\text{min}}, S_{\text{max}}$	$S_{\text{validated}}$	$S_{\text{min}}, S_{\text{max}}$	Fitting Error
Kahiltna Pass	100.0 %	-	-	-	-	-	-
Lower Kantishna River	74.3 %	± 5.0 %	28.2	21.6, 37.3	28.5	22.4, 36.6	-1.1 %
Herron Glacier	100.0 %	-	9.9	6.1, 16.7	9.9	6.1, 16.7	0.0 %
McKinley Bar Trail	89.5 %	± 4.1 %	16.6	10.4, 27.4	17.5	14.4, 21.4	-5.1 %
North Triple Lakes Trail	100.0 %	-	6.7	2.7, 20.9	6.7	2.7, 20.9	0.0 %
Hogan Creek	95.1 %	± 2.4 %	13.3	7.9, 24.6	13.3	7.9, 24.6	0.0 %
Igloo Canyon	98.4 %	± 1.6 %	10.6	7.8, 14.5	10.6	7.8, 14.5	0.0 %
Kichatna Mountains	98.2 %	± 1.1 %	21.6	14.9, 32.9	19.2	14.6, 26.0	12.3 %
Polychrome Mountain 2	100.0 %	-	16.0	10.1, 27.6	16.0	10.1, 27.6	0.0 %
Polychrome Mountain 4	73.4 %	± 5.3 %	15.0	9.0, 28.5	15.0	9.0, 28.5	0.0 %
Sanctuary River 3	100.0 %	-	-	-	-	-	-
Sushana Ridge	92.9 %	± 4.7 %	19.4	7.9, 157.9	12.4	5.1, 50.5	56.6 %
Toe of the Kanikula Glacier	79.6 %	± 5.7 %	16.8	11.1, 26.2	17.3	13.8, 22.0	-3.3 %
Upper Yentna Glacier	94.6 %	± 3.8 %	4.6	1.1, 136.3	6.0	2.8, 18.6	-24.2 %
Cabin Peak	98.8 %	± 0.9 %	11.7	9.2, 15.1	10.1	6.1, 17.6	15.5 %
Fang Mountain	100.0 %	-	-	-	-	-	-
Flume Creek	94.3 %	± 1.2 %	21.3	13.5, 35.6	21.3	13.5, 35.6	0.0 %
Mount Lee	100.0 %	-	3.5	2.0, 6.4	3.5	2.0, 6.4	0.0 %
Upper Eldridge Glacier	100.0 %	-	-	-	-	-	-
Backside Lake	99.7 %	± 0.3 %	-	-	-	-	-
Blind Creek	99.7 %	± 0.3 %	-	-	33.4	23.7, 49.4	-
Hauke Creek	82.0 %	± 4.6 %	36.6	31.7, 42.4	33.5	28.7, 39.3	9.2 %
Hot Slough	99.2 %	± 0.8 %	19.2	14.2, 26.7	21.9	18.2, 26.7	-12.2 %
Lower Dall Glacier	100.0 %	-	-	-	-	-	-

Community and Regional Level Descriptions

Rank-abundance plots of avian relative abundance (unit: *annotations per second of audio*) are shown for each site (Figures 11, 13, 15, 17, 19, 21, 23, 25). These plots provide an indication of the evenness of diversity at each site (Magurran 1988, pg 13.) With the rank-abundance plot we pair a map for the same site (Figures 12, 14, 16, 18, 20, 22, 24, 26). The map shows the similarity between a focal site's species list and species lists of other geographic locations across the park. Warmer colors on the map indicate a greater probability that species are shared. Note that neither evenness nor abundance are reflected in the comparison.

From measures of spatial similarity we distinguish groups of sites that appear to represent at least three distinct biogeographic regions of avifauna: **(1)** low-elevation sites in the Minchumina Basin and Kuskokwim, **(2)** mid-elevation subalpine sites of the eastern Alaska Range within the park, and **(3)** mid-elevation sites on the south and western portions of the Alaska Range within the park. We also highlight one site, Sushana Ridge 2012, that appears to be unlike any other site sampled as part of the inventory (Figures 25, 26).

Table 3. Examples of sites related at the community level.

Ecoregion	Example Inventory Locations	Shared Species
Minchumina Basin / Kuskokwim	McKinley Bar Trail, Flume Creek, Hot Slough	SWTH, AMRO, DEJU, RCKI, LEYE, MYWA
Subalpine Mountains East	Cabin Peak, Igloo Canyon, Hogan Creek	WCSP, OCWA, FOSP, WIWA, WIPT, GRAJ
Subalpine Mountains South/West	Mount Lee, Herron Glacier, Lower Dall Glacier	GCSP, WTPT, HETH

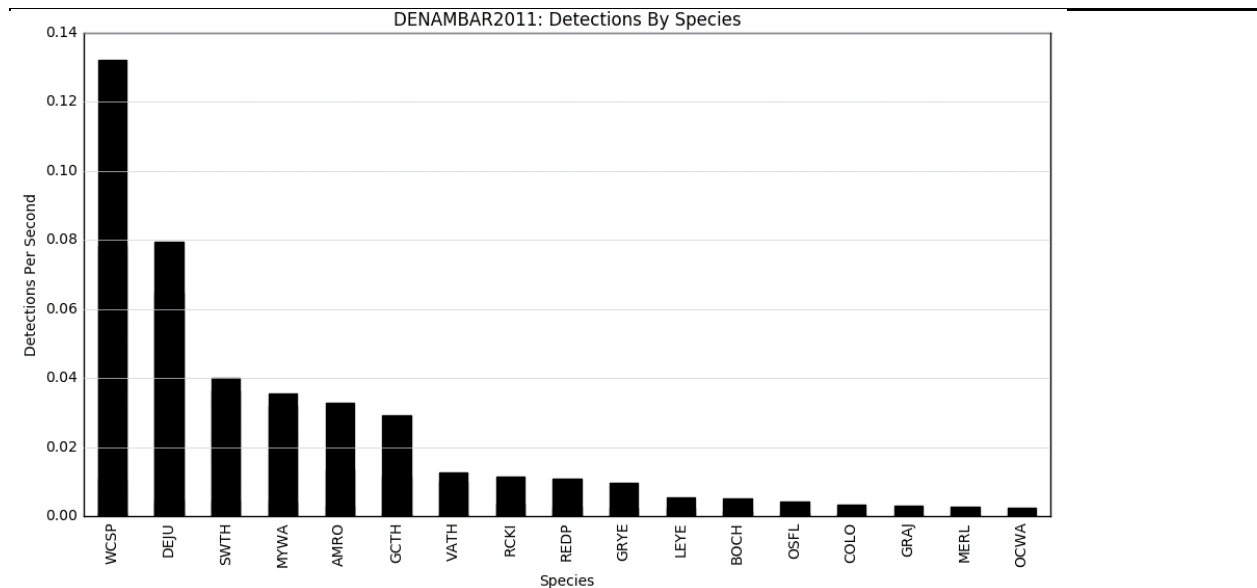


Figure 11. Rank-abundance plot for avian species detected at McKinley Bar Trail (MBAR) 2011. Relative abundance is reported as detections per second of audio analyzed.

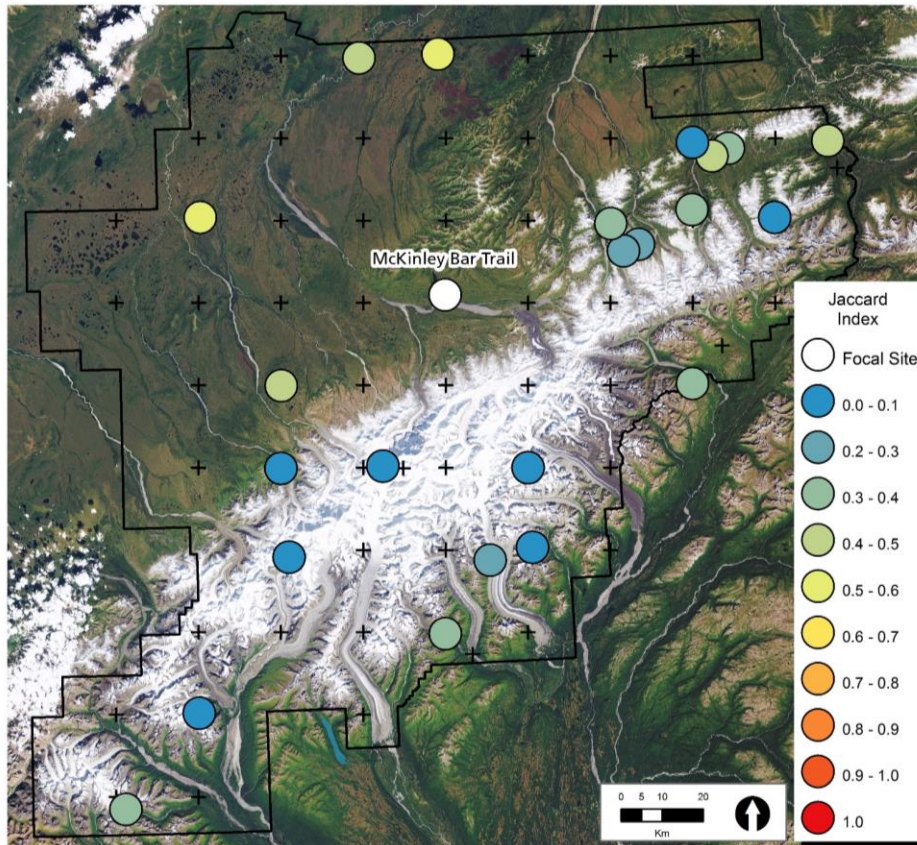


Figure 12. Map of Jaccard similarity for the McKinley Bar Trail 2011 species list. Higher values indicate a greater probability of sharing species in common.

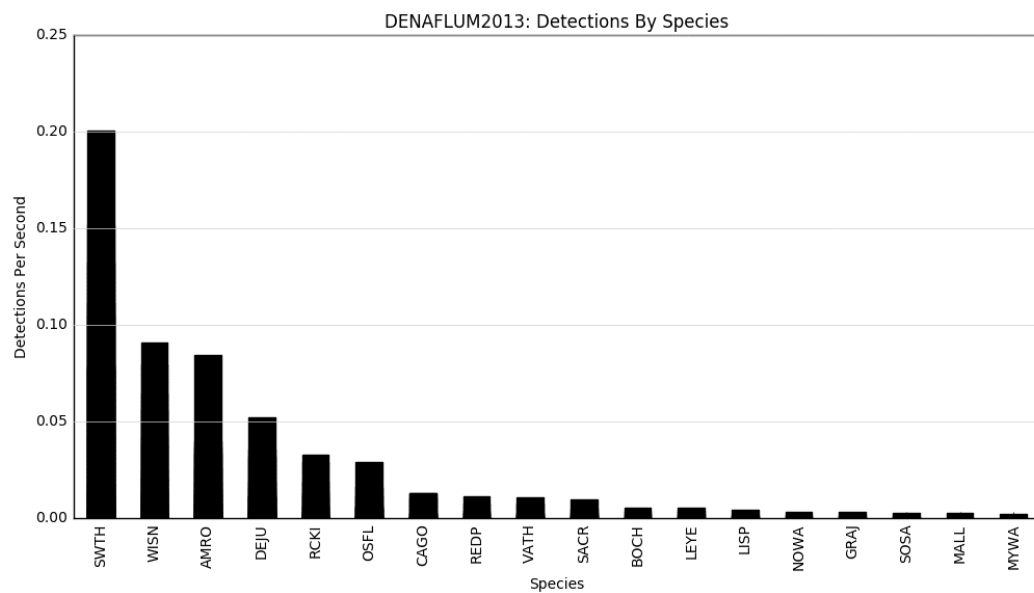


Figure 13. Rank-abundance plot for avian species detected at Flume Creek (FLUM) 2013. Relative abundance is reported as detections per second of audio analyzed.

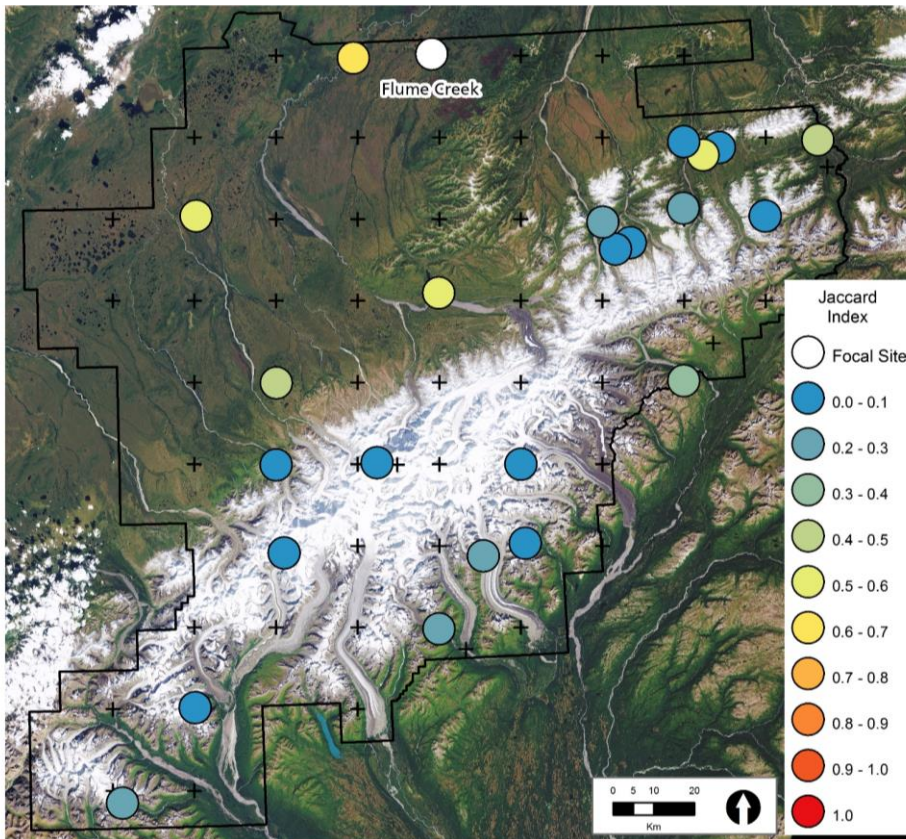


Figure 14. Map of Jaccard similarity for the Flume Creek 2013 species list. Higher values indicate a greater probability of sharing species in common.

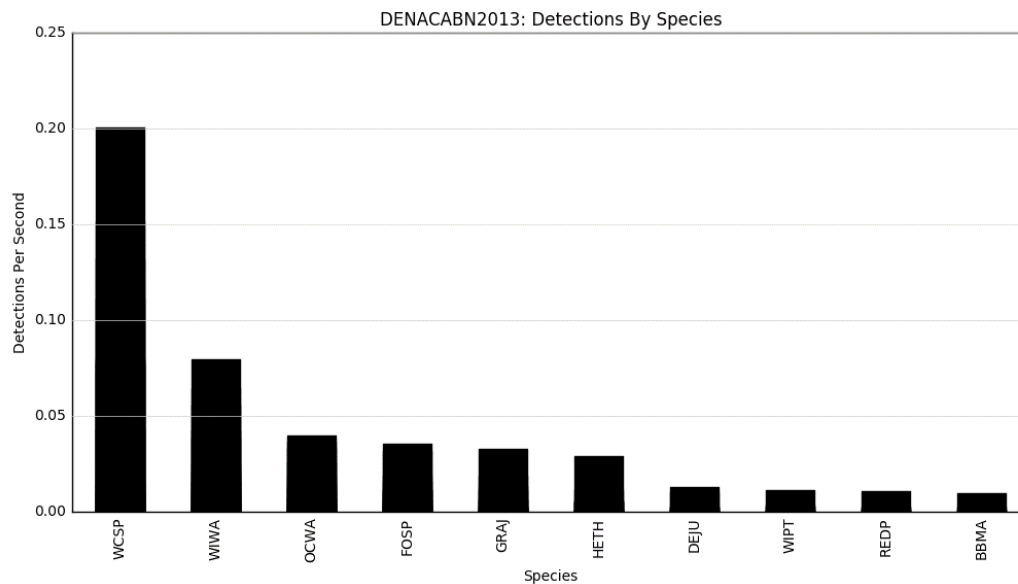


Figure 15. Rank-abundance plot for avian species detected at Cabin Peak (CABN) 2013. Relative abundance is reported as detections per second of audio analyzed.

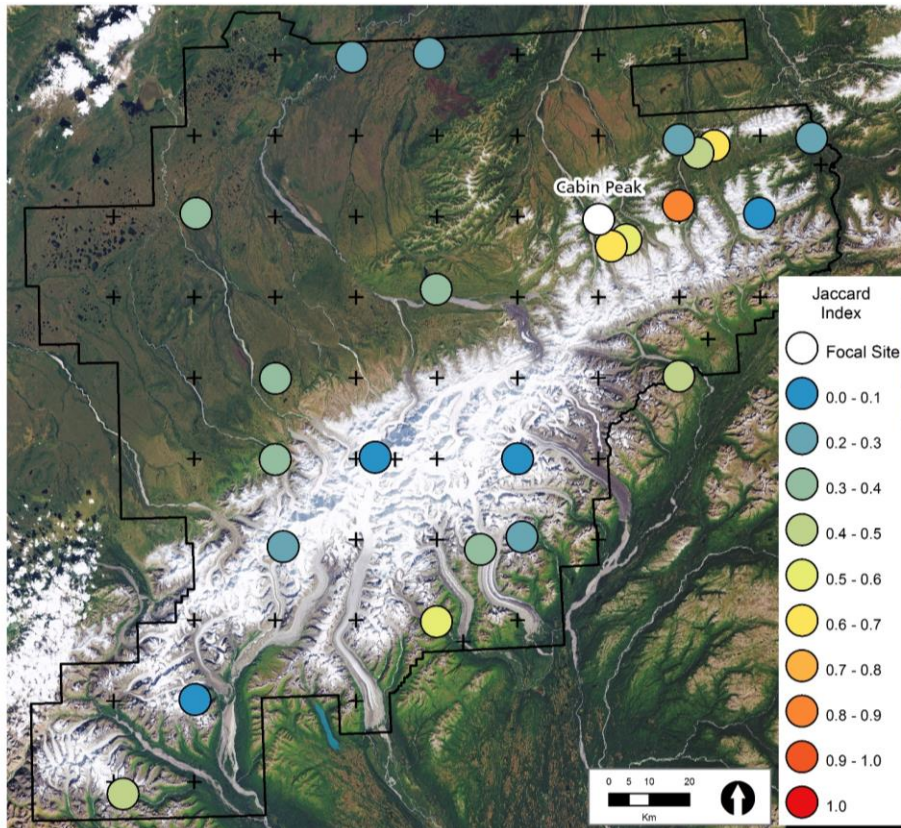


Figure 16. Map of Jaccard similarity for the Cabin Peak 2013 species list. Higher values indicate a greater probability of sharing species in common.

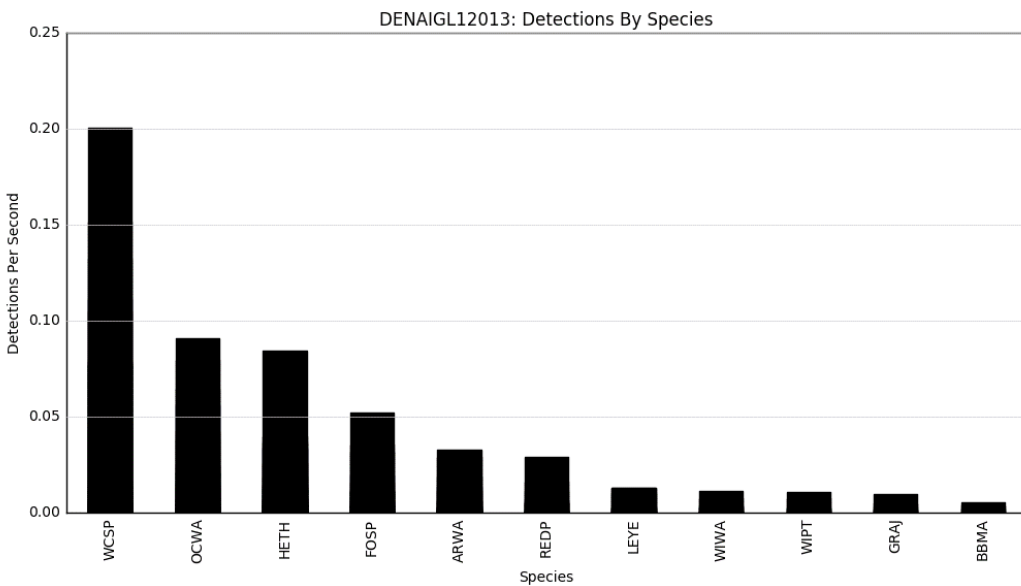


Figure 17. Rank-abundance plot for avian species detected at Igloo Canyon 1 (IGL1) 2013. Relative abundance is reported as detections per second of audio analyzed.

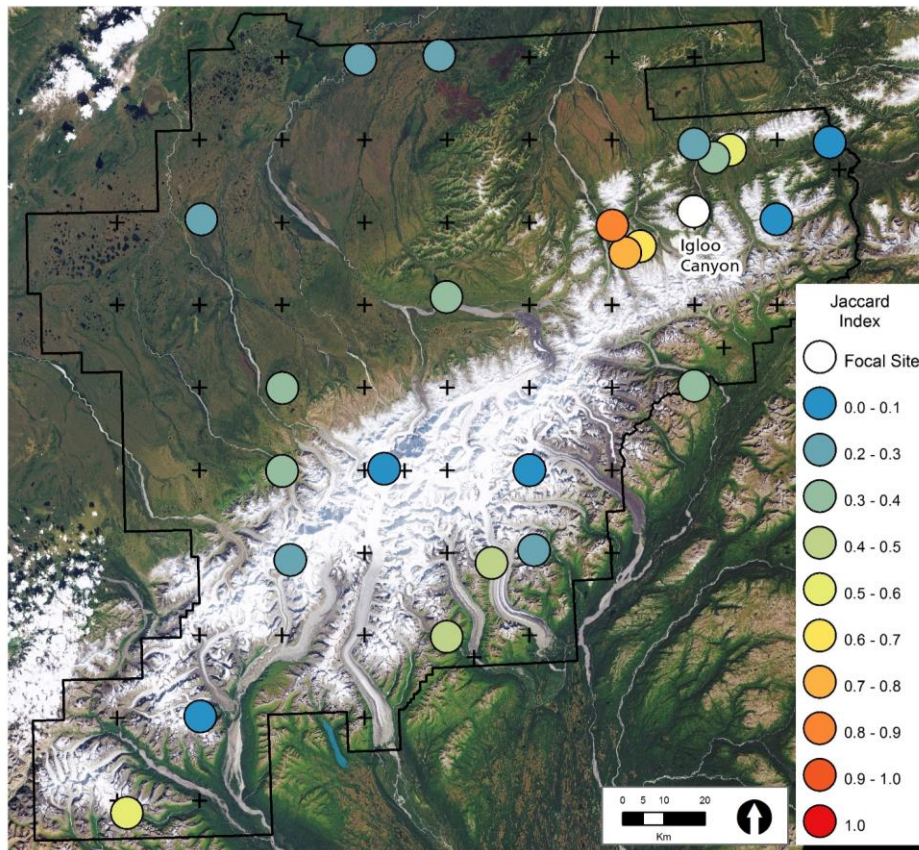


Figure 18. Map of Jaccard similarity for the Igloo Canyon 1 2013 species list. Higher values indicate a greater probability of sharing species in common.

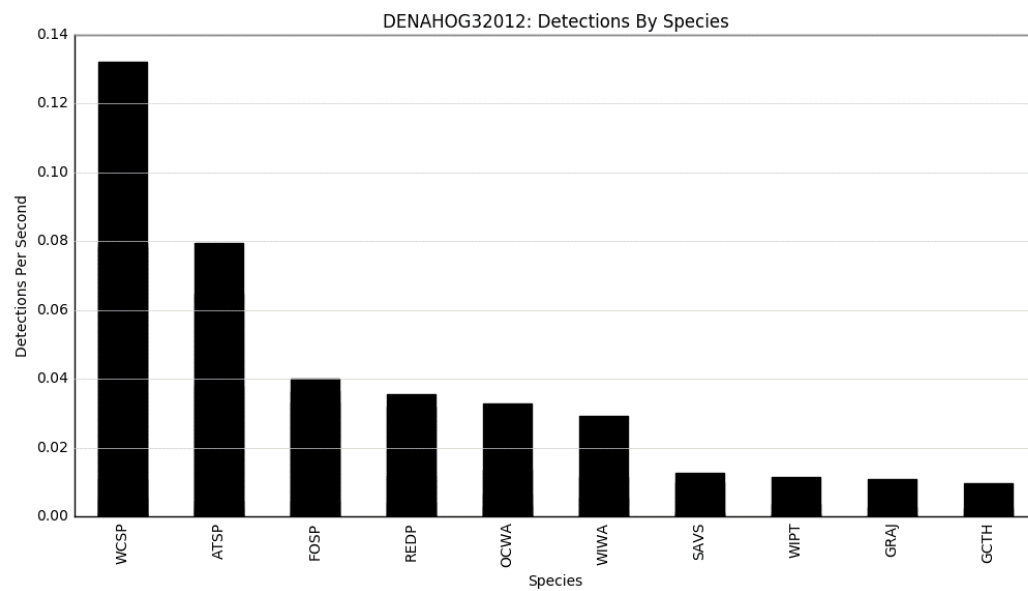


Figure 19. Rank-abundance plot for avian species detected at Hogan Creek 3 (HOG3) 2012. Relative abundance is reported as detections per second of audio analyzed.

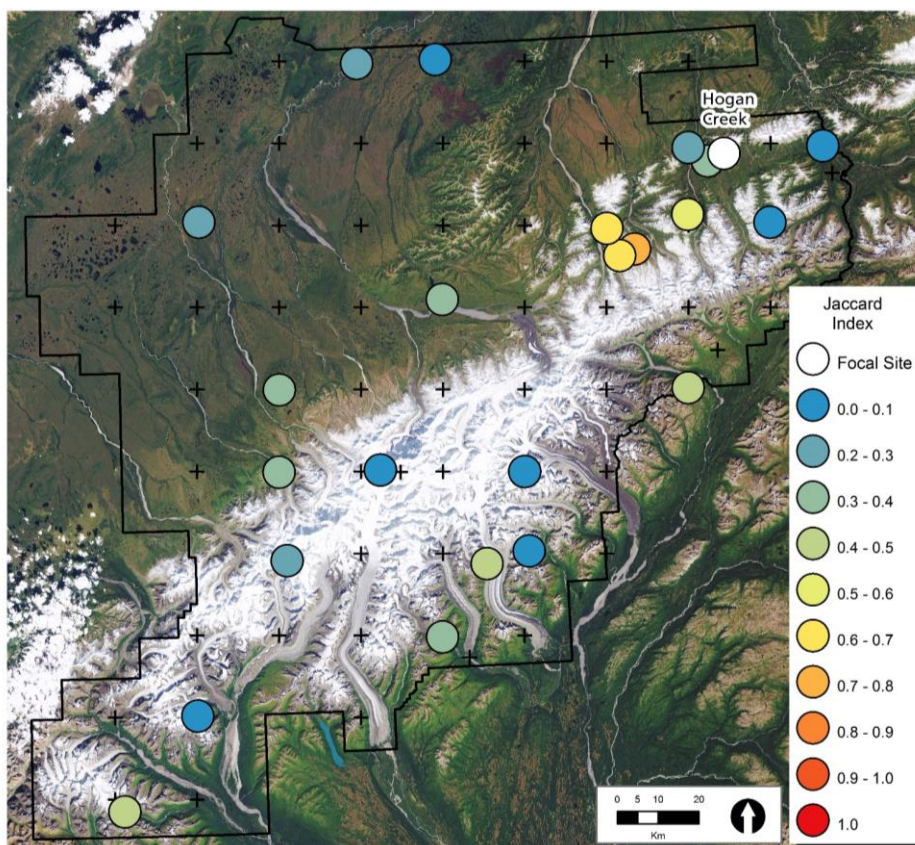


Figure 20. Map of Jaccard similarity for the Hogan Creek 3 2012 species list. Higher values indicate a greater probability of sharing species in common.

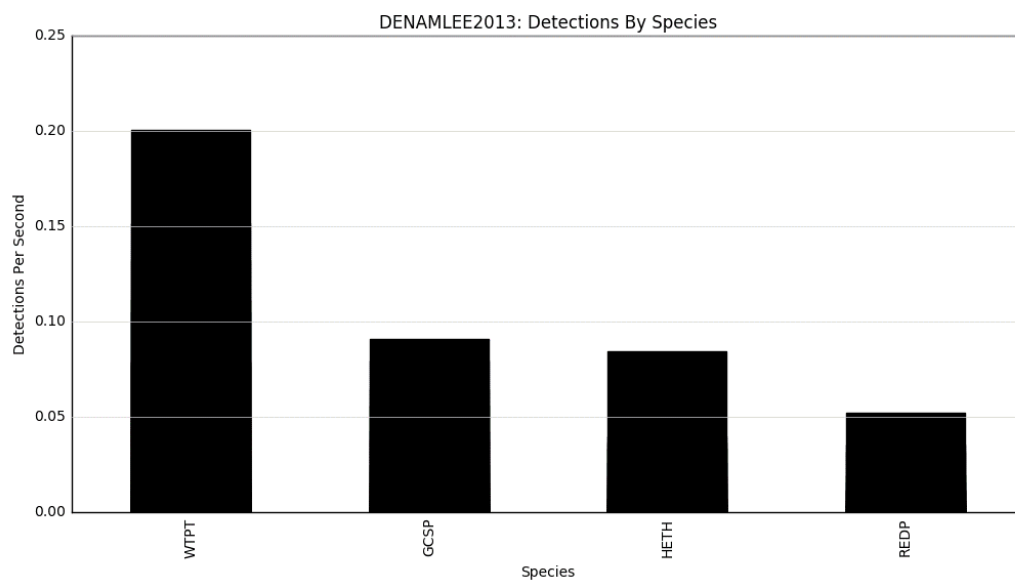


Figure 21. Rank-abundance plot for avian species detected at Mount Lee (MLEE) 2013. Relative abundance is reported as detections per second of audio analyzed.

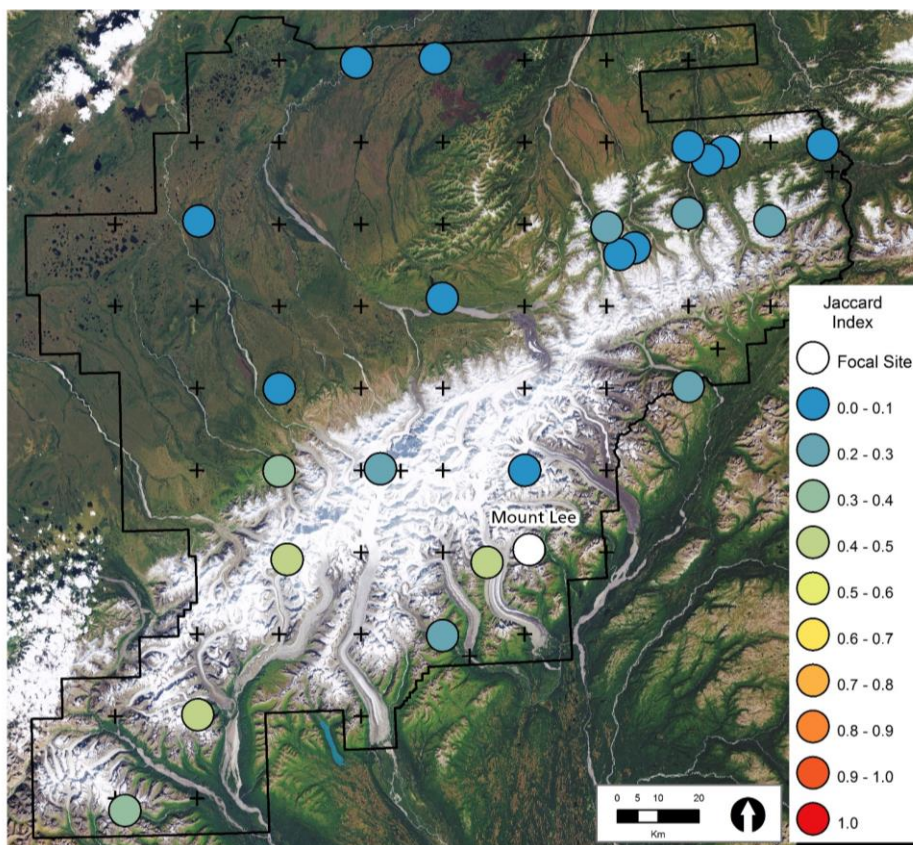


Figure 22. Map of Jaccard similarity for the Mount Lee 2013 species list. Higher values indicate a greater probability of sharing species in common.

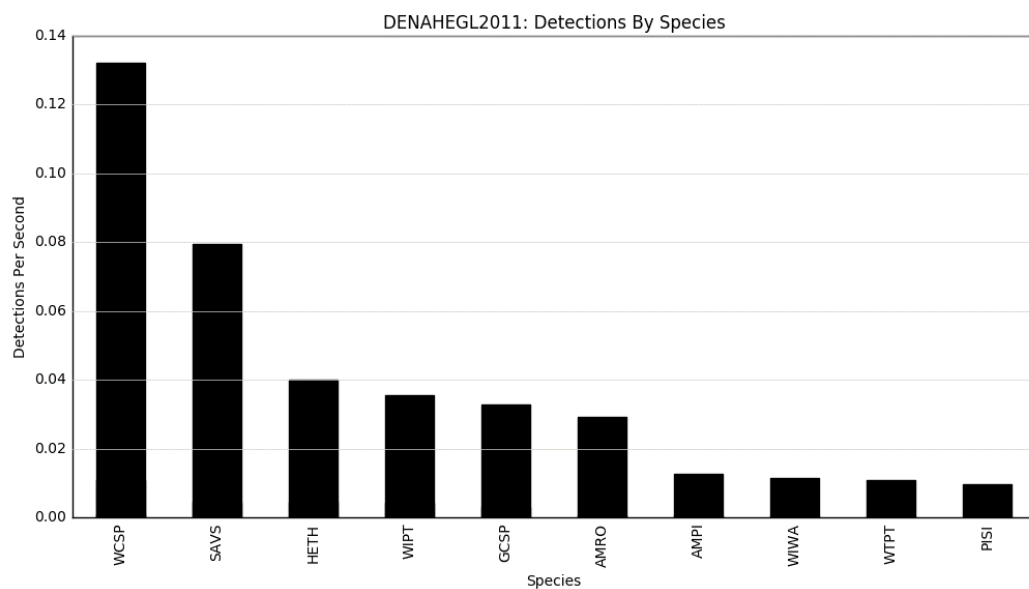


Figure 23. Rank-abundance plot for avian species detected at Herron Glacier (HEGL) 2011. Relative abundance is reported as detections per second of audio analyzed.

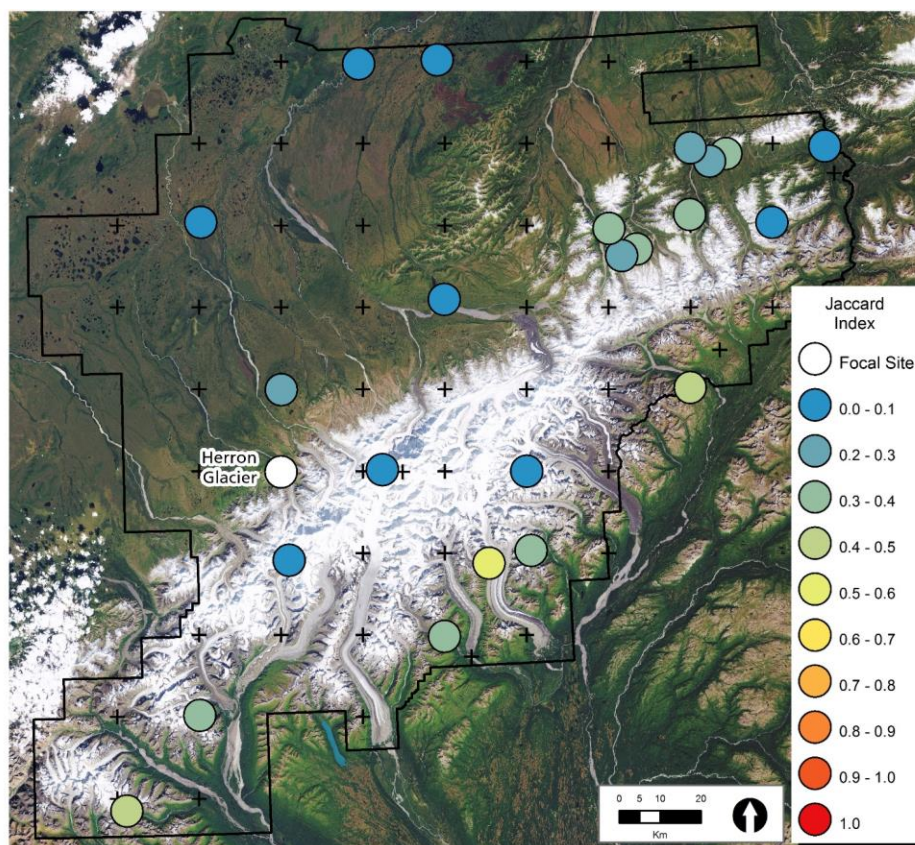


Figure 24. Map of Jaccard similarity for the Herron Glacier 2011 species list. Higher values indicate a greater probability of sharing species in common.

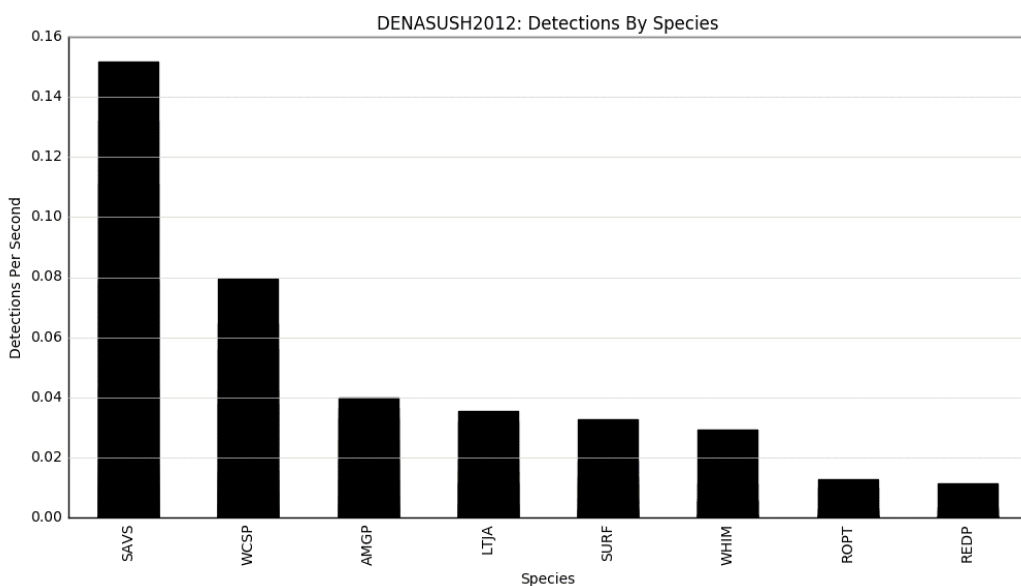


Figure 25. Rank-abundance plot for avian species detected at Sushana Ridge (SUSH) 2012. Relative abundance is reported as detections per second of audio analyzed.

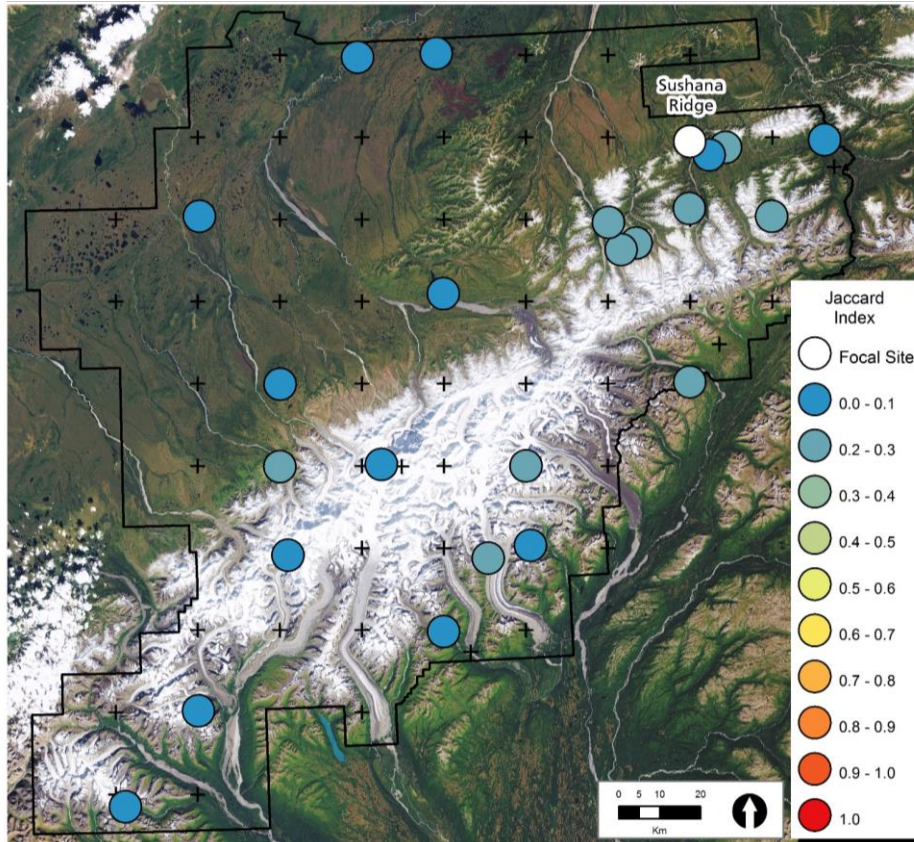


Figure 26. Map of Jaccard similarity for the Sushana Ridge 2011 species list. Higher values indicate a greater probability of sharing species in common. Notably few sites are similar.

Discussion

Comparison to roadside Breeding Bird Surveys

To open the discussion of error, we begin with a superficial comparison of the current methods to Denali's traditional roadside Breeding Bird Surveys (BBS). There is considerable overlap between species detected using either method. As with BBS, most acoustic records from Denali contain a species from each of two families, the *Emberizidae* (Sparrows) and *Fringillidae* (Finches). White-crowned Sparrow (*Zonotrichia leucophrys*) was the most-detected species on the roadside point counts, and second most-detected in acoustic records. Redpoll sp. (*Fringillidae*) was most-detected at acoustic sites.

While BBS methods result in detections of a larger number of overall species (90+ accumulated in a typical year), there are species detected at acoustic sites that have not yet been detected along BBS routes. Common Loon (*Gavia immer*), Sandhill Crane (*Grus canadensis*), and Greater Yellowlegs

(*Tringa melanoleuca*) were all species detected at acoustic sites that have not yet been detected along BBS routes. The acoustic inventory records represent many difficult-to-access places with geographies considerably different than what is experienced along the Denali Park Road (e.g., sites like Kahiltna Glacier, Backside Lake). We assume – and continue to assume even after this work – that acoustic sites spread over a greater diversity of habitat types should always result in species richness greater than or equal to the spatially-constrained roadside BBS routes.

Conversely, some species regularly detected via BBS *were absent from acoustic records*. This is at odds with expectation, and so we dichotomously explore two potential sources of error:

- differences in physical characteristics of the environment at acoustic sites (ambient sound level, elevation, etc.; discussed below) affecting the presence and/or detection of birds
- observers' abilities to mitigate perception effects while cueing onto and subsequently annotating avian sounds to species (i.e., human error).

Validation of Species Annotations

At a majority of sites ($n = 18$), we estimate the proportion of detections with annotation error to be less than or equal to 5% (Table 1.) The greatest total error rate at a site was $26 \pm 5\%$ of detections with mistaken annotation (Polychrome Mountain 4). Where do such large errors arise from?

The theoretical lower limit on classification into multiple categories (i.e., *classification error* – one part of the total error) is the Bayes Error Rate (Hastie et al 2009). For skilled human observers we expect this to be close to zero, which is exactly what we found in practice. Classification error overall was negligible: $0.3 \pm 0.2\%$.

Instead, we found that total annotation error was driven by faint vocalizations of common species. Sometimes the analyst annotated a faint sound but the validator did not, and vice versa. These types of errors are implicit to detection processes in the presence of noise, thus are site-dependent, and can never be completely eliminated (Wiley 2015, pg. 140). However, for every site with annotation errors, we found that the changes proposed by the validator *always resulted in a neutral or net-positive change in annotations*. In other words, observers almost always have the opportunity to identify more vocalizations. This suggests that like our automated detector, analysts also have a lower threshold for false negatives than false positives. Given the choice between dismissing faint signals from consideration and misclassifying them, they choose the former (or categorize as an unknown.) Whether this decision is operating at a sensory or cognitive level is unknown. From an analytical perspective, this means that faint calls from rare species present a bias in our inventory.

Physical Factors Affecting Species Richness

In this study we observed at least two factors, elevation and natural ambience, which appear to be predictive of avian species richness. Like several previous researchers (Terborgh 1977, Rahbek 1997) we found elevation to be inversely correlated to richness. Considering that upward shifts in the elevational distribution of shrub-tundra species in Denali over the past 19 years (Mizel et al. 2016), further exploration of the relationship of habitat productivity to richness (such as in Wright 1983,

Rosenzweig and Abramsky 1993) at park-wide scales seems a beneficial area of research in understanding species movements in Denali.

However: for any such work caution should be exercised when interpreting raw richness estimates. For all auditory sampling methods (especially BBS point counts) there exists a potential for bias in the prediction of richness due to acoustical masking. Controlling for elevational effects by considering only sites below 750 meters (on Figure 10, above; reddish points), a strong inverse correlation between sound pressure level and richness emerges ($r = -0.8$). Acoustically this makes some sense – the difference in L_{90} between the quietest site below 750 meters (Hauke Creek) and the loudest (North Triple Lakes Trail) is 22.6 decibels. This suggests a theoretical reduction in sampling area of 99.5%, and we observed a reduction in richness of 91.5%.

Consider that sound level in Alaska is primarily driven by flowing water (Betchkal 2019, pp. 65 - 68). Add to this the uncertain changes in precipitation (Hinzman et al. 2002), permafrost thaw (Ostercamp and Romanovsky 1999), and glacier loss (Fountain 2012) predicted for Alaska. Together these statements imply that an understanding of acoustic masking is fundamental to a successful avian biodiversity monitoring program: if watercourses change through time, so does the detection of birds in their vicinity. To control for this, it may be worthwhile for the park to design an experiment where richness is estimated in similar habitat but with varying ambience (i.e., transects away from a river, etc.) It may also be possible to deduce these relationships through a predictive modeling approach.

Future Approaches

The primary appeals of using digital audio recorders to support avian ecology projects are: (1) their ability to provide continuous sampling effort in inaccessible areas, (2) potential for simultaneous observation at many points on the landscape, and (3) the possibility to permanently archive rich observational data. All of these things combine to make acoustic inventory methods an excellent choice for a wide variety of projects. Their value has already been seen with NPS phenology monitoring (Buxton et al. 2016) and this project represents a compliment *in space*: audio can feasibly be used to study birds on a landscape scale. Considering the unique nature of sites like Sushana Ridge (Figures 25, 26) the use of acoustic records to selectively improve ecological knowledge of remote alpine habitats appears to be equally valid.

To temper that enthusiasm, the miniscule 100 hours of audio we analyzed in this study required one skilled, full-time winter seasonal to annotate. Though we believe the results of this work to have been fruitful, additional efficiency in the identification of species would make this type of work much more feasible for other NPS units.

Recent advances in artificial intelligence technology have drastically improved the ability of machines to perceive audio signals at human levels. From the annotation results this project produced, we also worked with a contractor to develop a {Python} library that can be used to detect the vocalizations of ten different avian species (AMRO, BLPW, FOSP, WCSP, CORA, DEJU, GRYE, HETH, SWTH, and WTPT). The open source library – [Avian Acoustic Discovery: Alaska](#) – uses machine listening models pre-trained on Denali audio to help automatically identify avian

sound, allowing the speed of analysis to be increased several fold for species-specific research. This tool was available for use within the DOI as well as by other Federal, State, academic, and non-governmental organizations in Alaska.

Additionally, considerable progress has been made in recent years supporting Acoustic Complexity Index (ACI; Pieretti et al. 2011) as a promising metric for avian community ecology research. Because ACI can be calculated directly from audio, it has the potential to provide a rapid assessment of the diversity of vocalizations at a location. In Alaska, its application has been already been demonstrated as part of a phenology study in Glacier Bay (Buxton et al. 2016). The richness data presented in this report represent another opportunity to assess ACI as an index of avian biodiversity in Alaska. Furthermore, because each avian record is paired with precise acoustic data, they also represent an opportunity to test for potential bias in ACI due to varied natural ambient levels.

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Appendix A – Species Detection Table For All Sites

Table APP 1 summarizes presence/absence of species at each avian inventory site. The table is presented in conventional taxonomic order.

Table APP 1. Species annotated at each avian inventory site (1 = annotated at least once, - = not annotated). The soundscape sites are Kahiltna Pass = K, Lower Kantishna River = LK, Herron Glacier = HG, McKinley Bar Trail = MB, North Triple Lakes Trail = NT, Upper Kahiltna Glacier = UK, Hogan Creek = HO, Igloo Canyon = IC, Kichatna Mountains = KM, Polychrome Mountain 2 = P2, Polychrome Mountain 4 = P4, Sanctuary River 3 = SR3, Sushana Ridge = SR, Toe of the Kanikula Glacier = TK, Upper Yentna Glacier = UY, Cabin Peak = CP, Fang Mountain = FM, Flume Creek = FC, Mount Lee = ML, Upper Eldridge Glacier = UE, Backside Lake = BL, Blind Creek = B, Hauke Creek = HC, Hot Slough = HS, and Lower Dall Glacier = LD.

English Name	K	LK	HG	MB	NT	UK	HO	IC	KM	P2	P4	SR3	SR	TK	UY	CP	FM	FC	ML	UE	BL	HC	HS	LD	B
Trumpeter Swan	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-	-
Mallard	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-	-	-	-	-	-
Long-tailed Duck	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-	-
Common Goldeneye	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Ruffed Grouse	-	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Willow Ptarmigan	-	-	1	-	-	-	1	1	1	1	1	1	-	1	-	1	-	-	-	-	1	-	-	-	1
Rock Ptarmigan	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-	-	-	-	-	-	1	-	-	-	1
White-tailed Ptarmigan	-	-	1	-	-	-	-	-	1	-	-	-	-	-	1	-	1	-	1	-	1	-	-	-	-
Common Loon	-	-	-	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Bald Eagle	-	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Northern Goshawk	-	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Golden Eagle	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-	-	-	-	-	-	-	-	-	-
Merlin	-	-	-	1	-	-	-	-	-	-	-	-	-	1	-	-	-	-	-	-	-	-	1	-	-
Sandhill Crane	-	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-	-	-	-	-	-
American Golden-Plover	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-	-	-	-	-	-	-	-	-	-	-

English Name	K	LK	HG	MB	NT	UK	HO	IC	KM	P2	P4	SR3	SR	TK	UY	CP	FM	FC	ML	UE	BL	HC	HS	LD	B
Solitary Sandpiper	-	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-	-	-	-	-	-
Greater Yellowlegs	-	-	-	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Lesser Yellowlegs	-	1	-	1	-	-	-	1	-	-	-	-	-	-	-	-	-	1	-	-	1	1	1	-	-
Whimbrel	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-	-	-	-	-	1	-	-	-	-	-
Surfbird	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-	-	1	-	-	-	-	-	-	-	-
Wilson's Snipe	-	1	-	-	-	-	-	-	-	-	-	1	-	-	-	-	-	1	-	-	1	1	1	-	1
Mew Gull	-	-	-	-	-	-	-	-	-	-	-	1	-	-	-	-	-	-	-	-	-	-	-	-	-
Long-tailed Jaeger	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-	-	-	-	-	-	-	-	-	-	-
American Three-toed Woodpecker	-	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Northern Flicker	-	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-	-	-	-	-	-
Olive-sided Flycatcher	-	1	-	1	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-	-	-	1	-	-
Alder Flycatcher	-	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-	-
Gray Jay	-	1	-	1	1	-	1	1	1	-	-	1	-	-	-	1	-	1	-	-	-	1	1	-	-
Black-billed Magpie	-	-	-	-	-	-	-	1	-	1	1	-	-	-	-	1	-	-	-	-	-	-	-	-	-
Common Raven	1	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-	-
Boreal Chickadee	-	1	-	1	1	-	-	-	-	-	-	1	-	-	-	-	-	1	-	-	-	1	-	-	-
Ruby-crowned Kinglet	-	-	-	1	-	-	-	-	-	-	-	1	-	1	-	-	-	1	-	-	-	1	1	-	-
Arctic Warbler	-	-	-	-	-	-	-	1	1	1	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Gray-cheeked Thrush	-	-	-	1	-	-	1	-	1	1	-	-	-	-	-	-	-	-	-	-	1	1	-	-	1
Swainson's Thrush	-	1	-	1	1	-	-	-	1	-	-	-	1	-	-	-	-	1	-	-	-	1	1	-	1
Hermit Thrush	-	-	1	-	-	-	-	1	1	-	-	-	-	1	-	1	-	-	1	-	1	-	-	1	1
American Robin	-	1	1	1	-	-	-	-	1	-	-	1	-	-	-	-	-	1	-	-	-	1	1	1	1

English Name	K	LK	HG	MB	NT	UK	HO	IC	KM	P2	P4	SR3	SR	TK	UY	CP	FM	FC	ML	UE	BL	HC	HS	LD	B
Varied Thrush	-	1	-	1	1	-	-	-	1	-	-	1	-	-	-	-	1	-	-	-	-	1	-	-	1
American Pipit	-	-	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-	-	-
Lapland Longspur	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-	-	-	-	-	-	-	-	-
Northern Waterthrush	-	1	-	-	-	-	-	-	-	-	-	-	-	1	-	-	-	1	-	-	-	1	-	-	1
Orange-crowned Warbler	-	1	-	1	-	-	1	1	-	1	1	-	-	-	-	1	-	-	-	-	1	1	-	-	-
Blackpoll Warbler	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-	-	-	-	-	-	1	-	-	-
Myrtle Warbler	-	-	-	1	1	-	-	-	-	-	-	1	-	1	-	-	-	1	-	-	-	1	1	-	-
Wilson's Warbler	-	-	1	-	-	-	1	1	1	1	1	1	-	1	-	1	-	-	-	-	1	1	1	-	1
American Tree Sparrow	-	-	-	-	-	-	1	-	-	1	1	-	-	-	-	-	-	-	-	-	-	1	-	-	1
Savannah Sparrow	-	1	1	-	-	-	1	-	-	1	-	-	1	-	-	-	-	-	-	-	1	-	-	-	1
Fox Sparrow	-	-	-	-	-	-	1	1	1	1	1	1	-	1	1	1	-	-	-	-	-	1	-	-	1
Lincoln's Sparrow	-	1	-	-	-	-	-	-	-	1	-	1	-	-	-	-	-	1	-	-	1	1	-	-	-
White-crowned Sparrow	-	1	1	1	-	-	1	1	1	1	1	1	1	1	-	1	-	-	-	-	1	1	-	-	1
Golden-crowned Sparrow	-	-	1	-	-	-	-	-	1	-	-	-	-	1	-	-	-	-	1	-	1	1	-	-	1
Dark-eyed Junco	-	1	-	1	1	-	-	-	-	-	-	1	-	1	-	1	-	1	-	-	-	1	1	-	1
Rusty Blackbird	-	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-	-
Gray-crowned Rosy-Finch	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-
Pine Grosbeak	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-	-
White-winged Crossbill	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	1	-	1
Redpoll sp.	1	1	-	1	-	-	1	1	1	1	1	-	1	1	1	1	-	1	1	-	1	1	1	-	1
Pine Siskin	-	-	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-

Appendix B – Full Analysis Procedure

This procedure utilize scripts written in two different programming languages: Processing (available from <https://processing.org/download>, and scripts with extension *.pde*) and Python 3.5 (available from <https://www.anaconda.com/download>, and scripts with extension *.ipynb*). Most scripts and presets are included as associated files within the IRMA reference where this report was originally published.

Note: at the time of publication this procedure is antiquated! It is only provided as a sketch for the conscientious scientist wishing to reproduce the results of this inventory exactly as we did in 2014. For more modern tools, please contact the author.

A1.) Audio Subsampling Procedure

Purpose:

- 1) Open Processing script *"Avian_Inventory_Analysis_Times.pde"*
 - 2) Navigate to http://aa.usno.navy.mil/data/docs/RS_OneYear.php
 - 3) Use 'Form B'. Enter the year and type of table (= 'sunrise/sunset')
 - 4) Place Name Label is the site's full name WITH NO SPACES
 - 5) Denali's time zone is 9 hours west of Greenwich (GMT -9)
 - 6) Click 'Compute Table' and double-check that the sunrise times are sensible.
 - 7) Right-click the center of the page and select 'Save Page As...'
 - 8) Replace ".htm" with ".txt" and click 'Save'. The title of the file should now be *"Sun or Moon Rise_Set Table for One Year.txt"*
 - 9) Move the file into the "data" folder of the Processing sketch by pressing 'Ctrl + K', double clicking "data", then dragging the file in from the desktop (or wherever it was saved.)
-
- 1-) Run *"Avian_Inventory_Analysis_Times.pde"*. The output file will be in the script's root directory. (Again, 'Ctrl + K' is an easy way to access this location.)
 - 11) Open the file you just created, *"SITENAME_Analysis_Times.txt"*
 - 12) Open *NPS Acoustic Monitoring Toolbox* → *Audio Sampler*
 - 13) *File* → *Choose MP3 Directory*. Navigate to site AUDIO folder, click "OK."
 - 14) Enter the following parameters: Mode = Subsample, Sample length (seconds) = 36--, Sample interval (minutes) = 6-.
 - 15) From *"SITENAME_Analysis_Times.txt"*, find the block of dates that matches the set in AMT. For those dates, look at the columns 5 & 6, "split_FROM" and "split_TO". There could be several different sets of times to start and stop splitting. You'll have to split each of these sets separately.
 - 16) Start with the first set. Click the check boxes next to the dates you'd like to split.
 - 17) Time Range From = split_FROM, Time Range To = split_TO
 - 18) *File* → *Alternate Output Directory*. Navigate to *V:\AVES\1_Data\YYYY DENASITE Site Name Here\Fifteen-minute Clips*
 - 19) Press the 'Split files' button.
 - 2-) Repeat steps 16 - 19 for all unique sets of splitting start and end times.

A.2) What to do if automatically-split audio is blank (due to a split-point between audio files)

Purpose: Create new audio clips...

- 1) Check for gaps between audio files using Processing script, "*Gap_Detector_10_23_2014.pde*"
 - 2) Double-check these predictions by opening Raven and checking for blank audio.
 - 3) If blank audio is confirmed, open that given date + hour in SPLAT software.
 - 4) Similarly, navigate to the site's raw data folder and open the AUDIO folder.
 - 5) Using SPLAT, extract two audio files - one on each side of the gap. Usually a 2-second buffer before the new file and a 1-second buffer after it starts is appropriate.
 - 6) Save these two files into *V:\AVES\1_Data\YYYY DENASITE Site Name Here\Inputs* as "DENASITE_YYYYMMDD_HH---- first part.wav" and "DENASITE_YYYYMMDD_HH---- second part".
 - 7) Open both files with CoolEdit software. (Or any other audio editing software program. Raven Pro 1.5 could also serve this purpose.)
 - 8) Copy the audio out of the second file and paste it at the end of the first file.
 - 9) Save the combined audio as a duplicate of the original by navigating into *V:\AVES\1_Data\YYYY DENASITE Site Name Here\Inputs\Fifteen-minute Clips* and clicking the file to be replaced. Then right-click the original file and choose "Rename." Add the suffix 'ORIGINAL' to the original file. Click 'Save' to save the new file.
- 1-) If you are processing multiple gaps, in CoolEdit, choose *File → Close All*.
- 11) Repeat steps 1 - 9 until all gaps have been bridged.

B.1) Loading Audio Files into Raven Pro 1.5 for Analysis

- 1) Navigate to *V:\AVES\1_Data\YYYY DENA Site Name Here\Inputs\Fifteen-minute Clips*
- 2) Holding the shift key, select a day's worth of audio files – they will all have the same datestamp in the format YYYY-MM-DD. Then click 'Open'.
- 3) Press the circular button next to 'Page sound' if it isn't already selected. Too large a page size will cause Raven to crash but 15 minutes is usually ok. After entering the value you'd like to use, click 'OK'.
- 4) Once Raven opens the audio, navigate to *View → Window Preset → DENA_Avian_WINDOW_07242014*; the preset uses a Hamming window with an FFT size of 1024 samples.

B.2) Determining the Exclusion Band for Loaded Audio Files

- 1) Briefly scan through a site's audio. If there are no sections of high wind, proceed to **B.3**
- 2) If there are sections with high winds, then try to find a faint but decipherable song or call in the windy section.
- 3) Select *View → Interactive Detectors...* then run the *DENA_Avian_08262014_exclusionBand* preset with default settings.
- 4) If the faint song or call is selected, and there are very few false detections, the SNR setting is correct. Proceed to step 8.
- 5) If the faint song or call is selected, but there are still many false detections, the SNR ratio should be turned down. Re-run the detector.

- 6) If the faint song or call does not show up on the detector, the SNR ratio must be turned up. (Unlikely to occur!) Re-run the detector.
- 7) Repeat steps 5 or 6 until the condition in step 4 is satisfied.
- 8) Record the SNR ratio you used in the new 'SNR ratio' column of '2014 Avian Inventory Analysis V.xlsx'.
- 9) Click "Run Full" from the interactive detectors dialog. You can tell it is finished when the raven in the bottom-right hand corner of the screen stops flying. Proceed to **B.4**

B.3) Running the Detector

- 1) Navigate to 'Tools' -> 'Detector' -> 'Band Limited Energy Detector'.
- 2) Double click "Spectrogram 1(Sound 1)". It will move to the required inputs panel and turn green. Click 'OK'.
- 3) At the very top of the configuration screen is a single drop-down menu entitled 'Preset'. You'll want to use the *DENA_Avian_08262014_exclusionBand* preset. Click 'OK'. The detector will run. You can tell it is finished when the raven in the bottom-right hand corner of the screen stops flying.

B.4) Creating Selection Tables for Audio Files

- 1) Right-click anywhere on the table of selections. From the list that appears, click 'Choose Measurements...'
- 2) Click *Preset* → *DENA_Avian_Measurment_List_07242014*. Then click 'OK'.
- 3) Right-click anywhere on the table of selections. 'Add Annotation Column...'
- 4) When the dialog appears, type "Species_1", then click 'OK'. Add annotation columns in the same way for "Species_2", "Species_3", and "Species_4". Up to 8 species annotation columns can be added for busy sites.
- 5) Right-click the colored tab that says 'Band Limited Energy Detector' at the top of the table. Select 'Save Table As...' (or *File* → *Save SelectionTable As*).
- 6) Navigate to V:\AVES\1_Data\YYYY DENASITE Site Name Here\Outputs\Selection Tables
- 7) The file name needs to be shortened a little. In the end it will have the following format: DENASITE_YYYY_MM_DD.txt
- 8) When saving a selection table for a site keep it in order of selections, otherwise the accumulation curves (see step **D.1**) cannot be generated correctly.

C.1) Unknown Bird Annotations

- 1) For each site analysis create Excel workbook with the following column headings: Site | Date | SNR | Total | Selections | Selection # | Song or Call Description | Notes | Sound Clipped | Final Determination
- 2) For each date analyzed at the site create a tab in the workbook named with the short site name and date (DENASITE_YYYY-MM-DD).
- 3) Save the workbook as DENASITE_UNBI at V:\AVES\1_Data\YYYY DENASITE Site Name Here\Outputs\Unknowns

- 4) While annotating bird species in Raven annotate unknown birds in the selection table as S-UNBI or C-UNBI.
- 5) When a bird is ID'd as unknown create a new row in the UNBI workbook and fill in the named columns (above). Skip this if the call or song is considered too obscured (weather, or other noise) or too faint for identification.
- 6) Particularly if there are multiple species in the selection, add "Notes" to direct attention to the call or song of interest.
- 7) Highlight records/rows which you would particularly like to be reviewed by another expert bird mind.
- 8) Save your workspace in Raven. File -> Save Workspace As DENASITE _YYYY-MM-DD to V:\AVES\1_Data\YYYY DENASITE Site Name Here\Outputs\Workspaces
- 9) If a bird song or call seems of particular interest clip the audio and spectrogram image following the steps outlined in **C.2**, below.

C.2) Preparing Audio and Spectrogram Image Clips of Unknown Species

- 1) Follow steps for Unknown Bird Annotations in **C.1**
 - 2) In Raven, select the "Create Selection Mode" button  from the tool bar.
 - 3) Select an area within the spectrogram to best isolate the unknown bird song/call. Be sure to select enough audio, capturing additional songs or calls of the unknown bird to provide context.
 - 4) Choose *File -> Save Active Selection as*
 - 5) Save to the path V:\AVES\1_Data\YYYY DENASITE Site Name Here\Outputs\Unknowns
 - 6) File Name: DENAxxxx_YYYY_MM_DD_SELxxxx
 - 7) File Type: 24-bit (*.wav)
 - 8) Adjust the view in the window to optimize zoom and adjust "Brightness" and "Contrast" to best isolate the unknown sound in the spectrogram.
 - 9) If working with thumbnails it is usually best to enlarge the context window and adjust the image there (go to *Review Thumbnails -> Table*, then drag the window down. Settings under Context Window can also be used but sometimes require reopening Raven). There is also an option to export image of single thumbnail, if using this option display the axes first.
-
- 1-) Save an image of the visible window: *File -> Export Image Of -> View "Spectrogram 1" Of Window "Sound X"*.
 - 11) Save in same file with the audio. File type: .png
 - 12) Copy pathway to "Sound Clipped" column of UNBI excel file.

C.3) Steps for Review of Unknowns

- 1) Use UNBI Site Overview.xlsx to see which sites are particularly in need of review.
- 2) Open UNBI file for site at V:\AVES\1_Data\YYYY DENASiteNameHere\Outputs\Unknowns\DENASite_UNBI
- 3) Each date analyzed at a site will have a separate tab in the workbook, open date of interest. Rows that are in need of attention are highlighted.

- 4) Locate the Selection Number column; this number will be what you use to locate the desired song.
- 5) Look for Raven workspace for site at V:\AVES\1_Data\ (YYYY DENASite Name Here)\Outputs\Workspaces\ DENASite Date.wsp
- 6) The workspace makes it so you shouldn't have to load the audio & selection table into Raven – just double click on file & they should open in Raven.
- 7) Otherwise you'll need to open Raven, go to *File* → *Open Sound Files* from V:\AVES\1_Data\ (YYYY DENASite Name Here)\Inputs\Fifteen-minute Clips and
File → *Open Selection Table* from V:\AVES\1_Data\ (YYYY DENASite Name Here)\Outputs\Selection Tables\
- 8) Select the hand with the pointy finger instead of the crosshairs (Activate Selection Mode instead of Create Selection Mode, usually on toolbar in upper left of screen).
- 9) Once Raven is loaded there are a few ways of locating a specific Selection:
 - 1) You can use the scrollbar below the sound window to navigate through selections. You won't be able to scroll through all the audio selections at once. The window size available is controlled under Paging (right click on window or *View* → *Configure Paging*). Once you reach the end of the "Page" you can use the black arrow in the upper right hand screen (below the x) to move to the next page. Or I prefer to set my Page size to 15 minutes / 9-- seconds & then select the 15 minute sound File I want from the upper left of the sound window.
 - 2) You can use the box on the right of the screen between the sound window and the selection table to enter in the number and go directly to the selection number.
 - 3) Scrolling through the table and selecting the row also works but Raven is often very slow to catch up.
- 1-) Once you've come up with a bird IDs, you can change the 4 letter code in the Species column and save the workspace. Alternatively you can also open the selection table separately and enter them directly in Excel.

C.4) Proofing detections that have been positively annotated.

- 1) Open Processing sketch "*DataValidation_12012016.pde*"
- 2) Copy and paste the selection table for the day to be validated into the data folder of the sketch.
- 3) Lines 49 and 50 of the sketch list the only variables that need to be set. The first variable, 'validation_percentage' represents the fraction of detections with birds in them that are to be selected at random and validated. By default it is set at 0.05, or 5%. Increasing this variable will decrease the uncertainty around the standard error of a proportion later in the validation process. The second variable, 'rarity_percentage' represents the threshold at which a species is considered rare on that day. By default it is set at 0.01, or the species showing up in 1% or less of the total number of detections.

- 4) Run the script. Two output files are created. The first, "UNITSITE_YYYY-MM-DD_validation_at_X%.txt" contains a guideline and data entry sheet for validation purposes. The second, "UNITSITE_YYYY-MM-DD_species_counts.txt" is a static list of all the species ever detected in Denali and a figure showing how many times a particular species was detected on that particular day.
- 5) For the day of interest, follow the procedure for loading audio as described in **C.1**
- 6) Find the selection table that was annotated during step **C.3** and reopen it in Raven.
- 7) In Raven, click on the 'Review' tab located to the right of the main window. Under 'Layout' enter Rows: 1, Columns: 3. Under 'Context Window' choose Size: 800 pixels.
- 8) Open "UNITSITE_YYYY-MM-DD_validation_at_X%.txt" that was created in step 4. Using it as a guide, check all the 'rare' species listed at the top. Within the 'Review' tab under 'Review Thumbnails', make sure the dropdown box 'Table', has the appropriate name for your selection table chosen. Under 'Annotations, Filter' select Species 1. Then click the radio box next to 'Show' and type in the four-letter code of the species you are interested in. Then click 'Apply' under 'Navigation'. If the species is not in the column, nothing will happen. Move on to Species 2 within the 'Annotations, Filter'. (Eventually it is necessary to check all annotation columns for this species.)
- 9) Listen back to the detections containing the 'rare' species. Affirm whether or not each is correct. Repeat step 8 for each such 'rare' species listed on the first row of "UNITSITE_YYYY-MM-DD_validation_at_X%.txt"
- 1-) Still referring to the same file, move down into the lower section. Find the first number which indicates a detection to be validated.
- 11) Under 'Annotations', uncheck 'Show'.
- 12) Under 'Navigation' type the detection number you'd like to navigate to, then click 'Apply'
- 13) Listen to the detection and in "UNITSITE_YYYY-MM-DD_validation_at_X%.txt" enter either: 1, -, or U into the column next to the detection number. 1 stands for the existing annotation was completely correct. - stands for some mistake was present in the original annotation. U stands for it is unknown/undeterminable whether the original annotation is correct.
- 14) Make the necessary changes to the selection table in Raven. After the first time you make a change, save the selection table as V:\AVES\1_Data\ (YYYY DENA Site Name Here)\Outputs\Selection Tables\DENASITE_YYYY-MM-DD_V-FL, where F is your first initial, and L is your last initial
- 14) If you entered -, also annotate what you did to correct the original annotation. If you removed a species, type a minus sign (-) after the species code. If you added a species, type a plus sign (+) after the species code. Use as many columns as necessary after the annotation status to document all the changes you made.
- 15) When all the detections on the list have been validated, save "UNITSITE_YYYY-MM-DD_validation_at_X%.txt" to V:\AVES\1_Data\ (YYYY DENA Site Name Here)\Outputs\Validation\
- 16) Make a final save of the Selection Table as you did in step 14.
- 17) Repeat this process for each day to be validated.

D.1) Constructing a Species Accumulation Curve from Raven Selection Tables

- 1) NOTE: This step can only be conducted meaningfully with datasets that have been proofed and contain minimal unknowns (steps C.1, C.2, C.3, and C.4 all completed.)

- 2) Open Python script "2018 08 07 Analyze validation.ipynb". Run all cells.

F.1) Calculating a Jaccard Index matrix and summary graphics for all sites across the park.

- 1) NOTE: This step can only be conducted meaningfully with datasets that have been proofed and contain minimal unknowns (i.e., steps C.1, C.2, C.3, and C.4 have all been completed.)
- 2) Open Python script "2018 08 03 all graphics generated for avian reports.ipynb" and run all cells.