Fort Bragg Landbird Monitoring Program

Report for the 2018 Field Season

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The INSTITUTE for BIRD POPULATIONS

FORT BRAGG

U.S. ARMY AIRBORNE

NORTH CAROLINA

Fort Bragg Landbird Monitoring Program

Report for the 2018 Field Season

Steven Albert, Chris Ray, and Lynn Schofield
The Institute for Bird Populations
P.O. Box 1346
Point Reyes Station, CA 94956-1346

and

Jessie Schillaci
RCW Monitoring Program Coordinator
Directorate of Public Works IMBG-PWE-E
2175 Reilly Road Stop A
Fort Bragg, NC 28310-5000

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Acknowledgments

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This report is Contribution No. 616 of The Institute for Bird Populations.

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Executive Summary

The primary goal of Fort Bragg, North Carolina is to maintain Army mission readiness and a high level of training for the soldiers operating there. To accomplish this, trainers, planners, land managers, administrators, and others, must balance many competing needs and uses that occur on the base, including the protection of natural resources and adherence to federal land use and wildlife laws such as the Endangered Species Act and the Migratory Bird Treaty Act. The Institute for Bird Populations (IBP) has been an active partner with Fort Bragg since 1995, when it assisted with the establishment and operation of several bird monitoring and banding stations under the Monitoring Avian Productivity and Survivorship (MAPS) demographic monitoring program. To supplement these data, in 2017, in cooperation with base natural resources management staff, IBP developed and carried out a series of point count surveys to detect presence and density of landbirds across the base. The goals of the program are to gain an accurate picture of the summer resident breeding species and their densities on Fort Bragg within the most prevalent habitat types, track population changes in these species over time, and provide information to base natural resource personnel that will help them manage Fort Bragg's terrestrial ecosystems.

This report summarizes results of the 2018 field season. We detected 5,163 individuals of 82 bird species, including species of management interest such as the Red-cockaded Woodpecker (*Leuconotopicus borealis*), Swainson's Warbler (*Limnothlypis swainsonii*), and Bachman's Sparrow (*Peucaea aestivalis*). Density and diversity were relatively evenly distributed across the project area, though some portions of the base were not surveyed due to access constraints. In 2018, we added four transects in grassland habitat in drop zones not surveyed in 2017. We used Bayesian hierarchical modeling to produce density estimates for 33 species, an increase from 23 species we were able to model in 2017. This increase was made possible by a rise in diversity of birds encountered as a result of the additional transects and counts conducted in 2018 and to an increase in robustness of the model with one additional year of data. With more data collected in the coming years, the number of species successfully modeled should continue to increase as we shift to modeling trends over time.

Introduction

At more than 255 square miles, Fort Bragg is one of the largest military installations in the world. In addition to training facilities and housing, the base has a variety of natural habitats, including some of the largest remnants of the endangered longleaf pine ecosystem. Competing demands on this landscape -- most importantly training and mission readiness, but also including wildlife, watershed protection, hunting, outdoor recreation, and compliance with federal laws such as the Endangered Species and Migratory Bird Treaty Act -- mean that base managers must balance a variety of activities for multiple stakeholders and objectives.

Fort Bragg has an active land management program that has won several awards for its bird conservation. The Fort Bragg Integrated Natural Resources Management Plan and the Adaptive Ecosystem Management Program Endangered Species Management Component require that migratory birds are considered in natural resource management planning and project implementation. Central to these strategies are the base's efforts to restore and maintain habitat for the federally-endangered Red-cockaded Woodpecker. Current management includes frequent prescribed fires to maintain the open, mature stands of longleaf pine in which the species thrives. Another objectives of base natural resource managers is to understand broader changes to flora and fauna so that ecosystem management can proceed in sustainable and appropriate direction.

Birds, with their rapid metabolism and high ecological position on most food webs, are excellent indicators of habitat quality and environmental change (Carignan and Villard 2002). In addition, birds' relative abundance in terrestrial ecosystems and their high detectability make them easy and cost-efficient to monitor. Since 1995, base personnel have collaborated with the Institute for Bird Populations to operate a series of avian monitoring stations under two programs. Birds were banded under the Monitoring Avian Productivity and Survivorship (MAPS) Program (Albert et al. 2017, Nott et al. 2010) during 1995-2009 and 2015-2016 to determine species-specific "vital rates" of productivity, survivorship, and recruitment. MAPS data on bird species, age, sex and other physical parameters provided detailed baseline information about landbirds that use Fort Bragg habitats. In order to supplement demographic data and include a wider suite of species in the monitoring effort, base natural resource managers and IBP initiated a standardized point-count protocol in 2017.

The objectives of the partnership between Fort Bragg and IBP are to:

- Develop an accurate record of the summer resident breeding species and their densities within the most prevalent habitat types on Fort Bragg.
- Track population changes in these species over time.
- Provide information to base natural resource personnel to promote effective management for a natural suite of species within Fort Bragg's terrestrial ecosystems.

Study Area

Natural vegetation on Fort Bragg is dominated by plant communities associated with the imperiled longleaf pine-wiregrass ecosystem (Table 1, Figures 1 and 2). Of the historical 90-million acres of old-growth longleaf pine ecosystem of the Southeastern U.S., only about 3% remains today. Fort Bragg contains approximately 81,000 contiguous acres -- one of the largest remaining blocks of this habitat -- and conducts extensive restoration and active management every year. Habitat management is generally focused on efforts to restore and manage populations of the federally-endangered Red-cockaded Woodpecker, which prefers old-growth pine stands largely free of understory. Other habitats on the base include bottomland forest, mixed shrubland, and scattered stands of hardwoods (Table 1).

Table 1. Habitat types on Fort Bragg (data from Fort Bragg GIS Department).

Habitat Type	Acres
Southern Yellow Pine	98,160
Bottomland Forest/Hardwood Swamp	14,031
Mixed Shrubland	6,686
High Intensity Developed	6,535
Managed Herbaceous Cover	5,659
Mixed Upland Hardwoods	5,457
Mixed Hardwoods/Conifer	5,343
Unmanaged Herbaceous Upland	5,065
Unconsolidated Sediment	2,636
Low Intensity Developed	1,229
Deciduous Shrubland	1,208
Cultivated	804
Evergreen Shrubland	706
Oak/Gum/Cypress	692
Water Bodies	636
Unmanaged Herbaceous Wetland	92
Needleleaf Deciduous	22
Total	**154,961**

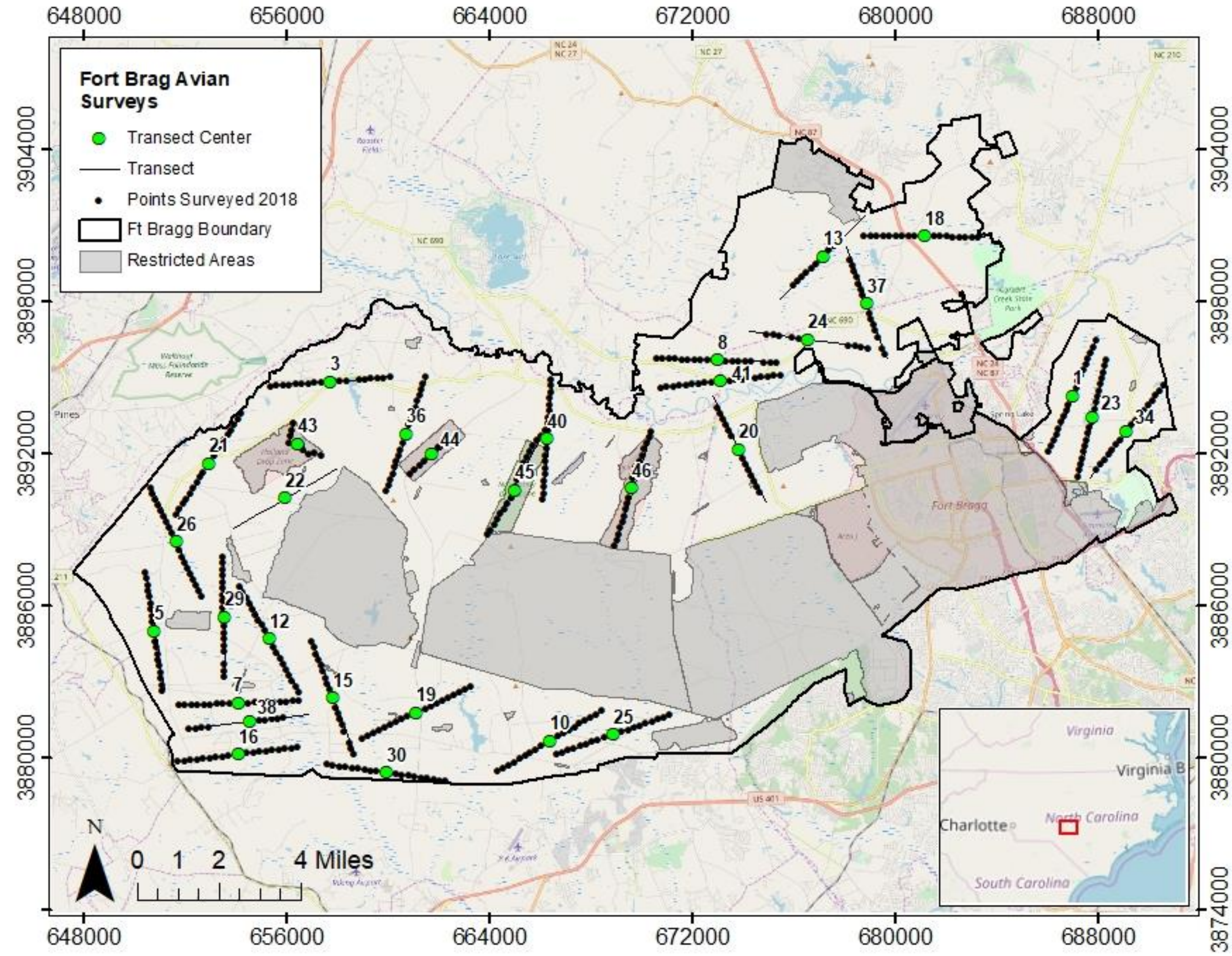

Figure 1. Study area and all transects surveyed at Fort Bragg, 2018.

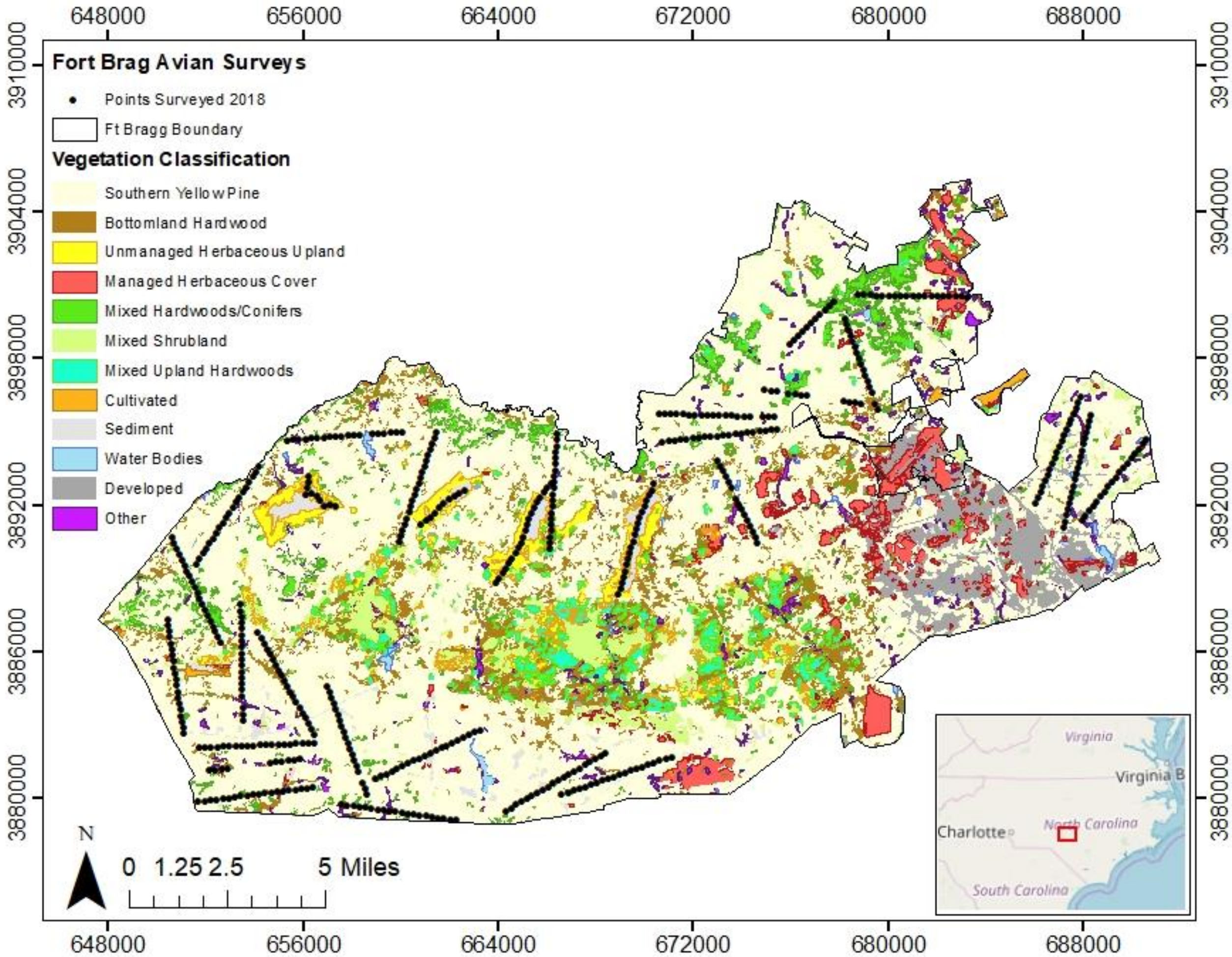

Figure 2. Habitats in the study area with surveyed points. (Habitat data from Fort Bragg GIS Department.)

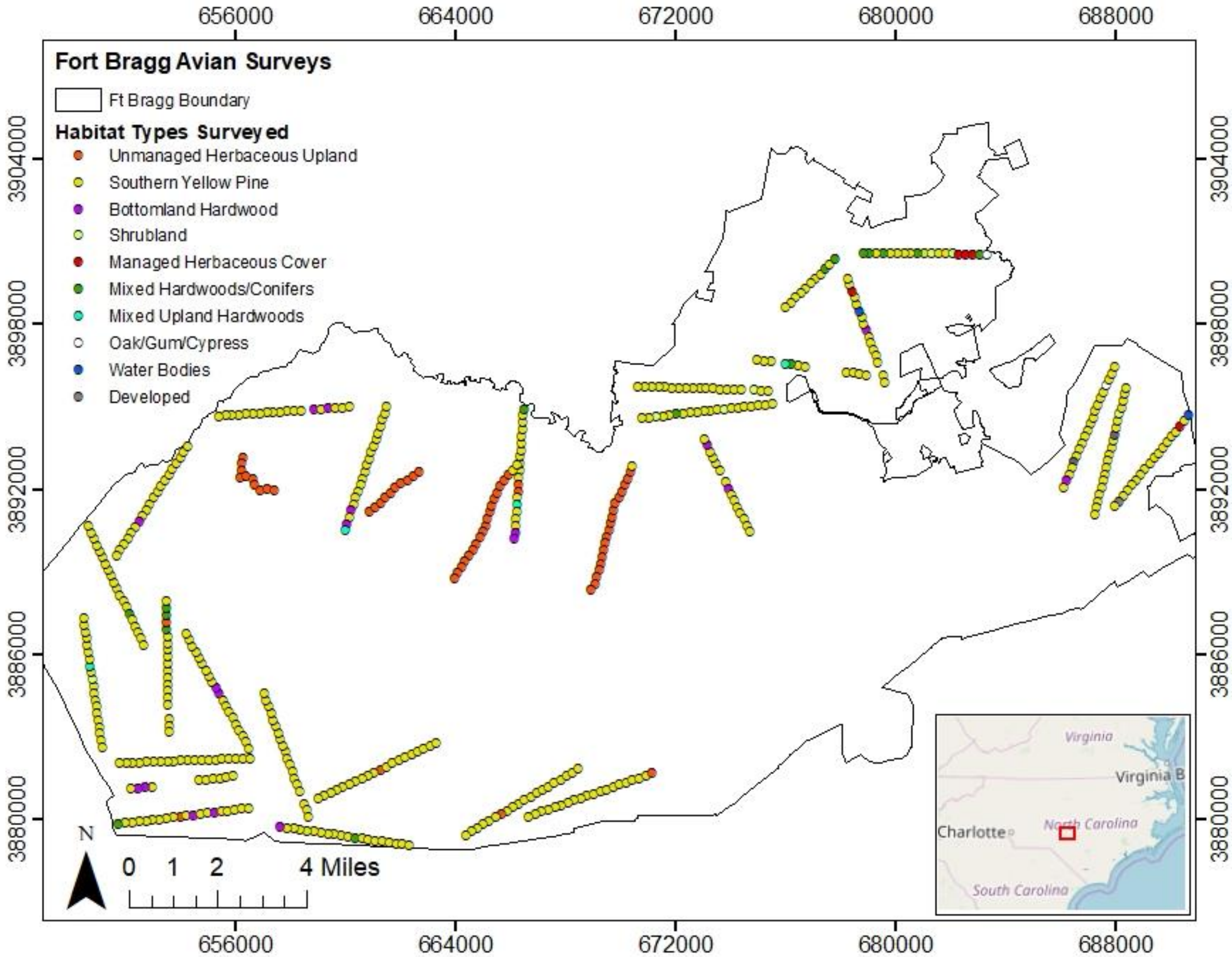

Figure 3. Detail of actual points surveyed by habitat.

Methods

Sample Design

Transects were established in GIS by selecting randomly generated points within the accessible areas of Fort Bragg, i.e. excluding areas of dense development, impact or other off limits areas, the cantonment area, the military landing zone, areas behind locked gates, or any areas determined by base staff to be off limits due to training, sensitivity, or other reasons (Figures 1, 2, and 3). From each random point, we generated a linear transect of 20 points, spaced every 250 m, extending a total of 4,750 meters along a randomly generated bearing (0-360 degrees). Transects that intersected existing transects or areas not targeted for survey were dropped or their axes oriented in a direction that did not intersect with other transects or off-limits areas. Transects were divided into two halves (A and B) and points along each half were numbered A1-A10 and B1-B10, starting at the point closest to the center.

In 2017, we did not sample drop zones, but close coordination with base logistics staff enabled successful sampling of four drop zones in 2018. The drop zone contained open grass and shrubland habitats not found in other areas of the base, and we expected several new species to be detected in these habitats.

Crew Training and Certification

We deployed two biologists with extensive birding experience and familiarity with birds of the region by sight, song, and call. From May 2 to May 5, the biologists were trained in field and data management protocols. For the first 5 days of field studies, the crew worked together so they could gain a familiarity with the base and to verify that they both understood the protocols. From the second week on, they worked independently.

Data Collection

Point count data were collected between May 5 and June 20, 2018. Crew members worked together to survey a single 20-point transect each morning, starting together at the midpoint, and proceeding in opposite directions to the ends, before meeting up again at the termination of their work. They were provided with maps, GPS units, and coordinates with all transect points. In addition, crew members were provided with an electronic copy of the field map, which they downloaded to their smartphones, and used the *Avenza Maps* application, which displayed their real-time location in relation to each transect point on the electronic field map. All of these tools enabled the crews to have high confidence that they had navigated to within a few meters of the selected points. Point counts began within 10 minutes of civil sunrise and were completed after surveying all points possible. All surveys were completed before 11:00 a.m.

At each point, observers recorded the starting time, scored the degree of noise interference (e.g., from wind or traffic), and recorded current weather conditions prior to beginning the point count. Counts lasted 7 minutes, partitioned into three time intervals (0 to 3 min, 3 to 5 min, and 5 to 7 min) to make the data more useful for occupancy modeling, which relies on detection or non-detection of individual birds within discrete intervals to estimate detection probability. Observers noted each time interval in which they detected each individual bird.

Distance estimation is an important part of modeling population density. Detection probability of an individual bird declines with distance from an observer at a rate that is generally most effectively modeled for each species. Accordingly, observers used electronic rangefinders to determine the distance to a bird, or estimated that distance to the best of their ability. Care was taken during training to “calibrate” observer distance estimation. Observers also recorded whether the distance estimates were based on an aural or visual detection, and whether the bird ever sang during the point count.

After completing their fieldwork each day, observers reviewed each other’s data forms for missing or incorrectly recorded data, discussed any interesting or surprising bird detections, and completed a Transect Visit Log summarizing the day’s efforts.

Data Management

At the end of each day, data were entered into a Microsoft Access database which was reviewed for completeness, missing or out-of-range values, and logical consistency. Errors were corrected immediately. At the end of the field season, field forms and digital records were stored at the IBP offices in Point Reyes Station, CA. GPS data were downloaded and processed, and the resulting coordinate data were uploaded to the project database.

Data Analysis

Detection probability includes effects of a species' availability for detection (how likely it is to be singing) and perceptibility (how likely it is that an observer will hear it). Recording the time intervals in which the bird was detected and the distance to the bird enabled analyses that accounted for birds present but undetected during each survey (a correction factor that has the potential to greatly impact density estimates; Royle et al. 2004, Alldredge et al. 2007) using a hierarchical Bayesian model suggested by Amundson et al. (2014). Population density was estimated for species detected frequently enough to support an estimate of detection probability. Observer effects on detection were included, if necessary, to improve model fit. A similar application of hierarchical Bayesian models to point-transect surveys with unequal count intervals was detailed in Ray et al. (2017*a* and 2017*b*). A detailed discussion of the methods used in data analysis and model development is presented in Appendix B.

Results

Habitats Surveyed and Species Detected

We surveyed 536 points arrayed along 30 transects. A majority (77.6%) of surveyed points fell in Southern Yellow Pine habitat (Figure 3). We detected 5,163 individual birds of 82 species, an average of 7.67 detections per point. The most frequently detected species were Mourning Dove (*Zenaida macroura*), Pine Warbler (*Setophaga pinus*), Carolina Wren (*Thryothorus ludovicianus*), Eastern Towhee (*Pipilo erythrophthalmus*), Eastern Wood Pewee (*Contopus virens*), Common Yellowthroat (*Geothlypis trichas*), Blue Jay (*Cyanocitta cristata*), and Great Crested Flycatcher (*Myiarchus crinitus*) (Table 3, Figure 4). Species detected fewer than 10 times were combined and listed as "RARE" in Figure 4.

Table 2. Total detections and number of points at which each species was detected (for scientific names of species, see Appendix A).

Species	Total # of Detections	# of Points with Detections	Species	Total # of Detections	# of Points with Detections
Canada Goose	2	2	Tufted Titmouse	138	125
Wood Duck	1	1	White-br. Nuthatch	135	119
Northern Bobwhite	149	105	Brown-headed Nuthatch	96	75
Wild Turkey	6	6	Carolina Wren	252	201
Mourning Dove	311	255	Blue-gray Gnatcatcher	102	89
Yellow-billed Cuckoo	56	50	Eastern Bluebird	40	38
Common Nighthawk	92	64	Wood Thrush	10	8
Chimney Swift	5	3	American Robin	55	45
Ruby-thr. Hummingbird	3	3	Gray Catbird	16	13
Killdeer	1	1	Brown Thrasher	45	41
Great Blue Heron	1	1	Northern Mockingbird	47	44
Green Heron	1	1	Cedar Waxwing	2	1
Turkey Vulture	1	1	American Goldfinch	2	2
Red-shouldered Hawk	2	2	Eastern Towhee	245	178
Red-tailed Hawk	2	2	Bachman's Sparrow	144	113
Barred Owl	3	3	Chipping Sparrow	157	108
Belted Kingfisher	3	3	Field Sparrow	7	7
Red-headed Woodpecker	98	82	Grasshopper Sparrow	6	6
Red-bellied Woodpecker	45	41	Song Sparrow	2	1
Downy Woodpecker	29	29	Yellow-breasted Chat	14	11
Hairy Woodpecker	7	7	Eastern Meadowlark	126	55
Red-cock. Woodpecker	112	53	Orchard Oriole	5	5
Northern Flicker	51	50	Red-winged Blackbird	26	16
Pileated Woodpecker	62	58	Brown-headed Cowbird	54	46
American Kestrel	1	1	Common Grackle	3	3
Eastern Wood-Pewee	223	192	Ovenbird	29	27
Acadian Flycatcher	15	13	Louisiana Waterthrush	2	1
Great Crested Flycatcher	189	159	Blue-winged Warbler	1	1
Eastern Kingbird	35	26	Black-and-white Warbler	12	12
Loggerhead Shrike	1	1	Swainson's Warbler	6	6
White-eyed Vireo	75	68	Or.-crowned Warbler	2	2
Yellow-throated Vireo	18	17	Common Yellowthroat	215	176
Blue-headed Vireo	18	18	Hooded Warbler	23	22
Red-eyed Vireo	22	21	American Redstart	8	6
Blue Jay	192	150	Pine Warbler	302	202
American Crow	170	135	Yellow-throated Warbler	2	1
Fish Crow	59	55	Prairie Warbler	51	47
Horned Lark	35	22	Summer Tanager	177	140
Purple Martin	4	3	Northern Cardinal	151	124
Barn Swallow	2	2	Blue Grosbeak	116	104
Carolina Chickadee	108	81	Indigo Bunting	127	104

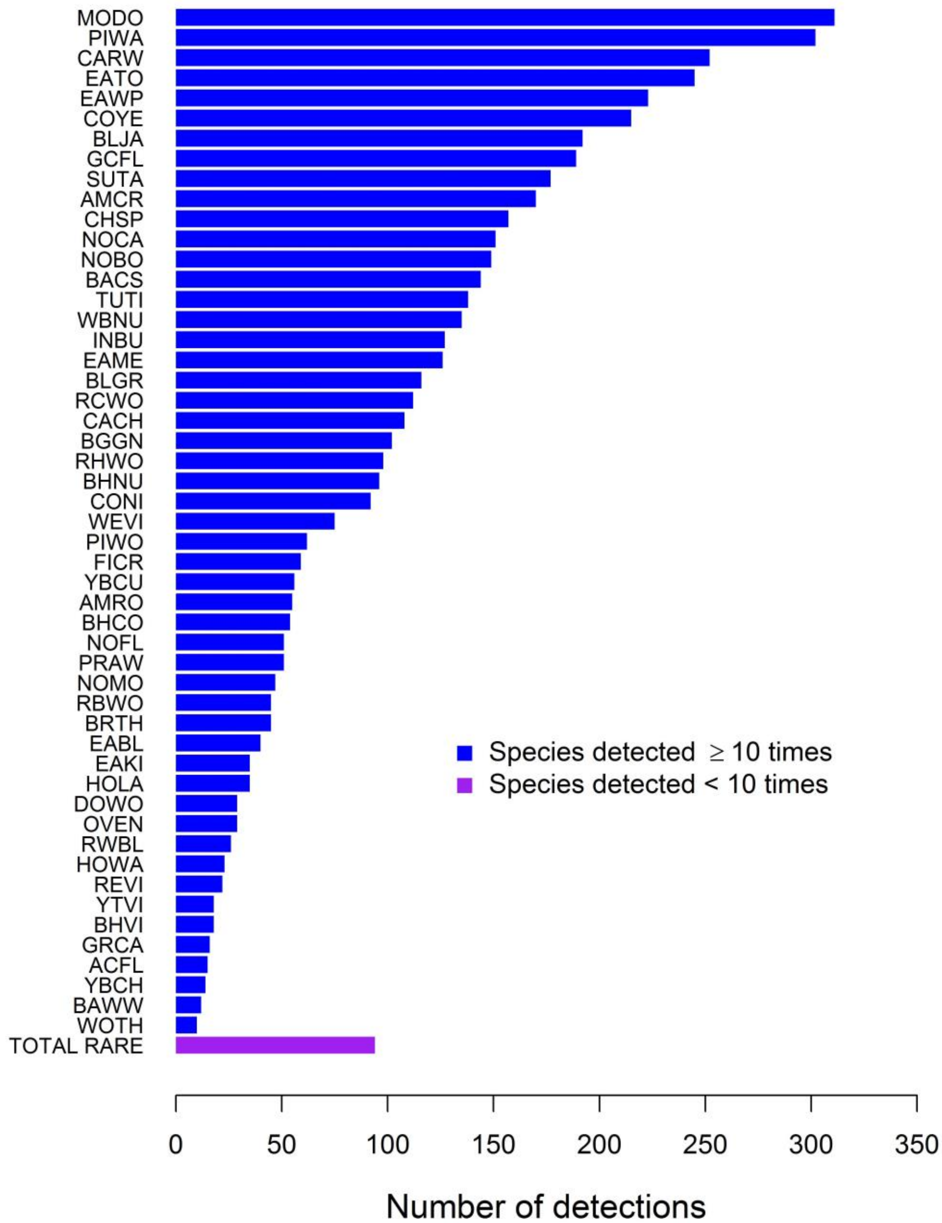

Figure 4. Number of detections, by species, during point counts at Fort Bragg point counts in 2018. "RARE" pools all species that were detected fewer than 10 times. (For species abbreviations, see Appendix A).

Apparent avian abundance was relatively evenly distributed throughout the base (Figure 5). Due to the limited abundance of habitats other than Southern Yellow Pine, we estimated effects of Southern Yellow Pine on species density, rather than analyzing density or species richness data by habitat.

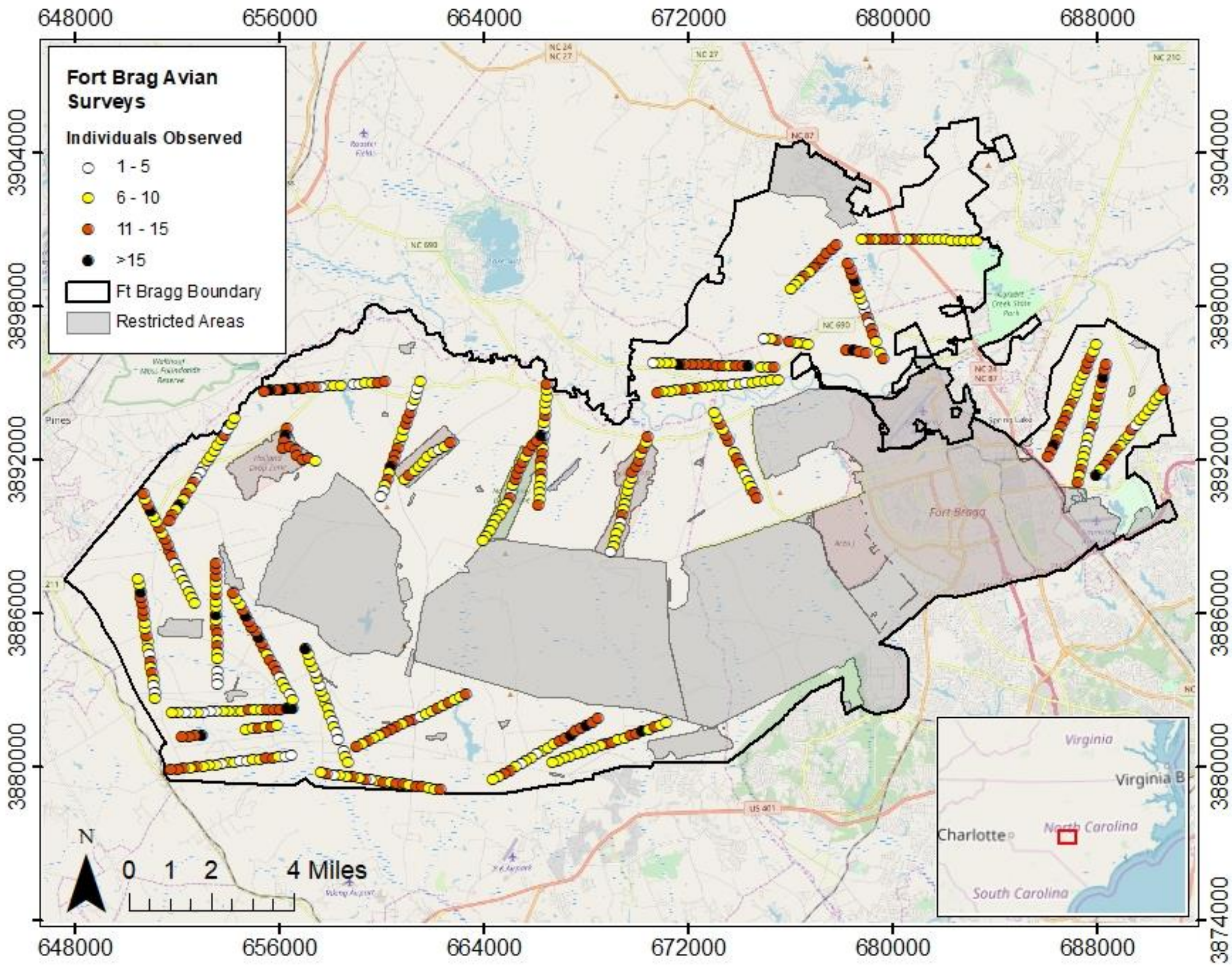

Figure 5. Point counts completed at Fort Bragg in 2018, with number of birds detected. Points with few detections (light circles) and many detections (dark circles) were relatively evenly distributed across the base.

Species Density

We estimated population density of species with >40 detections, and were able to model 33 species with >45 detections (Table 3 and Figure 6). Although it was possible to fit models of population density using the 112 detections of Red-cockaded Woodpecker (Table 2), the cooperative breeding system of this species does not conform to the assumptions of our detection sub-model. Therefore, we did not quantify population density for Red-cockaded Woodpecker in this report. Because estimates of population density are sensitive to estimates of detection probability, we report metrics of fit for sub-models of species detectability (Table 3 and Figure 6). For the sub-model of availability, Bayesian P-values cluster near 0.5, suggesting good fit for all species. For the sub-model of detectability, which incorporates both availability and the distance-mediated effects of species perceptibility, Bayesian P-values range 0.06-0.90, suggesting adequate fit for all species except Carolina Chickadee and Common Nighthawk. Compared to 2017, model fit was generally improved, confirming our prediction that additional data would facilitate parameter estimation for more species (in 2017, we were able to fit the model for 23 species).

Table 3. Modeled species density (birds per hectare), for 34 commonly-detected species.

Species	Mean density (number per ha)	95% CI lower density estimate	95% CI upper density estimate
Mourning Dove	0.08	0.06	0.09
Pine Warbler	0.56	0.46	0.66
Carolina Wren	0.62	0.35	1.68
Eastern Towhee	0.38	0.30	0.49
Eastern Wood Pewee	0.30	0.25	0.39
Common Yellowthroat	0.40	0.32	0.49
Blue Jay	0.07	0.05	0.09
Great Crested Flycatcher	0.23	0.18	0.30
Summer Tanager	0.37	0.29	0.46
American Crow	0.04	0.03	0.07
Chipping Sparrow	0.26	0.18	0.46
Northern Cardinal	0.34	0.18	0.89
Northern Bobwhite	0.05	0.04	0.06
Bachman's Sparrow	0.26	0.18	0.38
Tufted Titmouse	0.28	0.19	0.45
White-breasted Nuthatch	0.19	0.11	0.35
Indigo Bunting	0.71	0.45	1.21
Eastern Meadowlark	0.14	0.11	0.18
Blue Grosbeak	0.17	0.11	0.29
Red-cockaded Woodpecker	0.43	0.29	0.62
Carolina Chickadee	0.32	0.18	0.61
Blue-gray Gnatcatcher	1.05	0.43	3.19
Red-headed Woodpecker	0.23	0.12	0.52
Brown-headed Nuthatch	1.62	0.67	4.12
Common Nighthawk	0.10	0.06	0.15
White-eyed Vireo	0.17	0.10	0.33
Pileated Woodpecker	0.03	0.02	0.04
Fish Crow	0.03	0.01	0.09
Yellow-billed Cuckoo	0.25	0.07	0.64
American Robin	0.10	0.05	0.22
Brown-headed Cowbird	1.08	0.17	3.61
Northern Flicker	0.20	0.04	0.49
Prairie Warbler	0.06	0.03	0.13
Northern Mockingbird	0.10	0.04	0.29

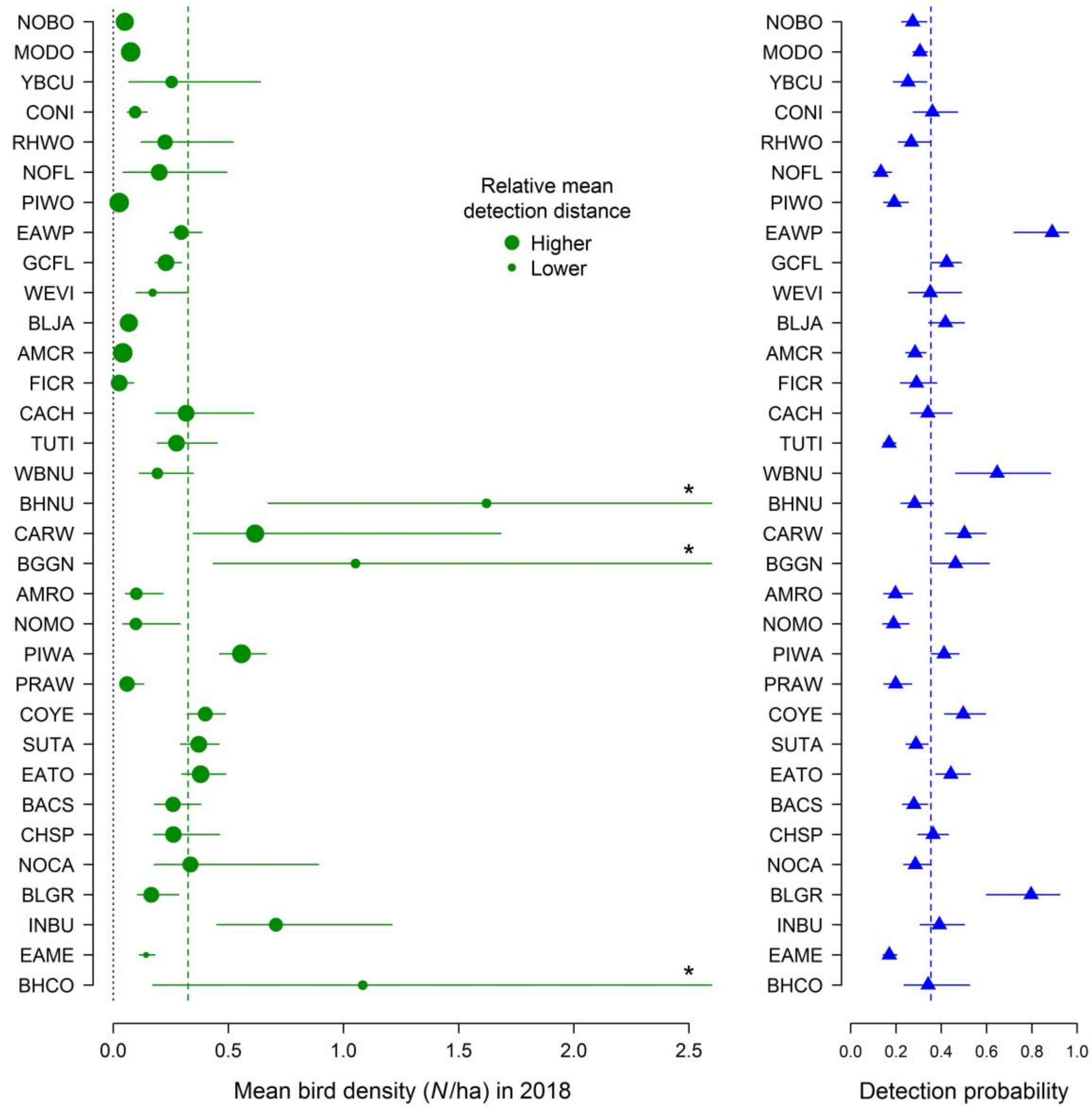

Figure 6. Estimates of population density (left-hand panel) and detection probability (right-hand panel) for 33 species commonly detected in 2018 point counts, including means across species (dashed vertical lines) and 95% credible intervals for each species (horizontal lines; asterisks indicate that CRIs for 3 species extend beyond the left-hand panel). Species are listed in descending order of raw count to illustrate influences of maximum detection distance (relative dot sizes) and detection probability on the relationship between raw count and estimated density. Detection probability includes effects of a bird's availability for detection (will it sing?) and perceptibility (will we hear it?). Species abbreviations are listed in Appendix A.

These density estimates are similar to values reported by other studies of several of these species conducted within the southeastern United States. For example, our estimate of 0.56 Pine

Warblers/ha was similar to estimates from several other studies (Johnston and Odom 1956) and our density estimates were similar to other regional estimates for Blue Gray Gnatcatcher (Strom 1983, Christman 1983), Brown-headed Nuthatch (Hamel 1992) and Northern Cardinal (Halkin and Linville 1999). As additional years of data are gathered, the precision of our density estimates will increase, and we will be able to model trends in density over time.

Analysis of Trends

While two years of data is not sufficient to support a model of trends in density, 2018 estimates can be compared qualitatively with those of 2017. Although most of the bird species that were commonly detected in 2017 were also common in 2018, a few differences stood out (Table 5). Eleven species were detected in 2018 that were not detected in 2017: Canada Goose (*Branta canadensis*), Great Blue Heron (*Ardea herodias*), Green Heron (*Butorides virescens*), American Kestrel (*Falco sparverius*), Loggerhead Shrike (*Lanius ludovicianus*), Horned Lark (*Eremophila alpestris*), Grasshopper Sparrow (*Ammodramus savannarum*), Song Sparrow (*Melospiza melodia*), Orchard Oriole (*Icterus spurius*), Louisiana Waterthrush (*Parkesia motacilla*), and Black-and-White Warbler (*Mniotilta varia*). Eastern Screech Owl (*Megascops asio*) was the only species detected in 2017 that was not detected in 2018. Most of the new 2018 detections were species recorded only once; however, 35 Horned Larks and six Grasshopper Sparrows were detected in the Drop Zone grasslands, which were surveyed for the first time in 2018. Of species that were detected in both 2017 and 2018, Blue Jay, Great-crested Flycatcher, Mourning Dove, Pine Warbler, and Prairie Warbler (*Setophaga discolor*) were all estimated at lower density in 2018 than 2017 (i.e., the 95% credible intervals did not overlap between years). No species that were detected in both years were estimated at higher density in 2018 than 2017.

Table 4. Total detections by species, 2017 and 2018. Blue shading indicated species detected in 2017 but not 2018; green are species detected in 2018 but not 2017.

Species	2017	2018	Species	2017	2018
Canada Goose	0	2	Carolina Chickadee	113	108
Wood Duck	2	1	Tufted Titmouse	172	138
Mallard	1	1	White-breasted Nuthatch	68	135
Northern Bobwhite	33	149	Brown-headed Nuthatch	164	96
Wild Turkey	3	6	Carolina Wren	163	252
Mourning Dove	244	311	Blue-gray Gnatcatcher	193	102
Yellow-billed Cuckoo	67	56	Eastern Bluebird	100	40
Common Nighthawk	44	92	Wood Thrush	3	10
Chimney Swift	10	5	American Robin	53	55
Ruby-throated Hummingbird	6	3	Gray Catbird	9	16
Killdeer	1	1	Brown Thrasher	31	45
Great Blue Heron	0	1	Northern Mockingbird	51	47
Green Heron	0	1	Cedar Waxwing	25	2
Turkey Vulture	1	1	American Goldfinch	9	2
Red-shouldered Hawk	1	2	Eastern Towhee	208	245
Red-tailed Hawk	4	2	Bachman's Sparrow	187	144
Eastern Screech Owl	1	0	Chipping Sparrow	97	157
Barred Owl	2	3	Field Sparrow	2	7
Belted Kingfisher	1	3	Grasshopper Sparrow	0	6
Red-headed Woodpecker	118	98	Song Sparrow	0	2
Red-bellied Woodpecker	51	45	Yellow-breasted Chat	18	14
Downy Woodpecker	31	29	Eastern Meadowlark	3	126
Hairy Woodpecker	8	7	Orchard Oriole	0	5
Red-cockaded Woodpecker	98	112	Red-winged Blackbird	10	26
Northern Flicker	71	51	Brown-headed Cowbird	90	54
Pileated Woodpecker	74	62	Common Grackle	17	3
American Kestrel	0	1	Ovenbird	36	29
Eastern Wood-Pewee	143	223	Louisiana Waterthrush	0	2
Acadian Flycatcher	7	15	Blue-winged Warbler	1	1
Great Crested Flycatcher	276	189	Black-and-white Warbler	0	12
Eastern Kingbird	143	35	Swainson's Warbler	10	6
Loggerhead Shrike	0	1	Orange-crowned Warbler	1	2
White-eyed Vireo	32	75	Common Yellowthroat	184	215
Yellow-throated Vireo	9	18	Hooded Warbler	9	23
Blue-headed Vireo	5	18	American Redstart	3	8
Red-eyed Vireo	24	22	Pine Warbler	579	302
Blue Jay	203	192	Yellow-throated Warbler	11	2
American Crow	182	170	Prairie Warbler	186	51
Fish Crow	23	59	Summer Tanager	181	177
Horned Lark	0	35	Northern Cardinal	160	151
Purple Martin	5	4	Blue Grosbeak	86	116
Barn Swallow	4	2	Indigo Bunting	135	127

Species of Management Interest

In addition to Red-cockaded Woodpecker, base natural resource managers expressed an interest in Swainson's Warbler, a species which may be declining regionally (North American Breeding Bird Survey 2018) and Bachman's Sparrow. Over the course of the field season, Swainson's

Warbler was detected six times, all when the bird sang. Three of the six detections in Southern Yellow Pine, one was in Evergreen Shrubland, one was in Mixed Hardwoods/Conifers, and one was in Bottomland Forest/Hardwood Swamps (Figure 7). These results strongly suggest the presence of breeding Swainson's Warblers on the base in 2018.

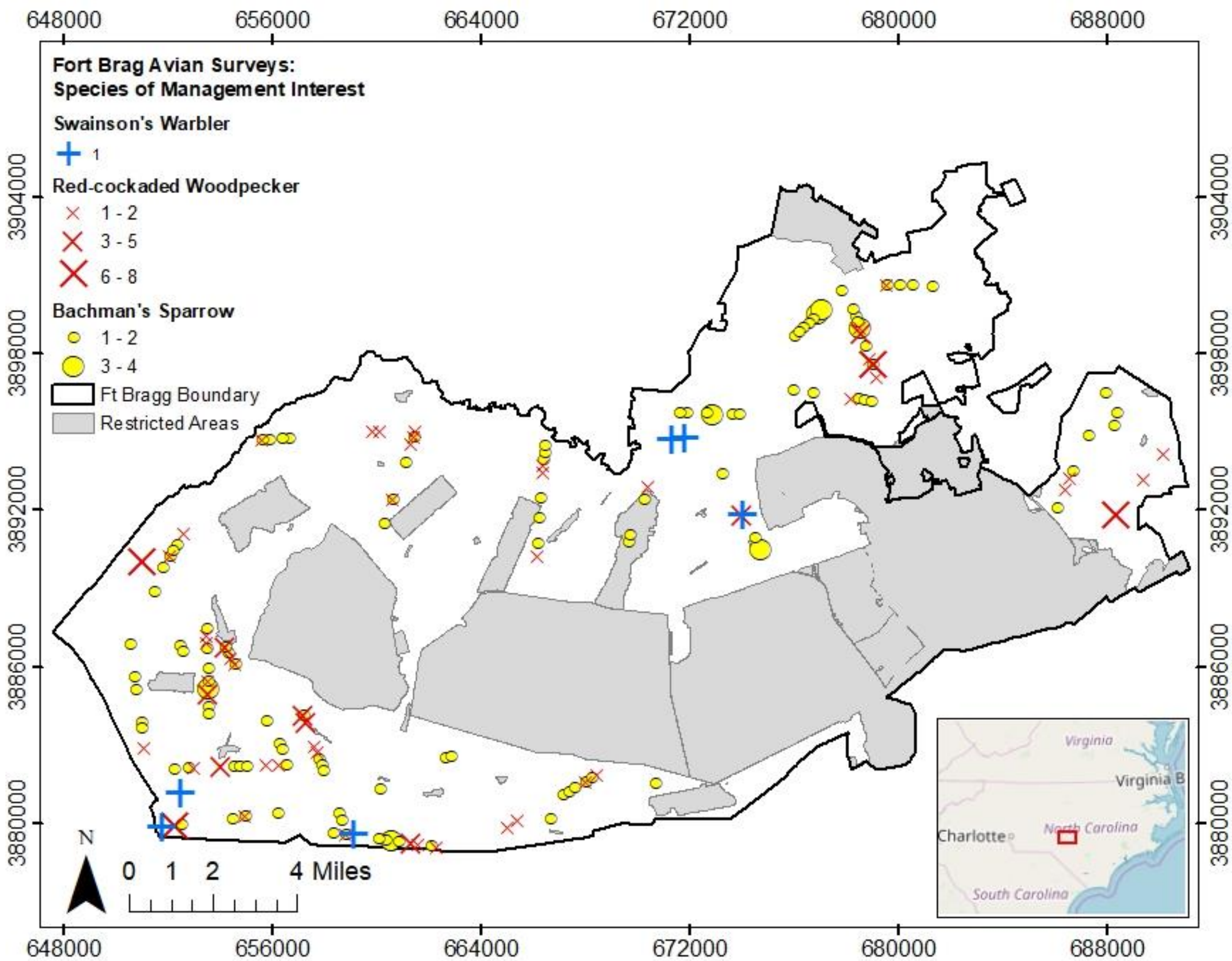

Figure 7. Swainson's Warbler, Red-cockaded Woodpecker, and Bachman's Sparrow detections during point counts in 2018.

Discussion

The sample sizes obtained from point-count surveys in 2018 allowed us to estimate population density for 33 species, including all species that were detected at least 47 times. Collecting additional years of data will allow us to estimate annual densities for species encountered even less frequently, because the amount of data (detections) for each species will rise faster than the number of parameters estimated from those data. Through this process, the number of species with sufficient data for estimating trends will increase every year.

Effects of habitat on population density

The generally positive effect of the Southern Yellow Pine (SYP) habitat type on several species that we detected was an expected result, as many of the species have a known affinity for this habitat. Other habitats are much less common and widely scattered, limiting our ability to use habitat effect as a variable. If habitat effects are a key question for some species in the future, we could increase the number of point-count stations in non-SYP habitats to address this question.

Survey point locations

The subset of points selected for survey can vary among years without compromising annual estimates of population density on the base. Using the current modeling framework, population density can be estimated for every point and year in the dataset, even for points surveyed only once. This feature allows for seamless comparison of population density estimates across years, even when surveyed points differ among years. This same feature also ensures that density estimates are robust to any number of years of missing data from each point-count station, provided appropriate covariates exist or can be estimated for each point in each year (Kéry and Royle 2016).

Summary and Next Steps

The point count protocols and analysis summarized here provided a successful approach for estimating the density of nearly three dozen landbird species at Fort Bragg, including species of management concern. Density estimates for the species analyzed were similar to regional estimates for the same species. It is notable that five of 33 species analyzed declined in density between 2017 and 2018, while no species increased in density. Increasing data size and refining distance estimation in the coming years will increase the accuracy and precision of the density estimates, and likely enable estimates of density for additional species. Combined with historical data on demographic rates from the MAPS program, we are developing a more complete picture of avian population dynamics on the base. The 2018 addition of several new sampling transects in habitats other than Southern Yellow Pine contributed to an increase in the number of bird species detected and the number of species for which we were able to estimate population density. We expect these contributions to accumulate at these and other transects with each annual count, increasing the number of populations quantified on the base.

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Appendix A. Common and Scientific Names, and 4-letter Codes of Species Detected

Common Name	Abbr.	Scientific Name	Common Name	Abbr.	Scientific Name
Wood Duck	WODO	*Aix sponsa*	Tufted Titmouse	TUTI	*Baeolophus bicolor*
Mallard	MALL	*Anas platyrhynchos*	Brown-headed Nuthatch	BHNU	*Sitta pusilla*
Northern Bobwhite	NOBO	*Colinus virginianus*	White-breasted Nuthatch	WBNU	*Sitta carolinensis*
Wild Turkey	WITU	*Meleagris gallopavo*	Carolina Wren	CARW	*Thryothorus ludovicianus*
Mourning Dove	MODO	*Zenaida macroura*	Blue-gray Gnatcatcher	BGGN	*Polioptila caerulea*
Yellow-billed Cuckoo	YBCU	*Coccyzus americanus*	Eastern Bluebird	EABL	*Sialia sialis*
Common Nighthawk	CONI	*Chordeiles minor*	Wood Thrush	WOTH	*Hylocichla mustelina*
Chimney Swift	CHSW	*Chaetura pelagica*	American Robin	AMRO	*Turdus migratorius*
Ruby-throated Hummingbird	RTHU	*Archilochus colubris*	Gray Catbird	GRCA	*Dumetella carolinensis*
Killdeer	KILL	*Charadrius vociferus*	Brown Thrasher	BRTH	*Toxostoma rufum*
Turkey Vulture	TUVA	*Cathartes aura*	Northern Mockingbird	NOMO	*Mimus polyglottos*
Red-shouldered Hawk	RSHA	*Buteo lineatus*	Cedar Waxwing	CEDW	*Bombycilla cedrorum*
Red-tailed Hawk	RTHA	*Buteo jamaicensis*	American Goldfinch	AMGO	*Spinus tristis*
Eastern Screech-Owl	EASO	*Megascops asio*	Eastern Towhee	EATO	*Pipilo erythrophthalmus*
Barred Owl	BAOW	*Strix varia*	Bachman's Sparrow	BACS	*Peucaea aestivalis*
Belted Kingfisher	BEKI	*Megaceryle alcyon*	Chipping Sparrow	CHSP	*Spizella passerina*
Red-headed Woodpecker	RHWO	*Melanerpes erythrocephalus*	Field Sparrow	FISP	*Spizella pusilla*
Red-bellied Woodpecker	RBWO	*Melanerpes carolinus*	Yellow-breasted Chat	YBCH	*Icteria virens*
Downy Woodpecker	DOWO	*Picoides pubescens*	Eastern Meadowlark	EAME	*Sturnella magna*
Hairy Woodpecker	HAWO	*Leuconotopicus villosus*	Red-winged Blackbird	RWBL	*Agelaius phoeniceus*
Red-cockaded Woodpecker	RCWO	*Leuconotopicus borealis*	Brown-headed Cowbird	BHCO	*Molothrus ater*
Northern Flicker	NOFL	*Colaptes auratus*	Common Grackle	COGR	*Quiscalus quiscula*
Pileated Woodpecker	PIWO	*Hylatomus pileatus*	Ovenbird	OVEN	*Seiurus aurocapillus*
Eastern Wood-Pewee	EAWP	*Contopus virens*	Blue-winged Warbler	BWWA	*Vermivora cyanoptera*
Acadian Flycatcher	ACFL	*Empidonax virescens*	Swainson's Warbler	SWWA	*Limnothlypis swainsonii*
Great-crested Flycatcher	GCFL	*Myiarchus crinitus*	Orange-crowned Warbler	OCWA	*Vermivora celata*
Eastern Kingbird	EAKI	*Tyrannus tyrannus*	Common Yellowthroat	COYE	*Geothlypis trichas*
White-eyed Vireo	WEVI	*Vireo griseus*	Hooded Warbler	HOWA	*Setophaga citrina*
Yellow-throated Vireo	YTVI	*Vireo flavifrons*	American Redstart	AMRE	*Setophaga ruticilla*
Blue-headed Vireo	BHVI	*Vireo solitarius*	Pine Warbler	PIWA	*Setophaga pinus*
Red-eyed Vireo	REVI	*Vireo olivaceus*	Yellow-throated Warbler	YTWA	*Setophaga dominica*
Blue Jay	BLJA	*Cyanocitta cristata*	Prairie Warbler	PRAW	*Setophaga discolor*
American Crow	AMCR	*Empidonax virescens*	Summer Tanager	SUTA	*Piranga rubra*
Fish Crow	FICR	*Corvus ossifragus*	Northern Cardinal	NOCA	*Cardinalis cardinalis*
Purple Martin	PUMA	*Progne subis*	Blue Grosbeak	BLGR	*Passerina caerulea*
Barn Swallow	BASW	*Hirundo rustica*	Indigo Bunting	INBU	*Passerina cyanea*
Carolina Chickadee	CACH	*Poecile carolinensis*			

Appendix B. Detailed Model Development and Data Analysis Methods

Models that distinguish the *detected population* from the *whole population* are often termed hierarchical (Royle 2004), and hierarchical models are often used to estimate population parameters as well as the level of uncertainty in each parameter estimate. A simple example would involve a count of y individuals from a population of size N and an individual detection probability of p. The hierarchy in this example involves one level at which y is a function of parameters N and p, and another level at which p is a function of potential covariates like observer identity. Bayesian models allow us to estimate the "posterior" probability density of each parameter value, provided that we supply a "prior" probability density summarizing any prior information about the distribution of values the parameter might take. Bayesian methods require estimation of the joint probability density of all model parameters, a computationally intensive process facilitated by simulation methods such as Markov chain Monte Carlo (MCMC). MCMC can be used to sample from the joint posterior distribution of model parameters by following a semi-random walk through parameter space and biasing most steps toward values that increase the probability of obtaining the observed data given the proposed model. If we require that the joint probability of obtaining the observed data generally increases as we step through parameter estimates, then a long series or "chain" of MCMC samples will eventually converge on the best estimate for each parameter. Plotting a histogram of samples from this vicinity will reveal the shape of each parameter's posterior distribution.

We used the JAGS programmable platform (Plummer 2003) to perform MCMC simulation and to provide summaries of the resulting samples, such as a credible interval (CRI) for each parameter estimate. In this report, a 95% CRI refers to a Bayesian credible interval which contains the value of the focal parameter with a subjective probability of 0.95, assuming an appropriate prior distribution for the parameter. In every case, we used a "flat" prior to minimize any influence on the posterior estimate of each parameter. All analyses were implemented in the R statistical computing environment (R Core Team 2017), using jagsUI (Kellner 2015) to call JAGS from R.

Our hierarchical model accounted for two components of individual detection: 1) availability, the probability that a bird will perform a detectable action, like singing; and 2) perceptibility, the probability that observers will perceive that action. Data from multiple count intervals were used to generate individual detection histories modeled within a closed-population framework to characterize availability (Alldredge et al. 2007). We followed Farnsworth et al. (2002) in modeling availability from time-removal data, in which the initial detection of a unique individual was assigned to one of three count intervals (minutes 0-3, 3-5 or 5-7), and subsequent detections of the same individual were ignored. We modeled availability as a function of q, the per-minute probability of a bird's failure to sing or otherwise be available for detection. The probability that a bird was present and not available during all three count intervals (totaling seven minutes) was q^7, and availability was $1-q^7$. If covariates of availability were needed to improve model performance, availability could be modeled as a function of point-specific covariates, x_k, as $\text{logit}(q_k) = \alpha_0 + \sum_x \alpha_x x_k$, where subscript k indicates point. To characterize effects of distance on perceptibility, we first dropped about 10% of the farthest (and presumably least accurate) detections of each species to obtain the maximum effective detection distance (per Kéry and Royle 2016). We then sorted the remaining detection distances into variable-width bins, equalizing the number of detections in each bin (Amundson et al. 2014). We followed Buckland et al. (2001) in modeling the probability of detecting a bird in a given distance bin using the half-normal distribution. The steepness of the half-normal is controlled by shape parameter σ, the decay rate of detections with distance, potentially modeled as a function of point-specific covariates as $\log(\sigma_k) = \log(\sigma_0) + \sum_x b_x x_k$.

We combined these models of q and σ (components of p) with a model of N in an "N-mixture" or binomial mixture model (Royle et al. 2004). N-mixture models typically pair a Poisson model of N (abundance) with a binomial model of y (count). N-mixture models provide a hierarchical extension of generalized linear models (GLMs), linking multiple GLMs to allow for structure in parameters at each hierarchical level (Royle 2004). In this report, a Poisson model of λ (expected N) as a function of environmental covariates is linked with two binomial models expressing detection as functions of survey conditions. Specifically, observed counts y_k are assumed to derive from a binomial distribution with parameters determined by the number of birds available for detection n_k and their probabilities of detection (a function of σ_k), while n_k values derive from a binomial distribution with parameters determined by the true abundance of birds N_k and the probability that each bird present is available for detection (a function of q_k). Finally, N_k values derive from a Poisson distribution with parameter λ (a function of covariates), as
$y_k \sim \text{binomial}(f(\sigma_k), n_k)$,
$n_k \sim \text{binomial}(f(q_k), N_k)$ and
$N_k \sim \text{Poisson}(\lambda = f(x_k))$.

Components of model fit were characterized using Bayesian P-values, which suggest adequate fit when in the range 0.1-0.9 and good fit when near 0.5. Fit to each component of detection probability was determined separately so that models could be adjusted appropriately in cases of poor fit. For each species, we began the modeling process using the simplest model of availability ($\text{logit}(q_k) = \alpha_0$) and the simplest model of perceptibility ($\log(\sigma_k) = \log(\sigma_0)$). If the fit to a simple model of availability was poor, we added potential effects of day or hour as $\text{logit}(q_k) = \alpha_0 + a_1 x_k$, where x_k was the day or hour of the count at point k and a_1 was a fitted coefficient. We retained effects of day or hour if their inclusion in the model resulted in adequate fit. If the fit to a simple model of perceptibility was poor, we added potential effects of observer as $\log(\sigma_k) = \log(\sigma_0) + b_1 x_k$, where x_k was observer identity and b_1 was a fitted coefficient. Poor fit to the model of perceptibility was also addressed by altering the number of bins used for aggregating records by detection distance, so that the decline in perception of individuals with distance was better described by the half-normal distribution.

After identifying adequate models of species availability and perceptibility, we allowed for log-linear effects of habitat (vegetation type) and transect on expected N (λ_k) as $\log(\lambda_k) = \beta_0 + \beta_1 \mathit{habitat}_k + \mathit{transect}_k^*$, where $\mathit{habitat}_k$ was the habitat at point k, β_1 was a fitted coefficient estimating the direction and magnitude of the habitat effect, and $\mathit{transect}_k^*$ was a fitted random effect of the transect containing point k. Allowing for a random effect of transect helped account for spatial autocorrelation in counts among point-count stations and for effects of survey timing (including weather) that might cause counts to be more similar within than among transects. The fixed effect of habitat was coded as an effect of Southern Yellow Pine presence (1) or absence (0) at the point-count station, rather than accounting for each vegetation type, due to the predominance of Southern Yellow Pine on the base.An effect of Southern Yellow Pine was reported for the species only if the CRI of β_1 did not overlap zero.

Mean population density (N per hectare) was calculated by averaging λ_k over all k point-count stations surveyed and dividing by the effective area surveyed at each station. Effective area surveyed varied with maximum detection distance for each species (d_{max}), which was taken as the maximum detection distance after censoring the farthest 10% of detection distances for the species. In some cases, we censored additional detection distances to avoid significant covariance in distance- and time-to-detection, which would violate model assumptions. As detailed in Ray et al. (2017*a*), model convergence of parameter estimates was assessed using the Gelman-Rubin potential scale reduction parameter, R-hat, and visual inspection of MCMC samples from three chains of length 60000, after discarding the first 10000 steps and thinning to 5000 samples.