Monitoring population dynamics of Maine ruffed grouse using spring drumming surveys: Year 4 Report

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Disclaimer: The findings contained in this report represent preliminary results of ongoing research, and they should be cited as such until they have undergone peer review and publication.

SUMMARY

The ruffed grouse (*Bonasa umbellus*) is one of the most popular game species in the state of Maine. Drumming surveys provide a non-invasive method for monitoring populations of this species. We conducted drumming surveys along roadside survey routes located throughout Maine during springs 2014-2017. We established regional study areas where one to four routes with 15 stops each were surveyed for drumming activity, and surveys were repeated 3 to 4 times per season. Data were analyzed using N-mixture models to estimate the density of territorial male ruffed grouse at each survey stop, while accounting for imperfect detection. Here we summarize results from the first four years of data collection. For routes sampled during all years 2014 - 2017, estimates of density showed annual variation within sites, however there were no consistent patterns to suggest general statewide trends during this time frame. When extrapolated to males per 100 ha based on the average audible distance of drumming males (~200 m), the estimated densities from our data ranged from a high of 28.4 males/100 ha to a low of 2.14 males/100 ha. Among sites that were sampled either three or four years, we observed consistently intermediate to high densities at routes in Aroostook County and the Stud Mill Road

area, whereas we observed consistently low to intermediate densities at routes on or around Moosehorn National Wildlife Refuge, in the Rangely area, and mid-coast Maine. One route on Frye Mountain Wildlife Management Area was highly variable among years, but produced very high densities during 2014 and 2015. During 2017 we established two new routes in central Maine, and observed both the highest and lowest densities of males that we have recorded to date at these sites. We found that detection probability was most strongly affected by the day of the year a survey was conducted, the average temperature during a survey, the time past sunrise a stop was surveyed, and levels of noise disturbances (e.g. passing cars) along a route. Detection probability was also affected to a lesser extent by the average wind speed during a survey. Our field protocols and data analysis methods appear sufficient to account for these potential sources of error. Densities of male ruffed grouse in Maine are comparable to densities previously reported for the species in the core of its range.

BACKGROUND

Ruffed grouse (*Bonasa umbellus*) are an important game bird in Maine, with approximately half a million individuals harvested annually (MDIFW 2001). Drumming surveys are conducted during the breeding season when male ruffed grouse drum to attract females and defend territories (Guillion 1967), and offer an efficient and non-invasive technique for population monitoring of ruffed grouse. Ruffed grouse are commonly found to have a 1:1 sex ratio during the breeding season (Guillion 1967, Zimmerman and Gutierrez 2007), and counts of drumming males are thus assumed to provide an index to population abundance. A number of states throughout the U.S. rely on drumming surveys as a population index, and researchers have also used this monitoring technique to collect data on ruffed grouse distribution and abundance (e.g. Guillion 1967, Zimmerman and Gutierrez 2007, Hansen et al. 2011 Kouffeld et al. 2013). In

2014 the Maine Department of Inland Fisheries and Wildlife and University of Maine initiated a program to conduct spring roadside drumming surveys at focal study areas throughout Maine to better-characterize patterns in ruffed grouse population dynamics within the state.

It is widely recognized that not all animals are counted during most visual or auditory surveys (Anderson 2001), which is to say that the probability of detecting an animal, given that it is present, is very commonly <1.0. In the case of ruffed grouse, at least three factors may result in an observer not recording a drumming male during a survey. First, ruffed grouse may be truly absent from the site. Second, if a male is in fact present, that male may not drum during the survey, and thus would not be recorded. Third, given that a male is present and that it drums during a survey, the observer may fail to hear the sound and thus fail to record its presence. Distinguishing the first case from the latter two is important for population monitoring, because absence reflects the true biological process of interest, whereas failed detection reflects the imperfect ability to record that biological process accurately. Repeated surveys offer one way to account for imperfect detection probabilities and correct monitoring data accordingly. Recently methods have been formalized to analyze such data to generate detection-corrected estimates of species abundance (Royale 2004). These methods allow investigators to also evaluate sources of variation in both detection and the true state process (i.e. abundance) using regression-based techniques and model selection procedures. For detection, this allows the inclusion of predictor variables that could influence the detection process, such as wind speed, anthropogenic noise, date and time, etc. The resulting models produce estimate of abundance that are corrected for variation in the detection process among surveys.

Our objectives for this work were to 1) develop field protocols for ruffed grouse drumming surveys in Maine, 2) analyze data to explore sources of variation in detection

probability, and 3) derive estimates of abundance of drumming male ruffed grouse, given the collected data. We have previously reported results from objective 1 and 2 (Martin and Blomberg 2015, Blomberg and Martin 2016), and this report is largely focused on objective 3 with updated results for objective 2.

METHODS

We began collecting data at three study sites in 2014: Frye Mountain Wildlife Management Area (FM), Stud Mill Road (SM), and western Aroostook County (AC). The FM site was centered on a state-owned property that is managed actively for upland game habitat, including ruffed grouse, however a second route was located on adjacent private lands comprised mostly of second-growth deciduous forest and small-scale agriculture typical of rural southern Maine. The SM and AC sites were largely comprised of commercial forest lands typical of northern Maine where ruffed grouse habitat is provided as a by-product of commercial forest management. In 2015, we conducted surveys at additional routes in the Rangely area of western Maine (RA), near Bowdoinham in southwestern Maine (SW), and in the Downeast region near Moosehorn National Wildlife Refuge (MH). In 2017, we established survey routes in southern Somerset County in central Maine (CM) and the Telos area (T), located west of Baxter State Park in the North Maine Woods. General descriptions of all routes (N=17) are summarized in Table 1.

We established 1 to 4 driving routes, comprised of 15 stops each, at each area. In 2014 we surveyed each route 4 times during the breeding season. Based on the results of preliminary analyses following the 2014 season (Martin and Blomberg 2015), we modified our protocol to involve only 3 repeated surveys from 2015 onward. We targeted survey dates to occur between 15 April and 7 June, while allowing for variation in survey dates across sites due to road

accessibility and observer schedules. At each stop, observers conducted 5-minute listening surveys and recorded the total number of drums heard and the estimated number of unique individuals. A number of variables designed to address variation in detection probability among surveys, including environmental factors such as wind speed and precipitation, were also recorded. Observers were typically state or federal biologists, university faculty or students, or experienced volunteers. Full details of the field sampling and survey design can be found in the protocols listed in Appendix S1.

We condensed survey data into encounter histories designed to address the "state" process of interest, male density (N), which we defined as the number of drumming males available for detection at each survey location. Density estimates were informed by the recorded number of individuals at each stop. Because male ruffed grouse are audible to a distance of approximately 200 m (Zimmerman and Gutierrez 2007, Kouffeld et al. 2013), density in this context reflects the number of males within an ~12.6 ha circle centered at the survey stop. We analyzed repeated counts of males for each stop/year combination using the 'pcount' function in the R package 'unmarked' (Fiske et al. 2015), which fits the N-mixture model as described by Royale (2004). N-mixture analysis assumes closure among repeated surveys within years, meaning that an individual male heard at a stop during one survey was assumed to be present during all surveys. Therefore, failure to hear drumming during a survey where it was previously heard was assumed to reflect failed detection rather than absence. Data from a concurrent radio-telemetry study indicated that survival of male ruffed grouse during the drumming season is high (Davis et al. *in revision*), suggesting that the closure assumption is likely valid. We incorporated a number of temporal and environmental variables that were collected during surveys (Table 2) as covariates modelled on the detection function in our analyses.

We approached this analysis in a multi-step process designed to first assess nuisance parameters and model assumptions, and then to evaluate sources of variation in density. We first evaluated support for the best approximating distribution of the response variable (Poisson, Negative Binomial, Zero-inflated Poisson) using a model where N and p were allowed full route-level variation. We then evaluated the effect of each detection covariate (Table 2) in a series of univariate models. For day of year and time past sunrise, we hypothesized a quadratic relationship, and so we tested both linear and quadratic models. Using Akaike's Information Criteria (AIC), we then considered these univariate models to have a meaningful effect on detection when they outcompeted an intercept-only null model based on a criterion of $\Delta AIC_c \leq 2.0$. We also evaluated beta coefficients and their associated 85% confidence intervals to evaluate the effects of, and support for, these individual variables. We then combined all supported covariates into a single "best-fit" structure on the detection covariate, and then using this structure evaluated variance in N related to area, route, and year, as well as models that included additive and interactive effects of area and year and route and year. We based support for this second model set on a criteria of $\Delta AIC_c \leq 2.0$. R code for all analyses are provided as Appendix S2.

RESULTS

Model selection results are summarized in Tables 3, 4, and 5. We found that repeated count data were best approximated using a Poisson distribution, however Negative Binomial and Zero-inflated Poisson were also competitive and likely adequate (Table 3). We found that day of year, time of survey, temperature, and noise disturbance all strongly influenced on the probability of detecting drumming grouse (supported at 95% CIs; Table 4), and that average wind speed affected the detection to a lesser degree (supported at 85% CIs; Table 4). We found

clear evidence for a quadratic effect of day of year on the probability of detecting a drumming male (Fig. 1), where detection peaked around May 8th (p=0.30 +/- 0.03 SE) and was generally low early (p = 0.22 +/- 0.05 SE) and late (p=0.17 +/- 0.02 SE) in the season. We also found evidence for a quadratic effect of time of survey on detection (Fig. 1), such that the probability of detecting a drumming male peaked approximately 5 min after sunrise (p=0.26 +/- 0.03 SE), and detection was slightly lower before sunrise (p=0.25 +/- 0.04 SE) and substantially lower later in the morning (p=0.18 +/- 0.03 SE). The probability of detecting a drumming male was negatively associated with average morning temperature (Fig. 2), noise disturbance (Fig. 2) and average wind speed (Fig. 2). One standard deviation increases in each of these variables were associated with decreases in detection of 0.04, 0.02, and 0.02, respectively. We found no evidence that precipitation or study year affected detection (Table 4).

Route by year variation in male density was best-supported by the data (Table 5). Predicted densities >25 males/100 ha (i.e. the highest densities we observed) were recorded in 2017 along routes CM1 (28.4 males/100 ha) and SM1 (26.1 males/100 ha), and in 2015 along route FM1 (25.7 males/100 ha; Table 6, Fig. 3). Other high density (i.e. >20 males/100 ha) route by year combinations included SM2 in 2014 and 2017, T1 in 2017, AC2 in 2014, and FM1 in 2014 (Table 6, Fig. 3). Many of the lowest density route by year combinations were recorded in the Downeast region both on (MH1 and MH2) and off (MH3) of Moosehorn National Wildlife Refuge, in Aroostook County (AC2 and AC3), and in the Rangely area of western Maine (RA1 and RA2; Table 6, Fig. 3).

A general effect of year on male density was not supported in model selection (Table 4), suggesting that ruffed grouse populations, as indexed by male density, neither increased nor declined between 2014 and 2017. This result may be partially confounded by changes in the

number of routes surveyed among years. Changes between years in the point estimates of density were variable among sites, with some sites showing increases and others declines (Fig. 3). Overall we found no compelling evidence to support consistent statewide trends in male abundance over 4 years, however individual routes clearly showed systematic increase or decline (Fig. 3).

DISCUSSION AND RECOMMENDATIONS

This report updates the most recent estimates of male ruffed grouse densities for the state of Maine (i.e. Blomberg and Martin 2016). If we assume that drumming can be heard at an average maximum distance of 200 m (Zimmerman and Gutierrez 2007, Kouffeld et al. 2013), then the density estimates we obtained from N-mixture models are relative to a land area of approximately 12.6 ha. Previous authors commonly report ruffed grouse densities in terms of numbers per 100 ha, and these values are summarized in Rusch et al. (2000; see Table 4). When we convert our estimated number of males per stop to an approximated density per 100 ha (Table 6) the current range of values for ruffed grouse density in Maine (2.1 – 28.4 males/100 ha) are greater than or approximately equivalent to those summarized by Rusch et al. (2000). Notably, the average density of drumming males recorded during our surveys (12.2 males/100 ha) is exceeded in the literature only by estimates reported for northwest Wisconsin (14.6 males/100 ha) and Alberta (12.5 males/100 ha). The maximum density recording during our study, 28.4 males/100 ha at the CM study site, is greater than peak male densities reported for Alberta (22.4 males/100 ha), Manitoba (23.6 males/100 ha), and northwest Wisconsin (26.0 males/100 ha). One important caveat is that many previous investigators estimated male density through carefully-executed territory mapping on a relatively small scale. In contrast, we calculated a detection-corrected density based on repeated count surveys; as such we make an inherent

assumption about the audible distance of drumming grouse. If drumming males can be heard regularly from a distance greater than 200 m, then our approach would overestimate density when expressed per 100 ha. Nevertheless, these results provide evidence suggesting that current densities of territorial male ruffed grouse in Maine are, on average, comparable with densities reported from the core of the species' range. Furthermore, densities of drumming males at several of our study sites appear to be comparable with the highest densities that have been reported elsewhere.

We found substantial variation in drumming male densities between routes within the same study site. For example, FM and CM each contained one route had among the highest densities we recorded and secondary routes that had among the lowest. At both sites, differences in densities between routes likely reflected the availability of early-successional forest. Forest management along the high density routes at FM and CM appears to adequately create high-quality ruffed grouse habitat, despite their differing management goals between these areas (wildlife habitat and commercial forestry, respectively). In contrast, rural private lands nearby these areas likely had undergone more advanced forest succession that reduced the amount high-quality ruffed grouse habitat, resulting in lower observed densities. The SM, AC, RA, and T sites are all located in areas managed primarily for production of forest products; moderate to high densities of grouse in these areas are surely driven by the regular disturbance associated with commercial forestry. However, variation among sites, even within regions (e.g. AC1 vs AC2) suggests that other factors may influence the degree to which commercial forests promote ruffed grouse populations. Our monitoring program will be useful to track ruffed grouse population dynamics in the event that local or regional forest practices change through time.

Although a number of studies have estimated detection probability of ruffed grouse using drumming surveys, the results are often variable. Part of this difference is related to the distinction between detection of an individual grouse (as in the N-mixture models to evaluate density) versus the detection of any grouse to establish occupancy. A previous version of this report established that occupancy probability in our system was generally predictive of density, and vice versa, except at very high densities (Blomberg and Martin 2016). The peak detection probability we obtained from our updated density analysis was p=0.30 (+/- 0.03 SE on May 8th), while our previous occupancy analysis had a peak detection probability of p=0.54 (+/- 0.03 SE on May 14th; Blomberg and Martin 2016). The detection rate from our density analysis was lower than that observed at the Cloquet Forestry Center in Minnesota, where observers found that detection probability of individual males peaked at p=0.51 (on May 7th; Zimmerman and Gutierrez 2007). However, these authors used walking transect rather than point-based roadside surveys, which may explain a large deal of the differences in detection rates. The previously reported detection rate from our occupancy analysis was higher than that observed in the Black Hills National Forest by Hansen et al. (2011; p=0.35), who also conducted roadside surveys. This result may reflect generally higher densities of ruffed grouse in our survey areas, given that the probability of detecting ≥1 drumming male is likely to increase with population density.

Our results largely support the conclusions of a previous assessments of detection probability for this monitoring program (Martin and Blomberg 2015, Blomberg and Martin 2016). A clear quadratic effect of day of year suggests that by conducting a number of surveys during the last week of May and first week of June in 2015, as well as by adding additional survey sites, we were better able to capture the non-linear dynamics of male drumming intensity. In future years we should continue to use the same general timeframe for surveys (April 15-June

1 with flexibility) as it appears adequate for analysis purposes. However, to the extent that we can target the bulk of survey effort towards the period of approximately May 1 to May 21, we may be able to improve on the precision of annual estimates. The specific timing of the drumming season may vary among years, however, and so this result should be updated annually, and other considerations (e.g. an early spring) should be taken into account as needed. Furthermore, a quadratic and asymmetric effect of time relative to sunrise suggests greater detection at stops surveyed earlier in the morning than later. We advise surveyors in our study to make an effort to begin survey as close to the starting time listed in the protocol (i.e. 30 mins before sunrise) as possible to improve detection at stops surveyed later in the morning.

We imagine two useful directions for this monitoring program in the future. First, as surveys are repeated at each site across more years, data will become available to estimate trends in either abundance or occupancy through time, which will provide the opportunity to assess the temporal dynamics of ruffed grouse populations across the state. With 4 or fewer years of data from each site currently, that ability is somewhat limited. This of course means that maintaining consistent data collection at each site across years will be important. However, if data cannot be collected on a particular route during a single year, that will not preclude the utility of the route for the dataset as a whole because these analysis methods are relatively robust to small amounts of missing data (i.e. some gaps in the data here and there is acceptable). Secondly, spatial analyses could be incorporated to evaluate variation in density and/or occupancy rates among study areas, and to guide the selection of future sites. Other studies of ruffed grouse habitat relationships have classified forest composition using GIS and remote sensing technologies (Tirpak 2010, Felix-Locher and Campa 2010, Kouffeld et al. 2013) and have related these to ruffed grouse. Given the availability of satellite imagery, and programs to incorporate them (e.g.

ERDAS, ArcGIS), such analyses would be relatively easy and informative to implement. Factors identified by previous studies, such as local forest composition and road density, were associated with lower occupancy of ruffed grouse in other areas, and could aid us in designing future research for Maine. This information would be useful in guiding grouse habitat management or further improving the monitoring program.

Finally, it is important to recognize that these surveys target displaying male ruffed grouse specifically. While male density has long been presumed to reflect the dynamics of the population as a whole (Rusch et al. 2000), it is not a direct measure of the total population size nor is it a direct assessment of the number of birds available during other times of the year (e.g. prior to the hunting season). Therefore, the results of drumming surveys are useful to illustrate spatial and temporal patterns ruffed grouse populations, but their results should always be viewed with the caveat that male density may not always paint a complete picture of the state of the ruffed grouse population.

ACKNOWLEDGMENTS

SUPPLEMENTAL MATERIALS

Appendix S1. Field protocols for drumming surveys.

Appendix S2. R code to conduct all analyses described in this report.

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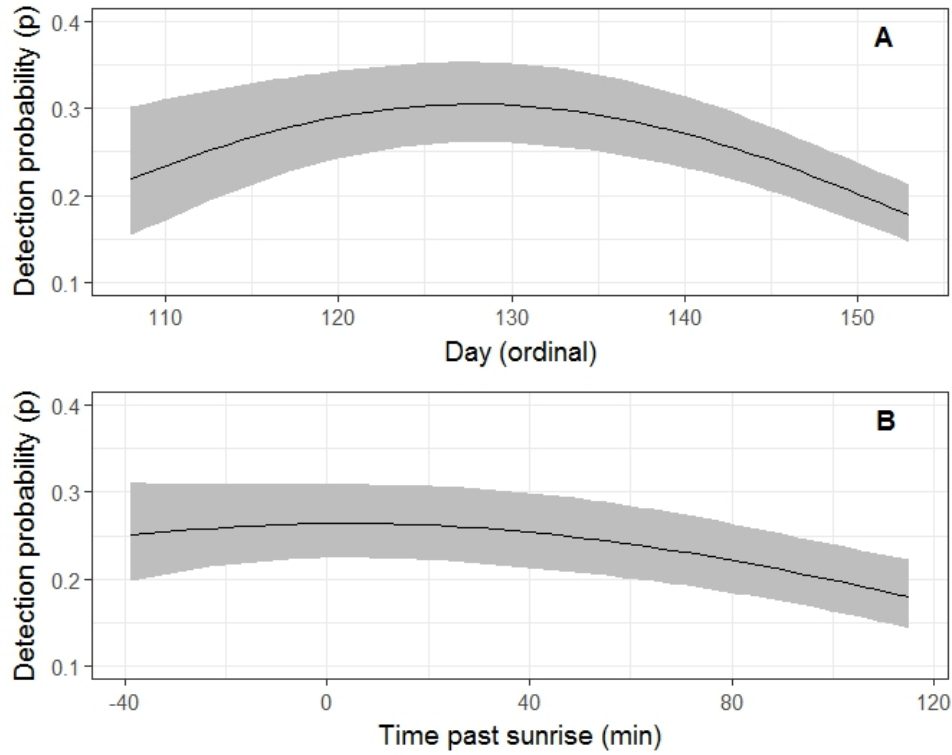Drumming Ruffed Grouse. Journal of Wildlife Management 71(6):1765-1772.

Figure 1. Effects of temporal variables A) day of year (ordinal date) and B) time past sunrise on the probability of detecting an individual male ruffed grouse during a 5 minute drumming survey. Both effects were modelled as quadratic effects on detection using repeated count N-mixture models (Royale 2004) implemented in the R package 'unmarked'. Gray ribbons reflect 85% confidence intervals. Ordinal day 110 is April 20th.
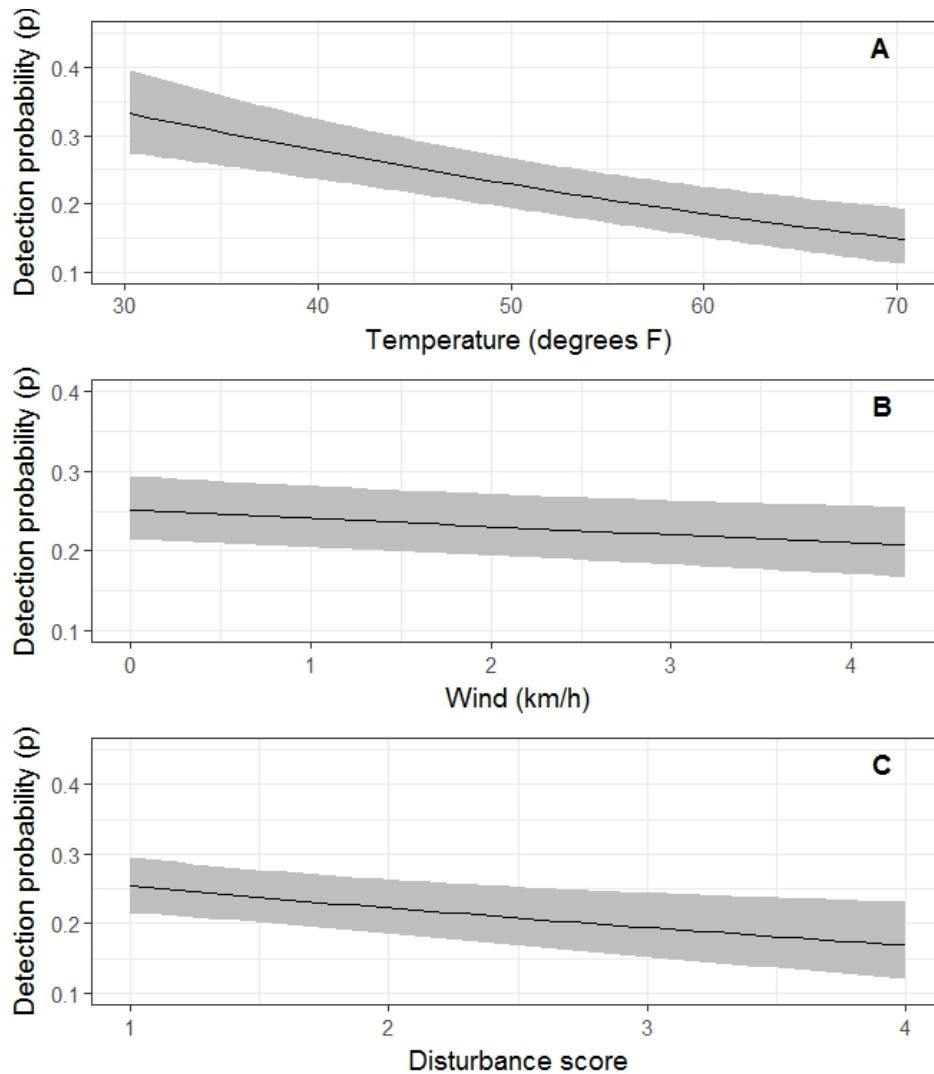
Figure 2. Effects of environmental variables on the probability of detecting an individual male ruffed grouse during a 5 minute drumming survey. Detection probability of drumming males was negatively associated with A) temperature, B) average wind speed, and C) non-wind noise (e.g. passing vehicles or rushing water). The temperature variable was the average degree readings, in Fahrenheit, taken at the starting and ending stops of each survey. Wind was derived based on the average of wind measurements taken at the starting and ending stops of each survey, or based on the average wind speed recorded at each stop of each survey. Disturbance was classified on a 1 to 4 scale, where an increasing value reflected greater non-wind noise. Figures were built using coefficients from repeated count N-mixture models (Royale 2004) implemented in the R package 'unmarked'. Gray ribbons reflect 85% confidence intervals.
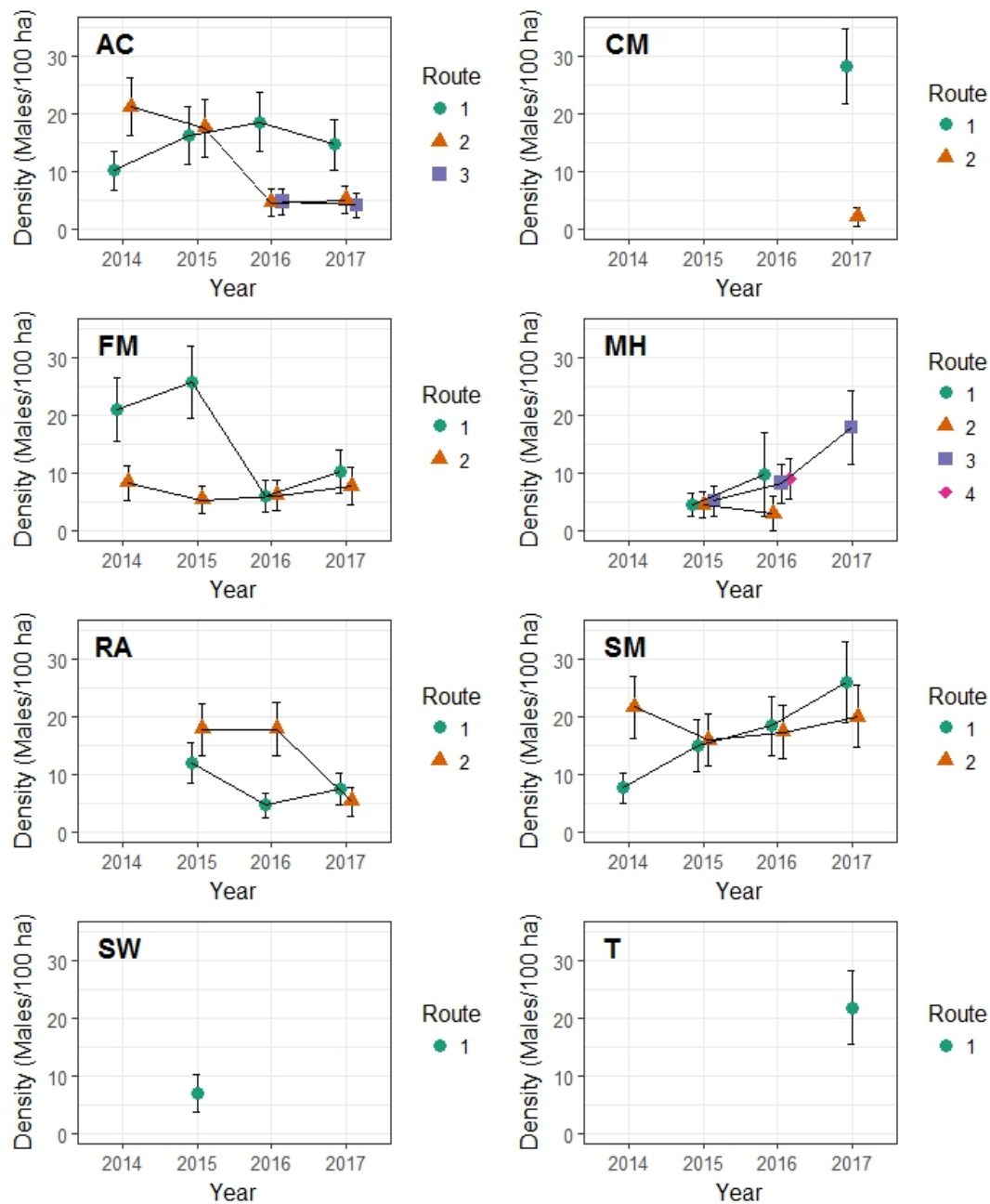
Figure 3. Year-specific density estimates for drumming male ruffed grouse along roadside survey routes located within 8 study sites throughout Maine during 2014-2017. Observers recorded the number of individual male ruffed grouse that were heard during 5 minute surveys, where each route consisted of 15 stops spaced 0.5 miles apart, and surveys were repeated 3 (2015-2017) or 4 (2014) times. Estimates of densities were calculated from the top performing repeated count N-mixture model (Royale 2004) analyzed in the R package 'unmarked'. Error bars reflect standard errors (SE). Site abbreviations are given in Table 1.

Table 1. Locations, descriptions, and abbreviations for ruffed grouse drumming survey routes located throughout Maine.

Route ID	Area Description	Route Description	First Survey
AC1	Western Aroostook Co	Hewes Brook Road	2014
AC2	Western Aroostook Co	Reality Road	2014
AC3	Western Aroostook Co	Carney Road	2016
CM1	Central Maine Area	Burrell Woods Road	2017
CM2	Central Maine Area	Phillips Corner Road	2017
FM1	Frye Mountain WMA	On Frye Mountain WMA	2014
FM2	Frye Mountain WMA	Off Frye Mountain WMA	2014
SM1	Stud Mill Road	Country Road/St Regis	2014
SM2	Stud Mill Road	Stud Mill and Titcomb Pond	2014
MH1	Moosehorn National Wildlife Refuge	Barring Unit Route "A"	2015
MH2	Moosehorn National Wildlife Refuge	Barring Unit Route "B"	2015
MH3	Moosehorn National Wildlife Refuge	Off-refuge/Dodge Road	2015
MH4	Moosehorn National Wildlife Refuge	Off-refuge/Bell Mtn Rd.	2016
RA1	Rangely Area	Tim Pond	2015
RA2	Rangely Area	Lincoln Pond	2015
SW1	Southwestern Maine	Bowdoinham/Lewis Hill	2015
T1	Telos Road Area	West of Baxter State Park	2017

Table 2. List of temporal and environmental survey variables, and their descriptions, collected in during ruffed grouse drumming surveys in Maine and applied to detection probability models.

Variable Type	Individual Variable	Description
Temporal	Day of year	Day survey was conducted, where January 1st = 1.
	Time past sunrise	Difference between individual stop time, and sunrise.
Environmental	Precipitation	Presence or absence of precipitation during the survey.
	Temperature	Average temperature (°F) between start and end of survey.
	Disturbance	Disturbance at an individual stop according to survey scale[a].
	Wind speed	Average wind speed recorded between start and end of route.

[a.] See Appendix S2 for survey protocol.

Table 3. Model selection results evaluating the relative fit of three alternative distributions for the abundance parameter (λ) in repeated count N-mixture models (Royale 2004) designed to evaluate density of drumming male ruffed grouse in Maine. All models were fit assuming full route-level variation on both the detection (p) and state (λ) process models.

Model	AIC	ΔAIC	*Wi*	*K*
Poisson	2767.49	0.00	0.58	34
Zero-Inflated Poisson	2769.49	2.00	0.21	35
Negative Binomial	2769.49	2.00	0.21	35

Table 4. Model selection results evaluating single-variable effects for the detection parameter (p) in repeated count N-mixture models (Royale 2004) designed to evaluate density of drumming male ruffed grouse in Maine. All models were fit assuming full route-level variation on the state (λ) process, and variable importance was inferred based on performance relative to the Null (intercept-only) model and by evaluating parameter coefficients (β+/- 1.44*SE).

Model	AIC	ΔAIC	*Wi*	*K*
Day of year^2	2751.90	0.00	0.99	20
Day of year	2761.63	9.73	0.01	19
Temperature	2769.25	17.36	0.00	19
Time past sunrise^2	2773.22	21.23	0.00	20
Time past sunrise	2773.79	21.90	0.00	19
Disturbance	2778.30	26.41	0.00	19
Wind speed	2778.91	27.02	0.00	19
Null	2780.23	28.34	0.00	18
Precipitation	2781.47	29.57	0.00	19
Year	2781.59	29.69	0.00	21

Table 5. Model selection results evaluating single-variable effects on the state process parameter (λ), which reflected the density (males/stop) of drumming ruffed grouse along roadside survey routes in Maine, as estimated by repeated count N-mixture models (Royale 2004). All models were fit using the best approximating model for the detection process (p), which was given as p = Day of Year^2 + Day of Year + Temperature + Time Past Sunrise^2 + Time Past Sunrise + Disturbance + Wind.

Model	AIC	ΔAIC	Wi	K
Route*Year	2726.13	0.00	1.00	52
Route	2736.86	10.72	0.00	25
Area*Year	2765.07	38.93	0.00	29
Area	2776.64	50.50	0.00	16
Null	2797.71	71.58	0.00	9
Year	2797.84	71.70	0.00	12
Area + Year	2831.34	105.21	0.00	17
Route + Year	2852.88	126.74	0.00	26

Table 6. Estimated densities (males per survey stop) of drumming male ruffed grouse available for detection along roadside surveys, as derived from repeated count N-mixture models (Royale 2004), and approximated spatial density (males/100 ha). Spatial density was approximated assuming a 200 m average audible distance for drumming ruffed grouse, which equates to an effective survey area of 12.6 ha at each stop.

Route ID	Year	Males/stop	SE	Males/100 ha
AC1	2014	1.28	0.43	10.19
	2015	2.07	0.64	16.39
	2016	2.36	0.64	18.70
	2017	1.86	0.55	14.73
AC2	2014	2.69	0.63	21.33
	2015	2.22	0.63	17.65
	2016	0.58	0.30	4.60
	2017	0.65	0.30	5.14
AC3	2016	0.60	0.27	4.77
	2017	0.53	0.27	4.21
CM1	2017	3.58	0.82	28.40
CM2	2017	0.27	0.19	2.14
FM1	2014	2.65	0.70	21.04
	2015	3.24	0.79	25.73
	2016	0.76	0.35	6.04
	2017	1.30	0.47	10.34
FM2	2014	1.06	0.38	8.40
	2015	0.68	0.31	5.41
	2016	0.77	0.32	6.11
	2017	0.98	0.41	7.82
MH1	2015	0.57	0.26	4.50
	2016	1.22	0.92	9.71
MH2	2015	0.56	0.29	4.43
	2016	0.38	0.38	3.02

Continued

Continued

Route ID	Year	Males/stop	SE	Males/100 ha
MH3	2015	0.65	0.34	5.17
	2016	1.04	0.42	8.26
	2017	2.26	0.81	17.96
MH4	2016	1.15	0.45	9.09
RA1	2015	1.53	0.44	12.15
	2016	0.60	0.27	4.74
	2017	0.96	0.35	7.58
RA2	2015	2.25	0.57	17.90
	2016	2.26	0.59	17.90
	2017	0.68	0.31	5.37
SM1	2014	0.98	0.34	7.77
	2015	1.91	0.56	15.14
	2016	2.33	0.66	18.47
	2017	3.29	0.89	26.08
SM2	2014	2.74	0.69	21.71
	2015	2.02	0.57	16.02
	2016	2.19	0.59	17.37
	2017	2.53	0.68	20.11
SW1	2015	0.89	0.41	7.05
T1	2017	2.76	0.80	21.92

Appendix S1. Field protocols for Maine ruffed grouse drumming surveys.

Maine Ruffed Grouse Drumming Count Protocol – 2017

Survey Background and Objectives

Roadside drumming surveys are used commonly to monitor populations of ruffed grouse, where in most cases the total number of grouse heard per survey stop are used as an index to the grouse population trends. Ruffed grouse drum more or less often depending on conditions like weather and time of the season. Some days they drum more frequently, some less so. The survey methods we have developed are designed to account for the fact that we will not hear every grouse during every survey. By using repeated surveys along the same routes and observing variation in the number of times grouse are detected at each survey point (stop along the route), we can estimate directly the proportion of times we are able to detect drumming males. These detection probabilities then can then be used to correct our population estimates based on the detection rate. This approach provides a rigorous monitoring tool that will be used to track population trends across the state, as well as to evaluate the influence of habitat on ruffed grouse populations in different parts of the state.

Route Selection and Placement

Attempt to establish at least two routes per area, route length = 7 miles, 15 stops every 0.5 miles. Routes should be placed on secondary roads with low traffic and in habitat representative of the larger region. Shorter routes are allowable if necessary to accommodate available road length.

Field Methods

Roadside drumming counts should be conducted three times on each route between 15 April and 31 May, although if access prevents surveys from occurring early in the year then surveys may be conducted in early June. Surveys should be spread relatively evenly across this time period, with at least one survey for each route conducted during the last week of April or first week of May. Begin surveys at the first stop 1/2 hour before sunrise (consult a sunrise chart). After stopping and exiting vehicle, record start time, date, temperature, wind speed and direction, sky conditions and precipitation prior to starting the route. To record wind speed, use a hand-held anemometer if available, or use the Beaufort scale (described on next page) in anemometer is not available. Surveys should not be conducted on mornings when wind speeds exceed 16 km/hr or during moderate or greater snow or rain.

Begin at the first stop and listen for grouse drumming for exactly 5 minutes, timed to the nearest second. Record the total number of drumming events heard, and if possible record number of individual grouse you believed were drumming. Also record the disturbance category (see description at end of sheet) based on the amount of noise present during the five minute survey period.

Important - Do not under any circumstance count individuals heard before or after the 5 minute survey period. This is very important, as we will be using the differences in grouse heard between repeated surveys to estimate a detection rate. The fact that you did not hear a grouse during a 5 minute stop, even though it was there, provides data that is just as important as the cases where you do hear the same bird during each repeated survey.

Once you've completed the first stop, drive to the second location 0.5 miles down the road. Use your vehicle odometer to measure the distance. Record any grouse seen while traveling between stops as a comment, and record the time that you begin each 5 minute survey. Repeat the survey procedures at each of the 15 stops. Record wind speed at each stop and categorize any disturbance that occurred during each 5 minute survey (see

below). At the end of all stops, record the ending temperature, wind speed and direction, sky conditions and precipitation.

Record the coordinates (UTM or Lat/Long) of each stop on your first visit, and stop at that same exact location during each successive visit. If possible, mark each stop using flagging or other markers to increase the efficiency of future surveys. During subsequent surveys, please alter the direction that you run the route. I.e., if you ended on stop 15 during the first survey, begin there and run the route backwards during the second survey. On the third survey, again run the route from stop 1 to 15. Please be sure to record stop numbers consistently and accurately on the data sheet during successive runs – the stop number refers to the specific point on the ground, not the order in which it was run.

Beaufort Wind Speed Index: In the event that an anemometer is not available to measure wind speed, use the Beaufort scale as an alternative.

0 – Calm <1km/hr. No discernable wind, smoke rises vertically.
1 – Light air 1.1-5.5 km/hr. Smoke drift indicates wind direction. Leaves and wind vanes are stationary.
2 – Light breeze 5.6-11 km/hr. Wind felt on exposed skin. Leaves rustle. Wind vanes begin to move.
3 – Gentle breeze 12-19 km/hr. Leaves and small twigs constantly moving, light flags extended.
4 – Moderate breeze 20-28 km/hr. Dust and loose paper raised. Small branches moving. Do not conduct survey in conditions these conditions or worse.

Disturbance Categories: These categories are designed to evaluate the amount of ambient noise that may affect our ability to hear a drumming grouse at any given stop. Ambient noise would include things like passing cars, distant traffic, construction equipment, or natural noise such as running water. Wind should not be included, as this will be accounted for based on wind speed measurements.

1 – No ambient noise of any kind that would limit the ability to detect a grouse.
2 – Low or short duration noises. 1 passing car on the road during the 5 minute survey, distant but low volume traffic noise, low volume running water. All but the most distant grouse still detectable.
3 – Moderate intensity or duration of noise. 2-3 passing cars during 5 minute survey period, noticeably distracting and persistent traffic noise from moderate distance, a rushing stream less than 100 yards from the survey point. More distant grouse difficult to detect.
4 – High intensity of duration of noise. 4-6 cars passing during the 5 minute survey, nearby and persistent traffic noise. Only grouse that are very near (<100 yards) detectable.
5 – Intense noise. This category should be used if you feel that noise would have completely hampered your ability to detect any grouse during the stop. Constant traffic on the survey road would be one case.

Appendix S2. R code to conduct all analyses described in this report.

```
##Need to change file path prior to running
data1 <- read.csv("C:/Users/nutting/Google Drive-Ellie/Ruffed Grouse (MASTER)/Drumming
Surveys/Updated 2017/Analytical Excel Files/Drumming Survey - Updated 2017.csv")

##Packages that must be installed prior to running
#install.packages('lubridate')
#install.packages('unmarked')
#install.packages('reshape2')
#install.packages('DataCombine')
#install.packages('ggplot2')

library(lubridate)
library(unmarked)
library(reshape2)
library(DataCombine)
library(ggplot2)


## Creates unique ID field for each stop
data1$StopID<- paste(data1$Area,data1$Route,"-",data1$StopNo,"-",data1$Year, sep="")

##Creates a variable for each area/route combination
data1$AreaRoute<- paste(data1$Area, data1$Route, sep="")


## Convert date and time variables and calculate time since sunrise for each stop
for(i in 1:nrow(data1)){
  data1$time[i]<- paste(data1$Year[i],"-",data1$Month[i],"-",data1$Day[i]," ",data1$Time[i], sep="")
}

for(i in 1:nrow(data1)){
  data1$SR[i]<- paste(data1$Year[i],"-",data1$Month[i],"-",data1$Day[i]," ",data1$Sunrise[i], sep="")
}

for(i in 1:nrow(data1)){
  data1$ST[i]<- paste(data1$Year[i],"-",data1$Month[i],"-",data1$Day[i]," ",data1$Start[i], sep="")
}

data1$time<-as.POSIXlt(data1$time)
data1$SR<-as.POSIXlt(data1$SR)
data1$ST<-as.POSIXlt(data1$ST)


for(i in 1:nrow(data1)){
  data1$time[i]<- paste(data1$Year[i],"-",data1$Month[i],"-",data1$Day[i]," ",data1$Time[i], sep="")
}

for(i in 1:nrow(data1)){
  data1$SR[i]<- paste(data1$Year[i],"-",data1$Month[i],"-",data1$Day[i]," ",data1$Sunrise[i], sep="")
}
```

```r
for(i in 1:nrow(data1)){
  data1$ST[i]<- paste(data1$Year[i],"-",data1$Month[i],"-",data1$Day[i]," ",data1$Start[i], sep="")
}


data1$min<-as.numeric(difftime(data1$time, data1$SR, unit="mins"))


##Create Julian (ordinal) Date of year terms for each stop
data1$Julian<- yday(data1$time)

##Calculate average temp from start and end temps
data1$TAvg<- (data1$TempS+data1$TempE)/2

##Return wind speed based on either the realized (measured) wind at each stop or the average of start and end
winds
data1$WindAvg<- (data1$WindS+data1$WindE)/2


WindX=function(z,a) {
  ifelse(is.na(a),z,a)
}

for(i in 1:nrow(data1)){
  data1$WindX[i] = WindX(data1$WindAvg[i], data1$Wind[i])
}

##Create a two Class Precip variable - None or Precip

Precip=function(a) {
  if (a == "Fog") {
    print("1")
  } else {
    if (a == "Mist/Fog"){
      print("1")
    } else {
      if (a == "Mist") {
        print("1")
          }else{
          if (a == "Light Rain") {
            print("1")
          } else {
            if (a == "Lt. Rain") {
              print("1")
            } else {
            if (a == "None"){
              print("0")
                }
              }
            }
          }
        }
```

```
        }
    }
}

for(i in 1:nrow(data1)){
  data1$pcp[i] = Precip(data1$Precip[i])
}

data1$pcp<- as.numeric(data1$pcp)
```

#####Begins N-Mixture analysis to evaluate the number of males/stop, equivalent to density.
#####This fits the models of Royale (2004)

##All packages will need to be installed before these functions will work
library(plyr)

##Creates table of site-level variables
Site.val<- data.frame(data1$Area, data1$Route, data1$StopID, data1$AreaRoute, data1$Year)
colnames(Site.val) <- c("Area","Route","StopID", "AreaRoute", "Year")

##Pivot table to covert number of individual males heard during each survey (N) into a history of how N varied by site within years

Drum.Pivot<- dcast(data1, StopID ~ SurvNo, mean, value.var="NoInd")
Drum.Pivot[Drum.Pivot=="-Inf"]<-NA

##Merge history with site-level time variables

#library(DataCombine)
Drum.Merge<- dMerge(Drum.Pivot, Site.val, "StopID", dropDups=TRUE)
colnames(Drum.Merge) <- c("StopID","O1", "O2", "O3", "O4", "Area", "Route", "AreaRoute", "Year")

Drum.Merge$AreaYear<- paste(Drum.Merge$Area, Drum.Merge$Year, sep="-")
Drum.Merge$RouteYear<- paste(Drum.Merge$AreaRoute, Drum.Merge$Year, sep="-")

##Extract site level variables with labels

Drum.cov<- data.frame(Drum.Merge$StopID, Drum.Merge$Area,
Drum.Merge$Route,Drum.Merge$AreaRoute, Drum.Merge$Year)
colnames(Drum.cov) <- c("StopID", "Area", "Route", "AreaRoute", "Year")

Drum.cov$RouteYear<- paste(Drum.cov$AreaRoute, Drum.cov$Year)

##Creates history to be read by 'unmarked'

Drum.Hist<- data.matrix(Drum.Pivot[,2:5])

##Z-standardize detection covariate values and replace missing values with 0.0

data1$WindZ<- scale(data1$WindX)

```
data1$TempZ<- scale(data1$TAvg)
Data1$MinZ<- scale(data1$min)
data1$DayZ<- scale(data1$Julian)
data1$DistZ<- scale(data1$Dist)
data1$PcpZ<- scale(data1$pcp)

#head(data1)

## Creates pivot table of time-varying covariates by site and replaces missing values with a 0 (mean)

Wind.Pivot<- dcast(data1, formula= StopID ~ SurvNo, fun.aggregate=mean, value.var="WindZ")
Wind.Pivot[Wind.Pivot=="NaN"]<-0

Temp.Pivot<- dcast(data1, formula= StopID ~ SurvNo, fun.aggregate=mean, value.var="TempZ")
Temp.Pivot[Temp.Pivot=="NaN"]<-0

Time.Pivot<- dcast(data1, formula= StopID ~ SurvNo, fun.aggregate=mean, value.var="MinZ")
Time.Pivot[Time.Pivot=="NaN"]<-0

Day.Pivot<- dcast(data1, formula= StopID ~ SurvNo, fun.aggregate=mean, value.var="DayZ")
Day.Pivot[Day.Pivot=="NaN"]<-"0"

Dist.Pivot<- dcast(data1, formula= StopID ~ SurvNo, fun.aggregate=mean, value.var="DistZ")
Dist.Pivot[Dist.Pivot=="NaN"]<-0

Pcp.Pivot<- dcast(data1, formula= StopID ~ SurvNo, fun.aggregate=mean, value.var="PcpZ")
Pcp.Pivot[Pcp.Pivot=="NaN"]<-0

data1.obs<-data1[,c(6,7,22)]
Obs.Pivot<- reshape(data1.obs, v.names="Observer", idvar="StopID", timevar="SurvNo", direction="wide")



## Creates a list specifying time-varying site-level covariates to be read by unmarked (and kicks out some
persistent NAs)

w = data.matrix(Wind.Pivot[,2:5])
w[is.na(w)]<-0

te = data.matrix(Temp.Pivot[,2:5])
te[is.na(te)]<-0

ti = data.matrix(Time.Pivot[,2:5])
d = data.matrix(Day.Pivot[,2:5])
di = data.matrix(Dist.Pivot[,2:5])
p = data.matrix(Pcp.Pivot[,2:5])
o = data.matrix(Obs.Pivot[,2:5])

obs.covs<- list(wind=w, temp=te, time=ti, day=d, dist=di, pcp=p, obs=o)
#utils::View(obs.covs)
##Create unmarked data frame
Mix<- unmarkedFramePCount(Drum.Hist, siteCovs=Drum.Merge, obsCovs=obs.covs)
```

```
##Check appropriate structure for models --- these take some time!
Pois<- pcount(~AreaRoute ~AreaRoute, Mix, mixture="P", K=50)
NegBi<- pcount(~AreaRoute ~AreaRoute, Mix, mixture="NB", K=50)
ZPois<- pcount(~AreaRoute ~AreaRoute, Mix, mixture="ZIP", K=50)


##create and display AIC table
fit.dist<- fitList(Pois, NegBi, ZPois)
fit.sel<- modSel(fit.dist)
fit.sel


##Saves table to file; note directory path will need to be changed
fit.table<- (toExport<-as(fit.sel, "data.frame"))
fit.AIC.table<- data.frame(fit.table$model, fit.table$AIC, fit.table$delta, fit.table$AICwt, fit.table$nPars)
colnames(fit.AIC.table)<- c("Model", "AIC", "DAIC", "W", "nPars")
write.table(fit.AIC.table, file="C:/Users/nutting/Google Drive-Ellie/Drumming Survey Report Update-
2017/Distributions_AICTable17.csv")


##detection covariate models
##using K<50 will decrease computation times
p.dot<- pcount(~1 ~AreaRoute, Mix, mixture="P", K=50)
p.wind<- pcount(~wind ~AreaRoute, Mix, mixture="P", K=50)
p.temp<- pcount(~temp ~AreaRoute, Mix, mixture="P",  K=50)
p.time<- pcount(~time ~AreaRoute, Mix, mixture="P", K=50)
p.time2<- pcount(~time + I(time^2) ~AreaRoute, Mix, mixture="P",  K=50)
p.day<- pcount(~day ~AreaRoute, Mix, mixture="P",  K=50)
p.day2<- pcount(~day + I(day^2) ~AreaRoute, Mix, mixture="P",  K=50)
p.dist<- pcount(~dist ~AreaRoute, Mix, mixture="P", K=50)
p.precip<- pcount(~pcp ~AreaRoute, Mix, mixture="P",  K=50)
p.year<- pcount(~as.factor(Year) ~AreaRoute, Mix, mixture="P",  K=50)


##create and save AIC table for detection process; note directory path will need to be changed

fms.p<- fitList(p.dot, p.wind, p.temp, p.time, p.time2, p.day, p.day2, p.precip, p.year, p.dist)
ms.p<- modSel(fms.p)
ms.p
detection.table<- (toExport<-as(ms.p, "data.frame"))
det.AIC.table<- data.frame(detection.table$model, detection.table$AIC, detection.table$delta,
detection.table$AICwt, detection.table$nPars)
colnames(det.AIC.table)<- c("Model", "AIC", "DAIC", "W", "nPars")
write.csv(det.AIC.table, file="C:/Users/nutting/Google Drive-Ellie/Drumming Survey Report Update-
2017/DetAICTable2017.csv")

## predict the mean detection probability from the dot model

p.dot.predict<- predict(p.dot, type="det")


## Full detection model that incorporates covariates with >2.0 delta AIC and 85% CI that differ from 0.0
```

2016- I did not include time^2 as a quadratic because the non-linear term for time was non-signficant
edit 2017- took pcp out because it was non-sig according to 85% CIs... Put wind and time^2 in bc 85% were sig

Future analyses will need to check det.AIC.table and adjust model structure accrodingly
Route- and area-level detection covariates are excluded because of convergence issues when considered in concert with route/area variance in lambda.

p.full <- pcount(~dist+day+I(day^2)+temp+time+I(time^2)+wind ~AreaRoute, Mix, mixture="P", K=50)

State process (abundance) models

N.Route<- pcount(~dist+day+I(day^2)+temp+time+I(time^2)+wind ~AreaRoute, Mix, mixture="P", K=50)
N.dot<- pcount(~dist+day+I(day^2)+temp+time+I(time^2)+wind ~1, Mix, mixture="P", K=50)
N.Area<- pcount(~dist+day+I(day^2)+temp+time+I(time^2)+wind ~Area, Mix, mixture="P", K=50)
N.Year.factor<- pcount(~dist+day+I(day^2)+temp+time+I(time^2)+wind ~as.factor(Year), Mix, mixture="P", K=50)
N.Year.trend<- pcount(~dist+day+I(day^2)+temp+time+I(time^2)+wind ~Year, Mix, mixture="P", K=50)
N.AreaYear<- pcount(~dist+day+I(day^2)+temp+time+I(time^2)+wind ~Area + Year, Mix, mixture="P", K=50)
N.AreabyYear<- pcount(~dist+day+I(day^2)+temp+time+I(time^2)+wind ~AreaYear, Mix,mixture="P", K=50)
N.RouteYear<- pcount(~dist+day+I(day^2)+temp+time+I(time^2)+wind ~AreaRoute + Year, Mix, mixture="P", K=50)
N.RoutebyYear<-pcount(~dist+day+I(day^2)+temp+time+I(time^2)+wind ~ RouteYear, Mix,mixture="P", K=50)

##create and save AIC table for state process; note directory path will need to be changed

fms.N<- fitList(N.Route, N.dot, N.Area, N.Year.factor, N.AreaYear, N.RouteYear, N.AreabyYear, N.RoutebyYear)
ms.N<- modSel(fms.N)
ms.N
state.table<- (toExport<-as(ms.N, "data.frame"))
state.AIC.table<- data.frame(state.table$model, state.table$AIC, state.table$delta, state.table$AICwt, state.table$nPars)
colnames(state.AIC.table)<- c("Model", "AIC", "DAIC", "W", "nPars")
write.csv(state.AIC.table, file="C:/Users/nutting/Google Drive-Ellie/Drumming Survey Report Update-2017/StateAICTable.csv")