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Acoustic Monitoring of American Woodcock

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ABSTRACT

American Woodcock *(Scolopax minor*) populations have been monitored with the Singing Ground Survey by human observers since 1968 while populations have steadily declined. In January-March 2016, 2017 and 2018, we tested the accuracy and feasibility of using a remote acoustic monitoring approach to achieve similar population monitoring goals while also describing the cycle of courtship activity at an eastern Tennessee site. We compared the effectiveness of an acoustic monitoring approach by conducting paired human observer counts (n = 35) with SongMeter SMII acoustic recorders at three strategically located point locations on each of three different publicly-owned management areas in eastern Tennessee. We developed a linear regression model that related the number of calls noted by human observers to the number of individual woodcock calling. Through application of this regression equation, we estimated the number of individuals present on the acoustic recordings. The recording device had a greater detection range (x = 207 m) than the effective detection distance from human observers (x = 78 m) and recorded data nightly throughout the courtship period with minimal cost. We analyzed the acoustic data for detections based on an automated template matching approach in Program R. The automated detection algorithm achieved a correct classification rate of 62% which could produce useable results of most monitoring objectives. We concluded that an acoustic monitoring approach eliminated some of the shortcomings of traditional point count surveys related to observer bias for monitoring woodcock and provided an avenue for more effective and time efficient monitoring of the species.

INTRODUCTION

The American Woodcock (*Scolopax minor*) is a migratory upland shorebird native to eastern North America which has been declining range wide over the past 70 years (Seamans and Rau

2018). Woodcock are also a popular upland gamebird hunted across its range, especially in the northern parts of its range in the eastern and midwestern United States and southern Canada (Seamans and Rau 2018). This fairly small, cryptic upland bird is most active at night, which makes monitoring efforts difficult. It is easiest to detect these birds during late winter and early spring at both dusk and dawn, when males are very vocal as part of their courtship displays (McAuley et al. 2013). These displays consist of a call, deemed the “peent” and an aerial flight display, where a male spirals over 60 m into the air before returning to the original location where the display started. This flight display is deemed the “twitter” and is produced as air filters through narrow primary feathers during the aerial display (McAuley et al. 2013). Most monitoring efforts have focused on the aural cues posed by peents and twitters (Goudy 1969, Mendall and Aldous 1943, Seamans and Rau 2018). Traditional avian monitoring techniques such as migration banding, Monitoring Avian Productivity and Survivorship (MAPS) banding stations, the Christmas Bird Count, and the North American Breeding Bird Survey do not document sufficient numbers of woodcock for accurate population estimates due to the unique life history of the species (Sauer et al. 2008). The U. S. Fish and Wildlife Service, which has management authority for this species, developed the Singing Ground Survey (SGS) in 1968 to address the gap in other monitoring programs for this species (Seamans and Rau 2018).

The Singing Ground Survey or similar surveys preceding the SGS have been the standard method for monitoring breeding woodcock since the 1930’s. The SGS consists of approximately 1500 survey routes across North America, with each route 5.4 kilometers in length with ten listening point stops located every 0.64 km. Routes are located along lightly travelled secondary roads roughly in the center of randomly chosen 10 minute-degree blocks in states and provinces in the northern and central part of the woodcock’s breeding range. The maximum distance an observer can detect a bird is estimated at 0.24 km so the 0.64-km point spacing justifies the assumption of no birds double counted. An observer listens for 2 minutes at each point, and peent calls are used to record the number of individual birds. The survey period is 38 minutes, with a start time of 22 minutes after sunset, or 15 minutes after sunset on nights with >75% cloud cover. Approximately 900 routes are surveyed annually, with remaining routes being recorded as constant zeros and only surveyed every 5 years. Surveys are scheduled to be conducted during peak display activity, but after migrant birds move through a given area; thus, survey dates vary based on latitude. Additionally, surveys are often conducted after peak breeding to avoid migrant birds. Woodcock populations are managed by the USFWS based on two management regions, Eastern and Central. Analysis of SGS data show a long-term declining trend of -1.18% per year in the eastern management region (credible interval -1.46, -.0.9, 50-year decline of 74%) and a -0.96% trend per year in the central management region (credible interval -1.20, -0.73, 50-year decline of 40%), (Seamans and Rau 2018). This declining trend highlights the need for increased research and monitoring of the species.

The SGS is both monetarily and temporally efficient and can be readily implemented on a wide scale. However, it has several shortcomings. There is an inherent road bias as with any road-based avian census (Betts et al. 2007). A single-visit survey approach may produce unreliable data because of variable climatic conditions, observer effects, noise, or other uncontrollable circumstances (Sauer et al. 2008). Additionally, the SGS has largely neglected the southern part of the bird’s range, which includes both wintering populations as well as breeding birds (Seamans and Rau 2018). Although the vast majority of woodcock hunting occurs in the northern parts of the bird’s range, the species has been declining range-wide since the 1960’s, making it even more important to monitor the bird across its range. The population that breeds in the South is especially in need of monitoring. Some state agencies have monitoring efforts focused on woodcock, but the majority of states in which the bird winters or breeds in the South do not make significant efforts for woodcock conservation (Tappe et al. 1989).

An ideal monitoring approach for American Woodcock allows for multiple surveys at a site every year with minimal observer effort. Acoustic technology has been rapidly progressing in recent years and is now considered to be a good alternative for human-observer based approaches for a wide variety of species (Shonfield and Bayne 2017). There is also a variety of software available to assist in classifying signals in acoustic data files without manually inspecting hours of recordings. The American Woodcock represents a prime candidate for this type of monitoring because it calls at a time of day when few other animals are vocalizing, and its peent calls are readily recognizable acoustic signals at a frequency that contains few other nocturnal noises. Thus, an acoustic-monitoring approach might allow for the development of a calling index, similar to that of the SGS, to be developed for American Woodcock.

Here we describe the seasonal chronology of the American Woodcock's courtship display activity in eastern Tennessee from January to April using acoustic recorders, and asses the effectiveness of using an acoustic-monitoring approach by comparing the effectiveness of Wildlife Acoustics SongMeter SMII recorders to human-observer based point counts. We also explore the potential for using automated detection to screen audio files for woodcock peent calls by using the monitoR package in program R (Hafner & Katz 2018, R Core Team 2018).

STUDY AREAS

Three sites were selected for woodcock monitoring in eastern Tennessee: two in Knox County and one in Blount County. These sites were selected because they support sufficient populations of woodcock that would allow for comparison of monitoring approaches. All three sites included wetland and upland cover types and were actively managed with prescribed fire to promote early successional vegetation. Forks of the River Wildlife Management Area (35.952572, -83.858632) is a 262-ha management area located along the Tennessee River in Knox County, Tennessee. Tennessee Wildlife Resources Agency (TWRA) actively manages the property and has been working to restore historic cedar glade habitat. This restoration project was ongoing throughout the project on this site. Seven Islands State Birding Park (35.95418, -83.68771) is a 166-ha state park located along the French Broad River in Knox County, and is actively managed for wildlife by Tennessee State Parks. Kyker Bottoms Wildlife Management Area (35.600720, -84.114217) is a 213-ha wildlife refuge in Blount County, Tennessee. The property is managed by TWRA for both waterfowl and upland birds such as Northern Bobwhite (*Colinus virginianus)* and American Woodcock.

METHODS

Acoustic Recorders

Three SongMeter SMII units were deployed from January to April on each site in 2016 and 2017 (9 units deployed each year). Seven Islands State Birding Park was excluded in 2018 because of the limited number of woodcock present, thus a total of 6 units were deployed in 2018. SMIIs recorded from one hour before sunrise to sunrise and from sunset to one hour after sunset each day. The units were either mounted on a fence post or attached to a small tree and were visited approximately monthly to replace batteries and memory cards. SMIIs were fitted with two microphones pointing horizontally from opposite sides of the unit. Units were set to record 32-bit WAV files in stereo.

Seasonal Chronology

The seasonal chronology of the American Woodcock's courtship display activity was sampled using one SMII unit deployed at Kyker Bottoms Refuge from January 8th, 2018 to April 14th,

2018. This unit was selected for characterizing the seasonal chronology because it received consistent woodcock activity during the entire monitoring period. The number of woodcock detected based on the number of peents and twitter displays was determined from analysis of 10-minute clips (n = 20), spaced as evenly as possible from January 18th to April 14th. Nights where there was significant noise interference from wind or rain were excluded, and the next suitable survey night was substituted. Each selected clip recorded from 25 to 35 minutes after sunset. The number of peents and twitter displays was determined by a single observer listening to each audio clip while simultaneously visually inspecting the sonogram for peent and twitter display signatures on the computer display.

Paired Counts

Thirty-five paired counts were conducted with human observers and the recording units. Approximately half of the counts included in the analysis were conducted by the author, with the remaining counts being conducted by trained volunteers from the University of Tennessee Student Chapter of the Wildlife Society. Human observers conducted a 10-minute point count within 1 m of a SongMeter unit, recording the number of individual woodcock present and the distance to each bird. Additionally, the number of peent calls produced by each bird and the number of twitter displays was recorded in 1-minute intervals. Observers started and ended counts with audible cues allowing audio files and human-recorded data to be precisely matched temporally.

The thirty-five 10-minute audio files paired with the human-observer counts were identified and clipped out of the one-hour recordings using Audacity acoustic software (Audacity Team 2019). The acoustic files were then split into 16-bit WAV mono files. The greater quality of the two stereo channels was selected based on quality of the spectrogram (lack of noise). Files were then imported into RavenPro 1.5 (Cornell Lab of Ornithology Bioacoustics Research

Program 2014) and spectrograms were visually inspected for peents and twitters. All visible vocalizations were selected within RavenPro. Following initial visual inspection, files were simultaneously aurally and visually inspected. Two visual inspections combined with a single aural inspection insured all vocalizations detectable on a track were selected. Number of birds in each recording was estimated from the recordings based on a combination of peent frequency, overlap between peents, and varying strength of acoustic signal. For example, if a loud peent was heard, and a barely audible peent was heard immediately after, two birds would be estimated present.

Automated Detection Using monitoR

Survey files were imported into the R package "monitoR" (R Core Team 2018, Hafner & Katz 2018). The spectrogram cross correlation function of monitoR uses spectrogram templates as a reference against spectrograms of survey files to search for vocalization of interest on survey files. I chose ten peent calls to serve as templates in monitoR based varying call intensity to represent a broad range of the woodcock's vocal repertoire. Detections by monitoR were compared to the selection tables exported from RavenPro which represented the truth. Initial output included the correlation score of each detection with the templates. Number of true positives as relating to correlation score was plotted. This was accomplished by sorting correlation scores in intervals of 0.01 and plotting against the percent of true positives from each interval. A cutoff value of 0.41 produced a 75% probability of a detection being a true positive for a woodcock peent (Figure 1).

The effective detection distance of a SongMeter for detecting woodcock peents was determined by walking away from a stationary, displaying bird at a known location and stopping at successive points to determine the breaking point where a bird could no longer be aurally detected on the SMII audio file. The same files used for this test were run through monitoR to determine the effective detection distance of woodcock peents detection and classified the program. The effective detection distance for human observers was estimated by inputting estimated distances into Program Distance (Thomas et al. 2010).

RESULTS

Seasonal Chronology

I examined acoustic survey files for one SMII unit at Kyker Bottoms Wildlife Management Area which had consistent American Woodcock activity throughout winter-spring 2018 to document the seasonal chronology of courtship behavior. The average number of peents per 10-minute sampling period was 76.8 (range 1-119; Figure 2). The average number of twitters was 2.05 (range 0-4; Figure 3). Only the closest bird's peents and twitters were plotted because additional birds were never close enough to get a precise picture of display activity (average number of peents detected was 4, range was 0-8, average number of twitter displays was 0.67, range 0-2).

No woodcock activity was detected in the first two survey periods in January 2018, and only one peent call was detected in the third period (19 Jan 2018; Table 1). However, on the fourth period (23 Jan 2018), a bird was observed in full display with 96 peents and a display flight. A second bird was detected starting on February 10th and continued to be detected in the majority of survey periods until March 9th. One bird consistently displayed near the unit, and the second bird was consistently near the edge of detectable range for the unit, undoubtedly affecting the number of peents and twitters recorded. The number of peents and display flights produced by the single bird peeked on 22 February and slowly declined before significantly dropping off around 1 April 2018, although the bird continued to display through April 14th, the end of the monitoring period.

Monitoring

The number of peents detected by human observers, detected by SongMeter SMII via human transcription of audio files, and detected by SMIIs via classification analysis of audio files in monitoR’s spectrogram cross correlation function had varying degrees of success in detecting woodcock vocalizations (Table 2). Human observers detected the greatest number of both individual birds and peents. We produced a linear regression relating number of birds detected on a survey to the number of peents recorded (Figure 4). This regression had a correlation coefficient of 0.54 and a P-value of <0.001.

Program Distance (Thomas et al. 2010) was used to estimate maximum effective distance of human-based point counts to be 78.2 +/- 7.29 m. This translates to an area coverage of 1.9 ha for a human from a single listening location. The maximum detection distance of an SMII with human transcription was 207 m with an area coverage of 13.5 ha, whereas the maximum distance of an SMII file analyzed with monitoR was 146 m for an area coverage of 6.7 ha.

The SMII units recorded up to 96% of the peents detected by human observers based on human transcription of the audio files. The number of birds estimated by an observer listening to audio files was 65% of what was reported in the field by human observers. The number of birds detected by both methods was highly correlated with a correlation coefficient of 0.87 and had a P-value of <0.001 for Pearson's product-moment correlation (Figure 5).

Automated detection through monitoR correctly classified 55% of the peents recorded by a human observer. The correlation coefficient for number of peents detected by a human and by monitoR was 0.57 and Pearson's product-moment correlation P-value was 0.0003 (Figure 6). Using the regression equation produced from human-based counts, monitoR detected an estimated 72% of the birds detected by human observers.

DISCUSSION

Seasonal Chronology

The beginning of the American Woodcock's breeding season starts out slowly, with birds only displaying on warm evenings (Duke 1966). This was consistent with the recordings from Kyker Bottoms Refuge, with the no or little activity detected in the first three weeks in January surveyed. As the breeding season progresses, woodcock display activity increases, with wintering, migrant, and year-round resident birds displaying. The SMII recorder documented the increase in activity, first with the addition of one individual, and eventually a second individual. This level of activity stayed relatively constant for several display periods (21 Jan-27 Feb) before the second bird was no longer detected (9 Mar), soon after which activity of the first bird significantly decreased. Individual woodcock have high display site fecundity (E. Buck, unpubl. data). Based on analysis of the acoustic data, one bird was consistently near the SMII for the majority of survey periods, and the second bird present in some recordings was consistently distant and consequently relatively few peents were recorded. Assuming high display site fidelity, these recordings could have represented the activity of the same two individuals. Several samples with two birds also record aggressive cackles by the closest bird, indicating territorial defense.

The closest bird on the recordings was likely a local breeder because it was present well past the time that a migrant bird would have left eastern Tennessee to breed farther north (Moore 2016). The first bird's display activity also decreased in concordance with the end of woodcock nesting in the Southeast (McAuley et al. 2013). The second bird may have been a migrant because it ceased to be detected in early March, corresponding with the timing of woodcock migration (Moore 2016). Tracking the woodcock detections of one SMII throughout a season allowed the activity of one bird to be effectively described and its residence status to be determined. It also highlights the inability of the recoding unit to consistently detect birds farther away, with a second bird only registering a maximum of 8 peents on the recorder when it was likely emitting a greater number of calls than recorded. Woodcock activity was at the highest levels from 21 January-27 February in this sample. High levels of display activity from a single bird, likely a local breeder, continued through the end of March.

Monitoring

Acoustic monitoring approaches have been shown to be useful for replacing or supplementing human-based bird monitoring for a host of species and settings (Digby et al. 2013, Sanders and Mennill 2014, Shonfield and Bayne 2017). In general, acoustic monitoring has proven to be accurate and has the distinct advantage of producing permanent audio records of vocalizations occurring at a given place and time (Kulaga and Budka 2019). In some cases, acoustic monitoring can be more cost-effective than human-based counts because automated recording units (ARUs) can be deployed and left unattended for prolonged periods of time (Shonfield and Bayne 2017). Other than the initial cost of ARUs, the effort and cost associated with extracting and classifying useable data form the ARUs can be significant depending on the monitoring approach and the ability to classify songs/calls through automated detection approaches (Digby et al. 2013).

ARU's have been shown to be effective as both a replacement for surveys traditionally conducted by humans (Digby et al. 2013, Kulaga and Budka 2019) and to explore new monitoring applications of species previously seldom surveyed by humans (Saunders and Mennill 2014). One such species traditionally surveyed by humans is the American Woodcock (Shonfield and Bayne 2018). Surveys by human observers such as the Singing Ground Survey have been the standard for monitoring woodcock since the 1930's. Because of the historic survey, we used human observer counts as the basis for comparison with the acoustic monitoring approach. However, human-observer monitoring methods may be subject to bias, associated with the experience, training, hearing ability, and age of the observer (Alldredge et al. 2007). Our results show that it is possible to successfully document the breeding display of woodcock by deploying automated recorders. With a detection rate of 96% for peents and 64% for individuals, monitoring woodcock with acoustic recorders is readily relatable to human-observer monitoring.

Automated detection of bird calls/songs on audio files by programs such as the R-based monitoR has been gaining popularity in the past 10 years as technology has progressed. In our results, monitoR was able to correctly classify a large proportion of peent calls present on an audio file. Within our compared count sample, monitoR had a correct classification rate of 55% for peents, as opposed to 96% for the SMII with human transcription (Table 2). The majority of incorrect classifications were false negative observations: the program failed to detect a call when the call was audible and/or visible (at least faintly) on the audio file. The cutoff for correlation score can easily be set lower than the 0.41 we used for a target 75% correct classification rate to address this issue. However, a lower cutoff threshold will result in more false positive detections and an overestimation of bird numbers. Thus, a balance must be struck between producing false positives versus false negatives. A threshold of 0.41 which produced a 75% correct classification rate may be a reasonable balance.

Woodcock are consistent about the time of day they begin displaying in the evening, with some variation corresponding with differing cloud cover (Duke 1966). This life history trait makes it possible to record and process very short periods of time nightly (e. g., record 30 min and process 10 min). Given this short recording time, audio files could be relatively easily examined and transcribed by humans. Based on our experience, it takes approximately 20 minutes to transcribe a 10-min file (2 min transcription per minute recording).

I estimated the amount of time required to complete 6 surveys of one point within a year using either human-based counts, an ARU with human transcription, or an ARU with detection in monitoR (Table 3). I used six sample periods for this estimate because this would allow a complete picture of the woodcock population to be obtained, with estimations of both wintering and breeding woodcock. The first year of any monitoring effort will consume the most time due to acquiring the necessary training. For the first year I estimated a total time of 12 hours for human-based surveys, 11 hours for an ARU with human transcription, and 14 hours for an ARU with monitoR analyses. After the initial training period, I estimated these times would drop to 7 hours for human-based counts, 5 hours for an ARU with human transcription, and 3.5 hours for an ARU with monitor analyses.

Given the above scenario, deploying acoustic recorders on areas where woodcock monitoring is high priority may be the most practical and cost-efficient approach. A land manager could deploy a series of recorders prior to the expected peak in courtship displays, leave them for approximately 10 weeks, and retrieve them at their convenience. Observers only need to concentrate on a sample period within the timeframe of 25-35 minutes after sunset when reviewing audio files. The period 60-20 minutes before sunrise could be used in a similar fashion, although historic monitoring efforts have focused on evening displays. The focus on evening displays is due to evening surveys being more consistent with the period of regular human activity; the morning period could also be used when using acoustic recorders if additional surveys are required. However, evening surveys also have an advantage of consistency with SGS and other woodcock surveys.

Whether acoustic recorders are used in place of or to supplement human observers, they remain a viable option for avian population monitoring. This has been demonstrated for a large suite of species, now including American Woodcock. Similar to our woodcock project, acoustic recorders have been used successfully to survey for Lesser Spotted Kiwi in New Zealand (Digby et al. 2013). Kiwis are nocturnal and are primarily monitored through point count surveys, similar to American Woodcock. Digby found that manually transcribing acoustic files was more time efficient than having a trained observer physically present to conduct the point count survey. Digby's manually transcribed recordings detected 85% of the birds an observer was able to detect; when analyzed with automated detection software, 42% of calls were detected. Our results show that monitoring woodcock with automated detection is more effective than Digby's methods for Kiwi both when manually reviewing audio files and when using automated detection software. Acoustic recorders can be effectively used to monitor woodcock at a small management area scale. With some modifications this strategy could be implemented on a much larger scale across a state or even the entire breeding range of the American Woodcock.

MANAGEMENT IMPLICATIONS

Based on our results, we conclude that ARUs are an accurate and efficient means to monitor American Woodcock. Given the detection distance of ~200 m with an SMII, one unit can effectively monitor 12.5 ha. Assuming a goal of monitoring 10% of a management area, a management area like Kyker Bottoms would only require 2 SMIIs to cover the 200-ha management area. If the management area was stratified into potential woodcock habitat, the deployment of SMIIs could be even more effective. For a WMA in the mid-South, an ARU should be deployed from 15 January - 30 March. This timeframe allows for both winter and breeding woodcock populations to be estimated, only requires two site visits (deployment and retrieval) and will not require memory or batteries to be replaced during the sampling period. Following audio collection, six survey periods could be examined for woodcock: three between 15 January and 15 February in order to survey for wintering birds, and 3 between 15 March and

30 March to survey for breeding birds. The period from 30-40 minutes after sunset should be examined for woodcock calls by simultaneously watching the sonogram and listening to the recording. If the area to be surveyed covers a large land area or an entire region (i.e., 1000s of ha), an automated detection and classification analysis, such as monitoR, to document the number of peents may be effective. With the effective distance of monitoR-based monitoring at ~146 m, an area of 6.7 ha can be surveyed with each ARU. The number of individual woodcock can then be estimated as we have shown here through a linear regression relating peents per minute to individual woodcock.

The total up-front cost for one ARU equivalent to a SongMeter SMII, batteries, and necessary memory cards is approximately $1000. After initial acquisition, the only supplies needed each year are batteries, which would cost under $10 per season of monitoring.

Acoustic recorders can be used to survey for other taxa such as other priority birds and anurans. The ability to use an acoustic approach for multiple monitoring needs would further reduce associated costs of implementing an acoustic monitoring approach.

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FIGURES AND TABLES

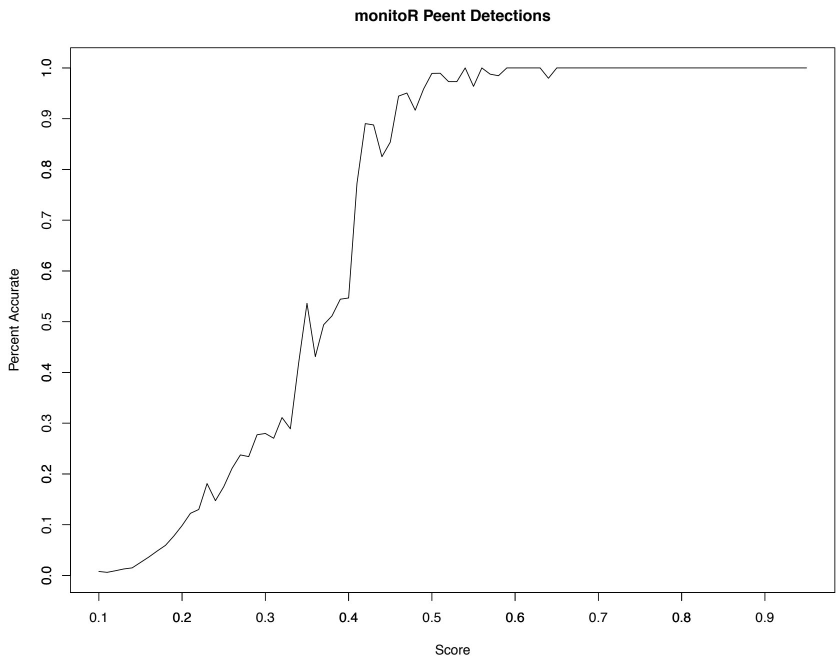

Figure 1. The correlation score of a peent vocalization plotted against the percent of true positive detections produced. The percent of true positives was calculated by dividing the number of true positives by the total number of detections within a given interval. The correlation score that optimizes the correct classification rate is then used to classify detections in recordings.

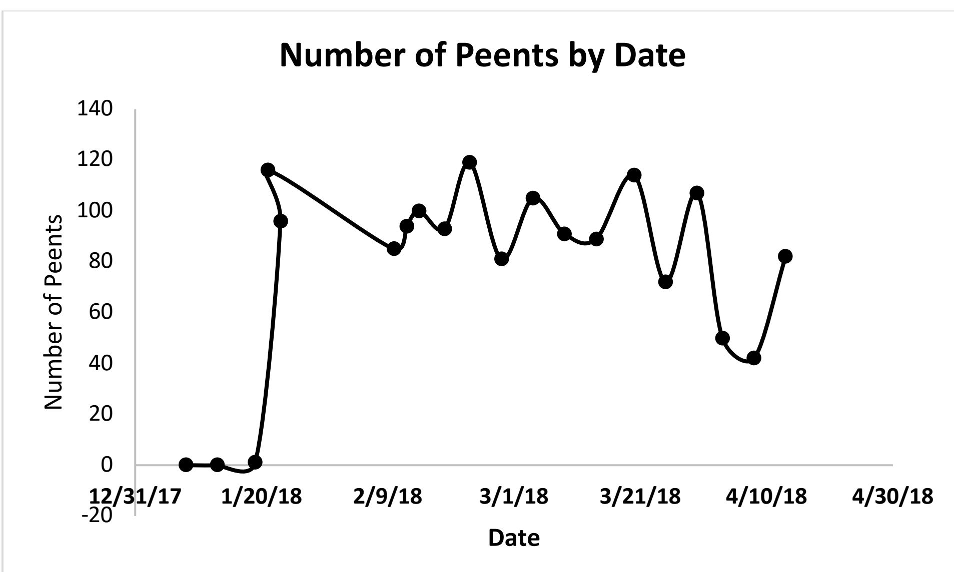

Figure 2. The number of peents produced by a single American Woodcock as recorded on a Wildlife Acoustics SMII automated recording unit within a 10-minute sample period plotted by date, January – April 2018, Kyker Bottoms Wildlife Management Area, Blount County, TN.

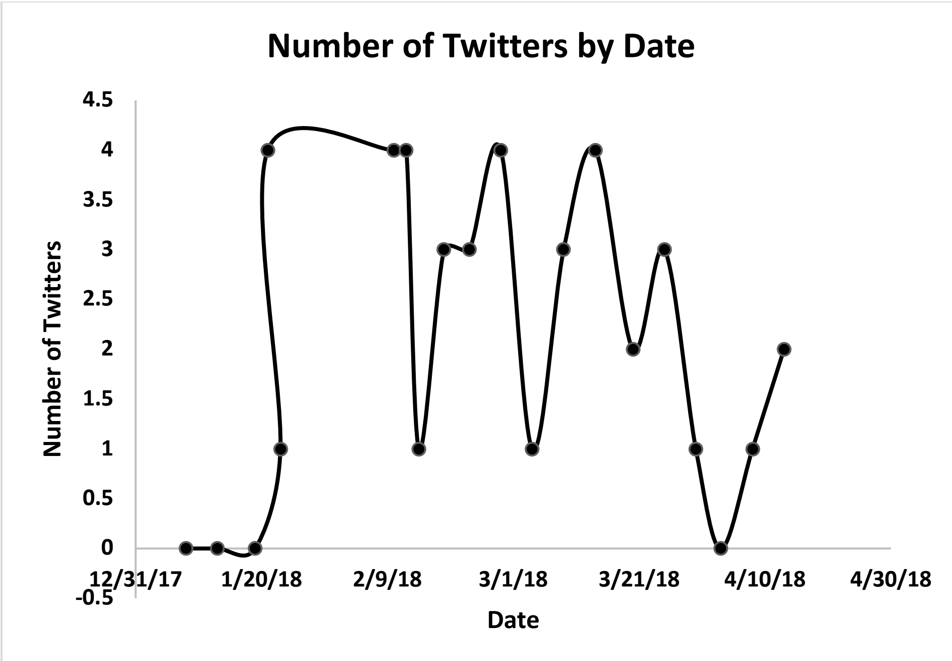

Figure 3. The number of twitter displays produced by a single woodcock as recorded on a Wildlife Acoustics SMII automated recording unit within a 10-minute sample period plotted by date, January – April 2018, Kyker Bottoms Wildlife Management Area, Blount County, TN.

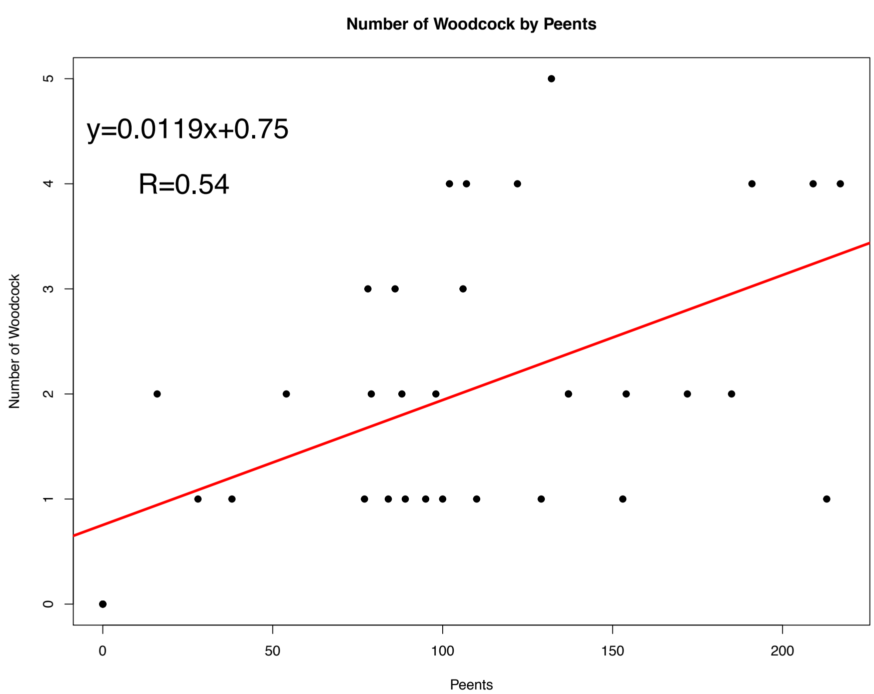

Figure 4: Number of individual woodcock as predicted by number of peents recorded by a human observer on three management areas in eastern Tennessee, Jan – Apr, 2016-2018.

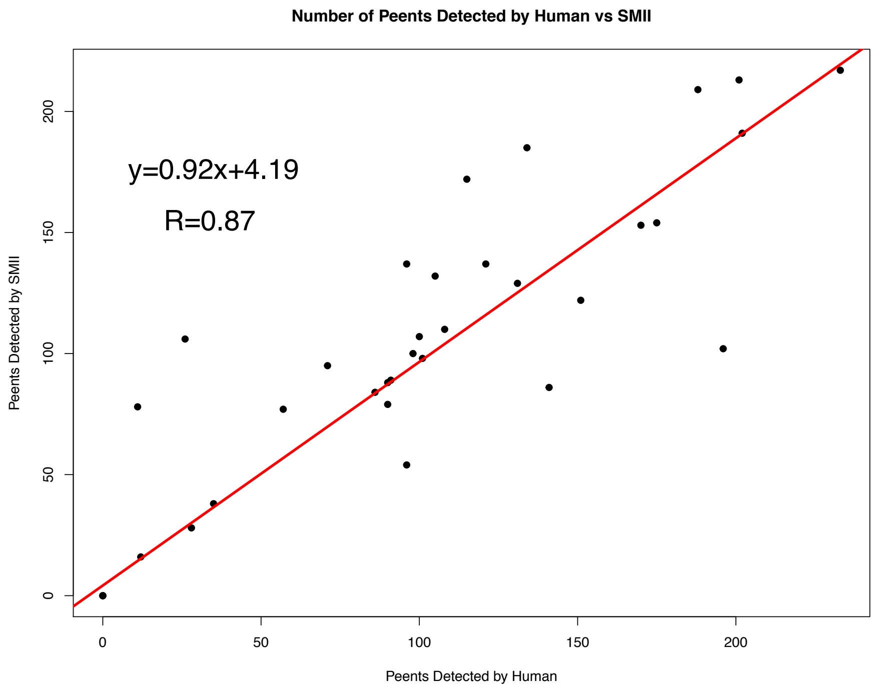

Figure 5: Number of woodcock peents detected by SongMeter SMII compared to number of peents recorded by a human observer on three management areas in eastern Tennessee, Jan – Apr, 2016-2018.

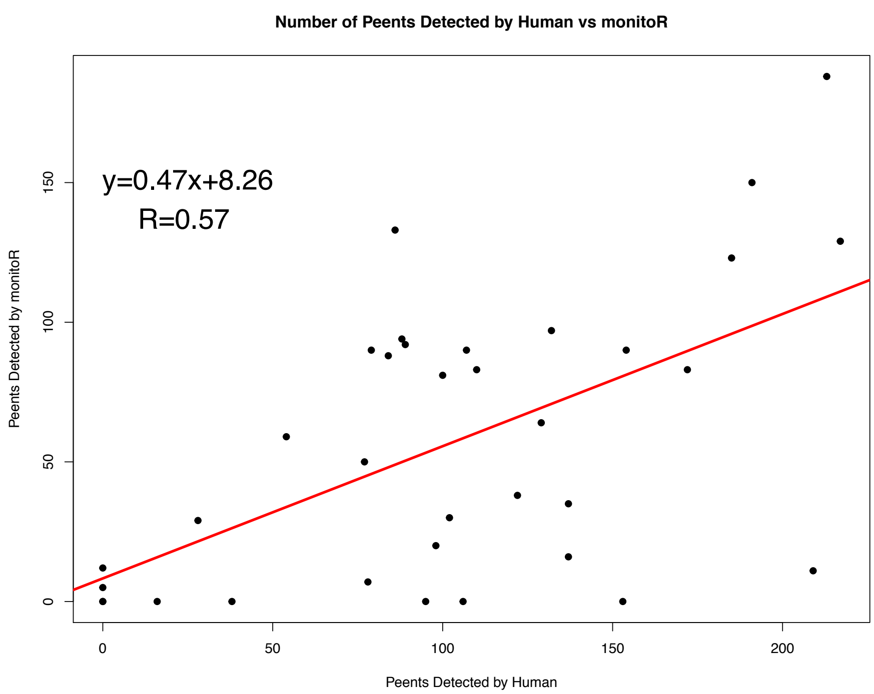

Figure 6: Number of woodcock peents detected by monitoR compared to number of peents recorded by a human observer.

Table 1. American Woodcock activity from January to April 2018 at Kyker Bottoms Wildlife Management Area, Blount County, TN

Date	Number of Birds	Peents Bird #1	Twitters Bird #1	Peents Bird #2	Twitters Bird #2
1/8/18	0	0	0	N/A	N/A
1/13/18	0	0	0	N/A	N/A
1/19/18	1	1	0	N/A	N/A
1/23/18	1	96	1	N/A	N/A
1/21/18	1	116	4	N/A	N/A
2/10/18	2	85	4	8	2
2/12/18	1	94	4	N/A	N/A
2/14/18	2	100	1	5	1
2/18/18	2	93	3	3	0
2/22/18	2	119	3	3	0
2/27/18	2	81	4	5	0
3/4/18	2	105	1	0	1
3/9/18	1	91	3	N/A	N/A
3/14/18	1	89	4	N/A	N/A
3/20/18	1	114	2	N/A	N/A
3/25/18	1	72	3	N/A	N/A
3/30/18	1	107	1	N/A	N/A
4/3/18	1	50	0	N/A	N/A
4/8/18	1	42	1	N/A	N/A
4/13/18	1	82	2	N/A	N/A

Table 2. Number of peent calls detected and number of individuals observed by human observer (considered the "truth"), birds detected by visually examining sonograms while listening to recordings, and birds detected by the monitoR package in R.

Survey ID	Birds Human	Peents Human	Birds SM II	Peents SMII	Birds Monitor	Peents monitoR
G_Forks_11Feb16	0	0	0	0	0.00	12
L_7Is_30Mar16	0	0	0	0	0.00	0
L_Kyker_06March18	0	0	0	0	0.00	5
M_Kyker_31March18	0	0	0	0	0.00	0
K_Kyker_08Mar16	2	16	1	12	0.00	0
F_Forks_04April18	1	28	1	28	1.10	29
M_Kyker_06Mar18	1	38	1	35	0.00	0
M_Kyker_02Feb17	2	54	2	96	1.45	59

Table 2. cont.

Survey ID	Birds Human	Peents Human	Birds SM II	Peents SMII	Birds Monitor	Peents monitoR
D_Kyker_23Feb16	1	77	1	57	1.35	50
G_Forks_26Feb16	3	78	2	11	0.83	7
F_Forks_27Feb17	2	79	1	90	1.82	90
E_Forks_25Mar18	1	84	1	86	1.80	88
H_7Is_25Feb16	3	86	2	141	2.33	133
E_Forks_27Feb17	2	88	2	90	1.87	94
H_7Is_08Mar17	1	89	1	91	1.84	92
I_7Is_30Mar17	1	95	1	71	0.00	0
F_Forks_08Mar16	2	98	1	101	0.99	20
K_Kyker_23Feb16	1	100	1	98	1.71	81
M_Kyker_23Feb16	4	102	2	196	1.11	30
G_Forks_08Mar16	3	106	1	26	0.00	0
G_Forks_25Mar18_2	4	107	2	100	1.82	90
D_Kyker_05Apr16	1	110	1	108	1.74	83
G_Forks_27Feb17	4	122	2	151	1.20	38
G_Forks_08Mar18	1	129	1	131	1.51	64
H_7Is_22Feb17	5	132	2	105	1.90	97
G_Forks_28Mar17	2	137	2	121	0.94	16
L_7Is_25Feb16	2	137	2	96	1.17	35
H_7Is_10Mar16	1	153	1	170	0.00	0
D_Kyker_23Mar16	2	154	1	175	1.82	90
L_7Is_08Mar17	2	172	1	115	1.74	83
D_Kyker_09Mar16	2	185	2	134	2.21	123
G_Forks_25Mar18_1	4	191	2	202	2.54	150
E_Forks_08Mar16	4	209	2	188	0.88	11
K_Kyker_20Feb17	1	213	1	201	2.99	188
I_7Is_29Feb16	4	217	2	233	2.29	129
Totals	**69**	**3586**	**45**	**3459**	**42.94**	**1987**
Percent Accurate	**100**	**100**	**65**	**96**	**62**	**55**

Table 3. Estimated time investment required for conducting six surveys of one site within a year, using human-based counts, an ARU with human transcription, and an ARU with monitoR for transcription. Total time including training reflects the initial learning time as a monitoring scheme is set up (first year), and the total time excluding training is the time once techniques are mastered in subsequent years.

Activity (hours)	Human-based Count	ARU with Human Transcription	ARU with monitoR
Training	5	6	9
Field Time	6	2	2
Office Time	1	3	3
Total Time (including training)	**12**	**11**	**14**
Total time (excluding training)	**7**	**5**	**3.5**