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Use of acoustic methods for monitoring avian communities in temperate and tropical ecosystems

Vijak Chimchome

To the Graduate Council:

I am submitting herewith a dissertation written by Vijak Chimchome entitled "Use of acoustic methods for monitoring avian communities in temperate and tropical ecosystems." I have examined the final electronic copy of this dissertation for form and content and recommend that it be accepted in partial fulfillment of the requirements for the degree of Doctor of Philosophy, with a major in Natural Resources.

David A. Buehler, Major Professor

We have read this dissertation and recommend its acceptance:

Arnold M. Saxton, Craig A. Harper, Frank T. van Manen

Accepted for the Council:
Carolyn R. Hodges

Vice Provost and Dean of the Graduate School

(Original signatures are on file with official student records.)

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USE OF ACOUSTIC METHODS FOR MONITORING AVIAN COMMUNITIES IN TEMPERATE AND TROPICAL ECOSYSTEMS

A Dissertation Presented for
The Doctor of Philosophy Degree
The University of Tennessee, Knoxville

Vijak Chimchome

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ABSTRACT

This research addressed acoustic monitoring for avian populations as a monitoring protocol in three different habitats in Tennessee and Kentucky (grassland at Fort Campbell Military Reserve in 2000; oldfield at Freel's Bend Wildlife Management Area, Oak Ridge in 2000; and mixed hardwood forest at Cherokee National Forest, Tellico District in 2002 and 2003) and two habitats in Thailand in 2002 (hill evergreen forest at Phu Luang Wildlife Sanctuary, Loei province; and grassland at KhaoYai National Park, Na Korn Ratchasima province). Four recording devices, originally built in 2000, were comprised of Sennheiser MKH20 omni-directional microphones with 18-volt phantom power supplies, Jensen videocassette recorders (Hi-Fi VCRs) with 12-volt marine batteries, and microphone amplifiers with 9-volt batteries. In 2002, the recording devices were modified in that VCRs were replaced by computers as recorders. A 9-ha plot (300 m x 300 m) was set up in each habitat and included the four monitoring stations at grid intersections with 150-m spacing between each station. On 10 mornings during the breeding season, the sites were acoustically monitored for 2 hours. The acoustic method was tested by conducting two standard census techniques currently used for bird monitoring: a series of 10-minute, unlimited-distance point counts at each monitoring station and territory mapping. In most habitats, acoustic monitoring detected an equal or greater number of bird species when compared to unlimited-distance point counts or territory mapping when these 3 methods were conducted simultaneously. Some overlooked species at great distances as well as species during the dawn chorus were detected acoustically but not by other methods. On the other hand, secretive species and

non-vocal flyovers were missed by the acoustic method. Sampling effort representing different combinations of number of visits, number of monitoring stations, and recording periods were investigated. In general, a greater number of recording periods, visits, and stations may be needed to detect most species in the area when species richness is high. I recorded 45 species in Fort Campbell grasslands and 54 species in Freel's Bend oldfields based on 10-day data from the 3 methods; the results suggested using ten 90-minute visits with 4 stations and ten 120-minute visits with 4 stations in those areas, respectively. Similar results were found in the temperate forest habitat. I recorded 33 species in Cherokee National Forest, Tennessee, based on 8 days of monitoring by the 3 methods. The optimal sampling effort was eight 80-minute visits with 4 acoustic monitoring stations to document the maximum number of species detected on Cherokee NF. In tropical ecosystems, I detected 72 species in KhaoYai based on 5 days of monitoring and 69 species in Phu Luang, Thailand based on 8 days of observation with the 3 methods. The optimal sampling effort for the maximum number of species was five 100-minute visits with 4 stations and eight 110-minute visits with 4 stations for Khao Yai and Phu Luang, respectively. The number of species detected within 10-minute increments during 2 hours of recording was used to estimate the detection probability of individual species by the acoustic method. Most species were detected each day within 2 hours of recording and were detected within 80-100 minutes in 1 visit for all habitats. Detection probability estimated by acoustic method was similar to aural observations from previous studies indicating that the capacity of acoustic devices to detect individual avian vocalizations was equivalent to the ability of human hearing. Based on the results of this study, acoustic monitoring should be viewed as a suitable monitoring technique under certain conditions: 1) when many sites need to be monitored simultaneously and expert observers are limited, 2) when the study sites are in area of restricted access, and 3) when the number and densities of species present are great. Acoustic approaches cannot provide abundance estimates unless the individual vocalization is identified by an array of microphones or by individual voice recognition software. An index to relative abundance can be developed with the acoustic method by using multiple monitoring sites and calculating (the number of sites with a species)/(total number of sites).

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CHAPTER 1

INTRODUCTION

Population monitoring plays a critical role in wildlife conservation by providing the information necessary to identify conservation problems at an early stage and to suggest possible solutions (Goldsmith 1991). However, it is impractical to monitor all groups of organisms on a wide scale. Birds usually are high in food chains and may be sensitive to environmental change and thus may provide valuable indicators of the state of the environment (Baillie 1991).

Bioacoustic methods have been used extensively for monitoring populations of marine fish and marine mammals. Russell (1998) and McDonald (1999) used acoustic monitoring to assess the abundance of Cetacean populations in the open ocean. Maravelias (1999) conducted acoustic surveys to determine the distribution and abundance of pelagic fish [Atlantic herring (*Clupea harengus*)] in the North Sea. Lawson (1999) conducted acoustic surveys for Atlantic cod (*Gazdus morhua* L.) in inshore Placentia Bay, Newfoundland, Canada, and reported greater acoustic density estimates during the day than at night.

Playback recordings have been used as a tool to census breeding bird populations for more than two decades (Johnson et al. 1981). However, bioacoustic methods have received limited use for monitoring avian communities. Parker (1991) advocated the use of acoustic monitoring as an alternative to specimen collection for building an inventory of a diverse avifauna; however, this method has rarely been used to survey avian communities (Foster 1995).

Efforts to use signal-processing technology to automate the recording, detection, and identification of night-flight calls are currently underway at the Cornell Lab of Ornithology (Evans and Rosenberg 2000). For example, a Texas audio-recording station detected a major migration of grassland sparrows, and a station in British Columbia detected hundreds of Swainson's thrushes (*Catharus ustulatus*); both phenomena were not detected with field monitoring efforts.

Little research on acoustic methods for diurnal bird monitoring has been reported in the literature. Haselmayer and Quinn (2000) tested the ability of sound recordings relative to that of point counts to estimate bird species richness in tropical forest of Tambopata Reserve in southeastern Peru. They concluded that sound recording was a suitable alternative to point counts for estimating species richness, particularly when species richness was high, as during the dawn chorus, because the technique allows for repeated listening. Hobson et al. (2002) compared richness and abundance of species recorded by field experts with richness and abundance determined by simultaneous recordings later analyzed by the same observer. They found that the acoustic recording technique worked well for bird communities associated with the southern boreal mixed forest of central Saskatchewan and western Ontario. Similarity measures for both presence-absence and abundance data ranged from 83 to 93%. Cunningham et al. (2004) used automatic sound recorders to examine the statistical properties of vocal activity and model the relationship between vocal activity and bird abundance in fragmented forest at

Tumut in south-eastern Australia. Their analysis suggested that sound recording data would be informative for analyzing temporal patterns in vocal activity but did not seem to be a useful method for estimating bird abundance.

Territory mapping and point counts have been used as standard protocols for avian monitoring. Territory mapping may provide the best estimate of density because the technique produces a map of distribution of birds (Bibby et al. 2000). Point counts can be used as an index to density or, with detection probability, to directly estimate density. The acoustic approaches can at best be used to develop an index to relative abundance by using multiple monitoring sites and using the (number of sites with a species)/(total number of sites) as an index to relative abundance. The acoustic monitoring can not be used to record abundance at a location unless software is developed that has the capacity to do individual voice recognition. However, the advantages of acoustic surveys include the archived record of point counts, the use of non-expert field staff to collect recordings and the standardization of field data through time, a permanent record of species presence, and monitoring of many sites simultaneously (Haselmayer and Quinn 2000, Hobson et al. 2002). The techniques also may provide alternative methods for monitoring bird populations in inaccessible areas, such as military reserves or remote areas.

The overall design for this research was aimed to develop an acoustic monitoring system and to apply monitoring protocols for bird populations in 5 different habitats during the breeding season. Rather than replicate the field experiment within a given habitat, I chose to conduct the experiment across a very broad range of conditions as a means to evaluate across habitat variability. Within habitat variability in results could be expected to be much less than across habitat variability. Ten visits with 4 recording stations and up to 2-hour recording per visit were conducted in 9-ha plot in 5 habitats. The effect of recording period, number of visits, and number of stations, and time of morning were investigated to answer the basic questions of how many visits, how many stations, when to record, and how long to record to detect the most species present in those areas. In addition, species detectability was determined for each species in each habitat to incorporate with the acoustic monitoring protocols. To determine the efficiency of the acoustic monitoring compared to the standard monitoring protocols, territory mapping and unlimited-distance point counts were conducted concurrently with the acoustic monitoring.

Chapter 2-6 document the use of acoustic method for monitoring avian species presence, and document species' detection probability by acoustic monitoring during the breeding season in different temperate and tropical habitats. At the end of each chapter, a set of recommendations is provided for managers and researchers for using acoustic methods to census bird population during the breeding season. The overall results and recommendations for implementing an acoustic monitoring program are summarized in Chapter 7.

CHAPTER 2

USE OF ACOUSTIC METHOD FOR MONITORING BIRDS IN TEMPERATE GRASSLAND AT FORT CAMPBELL, TENNESSEE-KENTUCKY

Fort Campbell Military Reservation (FCMR), a 42,000-ha base located on the Tennessee-Kentucky state line contains one of the largest remaining blocks of native prairie "barrens" east of the Mississippi. Barrens are grass-dominated, treeless areas occurring on hilly, karst topography in west central Kentucky and northwestern Tennessee (Chester et al. 1997). This area not only provides the opportunity to support military exercises, including airborne training into open drop zones, ground-based infantry and light-mechanized training, and various artillery ranges, but also contributes substantially to wildlife conservation goals (Moss 2001). Fort Campbell grasslands contain native warm season grasses including little bluestem (*Schizachyrium scoparium*), big bluestem (*Andropogon gerardii*), switchgrass (*Panicum virgatum*), Indiangrass (*Sorghastrum nutans*), and broomsedge (*Andropogon virginicus*) and non-native cool-season grasses. Oak/hickory forest types and a limited number of leased agricultural fields (hay, millet, and soybeans) were interspersed among the grasslands. Grasslands, the main habitat in those areas, provide ideal conditions for such training exercises because the grasslands are durable, provide for great visibility, and can be effectively managed with the use of fire by burning on a 3-year rotation. Thus, the habitat conditions provide an excellent living environment for grassland birds. Nevertheless, because of military activities, this area is not easily accessible for monitoring avian distribution and abundance and relating their occurrence to specific management regimes and habitat characteristics. Developing and implementing acoustic monitoring is necessary to evaluate avian use of otherwise inaccessible impact zones.

The objectives for this chapter were to analyze and develop an acoustic monitoring protocol for bird populations in temperate grassland habitat and compare it with standard protocols (point counts and territory mapping) for documenting species presence.

Study Plot

The acoustic monitoring system was set up in a 9-ha plot inside a native warm season grassland habitat. This area was an old airstrip in training area 17, which had reverted back to a native grass field. Vegetation consisted primarily of little bluestem and broomsedge mixed with forbs and woody vegetation. A woody area (35 m x 18 m) was located in the plot. The 65-ha field was bordered on one side by a cornfield and a road on the other side. The remaining two sides were surrounded by forest.

Methods

<u>Monitoring Protocols</u>

Territory mapping and point counts have been widely used to estimate the number of birds in terrestrial habitats. The territory mapping method has been considered the standard technique applied primarily to terrestrial and non-colonial passerines (Robbins

1970). This method is often used to derive population indices and used in the breeding bird census program to collect habitat information (Bibby et al. 2000). Unlimited-distance point counts are probably the simplest of all approaches and useful for long-term and comparative monitoring of bird populations (Blondel et al. 1981, Robbins et al. 1989). Unlike variable-radius point counts or the fixed-radius method, observers do not need to estimate the distance of each bird from the observer (Reynolds et al. 1980, Gate 1995).

The acoustic monitoring system was designed and constructed in 2000 based on discussions with personnel at the Cornell Lab of Ornithology. Four individual units were built, comprised of Sennheiser MKH20 omni-directional microphones with 18-volt phantom power supplies, Jensen videocassette recorders (Hi-Fi VCRs) with 12-volt marine batteries, and microphone amplifiers with 9-volt batteries. Recordings were stored on EP 8-hour videocassettes for further analysis.

The 9-ha plot (300 m x 300 m) was delineated and a 75 m x 75 m grid was marked off across the plot. The four recording devices were placed at grid intersections with 150-m spacing between each station (Figure 2-1; all tables and figures are located in Appendices). I conducted comparisons among territory-mapping, unlimited-distance point counts, and acoustic method on 10 mornings between 7 – 17 July 2000. Surveys were not conducted when it was raining, or when there was moderate wind (Beaufort scale: 13-19 kmph; leaves and twigs in constant motion and the wind extends a light flag).

Territory Mapping

Territory mapping was used to record all birds seen or heard while systematically walking along established grids. In general, I followed the territory-mapping protocol as described by Kendeigh (1944) and Verner (1985). Starting and ending points were rotated between censuses from A1 to E5 or E1 to A5 (Figure 2-1). During each of 10 visits, all birds seen or heard were recorded by plotting the locations of each individual on the map of the plot. Later the locations were transferred to separate maps for each species; and clusters of locations were identified that were assumed to represent centers of activity by individual territory holders. Whenever possible, species, sex, and the activity of each bird were recorded. Flyovers also were recorded and added to a species list.

Point Counts

Point counting involved an observer recording birds from a single point for a standardized time period (Ralph et. al 1995). While I mapped bird territories along the gridlines on each plot, I conducted 10-minute unlimited-distance point counts from a fixed station (B2, B4, D2, and D4; Figure 2-1). To ensure compatibility with a wide range of count durations currently being used by other researchers, I divided my 10-minute counts into 0-3 minute, 3-5 minute, and 5-10 minute time-interval data. Counts began immediately upon arrival at a station and all birds seen or heard were recorded in their respective time interval. The three time intervals were combined for a 10-minute counts for analysis. Birds observed flying over the plots were also added to the list for analysis. I followed the point count protocol as described by Hamel et al. (1996).

Acoustic Monitoring

The territory mapping and point counts were conducted after 4 acoustic devices were started recording so that all methods were conducted at the same time within a 2-hour period between 0600 to 0900. Recordings were collected and analyzed aurally by the same observer. To aid in identification during analysis, I visualized the recorded sound by displaying the spectrogram using Avisoft-SASLab Pro (Specht 2002).

Data and Statistical Analysis

"Supplemented count" or "cumulative number of species" was defined as the cumulative species detected based on each variable (i.e., recording periods from 10 to 120 minutes, number of visits from 1 to 10, and number of stations from 1 to 4). "Unsupplemented count" was defined as the number of species detected at each ten- minute increment during each visit and at each station.

Based on 10-day sampling visits of 4 point counts / day (40-point total), 2-hour territory mapping / day (10-day mapping), and 2-hour recordings of 4 stations / day (80-hour total), a species list was generated for each method and then pooled for the overall bird list. A similarity index was used to compare the methods: similarity index $= 2(Sab)/(Sa + Sb)$, where Sa is the number of species detected by method a, Sb is the number of species detected by method b, and Sab is the number of species detected by both methods. A paired t-test was used to compare the mean number of species per point per 10 minutes between unlimited-distance point counts and acoustic monitoring methods. To double check (validate) my species identifications an expert listened to ten recordings at point-count stations. Then, the number of species detected by an expert in each 10-minute recording was compared with my results.

Acoustic data based on the 2-hour recordings of 4 stations each day and 10-day visits were analyzed using SAS (2000) unless otherwise indicated in the following.

The effect of increasing ten-minute recording period was analyzed using the Mixed Models procedure with repeated measures. An autoregressive correlation pattern was used to address the correlation between repeated observations, with visit as the repeated subject. Least squares means (LSM) of cumulative species when adding ten-minute recording period were reported for interpretation. Because cumulative species were not independent, new species detected per successive recording period was used to statistically test the effect of increasing ten-minute recording period. In the model, recording period was used as a fixed effect whereas visit and the interaction between visit and recording period were random effects. Station formed the error term because it was used as a random replicate.

The effect of increased number of visits on new species detected was investigated using Mixed Models procedure with repeated measures. An autoregressive correlation pattern was used, with the interaction between visit and period as the repeated subject. The dependent variable was new species detected when adding more visits. However, LSM of cumulative species when adding more visits were reported for interpretation. In the model, visit, recording period, and their interactions were used as fixed effects whereas station formed the error term because it was used as a random replicate.

To investigate the effect of time of morning, the number of avian species detected in each 10-minute period were grouped into 30-minute categories (i.e., 0600, 0630, 0700, 0730, 0800, and 0830). For example, if 10-minute periods were between 0600-0630, data were grouped as 0600. Mixed Models procedure with repeated measures was run. An autoregressive correlation pattern was used, with visit as the repeated subject. LSM of number of species detected within 10-minute period were used to statistically test the difference on number of species detected among 30-minute categories. In the model, 10-minute recording period was used as a fixed effect whereas visit and the interaction between visit and recording period were random effects. Station formed the error term because it was used as a random replicate.

To investigate the difference among stations, Mixed Models procedure with repeated measure were run. An autoregressive correlation pattern was used, with visit as the repeated subject. LSM of species detected for each station were compared. In the model, station was used as a fixed effect whereas visit and the interaction between visit and period were random effects.

To investigate the effect of increasing number of stations in the area sampled, Mixed Models procedure with repeated measure were run. An autoregressive correlation pattern was used, with visit as the repeated subject. LSM of cumulative species when adding more stations were reported for interpretation. New species detected when adding more stations was used to statistically test the effect of increased number of stations. In the model, number of stations was used as a fixed effect whereas visit and the interaction between visit and period were random effects.

Six possible paired reciprocals (e.g., 1 visit-2 stations vs 2 stations-one visit) were compared using Wilcoxon Signed Rank Test (SAS 2000) to model cumulative number of species as a function of number of visits and number of stations.

Kaplan-Meier product limit estimators (Kaplan and Meier 1958, Cox and Oakes 1984) were used to estimate species detection probabilities as a function of count length (Dawson et al. 1995). The detection probability was the probability that the species was detected at a given point. The input data for each species consisted of presence (1) or absence (0) of individual species for 10-minute intervals from 10-120 minutes. Data from 10 visits were pooled for the analysis, and detection probabilities were calculated as the component of the survivor function from the Kaplan-Meier method (LIFETEST procedure, SAS 2000). Detection probabilities for twenty-two species were calculated. Eighteen additional species were omitted from this analysis because sample sizes were less than 30 observations.

To investigate how the number of cumulative species was affected by 3 combinations of visits, stations, and recording periods, a response surface analysis was run. Three-dimensional plots from multiple regression are used to visualize the appearance of the model from the response surface analysis.

Results

Species Richness

I identified 37 species of birds using the unlimited-distance point counts, and 36 species of birds, within the border of the 300-m x 300-m plot, using territory mapping. Only 6 species had territories inside the plot [American goldfinch (See Table 2-1 for scientific names), common yellowthroat, dickcissel, field sparrow, indigo bunting, and yellow–breasted chat]. The other 24 species were defined as visitors. Forty species were detected from 80 hours of acoustic recordings on 10 days. When data were pooled across the three methods, 45 species of birds were identified in 10 days of observations. The acoustic method at point count locations detected more species than unlimited point counts or territory mapping (Figure 2-2).

To compare the number of avian species found in 10 days of observation using each method, all species detected were listed (Table 2-2). The similarity index (SI) of the 3 paired reciprocals ranged from 85.7 to 90.4%. The unlimited-distance point counts (A) and territory mapping (B) showed the greatest similarity. Thirty-three species were detected by both methods. Unlimited-distance point count (A) and acoustic method (C) showed the least similarity (33 species with SI = 85.7%), whereas territory mapping (B) and the acoustic method (C) detected 33 species with SI = 86.84% (Figure 2-3).

Species richness per point (±SE) were 10.98 ± 0.28 and 11.95 ± 0.32, for point counts and acoustic monitoring, respectively. The number of species per point differed between the two methods (t = -2.74, df = 39, P < 0.01). Bell's vireo, brown-headed cowbird, chimney swift, eastern meadowlark, great blue heron, and orchard oriole were detected by point counts but were not detected by acoustic method (Figure 2-4). Wood thrush, eastern bluebird, purple martin, northern flicker, and downy woodpecker were not detected by point counts but were detected by acoustic monitoring. Only 2 species were detected by both methods for all individuals: American robin and field sparrow. Ruby-throated hummingbird was the only species that was only detected by territory mapping. Daniel Moss (Contractor, Conservation Branch, Fort Campbell Military Reserve), listened to ten 10-minute recordings at point-count stations (25% of total). He detected 25% more individual vocalizations and added 4 species to the bird list (Henslow's sparrow, brown thrasher, great crested flycatcher, and Bachman's sparrow).

Effect of Recording Period

The main effect of recording period was large ($F = 126.24$, df = 11, $P < 0.001$). Ten-minute recordings yielded 12.2 ± 0.5 species, on average; 56.5 percent of the total species noted on 2-hour recordings. New species were detected significantly (mean greater than zero) when the count period increased from 10 minutes to 90 minutes, ($P < 0.001$). However LSD mean separation indicated that the number of new species detected did not differ from 50 - 120 minutes ($P > 0.05$, Table 2-3). At time period 90 minutes, the cumulative number of species was 17.7 ± 0.5 and represented 95.2 percent of the 2-hour recording total. For additional 10-minute increments, from 90 minutes to 120 minutes, the total number of species increased at a lesser rate (Table 2-3 and Figure 2-5).

Effect of Number of Visits

The main effect of number of visits was large (F = 1061.29, df = 9, P < 0.001). New species were detected significantly (mean greater than zero) when the number of visits increased from 1 – 10 (P < 0.05). However, LSD mean separation indicated that no significant difference in number of new species was detected between 4 and 5 visits and between 6 - 10 (Table 2-4, Figure 2-6).

Effect of Time of Morning

The mean number of species detected per 10 minutes (unsupplemented count) among 30-minute categories differed (F = 5.74, df = 4, P < 0.001). The greatest number of species was found during 0630-0700 ($\bar{x}$ = 12.3 ± 0.4), and there were significant differences among other times of morning (P < 0.05). The mean number of species declined after 0700 with the 0800-0830 time period reporting the fewest species (Table 2-5).

Number of Stations versus Number of Visits

The mean number of species for unsupplemented counts differed among stations (F = 4.42, df = 3, P < 0.006). Station 4 yielded more species than the other three stations, and station 1 detected the least number of species compared to the other 3 stations (P < 0.05; Table 2-6; Figure 2-7). Increasing the number of stations from 1 to 4 affected the number of new species detected (F = 1262.37, df = 3, P < 0.001). One to three station recordings yielded 67.1%, 85.4%, and 94.5% of the total species detected by 2 hour-recordings of 4 stations, respectively. In all 6 possible paired reciprocals (e.g., 1 visit-2 stations vs 2 stations-one visit), more visits yielded more species than did more stations added to each visit ($S = -10.5$, df = 5, $P = 0.031$, Wilcoxon Signed Rank Test, Figure 2-8).

Detection Probabilities

Detection probabilities after 10 minutes of recording ranged from 0 for eastern bluebird to 1.000 for indigo bunting and yellow-breasted chat (Table 2-7, Figure 2-9). All detection probabilities for 2 hour-recordings equaled to 1 because all species analyzed were detected within this period.

Number of Stations versus Number of Visits versus Recording Periods

The linear effects of number of visits, number of stations, and recording period were important ($F = 3234.69$, df = 3, $P < 0.001$), including the quadratic effects ($F = 622.46$, df = 3, $P < 0.001$). This model fit the data extremely well, explaining 96.10% of cumulative species differences. The model predicted that the maximum number of species detected by acoustic method (i.e., 39.9 species) can be approached by conducting acoustic monitoring for 8.3 visits (days); each visit required 4.3 stations and 92-minute recordings. The response surface model fit quadratics and linear by linear interactions (Figure 2-10). For these 3 variables, the model equation was:

$$\begin{aligned} \text{number of species} = {} & 0.109848 + 3.173361(\text{visit}) + 5.186452(\text{station}) + 0.337662(\text{period}) \\ & - 0.186395(\text{visit}^2) - 0.577083(\text{station}^2) - 0.001669(\text{period}^2) \\ & + 0.013586(\text{visit*station}) - 0.001457(\text{visit*period}) \\ & - 0.004101(\text{station*period}) \end{aligned}$$

The model predicted that under the maximum unit effort in this context (10-day visits with 2-hour recording and 4 stations per visit), the number of species detected was 38. In actuality, the acoustic monitoring recorded 40 species.

Discussion

Acoustic Method, Point Counts, and Territory Mapping

Territory mapping has proven to be a good method for monitoring avian population density and more accurately records birds associated with plot and plot habitat. Territory mapping is considered the standard against which other methods should be compared to study avian populations (Bibby et al. 2000). However, territory mapping is time consuming to complete in the field and to analyze (Bibby et al. 2000). The unlimited-distance point counts and acoustic method detected species regardless of distance, within hearing and recording distance, whereas the mapped counts were limited to the plot. The total number of species reported by territory mapping was less than point counts and acoustic method because birds off the plot were not recorded. The similarity index between acoustic method and territory mapping was less than the similarity between point counts and acoustic method. However, 5 species were missed by acoustic methods, but were detected by territory mapping. Three species were identified as non-vocal flyovers (barn swallow, great blue heron, red-tailed hawk). Two species were detected infrequently visually only (ruby-throated hummingbird, orchard oriole). The species missed by point counts but detected by territory mapping were generally mapped when the observer started walking along the established grids and moved from one station to another.

Ten-Minute Point Counts versus Ten-Minute Acoustic Method

Unlimited-distance point counts and simultaneous acoustic monitoring at point count stations were most similar, because both methods recorded all species regardless of distance within the same time and place. These methods led to comparable results in terms of species composition. Both showed the greatest similarity, with the number of species detected by the acoustic method slightly greater than the number of species detected by point counts. Thirty to fifty percent of all singing males within hearing distance are likely to be overlooked by unlimited-distance point counts (Bart and Schoultz 1984). In this study, the calls of wood thrush, northern flicker, and downy woodpecker were detected at great distance by acoustic monitoring because the calls were loud enough to be recorded by at least one of the recording devices. These species were not detected by the observer, apparently because I overlooked these vocalizations. Observer bias is one of a number of factors influencing detection rate across species and across count period lengths by point counts. Observers sometimes filter out common species whenever less common species are calling (Verner 1985, Verner and Milne 1989). To test the repeatability of my observations, another observer listened to the recordings. This second observer had > 5 years of experience monitoring Fort Campbell birds. Whereas I had no previous experience with Fort Campbell birds. He detected 25% more individuals and added 4 species to the bird list. I likely missed these vocalizations because of less experience with parts of the songs with certain species or failing to detect the weak intensity of distant calls and songs. However, his work was not independent as he consulted my data while listening to the recordings. Therefore, this test verified the relative accuracy of my identifications but did not evaluate the variability of results among observers.

The acoustic method did not perform well for secretive or non-vocal species. A ruby-throated hummingbird was visually detected once by point counts based on its size and flight pattern. Ruby-throated hummingbird was missed by the acoustic method because they only make a low amplitude insect-like noise when flying. These noises from the hummingbird are easily confused with insects, unless they fly close to a microphone. Similarly, point counts detected chimney swifts, great blue herons, and barn swallows as flyovers. These species may not call when they fly, and none of the acoustic devices picked up their calls. The majority of avian species on the study area were detected by both techniques, including American robin, field sparrow, American goldfinch, eastern towhee, mourning dove, and northern bobwhite. These birds were easily identified by visual or aural cues. Some of these species were vocally active (e.g., indigo-bunting, common yellowthroat, and yellow-breasted chat) and were common or abundant on the study area.

There were some advantages of acoustic monitoring compared with the point counts and territory mapping. No requirement for an expert field observer was required, a permanent record of species presence was collected, and the monitoring of bird population can be conducted concurrently at multiple sites (Haselmayer and Quinn 2000, Hobson et al. 2002). Variation among observer is known to be a potential bias in bird surveys because of different abilities to detect and identify vocalizations (Rosenstock et al. 2002). Thus, using one observer to interprete recording data can control the variability. However, one limitation of the acoustic method compared with point counts was that it was impossible to determine the number of individuals of a given species singing at a given location (Dawson 1981). Thus, abundance estimates cannot be calculated for individual locations, although an index to abundance may be calculated based on the number (percent) of stations with a given species present. As such, the extent of a given species distribution could be monitored over space and time (years). Abundance estimates might be directly measured if an array of directional microphones was used to document where the sounds were coming from so that unique individuals could be identified or else if individual voice recognition software was used. Emlen and Dejong (1981) suggested the maximum distances from which birds can be heard are species specific and reasonably consistent among the habitats of interest, then the number of vocalizing individuals detected within that area may be used to calculate bird density.

Effect of Recording Period and Time of Day

The total number of species increased when the recording duration was increased, because of increased detection of less audible species, likely because of movements within the sampling area (Verner 1985). Fifty - ninety minutes of acoustic monitoring detected at least 84 - 95 percent of cumulative species of the 2-hour recordings with one visit. Based on this result, acoustic monitoring for 50 minutes may provide reasonable efficiency for monitoring birds in grassland habitats and yield sufficient information for monitoring avian populations. My study clearly showed that a recording period longer than 50 minutes gained relatively few new species (Table 2-3 and Figure 2-5).

Detection rates are greater and less variable if counts are restricted to daily periods with greatest bird activity (Gutzwiller 1991). Robbins (1981) noted each species has its own diurnal activity pattern. Based on analysis of BBS data, 20 out of 30 species (67%) had peak activities 1 to 4 hours after sunrise. The mean number of species (unsupplemented counts) detected in 10-minute recordings in my study declined by about 16.3 percent between 50 and 170 minutes after sunrise. Mean detections peaked at 50-80 minutes after sunrise supporting the findings of Robbin (1981). Bystrak (1981) noted the breeding bird survey data were least reliable during the flurry of activity associated with the dawn chorus. Observer confusion could result in more birds being overlooked at stations with high species richness. However, Haselmayer and Quinn (2000) suggested sound recording surveys in the Amazonian region of Peru were preferred over point counts when species richness is high, such as during the dawn chorus, because recordings allow for repeated listening. In this study, six species (i.e., Bell's vireo, downy woodpecker, eastern bluebird, eastern mockingbird, red eyed-vireo, and yellow-throated warbler) were not detected in the first 30 minutes of recordings (20 to 50 minutes after sunrise), but were recorded in the subsequent 30-minute period.

<u>Effect of Number of Visits and Number of Stations</u>

Based on 10-minute recordings, new species increased significantly with the number of visits (Table 2-4). In the grassland habitat at Fort Campbell, it may not be beneficial to monitor acoustically with >6 ten-minute visits within 2 weeks. To improve sampling efficiency, I suggest 6 visits, and extending the recording duration from 10 minutes to at least 50 minutes. The addition of more stations than 4 within the original plot may not be appropriate because of the proximity of stations and the need to maintain independence of count stations (Petit et al. 1995). Ralph et al. (1995) suggested distances greater than 250 m between stations are needed to ensure statistical independence of point counts in open environments. I placed my monitoring stations closer (150 m) to ensure there were no gaps in plot coverage. This resulted in some individuals being detected simultaneously at more than 1 station. Such overlap does not cause problems for estimates of species richness but would constitute "double-counting" for estimates of relative abundance.

Detection Probabilities

I calculated detection probabilities to determine the trend of detection of individual species rather than the frequency of presence of each species (the number of points at which a species is detected divided by the total number of points sampled). Although detectability varies across space (distance) and time, I only factored time into the detection probability estimate because distance was not determinable from the acoustic data (see Chapter 4 for more on detection probability by distance).

Detection probabilities varied among species. Species that were common and vocally active had greater detection probabilities (e.g., northern cardinal, northern bobwhite, American crow, indigo bunting, and yellow-breasted chat). These species were usually detected within the first 10 minutes and showed little change in detection probabilities as recording period increased. Some species, such as visitors, or flyovers (e.g. blue-gray gnatcatcher, eastern bluebird, and blue jay), were infrequently detected and showed substantial increases in detection probabilities as the recording period increased.

The detection probabilities suggested that 100-minute recordings resulted in detection probabilities greater than 0.8 for birds in grassland and adjacent habitats (Table 2-7). Increasing recording length may be necessary for species with a low probability of detection. If a particular species is of interest or if species richness at individual points is required, recording length may be optimized to address these objectives (Barker and Sauer 1995). Dawson et al. (1995) demonstrated that increasing the amount of time spent counting at points may reduce bias resulting from variation in detection probabilities. Regardless, detection probabilities should be considered when comparing species richness or abundance (density) (Farnsworth et al. 2002). It is possible that detection of some species were biased low because the study was conducted late in the breeding season (July). Some species (e.g., wood thrush) were not nesting or singing as much as they did earlier in the season (May). Changes in calling rates through the season will influence detection frequencies (Buskirk and McDonald 1995). The detection probabilities for some flyovers or visitors, such as blue jay, eastern towhee, and eastern bluebird, are probably biased low as well because they may not have been present to be detected during the first 10 minutes.

Utility of Acoustic Monitoring in Grassland Habitat

The utility of an acoustic monitoring program depends upon the study goals, and the required effort in terms of money, personnel, and time. Optimal sampling effort represents a tradeoff between the number of visits, the number of stations, the recording period, and the species detection probabilities. One monitoring goal may be to document the maximum number of species per unit monitoring effort. The response surface model demonstrated that conducting acoustic surveys for 8 visits with 4 stations and 90-minute recordings can approach the maximum number of species detected (40). The species detection probabilities for all 27 species that I analyzed were greater than 0.9 for a 90-minute recording interval, except for eastern towhee (0.73). This approach (8 visits x 4 stations x 90 minutes) seems reasonable and may be used for acoustic monitoring in temperate grassland habitat. However, if the required effort is limited, the combinations among visits, stations, and recording periods may be adjusted based upon the response surface analysis. I recommend a minimum effort for conducting acoustic surveys of 4 days with 3 stations and 50-minute recording periods. This combination, according to the response surface model, can detect 32 species (80%), which should be sufficient to monitor grassland bird populations at Fort Campbell. However, many of the suggested standards presented in this research will require future modification as components of acoustic methodology are tested under new habitats and new conditions.

CHAPTER 3

USE OF ACOUSTIC METHOD FOR MONITORING BIRDS IN OLDFIELD HABITAT AT FREEL'S BEND WILDLIFE MANAGEMENT AREA, OAK RIDGE, TENNESSEE

The Freel's Bend portion of the Three Bends Wildlife Management Area is located inside the Oak Ridge Reservation (ORR). ORR is about 15,000 ha of mostly natural forest in Roane and Anderson counties in eastern Tennessee. ORR is an important site for conservation of many plant and animal species (Mann et al. 1996). Almost 200 species of birds have been reported to use the ORR, including seven raptor species, six migrant waterfowl species, and two grassland bird species, including double crested cormorant (*Phalacrocorax auritus*), Canada goose (*Branta canadensis*), osprey (*Pandion haliaetus*), bald eagle (*Haliaeetus leucocephalus*), sandhill crane (*Grus canadensis*), willow flycatcher (*Empidonax traillii*), dickcissel (*Spiza americana*), and grasshopper sparrow (*Ammodramus savannarum*). ORR supports species of conservation concern, gamebirds, and species uncommon in the Ridge and Valley Physiographic Province (Mann et al. 1997, Mitchell and Hicks 1998). Freel's Bend is owned by the U.S. Department of Energy, but is managed by the Tennessee Wildlife Resources Agency (Parr and Evans 1992, Mann et al. 1996). The total area is 200 ha, divided into 6 habitat types: old field, hay field, mixed forest, pine forest, hardwood forest, and scrub-shrub (Warwick 2000). Freel's Bend provides quality grassland habitat for grassland birds for 3 reasons. It is extensive (87 ha of grassland-dominated cover types or 47% of total); it is isolated from human disturbance except for periodic mowing/burning; and it is surrounded by other undeveloped habitats, including forest land, riparian vegetation, and open water (Mann et al. 1997). Diskcissel, a rare species in eastern Tennessee, was seen in this area in crop stubble and crop fields that have been abandoned for one to six years or briar thickets adjacent to fields (Nicholson 1997). Grasshopper sparrow, one of several breeding species restricted to grasslands across Tennessee, was found nesting in the fields where mowing occurred previously (Nicholson 1997, Mitchell and Hicks 1998). Implementing an acoustic monitoring program for this area may supplement ongoing avian monitoring, such as the Breeding Bird Survey and the Breeding Bird Atlas in the future.

The objective of this chapter was to analyze and develop an acoustic monitoring protocol for bird populations in oldfield habitat and compare it with standard protocols (point counts and territory mapping) for documenting species presence.

Study Plot

The acoustic devices were placed in a 9-ha plot (300 m x 300 m) oldfield habitat, which had been maintained by periodic mowing. Vegetation consisted primarily of broomsedge and tall fescue (*Festuca arundinacea*). Shrubs that dominated this habitat included blackberry (*Rubus spp.*) and autumn olive (*Elaeagnus umbellate*). The oldfield was bordered on the south by a gravel farm road; the east side was forest; the west side was more oldfield; and the north side was scrub-shrub. There were 2 small wooded islands (60 m x 68 m, and 52 m x 60 m) in the plot consisting primarily of oak species, yellow poplar (*Liriodendron tulipifera*), and sugar maple (*Acer saccharum*). The elevation in the plot ranged from approximately 810 m at its lowest point on the northeast to 860 m near the northwest corner of the area. The slope ranged from 5 to 40%, and the aspect of the field was generally southeast.

Methods

Monitoring Protocols

Monitoring protocols were similar to those used at Fort Campbell (see Chapter 2 for details). The 9-ha plot was delineated and a 75 m x 75 m grid was marked off across the plot. The four recording devices were placed at grid intersections with 150-m spacing between each station (see Figure 2-1 for plot layout). I conducted comparisons among territory mapping, unlimited-distance point counts, and acoustic method on 10 mornings between 14-28 June 2000.

Data and Statistical Analysis

Based on 10-day data, a similarity index (SI) and a paired *t*-test were used to compare similarities among methods. Ten-day acoustic data were used to analyze the effect of recording period, number of visits, number of stations, and detection probabilities. Data and statistical analysis were similar to those used at Fort Campbell (see Chapter 2 for details).

Results

Species Richness

Thirty-six species of birds were identified using unlimited-distance point counts. Forty-eight species of birds were identified using territory mapping within the border of the 300-m x 300-m plot. Eight species had territories inside the plot including blue grosbeak (See Table 3-1 for scientific names), common yellowthroat, eastern towhee, field sparrow, indigo bunting, northern cardinal, yellow-breasted chat, and white-eyed vireo. The other 40 species were recorded as visitors or flyovers. Forty-three species were detected from 80 hours of acoustic recordings on 10 days. When data were pooled across the three methods, a total of 54 species of birds were found in 10 days of observations. The acoustic method at point-count locations detected more species than unlimited-distance point counts, but fewer than territory mapping (Figure 3-1).

To compare the number of avian species found in 10 days of observations using each method, all species detected were listed (Table 3-2). The territory mapping method and the acoustic method showed the greatest similarity. Thirty-eight species were detected by both methods; similarity index (SI) = 83.5%. Both point count and territory mapping methods detected 34 species of birds in common; SI = 81%, whereas point count and the acoustic method showed the least similarity (31 species with SI = 78.5%) (Figure 3-2).

Species richness per point was 12.39 ± SE 0.28 and 12.10 ± 0.30 for point counts and acoustic monitoring, respectively. The number of species per point did not differ between the two methods (t = -0.74, df =39, P = 0.461). Barn swallow was not detected by acoustic method but was detected by point counts (Figure 3-3). White-eyed vireo was detected only a few times by point counts but was often detected by acoustic method. Nine species (American crow, Canada goose, eastern towhee, field sparrow, hairy woodpecker, northern bobwhite, northern cardinal, indigo bunting and yellow-breasted chat) were detected almost equally by all three methods. Five species were not detected by point counts and acoustic method but were detected by territory mapping: brown thrasher, common grackle, osprey, white-breasted nuthatch, and willow flycatcher (Figure 3-3). James Giocomo (Department of Forestry, Wildlife & Fisheries, University of Tennessee), listened to 25% of all 10-minute recordings to double check identifications and agreed with 100% of my identifications and did not add any additional species to the list.

Effect of Recording Period

The main effect of recording period was large (F = 282.52, df = 11, $P < 0.001$). Ten-minute recordings yielded 11.3 ± 0.5 species, on average. These included 55.7 percent of the total species noted on 2-hour recordings. New species were detected significantly (mean greater than zero) when the count period increased from 10 minutes to 100 minutes and 110 minutes to 120 minutes ($P < 0.05$). However, LSD mean separation indicated that the number of new species detected did not differ from 60-120 minutes ($P > 0.05$, Table 3-3). At time period 60 minutes, the cumulative number of species was 17.6 ± 0.5, which represented 87.6% of the 2-hour recording total. For additional ten minute increments, from 60 minutes to 120 minutes, the total number of species increased at a lesser rate (Table 3-3 and Figure 3-4).

Effect of Number of Visits

The main effect of number of visits was large (F = 382.04, df = 9, P < 0.001). One visit yielded 11.74 ± 0.3 species, on average. New species were detected significantly when the number of visits increased from 1 to 8 and 9 to 10 (P < 0.05, Table 3-4; Figure 3-5). However, LSD mean separation indicated that no significant difference in number of new species was detected from 8 to 10 visits. Ten visits with one station recorded 52.6 percent, on average, of the species detected by four recording stations on the plot.

Effect of Time of Morning

No difference was found in the mean number of species among 30-minute categories from 0630-0900 (F = 0.36, df = 5, P = 0.904) (Table 3-5).

Number of Stations versus Number of Visits

The mean number of species for unsupplemented counts differed among stations (F = 5.41, df = 3, P = 0.001). The number of species detected did not differ among stations 1 - 3 (P > 0.05). Station 4 detected the least number of species compared to station 2 and 3 (P < 0.05; Table 3-6). Increasing the number of stations from 1 to 4 stations affected the mean number of species on the supplemented count (F = 1054.36, df = 3, P < 0.001). One to four station recordings yielded 66.3%, 83.1%, 93.6% and 100% of the total species detected by 2 hour-recordings of 4 stations, respectively. Even though the cumulative number of species increased by adding up to 4 stations, adding the fourth station increased the number of new species by only 1 species (P < 0.001, Figure 3-6). In all 6 possible paired reciprocals (e.g., 1 visit-2 stations vs 2 visits-1 stations), the number of species differed marginally when adding more visits to each station or adding more stations to each visit (S = 9.50, df = 5, P = 0.062, Wilcoxon Signed Rank Test, Figure 3-7).

Detection Probabilities

Detection probabilities after 10 minutes of recording ranged from 0.06 for eastern bluebird to 0.97 for yellow-breasted chat (Table 3-7, Figure 3-8). For most species, detection probabilities were greater than 0.8 after 80 minutes. All detection probabilities for 2-hour recordings equaled 1.00 because only species detected within this period were analyzed.

Number of Stations versus Number of Visits versus Recording Periods

The linear effects of number of visits, number of stations, and recording-period were important (F = 2509.37, df = 3, $P < 0.001$), as well as the quadratic effects (F = 285.21, df = 3, $P < 0.001$). This model fit the data extremely well, explaining 94.7% of cumulative species differences. The model predicted that the maximum number of species detected by acoustic method (i.e., 43 species) can be approached by conducting acoustic surveys for 10.1 visits; each visit required 3.8 stations and 138-minute recordings. The response surface model fit quadratics and linear by linear interactions (Figure 3-9). For these 3 variables, the model equation was:

$$\begin{aligned}\text{number of species} = {} & 0.079640 + 2.580066\text{visit} + 9.912576(\text{station}) + 0.165231(\text{period}) \\ & - 0.135653(\text{visit}^2) - 1.491667(\text{station}^2) - 0.000727(\text{period}^2) \\ & + 0.014848(\text{visit*station}) + 0.000699(\text{visit*period}) \\ & + 0.007678(\text{station*period})\end{aligned}$$

Under the maximum unit effort (10 visits with 2-hour recording and 4 stations per visit), the number of species detected was predicted to be 42.58 based on the model.

Discussion

Acoustic Method, Point Counts, and Territory Mapping

While territory mapping provides an accurate estimate of avian densities, mapped counts are time consuming to complete in the field and to analyze (Bibby et al. 2000). In this study, the territory mapping and acoustic method were conducted simultaneously. Individual birds were mapped while I walked along the grid line and the 4 acoustic devices were run at the same time. Point counts, in contrast, were only based on one 10-minute period for each point (i.e., 40 minutes per day for 4 points plus travel time between points). Territory mapping and acoustic method, therefore, probably detected more species than unlimited-distance point counts simply because of increased effort (time on plot). The similarity index between territory mapping and acoustic method was greater than the similarity between point counts and acoustic method or the similarity between point counts and territory mapping. However, 5 species were missed by acoustic methods, but were detected by point counts (barn swallow, ruby-throated hummingbird, turkey vulture, wild turkey, and yellow-throated warbler). Cooper's hawk was missed by territory mapping and acoustic monitoring but was recorded when conducting 10-minute point counts. Five species (brown thrasher, common grackle, osprey, white-breasted nuthatch, and willow flycatcher) missed by point counts and acoustic method were recorded when the observer walked along the established grids and moved from one station to another. In general, raptors (e.g., Cooper's hawk, osprey, and turkey vulture) and other flyovers such as barn swallow typically were missed by acoustic method. Theses species seldom vocalize when they fly.

Ten-Minute Point Counts versus Ten-Minute Acoustic Method

Unlimited-distance point counts and simultaneous acoustic monitoring at point-count stations were most similar when both methods recorded all species regardless of distance within the same time and place. Bart and Schoultz (1984) noted 30-50% of all singing males within hearing distance are likely to be overlooked by unlimited-distance point counts. In this study, white-eyed vireos were detected at great distances with acoustic method because the calls were loud enough to be recorded by at least one of the recording devices. This species was not detected by the observer, apparently because the observer was concentrating on other birds. Observer bias is one of a number of factors influencing detection rate across species and across count-period lengths by point counts. Observers sometimes filter out common species whenever species of concern or special interest is calling (Verner 1985, Verner and Milne 1989). In this study, to test the accuracy of my observations, another observer listened to the recordings and no new individuals or new species were detected. However, his work was not independent in that he reviewed my bird list while listening to the recordings.

The acoustic method did not perform well for secretive or non-vocal species. Point counts detected barn swallows and turkey vulture as flyovers. None of the acoustic devices, however, recorded their calls. Other species such as pileated woodpecker, brown thrasher, and wild turkey were missed by the acoustic method. These species were noted infrequently during point counts or territory mapping. The majority of avian species on the study area were detected by both methods, including American crow, field sparrow, American goldfinch, eastern towhee, and northern bobwhite. These birds were easily identified by visual or aural cues. Some of these species were vocally active (e.g., indigo bunting, common yellowthroat, and yellow-breasted chat) and were common or abundant on the study area. The advantages and disadvantages for acoustic method, compared to point counts and territory mapping in the oldfield habitat are similar to those discussed in Chapter 2.

Effect of Recording Period and Time of Day

The total number of species increased when the recording duration was increased likely because of increased detection of less conspicuous species, but also because of the movement of birds within the sampling area (Verner 1985). In this context, 60 minutes of acoustic methods detected at least 88 percent of cumulative species of the 2-hour recordings with only one visit. For this oldfield setting, a 60-minute recording would provide reasonable efficiency for monitoring birds.

Gutzwiller (1991) noted detection rates are greater and less variable if counts are restricted to daily periods with greatest bird activity. Robbins (1981) discovered from the BBS data that 20 out of 30 species (67%) had peak activities between 1 and 4 hours after sunrise and each species has its own diurnal activity pattern. The mean number of species (unsupplemented counts) detected in ten-minute recordings in my study did not differ between 10 minutes and 160 minutes after sunrise. Given the monitoring dates used for this study (June 2000), there did not appear to be a significant decrease in avian activity as morning progressed.

Effect of Number of Visits and Number of Stations

Based on 10-minute recordings, species number increased significantly with the number of visits (Table 3-4). I found that 8 visits recorded 22 species or approximately 97 percent of the 10-visit total. It did not appear to be beneficial to acoustic monitor for more than 8 days in the oldfield habitat at Freel's Bend because the species accumulation increased insignificantly. To improve sampling efficiency, the recording duration should be extended from 10 minutes to at least 60 minutes. Further investigation is needed to determine if acoustic monitoring can be applied to estimate the relative abundance when there is > 250 m between recording stations at Freel's Bend.

Detection Probabilities

Although detectability varies across space (distance) and time, I only factored time into the detection probability estimate because distance was not determinable from the acoustic data (see chapter 4 for more on detection probability by distance). Detection probabilities varied among species. Species that were common and vocally active had greater detection probabilities (Dawson et al. 1995). For the oldfield habitat, these included yellow-breasted chat, northern cardinal, field sparrow, American crow, indigo bunting, and Carolina wren. These species were usually detected within the first 10 minutes and showed little change in detection probabilities as recording period increased. Some species, such as visitors (e.g., American goldfinch, eastern bluebird, and brown-headed cowbird), were occasionally detected and the estimated detection probability within the first 10 minutes are probably biased low for these mobile species because they might not have been present during the first 10 minutes. Increased time allowed those mobile species to arrive on the plot and be detected.

The detection probabilities suggested that 80-minute recordings resulted in detection probabilities greater than 0.8 for most species in oldfield habitat and adjacent areas (Table 3-7). Increasing recording length may be necessary for species with a low probability of detection. If particular species are of interest or if total species richness at individual points is desired, recording length may be optimized to address these objectives (Barker and Sauer 1995). Dawson et al. (1995) noted that increasing the amount of time spent counting at points may reduce bias resulting from variation in detection probabilities among species. Regardless, detection probabilities should be considered when comparing species richness or abundance (density) (Farnsworth et al. 2002).

Utility of Acoustic Monitoring in Oldfield Habitat

Optimum sampling effort represents a tradeoff between the number of visits, the number of stations, the recording period, and the species detection probability. The response surface model demonstrated that conducting acoustic survey for 10 visits, with 4 stations, and 140-minute recordings can approach the maximum number of species detected. This approach may be used for acoustic monitoring in oldfield habitat. However, the combinations among visits, stations, and recording periods may be adjusted based upon my analyses and the intended purpose of the study including the target species in the study area. Monitoring with acoustic surveys for 5 days, with 3 stations, and 80-minute recording periods would detect 37 species (86%), which should be sufficient to monitor oldfield habitat bird populations at Freel's Bend. The suggested acoustic monitoring protocols presented in this chapter will require future modification as components of acoustic methodology are tested under new conditions and new habitats.

CHAPTER 4

USE OF ACOUSTIC METHOD FOR MONITORING BIRDS IN MIXED HARDWOOD FOREST AT CHEROKEE NATIONAL FOREST, TENNESSEE

The Cherokee National Forest (CNF) is located along Tennessee's eastern boundary from Georgia to Virginia. The 252,348-ha forest is divided into northern and southern sections; the Great Smoky Mountains National Park lies between them. The original management plan was developed to protect water quality and provide a continuous supply of timber (U.S. Department of Agriculture 1986). Because of the broad gradients of topography, elevation, and precipitation, CNF habitats are diverse including coniferous forests of red spruce (*Picea rubens*), pine (*Pinus* spp.) and hemlock (*Tsuga canadensis*), mixed oak-hickory forest, grassy balds, wide rivers and narrow streams. CNF, the largest wildlife management area in Tennessee, provides key nesting, denning or feeding habitat for about 400 species of terrestrial vertebrates and 150 species of fish. Two hundred and sixty-two avian species were reported to dwell on the Cherokee year-round or visit the forest seasonally (Alsop and Sullins 1993).

The study area was located in the southern portion of forest within Tellico Ranger District, approximately 10 km east of Tellico Plains, Monroe County, Tennessee. The Tellico District has elevations ranging from 244 m to 1668 m above sea level (U.S. Geological Survey 1985). The acoustic device was set up in a 72-year-old mixed hardwood stand. Overstory was dominated by white pine (*Pinus strobes),* white oak

(*Quercus alba*), red maple (*Acer rubrum*), sourwood (*Oxydendrum arboreum*), eastern hemlock (*Tsuga canadensis*) and flowering dogwood (*Cornus florida*). The canopy cover was 70%, on average. Greenbriar (*Smilax spp.*) was the dominant shrub in the understory. The dominant saplings included flowering dogwood, red maple, white pine, sassafras (*Sassafras albidum*), and sourwood. The study plot was bordered on the northeast by a gated logging road. The other three sides were surrounded by forest. The general elevation ranged from 400-470 m and the aspect was generally southwest down from the road; slopes ranged from 0-45%.

The objectives of this chapter were to 1) develop and analyze the effectiveness of the acoustic monitoring protocol for bird populations in mixed hardwood forest and compare with standard protocols (point counts and territory mapping) for documenting species presence; 2) determine detection ranges and detection probabilities of individual species by distance and compare it with direct observations from other count techniques.

Methods

Monitoring Protocols (2002)

Monitoring protocols were similar to those used at Fort Campbell (see Chapter 2 for details). To gain better quality recordings, an IBM Pentium I laptop with the Loop Recorder software replaced the videocassette as a recorder. Twelve-volt marine batteries were used to power all equipment by using power inverters and power adaptors. The recordings were recorded and stored in digital format in the hard drive and then transferred to CD-Rom for further analysis.

The four recording devices were placed in the 9-ha plot at grid intersections with 150-m spacing between each station (Figure 4-1). I conducted comparisons among territory-mapping, unlimited-distance point counts, and acoustic method on 10 mornings (12 June-1 July 2002).

<u>Monitoring Protocols (2003)</u>

To estimate the detection probability for avian species in mixed hardwood forest habitat, the acoustic devices were placed on the second transect (B) starting from the edge of the plot at the points (0,0), (0,25), (0,50) with 25-m spacing and point (0,100) with 50-m spacing between points (0,50) and (0,100) (Figure 4-1). All recording devices were calibrated and tested until the range of detection capability was the same. On 10 mornings between 27 May - 29 June 2002, I started recordings between 0600 and 0900. I then walked along the established line, stopped at each station for 10 minutes, and recorded and mapped all singing birds. I recorded the bearing to each individual bird measured by compass and estimated the distance (m) to each bird from the station where I stood. To reduce the error associated with estimating distances, I avoided estimating distances greater than 100 m for individual birds detected aurally and 200 m for individuals bird detected visually. The distances from the other 3 stations to the birds were calculated using the Law of Cosines: $c^2 = a^2 + b^2 + 2\ ab \cos \phi$. For example, if distance from the station (0,0) to an ovenbird was 10 m, and the bearing was 180°, then the distance from the detected bird to the points (0,25), (0,50), and (0,100) can be calculated to be 35, 60, and 110 m, respectively. All individual vocalizations from all stations were collected, analyzed, and compared synchronously among 4 recording devices to see whether each individual bird was detected by different stations (i.e., at different distances).

Data and Statistical Analysis

Year 2002- Two days of data of territory mapping, unlimited-distance point counts, and acoustic method were omitted from the analysis because of poor quality of some recordings or power failure of the recording devices. Based on 8-day data, a similarity index (SI) and a paired *t*-test were used to compare the similarity among methods. Eight days of acoustic data were also used to analyze the effect of recording period, number of visit, number of stations, and detection probabilities across twelve-10 minute increments. Data and statistical analysis were similar to those used at Fort Campbell (see Chapter 2 for details).

Year 2003- Distances for 19 species detected acoustically were calculated from the cosine rule to determine distance-detection probabilities. Probit analysis was used to describe the relationship between distance and detectability (Wolf et al. 1995). The detection probability was classified into 3 categories:

$D_{0.01}$ represented the maximum distance that a given species was detected by acoustic devices. Vocalizations of individual species were inaudible beyond these ranges.

$D_{0.99}$ represented the maximum distance that all individuals within a given species were detected. In other words, all vocalizations of individual species were audible within this distance with $P = 0.99$.

$D_{0.50}$ represented the distance where one-half of the vocalizations of a given species were audible (P = 0.50).

The $D_{0.50}$ values were compared among species because $D_{0.50}$ was a good measure of relative detectability. Species with high values of $D_{0.50}$ can be detected for greater distances from the acoustic devices than can species with a low $D_{0.50}$ (Wolf et al. 1995). Because of the small sample size at some distances (e.g., < 25 m and > 200 m), the 95% CI of detection probability could not be computed for some species.

Results

Species Richness

I identified 24 species of birds using the unlimited-distance point counts, and 23 species of birds, within the border of the 300-m x 300-m plot using the territory mapping method. Only six species had territories inside the plot: ovenbird (See Table 4-1 for scientific names), black-throated green warbler, Carolina chickadee, indigo bunting, pine warbler, and red-eyed vireo. The other 17 species were considered visitors. There were 3,425 total recorded calls and songs, of which 3,182 or 92.9 percent were identified to species. Thirty-one species were detected from 64 hours of acoustic recordings on 8 days. When data were pooled across the three methods, 33 species of birds were identified in 8 days of observations. The acoustic method at point-count locations detected more species than unlimited-distance point counts or territory mapping (Figure 4-1).

To compare the number of avian species found in 8 days of observations using each method, all species detected were listed (Table 4-2). The similarity index (SI) of the 3 paired reciprocals ranged from 81.5–85.1%. The unlimited-distance point counts and territory mapping showed the greatest similarity (20 species in common with SI = 85.1%). Territory mapping and acoustic method showed the least similarity (22 species in common with SI = 81.5%), whereas unlimited-distance point counts and acoustic method detected 23 species in common with SI = 83.6%.

Species richness per point (±SE) was 6.25 ± 0.27 and 7.91 ± 0.36, for point counts and acoustic monitoring, respectively (t = 5.46, df = 31, $P < 0.01$). Most species were detected by both methods but the average species' detection of acoustic method was 15% greater than point counts. White-breasted nuthatch, mourning dove, blue jay, and Carolina wren, for example, clearly showed the greater % species detection by acoustic method (Figure 4-3). American robin was the only species detected by point counts but not detected by acoustic method. Eastern towhee, hairy woodpecker, northern cardinal, red-bellied woodpecker, red-tailed hawk, and white-eyed vireo were not detected by point counts but were detected by acoustic monitoring. Chimney swift, a "flyover" species, was not detected by both methods but was detected by territory mapping. Daniel Moss (Contractor, Conservation Branch, Fort Campbell Military Reserve) listened to ten 10-minute recordings at point-count stations (25% of total). He agreed with 84% of my identifications and added 2 species to my bird list (ruby-throated hummingbird and blue-headed vireo).

Effect of Recording Period

The main effect of recording period was large (F = 126.24, df = 11, $P < 0.001$). The first ten-minute recordings yielded 8.2 ± 0.4 species, on average. The first 10 minutes contained 50% of the total species noted on 2-hour recordings or 26.5% of all species detected by four recording stations on plot by acoustic method. New species were detected significantly (mean greater than zero) when the recording period increased from 10 minutes to 80 minutes ($P < 0.05$). However, LSD mean separation indicated that the number of new species detected did not differ from 50 – 120 minutes (Table 4-3). The detection rate of new species decreased considerably after the first 10-minute recording and leveled-off after 20 minutes (Figure 4-4). At time period 80 minutes, the cumulative number of species was 15.1 ± 0.4, which represented 93% of the 2-hour recording total or 48.7% of all species detected on plot by acoustic method. For additional 10 minute increments, from 80 minutes to 120 minutes, the total number of species increased at a minimal rate (Table 4-3).

Effect of Number of Visits

The effect of number of visits was large (F = 397.40, df = 7, $P < 0.001$). The first visit yielded 8.7 ± 0.3 species, on average. The first visit recordings contained 49% of the total species noted on 2-hour recordings or 28.1% of all species detected on plot by acoustic method. New species were detected significantly from 1 – 8 visits ($P < 0.001$). However, LSD mean separation indicated that the number of new species detected did not differ from 5 – 8 visits (Table 4-4). The detection rate of new species decreased considerably after the first 10-minute period and leveled off after 4 visits (Figure 4-5).

Effect of Time of Morning

The mean number of species (unsupplemented count) differed among 30-minute time of morning categories ($F = 3.59$, df = 3, $P < 0.027$). The greatest number of species was found during 0700 - 0730 ($\bar{x} = 8.7 \pm 0.2$), and the mean number of species declined thereafter (Table 5-4).

Number of Stations versus Number of Visits

The mean number of species for unsupplemented counts differed among stations ($F = 10.81$, df = 3, $P < 0.001$). Station 1, 2, and 4 detected about the same number of species ($P > 0.05$), and station 3 detected the least number of species ($P < 0.001$; Table 4-6). Increasing the number of stations from 1 to 4 stations affected the number of new species detected ($F = 586.95$, df = 3, $P < 0.001$), one to three station recordings yielded 60.4%, 80.0%, and 91.8% of the total species detected by 2-hour recordings of 4 stations, respectively. The detection rate of new species decreased from 1 station and leveled off after that (Figure 4-6).

In all 6 possible paired reciprocals of 8 days and 4 stations (e.g., 1 visit-2 stations vs 2 visits-1 station), the number of species did not differ when adding more visits or adding more stations to each visit ($S = 0.0$, df = 5, $P = 1.0$, Wilcoxon Signed Rank Test, Figure 4-7).

Detection Probabilities across Recording Periods

The pattern of detection probability as a function of recording period differed among species and ranged from 0.2 to 1.0 (Figure 4-8). Red-eyed vireo was detected at the greatest frequency with 100 percent detection probability within the first 10-minute recording. Ovenbird and indigo bunting were also detected with great frequency. The detection probability slightly increased every 10-minute period after the first 10-minute recording. Some species, such as downy woodpecker, hooded warbler, Carolina wren, and tufted titmouse, were detected at low frequencies and the detection probabilities gradually increased over longer period. For most species, detection probabilities were greater than 0.8 after 60 minutes (Table 4-7). All species detection probabilities for 2-hour recordings equaled to 1 because I only analyzed species detected within this period.

Detection Probabilities across Distances

I recorded detectability of vocalizations at various distances for 19 bird species. For 7 species, detection distances extended well beyond my sampling distance thus I was unable to estimate the maximum range and detection probability. These were American crow (225 m) [See bird scientific name in Table 4-1; number in the parentheses indicates the longest distance (m) that vocalizations were detected by recording devices], red-eyed vireo (188 m), scarlet tanager (195 m), wild turkey (175 m), blue jay (170 m), red shouldered hawk (155 m), and white-breasted nuthatch (72 m). The recorders failed to detect eleven species between 100 m and 200 m: ovenbird (119 m) [numbers in the parentheses indicate the minimum distance (m) that vocalizations were not detected by recording devices], indigo bunting (149 m), yellow-billed cuckoo (200 m), pileated woodpecker (177 m), black-throated green warbler (125 m), hooded warbler (82 m), tufted titmouse (98 m), pine warbler (103 m), downy woodpecker (77 m), worm-eating warbler (78 m), and black-and-white warbler (98 m).

In general, the detection probability declined as a function of distance and differed among species. For $D_{0.01}$ (vocalization of individual species were inaudible beyond this range at $P = 0.99$), the maximum distance of 12 species ranged from 166 m (black-throated green warbler) to 480 m (pileated woodpecker). The recorders failed to detect hooded warbler, pine warbler, worm-eating warbler, Carolina chickadee, tufted titmouse, and ovenbird between 180-230 m. Indigo bunting and Carolina wren were the exception, these 2 small birds were audible on recordings to 291 m and 328 m, respectively. Three non-passerine species were detected out to greater distances ranging from 259 m (yellow-billed cuckoo) to 480 m (pileated woodpecker) (Table 4-8).

At $D_{0.01}$ (99% detection probability to detect individual species), the detection distance of 12 species ranged from 26 m to 242 m. All species except worm-eating warbler were detected within 50 m ($P = 0.99$). Carolina chickadee, downy woodpecker, hooded warbler, and pileated woodpecker have a 1% chance to fail detection within 100 m. Carolina wren, indigo bunting, ovenbird, and pine warbler had a 1% chance to fail detection at 150 m. Yellow-billed cuckoo could be detected at the greatest distance (242 m with $P = 0.99$).

At $D_{0.50}$ (the distance where one-half of birds of a given species were detected by an acoustic device), most species were detected from 118 m to 286 m (Figure 4-9).

Non-passerines (i.e., pileated woodpecker, yellow-billed cuckoo, and downy woodpecker) were detected at greater distances compared to passerines (e.g., indigo bunting and tufted titmouse). The slope of the model indicated that the detection threshold declined with increasing distance from the recording devices. Most species had relatively flat slopes, showing that detection probability tended to decrease gradually. Black-throated green warbler and tufted titmouse seemed to have steeper slopes than other species (- 0.68), indicating the detection threshold changed more rapidly than other species.

Number of Stations versus Number of Visits versus Recording Periods

The response surface analysis indicated that the linear effects of number of visits, number of stations, and recording-period were important (F = 1866.12, df = 3, $P < 0.001$) as well as the quadratic effects (F = 24.78, df = 3, $P < 0.001$). The model fit the data extremely well, explaining 94% of cumulative species differences. The model predicted that the maximum number of species detected by acoustic method (i.e., 36.6 species) can be approached by conducting acoustic surveys for 8 visits; each visit required 4 stations and 120-minute recordings [Figure 4-9 (1-3)]. The response surface model fit quadratics and linear by linear interactions. For these 3 variables, this produced the model as follows:

$$\begin{aligned}\text{Number of species} = {} & 8.904694 + 0.6884021(\text{visit}) + 1.827124(\text{station}) \\ & + 0.051364(\text{period}) - 0.044643(\text{visit}^2) - 0.359375(\text{station}^2) \\ & - 0.000369(\text{period}^2) + 0.384524(\text{visit*station}) \\ & + 0.004389(\text{visit*period}) + 0.012657(\text{station*period})\end{aligned}$$

Discussion

Acoustic Method, Point Counts, and Territory Mapping

The unlimited-distance point counts and acoustic method detected species regardless of distance while the territory mapped counts were limited within the plot. The total number of species and the similarity index reported by territory mapping were lower than acoustic method and unlimited-distance point counts because birds off the plot were not recorded. From acoustic results, 88% of the total were recorded by acoustic method. Seven percent of the total individual calls and songs (243) were unknown. If I assumed that all 5 species missed by acoustic method but noted by the other 2 methods vocalized and were recorded, then, the rate of missing species can be calculated as 5 species divided by 243, equaling 2.1 percent. This suggests that for every 100 unknown vocalizations, 2 species were missed by the acoustic method.

Ten-Minute Point Counts versus 10-Minute Acoustic Method

Unlimited-distance point counts and simultaneous acoustic monitoring at point-count stations were most similar, because both methods recorded all species regardless of distance within the same time and place. These methods led to comparable results in terms of species composition. The acoustic method gained more species than the point counts because most species detections of birds in forested habitats are based on vocalization (Skirven 1981, Lyrch 1995). Bart and Schoultz (1984) concluded that thirty-to-fifty percent of all singing males within hearing distance are likely to be overlooked by unlimited-distance point counts.

The acoustic method did not perform well, obviously, for secretive or non-vocal species. Chimney swifts were noted as flyovers by territory mapping and none of the acoustic devices recorded their calls. The majority of avian species on the study area were detected by both techniques, including Carolina chickadee, worm-eating warbler, scarlet tanager, and yellow-billed cuckoo. These birds were easily identified by visual, and/or aural cues. Some of these species were vocally active (e.g., indigo bunting, red-eyed vireo, ovenbird, pileated woodpecker) and were common-abundant on the study area.

Effect of Recording Period and Time of Day

The total number of species increased when the recording duration was increased, because more time allowed for inactive species to move onto the plot or give a call within the area sampled (Robbins 1981, Verner 1985). Birds that are far from the points or that vocalize infrequently have a greater probability of being detected with longer counting periods (Dawson et al. 1995). In this context, 50 minutes of acoustic methods detected at least 83 percent of cumulative species of the 2-hour recordings, and did so with one visit. A 50-minute recording, then, would provide reasonable efficiency for monitoring birds in mixed hardwood forest habitats. Recording period longer than 50 minutes gained proportionately fewer additional species (Table 4-3 and Figure 4-4).

The mean number of species (unsupplemented counts) detected in 10-minute recordings in this study declined by about 10 percent between 40 and 160 minutes after sunrise and the mean detections peaked at 40-70 minutes after sunrise. The result suggested that species detectability was greater in the early morning than in the late morning, thus the recorders should be started at least 40 minutes after dawn in this study.

However, the earlier monitoring time may be preferable because most birds are vocally active at dawn and acoustic monitoring allows for repeated listening to pick up some new species during the dawn chorus while point counts or territory mapping are limited to real-time observation.

Effect of Number of Visits and Number of Stations

Based on 10-minute recordings, new species number increased significantly with the number of visits from visit 1 to 8. However, according to the LSD mean separation, it was less beneficial to do acoustic monitoring for more than 5 visits within 3 weeks in the mixed hardwood forest at Cherokee National Forest. To improve sampling efficiency, I suggest 5 visits and extending the recording duration from 10 minutes to at least 50 minutes. This increased the number of species detected by 36% or 21% of total. The addition of more stations is recommended only if the stations were farther apart (greater than 250 m) to ensure statistical independence of point counts (Petit et al. 1995, Ralph et al 1995).

Detection Probabilities across Recording Periods

Detection probabilities vary among species, time of the season, and time of day presumably because of singing frequency (Farnsworth et al. 2002). Species that vocalize continuously (e.g., red-eyed vireo), and are present in groups or abundant (e.g., Carolina chickadee) will be detected within a short time period and show a slight change in detection probability as count period increases (Buskirk and McDonald 1995). These factors, individually or in combination with others, can cause the estimated detection probability and population estimates to be biased.

Detection probabilities as a function of twelve-10 minute increments were estimated based on 2002 data from acoustic monitoring. Common and vocal species (e.g., red-eyed vireo, indigo bunting) were usually detected within the first 10 minutes and showed little change in detection probabilities as recording period increased. Some species, such as visitors or flyovers (e.g., tufted titmouse, blue jay), were occasionally detected and the estimated detection probability were probably biased low because they might not have been physically present to be detected during the first 10 minutes. My detection probabilities suggested that birds in mixed hardwood forests were mostly detected by 80-minute recordings (detection probabilities greater than 0.8) (Table 4-7). Increasing recording period may increase species with a low probability of detection.

I assumed that acoustic monitoring did not differ in detection ability after calibrating the recording gain and testing in the field. My detection probabilities tended to be consistently lower than those reported by Farnsworth et al. (2002). For example, the detection probability of the 10-minute visit of ovenbird and black-throated green warbler were 0.84 (0.74) and 0.76 (0.40), respectively (the number in parentheses represents the results from this study). Red-eyed vireo was the only species found to have the greater detection probability 0.85 (1.00). However, Farnsworth et al. (2002) used point count-data to estimate the detection probability based on three time-intervals (the first 3 minutes, the subsequent 2 minutes, and the final 5 minues) while I used acoustic data to estimate the detection probability based on twelve-10 minute increments. I also suspect that my study was late in the breeding season for forest songbirds

(12 June-1 July 2002). Many species were not nesting/singing as much as earlier in the season (May) thus detection was probably biased low. It is also possible that birds in closed-canopy deciduous forest in Great Smoky Mountians National Park (GSM) could have greater detection probabilities than birds in closed-canopy mixed hardwood forest in CNF. Attenuation and distortion of sound might be lesser in the deciduous forest in GSM than in the mixed hardwood forest in CNF. Specific detection probabilities need to be measured by habitat type to evaluate this possibility.

Detection Probabilities across Distances

Birds tend to have 2 fundamental problems in vocal communication [i.e., attenuation and distortion or degradation of signal (Catchpole and Slater 1995)], when sending a call or song to receivers. Bird vocalization attenuates with distance according to physical principles whereby signal amplitude decreases by 6 dB for each doubling of distance (Emlen and DeJong 1981, Ryan and Kime 2002). Songs and calls are distorted by absorbtion and scattering by the air, ground, and physical attributes of habitat (Wiley and Richards 1978).

Detection probabilities across distances were estimated based on 2003 data from acoustic monitoring. I did not estimate the greatest distance of detection that an acoustic device can pick up the vocalizations for some species because it exceeded the capability of my sampling design. Nevertheless, I was able to estimate detection distances greater than 200 m for most species.

Based on maximum detection ranges ($D_{0.01}$), all 8 species of songbirds were detected from distances ranging from 166-328 m, whereas the three non-passerine calls were detected between 259-480 m. High frequency calls/songs with thin notes or trills showed more attenuation and scattering than lower frequency calls with sharp notes from non-passerines (Catchpole and Slater 1995). The detection distances recorded during my study generally agree with those reported by Emlen and DeJung (1981) or Wolf et al. (1995). The distances at $D_{0.50}$ of black-throated green warbler was 162 m (my study) vs 151 m (Wolf's study) and ovenbird was 174 m (my study) vs 182 m (Wolf's study). Thus, the overall differences were less than 10 m for these 2 species. Other species could not be compared because of the species differences between the 2 studies. The maximum detection distances of black-throated green warbler by Wolf et al. (1995) were greater than this study [i.e., 133 m (my study) vs 217 m (Wolf's study)]. However, ovenbird was detected at slightly greater distances from my study vs Wolf's study (i.e., 228 m vs 206 m, respectively). Two species were comparable among the 3 studies. Red-eyed vireo was detected within the maximum ranges at ≥188 m vs 188 m vs 135 m and white-breasted nuthatch was detected at ≥ 72 m vs 72 m vs 106 m (my study vs Wolf's study vs Emlen and DeJong's study, respectively). Detection probability between Carolina chickadee and black-capped chickadee might be comparable because of the similarity of song and amplitude. These 2 species seemed to have similar maximum ranges (127 m vs 125 m; my study vs Emlen and DeJong's study). All differences might be due to the habitat and observer differences. However, the results indicated that detection probability and maximum detection ranges of the species compared were generally similar and thus, acoustic method seemed to be as good as human direct observation in the field. I agreed with Wolf et al. (1995) that calculating detection probabilities for red-eyed vireo was problematic because of their abundance and their vocal activeness. These characteristics created potential bias by confusing individuals at different recording stations.

Variations in detection probability and detectability were caused by many factors such as the observer's ability to hear and identify individual species; season of year and time of day; wind, temperature, and other weather conditions; habitat attributes; and bird's characteristics and behaviors (Emlen and DeJong 1981, Richards 1981, Diefenbach et al. 2003). Further research is needed to estimate the detectability by taking these factors into account with sufficient sample size. The detection probability should be factored in to comparisons of species richness or abundance estimates to improve the precision and reduce the bias. Estimation of density of singing birds using the acoustic method in this context is possible. If we can prove that the maximum distances from which birds can be heard are species-specific within habitat and consistent among the habitats, then the number of individual singing birds detected can be used to calculate bird density (Emlen and DeJong 1981; Wolf et al. 1995).

Utility of Acoustic Monitoring in Mixed Hardwood Forest

Sampling effort represents a tradeoff between the number of visits, the number of stations, the recording period, and the species detection probability of specific species. The monitoring goal may be to document and monitor the maximum number of species per unit effort. The response surface model demonstrated that conducting acoustic survey for 8 visits, with 4 stations, and 120-minute recordings would yield the maximum number of species detected. The species detection probabilities for all 17 avian species analyzed were (by default) 100% for a 120-minute recording interval. This approach may be used for acoustic monitoring in mixed hardwood forest. However, different combination of the sampling effort can yield sufficient number of species detected with less investment in terms of money, time and personnel. Based on the analyses of effect of number of visits, number of stations, recording periods, I recommend that the reasonable effort for conducting acoustic surveys is 6 days, with 4 stations, and 80-minute recording periods. These combinations, according to the response surface model, would detect 30 species (82%), which would be sufficient to monitor forest bird populations on Cherokee National Forest. However, the suggested standards presented in this chapter will require future modification and testing under new conditions and habitats in which that study takes place.

CHAPTER 5

USE OF ACOUSTIC METHOD FOR MONITORING BIRDS IN HILL EVERGREEN FOREST AT PHU LUANG WILDLIFE SANCTUARY, LOEI PROVINCE, THAILAND

Phu Luang was designated as a wildlife sanctuary in 1974, covers an area of 897 square kilometers in northeastern Thailand (approximately 17° 3′ - 17° 24′ N; 101° 16′ - 101° 21′ E) with an altitudinal range of 400-1,571 m. Phu Luang is in one of the most important forest ecosystems in Thailand that provides habitat for many species of conservation concern, such as Asian elephant (*Elephus maximus*), serow (*Capricornis sumatraensis*), tiger (*Pantera tigris*), greater spotted eagle (*Aquila clanga*), and silver pheasant (*Lophura nycthemera*). Many of the wild orchids found in this area are endemic and endangered (Santisuk and Na Nakorn, nodate). Habitat types are diverse including tropical forest (elevation 400-800 m), hill evergreen forest (elevation >800 m), mixed deciduous forest, dry dipterocarp forest, coniferous forest, bush forest, and savannah. Vegetation in hill evergreen forest at Phu Luang is comprised of mostly temperate species that originated from northern and southern temperate zones including *Betula* spp. (Birch), *Quercus* spp. (oak), *Castanopsis* spp. (Chestnut), *Fraxinus* spp. (Ash), *Ulmus* spp. (Elm), *Acer* spp. (Maple), *Pinus* spp. (Pines), *Carpinus* spp. (Hornbeam) and *Prunus* spp. (Cherry) (Santisuk and Na Nakorn, nodate). Phu Luang supports a great variety of birds including year-round resident species and breeding and wintering residents such as ashy drongo (*Dicrurus leucophaeus*), golden-spectacled warbler (*Seicercus burkii*), greenish warbler (*Phylloscopus trochiloides*), and orange-headed thrush (*Zoothera citrina*). A total of 210 avian species have been recorded in this area (Royal Forest Department 2001).

The objective of this chapter was to develop and analyze the effectiveness of an acoustic monitoring protocol for bird populations in tropical hill evergreen forest habitat and compare this approach with standard protocols (point counts and territory mapping) for documenting species presence.

Study Plot

The acoustic monitoring devices were placed inside one of the largest forested areas near Phu Luang Wildlife Research Station. The plant community in the study area is described as hill evergreen forest. The vertical structure can be divided into 3 layers. The crown cover or primary cover (20-30 m) was dominated by *Lithocarcus spp.*, *Syzygium spp.*, *Walsura spp.*, *Nyssa javanica* (Blume) Wangerin, and *Gironniera nervosa* Planch. The crown cover was 90% on average. The secondary layer (10-20 m) was comprised of *Lithocarpus spp.*, *Dysoxylum andamannicum* King, *Walsure spp.*, *N. javanica* (Blume) Wangerin, *Carallia brachiata* (Lour.) Merr., *G. nervorosa* Planch, *Litsea spp.*, and *Gracinia spp.* The ground layer (5-10 m) was comprised of many species, such as *Ardisia spp.*, *Beilschmiedia gammieana* King ex Hook.f., *Drypetes spp.*, *Ostodes paniculata* Blume, *Litsea spp.*, *Artocarpus parva* Ganep, *D. andamannicum* King, and *Diospyros malabarica* (Desr.) Kostel including seedlings and saplings of tree species from the primary and secondary layer (Figure 5-1). The plot was located 200 m from east side of the patrol road. The plot elevation is 1,110 – 1,127 m. Aspect was generally north and the slope ranged from 0-5%.

Methods

Monitoring Protocols

Monitoring protocols were similar to those used at Fort Campbell (see Chapter 2 for details). The 9-ha plot (300 m x 300 m) was delineated and a 75-m x 75-m grid was marked off across the plot. The four recording devices (computers as recorders) were placed at grid intersections with 150-m spacing between each station (See Figure 2-1 for plot layout). I conducted comparisons among territory mapping, unlimited-distance point counts, and acoustic method on 10 mornings from 4-8 March 2002 during the breeding season.

Data and Statistical Analysis

Two days of data of territory mapping, unlimited-distance point counts, and acoustic method were omitted from the analysis because of poor quality of some recordings or power failure of the recording devices. Based on 8 days of data, a similarity index (SI) and a paired *t*-test were used to compare similarity among methods. Eight days of acoustic data were also used to analyze the effect of recording period, number of visits, number of stations, time of day, and detection probabilities. To determine species identification rate by acoustic method, individual calls and songs were tallied and the species identification rate was calculated by the number of individuals that were identified to species divided by the total number of individuals detected. Data and statistical analysis were similar to those used at Fort Campbell (see Chapter 2 for details).

Results

Species Richness

Forty-four species of birds were identified using the unlimited-distance point counts, and 45 species of birds, within the border of the 300-m x 300-m plot, using the territory mapping method. Sixteen species had territories inside the plot, including hill blue flycatcher (See Table 5-1 for scientific names), large niltava, lesser shortwing, lesser racket-tailed drongo, mountain tailorbird, puff-throated bulbul, silver-eared mesia, white-tailed leaf-warbler, and white-throated fantail. The other 29 species were considered as visitors and flyovers. Fifty-eight species were detected from 64 hours of acoustic recordings on 8 days. There were 4,147 total calls or songs recorded of which 3,713 or 89.5 percent were identified to species. When 8-day data were pooled across the three methods, 69 species of birds were documented which was 78% of the year-round bird list in the study plot documented by Simcharoen et al. (2004) between March 2002 to February 2003. The acoustic method at point-count locations detected more species than unlimited-distance point counts and territory mapping (Figure 5-2).

To compare the number of avian species found using each method, all species detected were listed (Table 5-2). Unlimited-distance point counts and the acoustic method had the greatest similarity (Figure 5-3). Forty species were detected by both methods; similarity index (SI) = 78.4%. Both territory mapping and the acoustic method detected 34 species of birds; SI = 66.0%, whereas point counts and territory mapping had the least similarity (29 species in common with SI = 65.2%)

Mean species richness (± SE) for 10-minute data was 9.28 ± 0.38 and 10.69 ± 0.30 for point counts and acoustic monitoring, respectively. The number of species per point differed between the two methods ($t = 3.12$, df = 31, $P < 0.01$). Individual songs of white-tailed leaf-warbler was detected equally (100%) by both methods (Figure 5-4). Six species (golden babbler, blue-throated barbet, silver-eared mesia, white-browed scimitar babbler, puff-throated bulbul, and grey-eyed bulbul) were detected at almost the same rate. The detection of 5 species from point counts (mountain tailorbird, mountain imperial pigeon, large niltava, red-headed trogon, and lesser shortwing) was greater than detection of these species by acoustic method. Black-crested bulbul, blue-eared barbet, grey-headed flycatcher, and hill blue flycatcher were detected more often by acoustic method than point counts. Seven species were not detected by point counts and acoustic method but were detected by territory mapping: blue-winged minla, chestnut-flanked white-eye, silver-breasted broadbill, eye-browed thrush, eye-browed wren babbler, speckled piculet, and velvet-fronted nuthatch (Figure 5-4). To double check my identifications and to test repeatability, Watchra Sayoensombat and Dome Pratumthong (Department of Forestry Biology, Faculty of Forestry, Kasetsart University), listened to ten 10-minute recording at point-count stations (25% of total). They agreed with 94% of my identifications and added 1 species (barred cuckoo dove).

Effect of Recording Period

Based on 2-hour recording data, the main effect of recording period was large (F = 161.15, df = 11, $P < 0.001$). On average, 10-minute recordings during 0700-0900 yielded 11.5 ± 0.5 species. These included 47% of the total species noted on 2-hour recordings or 20% of all species detected on plot by four recording stations. New species were detected significantly (mean greater than zero) when the recording period increased from 10 to 110 minutes ($P < 0.05$). However, the LSD mean separation indicated that the number of new species detected did not differ from 80- 120 minutes. The detection rate of new species decreased after the first 10-minute recording and leveled off after 50 minutes. After 110 minutes of recording, the cumulative number of species was 24.2 ± 0.5, which represented 98.0% of the 2-hour recording total. From 110 to 120 minutes, the total number of species increased at a lesser rate (Table 5-3, Figure 5-5). The number of species detected within 120-minute recordings from each station averaged 42.6% of the total species detected on plot by acoustic method with 4 recording stations.

Effect of Number of Visits

The main effect on number of visit was large (F = 146.59, df = 7, $P < 0.001$). New species were detected significantly from 1- 8 visits ($P < 0.001$). However, LSD mean separation indicated that the number of new species detected did not differ from visit 6 – 8 (Table 5-4). The detection rate of new species considerably decreased after the first visit and leveled off after 3 visits. Eight visits recorded 46.2 percent of all species detected on plot by four recording stations (Table 5-4; Figure 5-6).

Effect of Time of Morning

Variation in the mean number of species detections (unsupplemented count) among 30-minute time-of-morning categories was large ($F = 6.10$, df = 3, $P < 0.001$). The greatest number of species (unsupplemented count) was found during 0700 - 0730 (10.9 ± 0.3) and declined thereafter. However, there was no difference in number of species among 30-minute categories between 0730 - 0800 and 0800 - 0830 or between 0800 - 0830 and 0830 - 0900 ($P > 0.05$) (Table 5-5).

Number of Stations versus Number of Visits

The mean number of species for unsupplemented counts differed among stations ($F = 6.17$, df = 3, $P = 0.001$). Station 2 detected the least number of species compared to stations 1, 3 and 4 ($P < 0.001$; Table 5-6). The number of species detected among station 1, 3 and 4 were approximately equal ($P > 0.98$). Increasing the number of stations from 1 to 4 stations affected the number of new species on the supplemented count ($F = 362.42$, df = 3, $P < 0.001$). However, LSD mean separation indicated that the number of new species detected did not differ by adding station 2 to 4 ($P < 0.05$). One to four station recordings yielded 50.0%, 53.8%, 84.5% and 100% of the total species detected by 2-hour recordings of 4 stations, respectively. However, the detection rate of new species decreased from 1-2 stations and leveled off thereafter (Figure 5-7). All 6 possible paired reciprocals (e.g., 1 visit-2 stations vs 2 stations-1 visit) were compared. The first 3 paired reciprocals appeared to show that more visits yielded more species than did more stations added to each visit. However, the overall results did not differ because these apparent differences disappeared among the last 3 paired reciprocals (S = -6.00, df = 5, P = 0.188), Wilcoxon Signed Rank Test, Figure 5-8).

Detection Probabilities

The pattern of detection probability as a function of recording period differed among species and ranged from 0.0 to 0.97 after 10 minutes of recording. Black-throated barbet, golden babbler, great barbet, and white-tailed leaf-warbler were detected with great frequency. After the first 10 minutes of recording, the detection probability increased slightly for every subsequent 10-minute period (Figure 5-9; Table 5-7). Some species (e.g., blue-eared barbet, grey-eyed bulbul, large scimitar babbler, and mountain tailorbird) were detected at moderate frequencies. The detection probabilities gradually increased with longer recording periods. Other species such as bar-backed partridge, buffed-breasted babbler, large niltava, and white-browed scimitar babbler were detected at low probabilities at the beginning but the detection probabilities gradually increased over longer recording period. For most species, detection probabilities were greater than 0.8 after 90-minute periods. All species detection probabilities for 2-hour recordings were equal to 1 because all species analyzed were detected within this period.

Number of Stations versus Number of Visits versus Recording Periods

The response surface analysis showed that the linear effects of number of visits, number of stations, and recording-period were important (F = 1980.80, df = 3, P = 0.001), including quadratic effects (F = 296.02, df = 3, $P < 0.001$). The model fit the data extremely well, explaining 97.4% of cumulative species differences. It was predicted that the maximum number of species detected by acoustic method (i.e., 57 species) can be approached by conducting acoustic monitoring for 6.4 visits; each visit required 4.6 stations and 108 minutes of recordings (Figure 5-10). The response surface model fits quadratic and linear by linear interactions. For these 3 variables, the model equation was:

$$\text{number of species} = -13.264137 + 9.219483(\text{visit}) + 9.829065(\text{station}) + 0.342527(\text{period}) - 0.695561(\text{visit}^2) - 0.851562(\text{station}^2) - 0.001359(\text{period}^2) - 0.106448(\text{visit*station}) + 0.001410(\text{visit*period}) - 0.012941(\text{station*period})$$

The model predicted that under the maximum unit effort in this context (8-day visits with 2-hour recording and 4 stations per visit), the number of species detected would be 55. In actuality, the acoustic monitoring recorded 58 species.

Discussion

Acoustic Method, Point Counts, and Territory Mapping

Eight days of monitoring detected 69 species pooled from all methods, 78% of the year-round bird list in the study plot recorded by Simcharoen et al. (2004). Four of 11 winter visitors (blue whistling thrush, eye-browed thrush, and Japanese white-eyed) were found during the study. Eighteen species (e.g., black-throated laughingthrush, great coucal, grey-capped woodpecker, hair-crested drongo) were added to Simcharoen's year-round bird list. Simcharoen et al. (2004) emphasized nesting/breeding species in this plot, which might explain why my monitoring detected so many additional species. The results indicated reasonable efficiency for detecting species presence based on combining all three methods within the limited time and season. Tropical forest bird communities typically have greater species richness but lesser abundance per species (Primack 2000). As a result, species detections would likely be less than compared to detections in temperate forests per unit monitoring effort.

Territory mapping has been regarded as the most accurate method that is widely used to study territorial birds associated with plot and plot habitat in the temperate region during the breeding season (Verner 1985, Bibby et al. 2000). Raman (2003) demonstrated how territory mapping can be applied to the study of territorial rainforest birds in the Western Ghats in India. He also noted that variable-width point counts performed well in terms of density estimates for cryptic, sedentary, understory birds, and canopy birds that were often detected by calls. However, variable-width point counts may cause a high bias for vocal and mobile species. Comparing these three methods regarding census period, the territory mapping and acoustic method were conducted for 2 hours each morning. On point counts, in contrast, birds were recorded for only 10 minutes at each point (i.e., 40 minutes per day for 4 points). Therefore, the acoustic method detected more species than unlimited-distance point counts, in part because of increased monitoring time. However, the number of species detected by territory mapping and point counts were almost the same because birds off the plot were not included in the mapping. The similarity index between point counts and the acoustic method was greater than the similarity between territory mapping and the acoustic method or the similarity between point counts and territory mapping. Two species were missed by acoustic method, but were visually detected by point counts (Japanese white-eye and little pied flycatcher). These species were uncommon in this site; Japanese white-eyed produced a short thin wispy song and little-pied flycatcher produced thin, sweet and high pitch notes, often followed by a rattled call note (Robson 2000). None of these vocalizations were detected and identified as being from this species. Four species (silver-breasted broadbill, speckled piculet, velvet-fronted nuthatch and white-bellied yuhina) were missed by point counts and acoustic method but were detected by the observer while walking along the grid line from one station to another station. From the acoustic results, 89.5 percent of the detected calls and songs could be identified to species. If it is assumed that the total bird list of the three methods (69) was all of the species in the study plot, then 11 species were missed by the acoustic method and these species emitted 434 unknown vocalizations. Then the rate of missed detection of new species can be calculated as 11 species divided by 434 vocalizations, equaling 2.5%. The % detection in this study was similar to the study by Lynch (1995). He detected 88% of individual birds or conspecific groups by using unlimited-distance point counts in semi-evergreen tropical forests in Mexico.

Ten-Minute Point Counts versus Ten-Minute Acoustic Method

Unlimited-distance point counts and simultaneous acoustic monitoring at point-count stations were very similar when both methods recorded species regardless of distance within the same time period (10 minutes) and place. The acoustic method gained more species than the point counts because species were mostly detected aurally during the point counts. The acoustic devices recorded more species than the observer noted during the point counts, especially species at a great distance: collared-scoped owl, grey-capped woodpecker and little cuckoo dove. The observer evidently missed these birds because they had less audible vocalizations (Verner 1985, Verner and Milne 1989). However, these non-passerine species tend to have low-frequency calls with less attenuation compared to the songs of most passerines (Catchpole and Slater 1995).

The acoustic method did not perform well, obviously, for secretive or non-vocal species. Point counts detected crested serpent eagle as a flyover. All 4 acoustic devices, however, did not pick up their calls. Other species such as eye-browed thrush, eye-browed wren babbler, and black-throated sunbird were missed by the acoustic method. These species were noted infrequently during territory mapping. The majority of avian species on the study area were detected by both point counts and acoustic methods, including, black-crested bulbul, mountain tailorbird, hill blue flycatcher. These birds were easily identified by visual and/or aural cues. Some of these species were vocally active (e.g. blue throated barbet, golden babbler, and silver-eared mesia) and were common on the study area.

The advantages of the acoustic monitoring over the point counts were no expert field observer required, permanent records of species presence, and the ability to monitor many sites simultaneously (Haselmayer and Quinn 2000, Hobson et al. 2002). These advantages may be particularly important in tropical ecosystems where avain communities are diverse, and song recognition expertise may be limited to only a few individuals.

Effect of Recording Period and Time of Day

The total number of species increased when the recording duration was increased, because there was more time to detect inactive birds (Robbins 1981, Verner 1985). Detection probability will increase with longer counting periods for birds that are far from the points or vocalize infrequently (Dawson et al. 1995). In this context, 80 minutes of acoustic methods detected at least 90 percent of cumulative species of the 2-hour recordings, and did so with one visit. Using the acoustic methods, then, at least a 80-minute recording would provide reasonable efficiency for monitoring birds in hill evergreen forest. Even though 80-minute recordings did not record all species at a given point, the result should yield enough information for monitoring avian population.

Detection rates of birds in semi-evergreen tropical forests in Mexico were stable between sunrise and the ensuring 3-4 hours (Lynch 1995). In this study, the mean number of species (unsupplemented counts) detected in 10-minutes declined by about 14.7 percent between 30 minutes and 150 minutes after sunrise. This might be related to insect activity; insect calls increased gradually after sunrise leading to decreased quality of recordings. The insect noise interfered with the sound recording and made avian detection more difficult. To improve detection ability, the recording should be started before or at dawn.

Effect of Number of Visits and Number of Stations

Based on 10-minute recordings, detection of new species increased significantly with the number of visits from 1 to 8. Species accumulation may continue to increase even after 8 visits but no data were available to evaluate this hypothesis. Six 10-minute visits would allow the detection of at least 90 percent of species recorded which would provide enough information for bird monitoring. The recording duration, an alternative way for improving sampling efficiency, can be extended from 10 minutes to 80 minutes. The addition of more stations within the original plot may not be appropriate because of the proximity of stations and the need to maintain the independence of count stations (Petit et al. 1995), even though it did not cause problems for estimates of species richness in this study.

Detection Probabilities

In general, birds that were abundant and vocally active had greater estimated detection probabilities (Dawson et al. 1995). These included blue-throated barbet, great barbet, and golden babbler. These birds were usually detected within the first 10 minutes and showed little change in detection probabilities as recording period increased. Some species, such as bar-backed partridge, red-headed trogon, little spiderhunter, and grey-cheeked fulvetta were occasionally detected and showed significant increase in detection probabilities as recording period increased. My detection probabilities suggested that birds in hill evergreen forest were mostly detected by 90-minute recordings (detection probabilities greater than 0.8) (Table 5-7). Increasing recording length may increase species with a low probability of detection. If particular species are of interest or species richness at individual points is desired, recording period can be optimized so that target species or most species are detected (Barker and Sauer 1995, Dawson et al 1995, Ralph et al 1995).

Utility of Acoustic Monitoring in Hill Evergreen Forest

The response surface model demonstrated that conducting acoustic surveys for 6 visits with 4 stations and 110-minute recordings can approach the maximum number of species detected (57 species). This approach may be used for acoustic monitoring in the hill evergreen forest. However, if the sampling unit effort is limited, the combinations among visits, stations, and recording periods can be adjusted according to the response surface analysis. Additional factors such as monthly variation during the breeding season and time of day affect the species detection probability and should be taken into account. A reasonable effort for conducting acoustic surveys would be 3 visits, with 4 stations, and 80-minute recording periods. These combinations, according to the response surface model, would detect 47 species (81%), which would provide enough information for monitoring hill evergreen bird populations at Phu Luang Wildlife Sanctuary, Loei province, Thailand. Developing avian monitoring for tropical bird populations is more difficult than for temperate bird populations. Many factors affect the census accuracy such as the high diversity of species, vegetation density, patterns of activity (among days, seasons, and year), migration and nomadism, and secretive behavior of many species (Karr 1981, Raman 2003). The suggested acoustic monitoring protocols presented in this chapter may apply to other places in the tropical forest ecosystem but will need modification and testing under new conditions and new habitats in which that study takes place.

CHAPTER 6

USE OF ACOUSTIC METHOD FOR MONITORING BIRDS IN TROPICAL GRASSLAND AT KHAO YAI NATIONAL PARK, THAILAND

Khao Yai National Park is located within the Dongrak Mountain Range of the Korat plateau in central northern Thailand (14° 5′ - 14°15′ N; 101° 5′ - 101° 50′ E). Khao Yai was designated as a national park in 1962, and covers an area of 2,168 square kilometers. The park is generally mountainous varying from 250 to 1,351 m. The vegetation in Khao Yai is highly diverse. The five types of forest in the park are dry mixed deciduous, dry evergreen forest, tropical rain forest, hill evergreen forest, and savanna and secondary growth (Poonswad 1993). As a result, wildlife are abundant and diverse, comprised of 358 species of birds 72 species of mammals and 74 species of reptiles. Key species of mammals and birds of known and/or likely global or national conservation concern occur within KhaoYai including: Asian elephant (*Elephas maximus*), Asiatic black bear (*Ursus thibetanus*), sun bear (*Ursus malayanus*), Asiatic wild dog (*Cuon alpinus*), tiger (*Panthera tigris*), Clouded leopard (*Pardofelis nebulosa*), gaur (*Bos gaurus*), white-handed gibbon (*Hylobates lar*), pileated gibbon (*Hylobates pileatus*), Siamese fireback *(Lophura diardi)*, great slaty woodpecker *(Mulleripicus pulverulentus)*, four species of hornbills (*Bucerotidae*), coral-billed ground cuckoo *(Carpococcyx renauldi)*, javan frogmouth (*Batrachostomus javensis)*, pompadour pigeon (*Treron pompadora)*, black eagle *(Ictinaetus malayensis)*, mountain hawk eagle *(Spizaetus nipalensis)*, and hill myna *(Gracula religiosa)*.

Khao Yai and the other 4 protected areas referred to as The Dong Phayayen - Khao Yai Forest Complex, cover 6,155 square kilometers and have been recently nominated to be included on the list of World Heritage Sites. One of their management goals is to develop an ecosystem-based management approach which is based on existing scientific information and current issues facing the Complex. Developing and implementing acoustic monitoring is an alternative method for a manager to gain information of bird populations to help meet the management goal.

Point counts and territory mapping have been developed and widely used for most terrestrial bird surveys in temperate regions (Karr 1981). However, few studies have evaluated and standardized bird surveys in tropical habitats, especially tropical grasslands. Raman (2003) compared bird densities based on variable-width point and line transects, and suggested that territory mapping can be applied usefully to monitor territorial rainforest birds in the tropical forest habitat in India. My study is a first attempt to use acoustic method to record the species presence in the Asian tropical grassland habitat. Thus, the objective of this chapter was to develop and analyze the effectiveness of an acoustic monitoring protocol for bird populations in tropical grassland habitat and compare it with standard protocols (point counts and territory mapping) for documenting species presence.

Study Plot

The study plot was established in a 40-ha grassland patch surrounded by dry evergreen forest with a saltlick and a pond nearby. The distance between the boundary of the plot and the edge of surrounding forest ranged from 100 m for north and south sides, 200 m for west side and 300 m for east side. Like other grassland habitat in the park, it exists due to previous human settlement. Park managers maintain grassland by burning every 1-3 years basically for providing suitable habitat and food for sambar deer (*Cervus unicolor*) and other grazers. Dominant grass species included cogon grass (*Imparata cylindrical)*, silk reed *(Neyraudia reynaudiana)* and wild sugarcane *(Saccharum spontaneum)*. The elevation was 760 m and aspect was generally south with 1-5% slope.

Methods

Monitoring Protocols

Monitoring protocols were similar to those used at Fort Campbell (see Chapter 2 for details). The 9-ha plot (300 m x 300 m) was delineated and a 75 m x 75 m grid was marked off across the plot. The four recording devices (IBM Pentium I laptops as recorders) were placed at grid intersections with 150-m spacing between each station (See Figure 2-1 for plot layout). I conducted comparisons among territory-mapping, unlimited-distance point counts, and acoustic method on 10 mornings between 1-11 April 2004.

Data and Statistical Analysis

Five days of data were omitted from the analysis because of poor quality of the recordings or power failure which might have been caused by high temperature in the field. A similarity index was used to compare the similarity among these methods. A paired *t*-test was used to compare the mean number of species per point per 10 minutes between unlimited-distance point counts and acoustic method. Acoustic data were analyzed using SAS (2000) unless otherwise indicated (see Chapter 2 for details).

Results

I identified 33 avian species using the unlimited-distance point counts, and 32 species using the territory mapping. Three species were considered to have territories inside the plot: bright-capped cisticola (See Table 6-1 for scientific names), red-whiskered bulbul, and yellow-billied prinia. The other 29 species were considered visitors. Sixty species were detected from 40 hours of acoustic recordings on 5 days. There were 3,818 total calls or songs of which 3,280 or 85.9 percent were identified to species. When data were pooled across the three methods, 72 species were recorded in 5 days of observations. Only 8 species (chestnut-capped babbler, grey-breasted prinia, plain prinia, Radde's warbler, rufescent prinia, yellow-bellied prinia, and yellow-legged button quail) were identified as grassland birds or species whose habitat is mainly in grassland (Lekagul and Round 1991). The other species were detected from the edge of grassland habitat and from inside the forest. The acoustic method at point-count locations detected almost twice as many species as unlimited-distance point count or territory mapping (Figure 6-1).

To compare the number of avian species recorded among methods, all species detected were listed (Table 6-2). The similarity index (SI) of the 3 paired reciprocals ranged from 50 -56%. The unlimited distance point counts and acoustic method had the greatest similarity (Figure 6-2); 26 species were detected by both methods; similarity index (SI) = 56%. Territory mapping and acoustic method had the least similarity (23 species in common; SI = 50%), while unlimited-distance point counts and territory mapping detected 18 species in common with SI = 55%.

Mean number of species per point (±SE) was 14.40 ± 0.59 and 16.45 ± 0.63, for point counts and acoustic monitoring, respectively. The number of species per point differed between the two methods (t = 3.15, df = 19, P = 0.005). Barred cuckoo dove, rufescent prinia, and white-crested laughingthrush were detected by acoustic method but not detected by point counts (Figure 6-3). Scarlet minivet, black-headed bulbul, chestnut-headed bee-eater, and crested serpent eagle were only detected by the territory mapping method. Overall, acoustic method recorded 34% more species than unlimited-distance point counts. Most species detected by acoustic methods were from the edge of the forest around the plot.

<u>Effect of Recording Period</u>

The main effect of recording period was large (F = 189.58, df = 11, P < 0.001). Ten-minute recordings yielded 17.2 ± 1.1 species, on average. These included 60% of the total species noted on 2-hour recordings. New species were detected significantly (mean greater than zero) when the recording period increased from 10 minutes to 100 minutes, ($P < 0.05$). However, LSD mean separation indicated that the number of new species detected did not differ from 50-120 minutes ($P > 0.05$, Table 6-3). At time period 90 minutes, the cumulative number of species was 30.0 ± 1.1 and represented 95.5 percent of the 2-hour recording total. For additional 10 minute increments from 100 minutes, the total number of species increased at a lesser rate (Table 6-3 and Figure 6-4).

Effect of Number of Visits

The main effect of visit was large ($F = 355.25$, df = 4, $P < 0.001$). New species were detected significantly (mean greater than zero) from visit 1-5 ($P < 0.001$). However, the LSD mean separation indicated that the number of new species detected did not differ from 4 to 5 visits ($P > 0.05$, Table 6-4). The detection rate of new species decreased considerably and leveled off after the first visit. Five visits recorded 54.3 percent of all species detected on plot by four recording stations. Although the rate of gain of new species was slowing after 5 visits, there was no indication the species list was complete.

Effect of Time of Morning

Variation in the mean number of species detections (unsupplemented count) among 30-minute categories was large ($F = 11.61$, df = 5, $P < 0.001$). The greatest number of species was found during 0600 - 0630 (16.8 ± 0.5) and declined thereafter. However, there was no difference in number of species among 30-minute categories from 0600 - 0730, between 0700 - 0730 and 0730 - 0800, between 0730 - 0800 and 0800 - 0830 ($P > 0.05$) (Table 6-5).

Number of Stations versus Number of Visits

The mean number of species for unsupplemented counts differed (marginally) among stations ($F = 2.55$, df = 3, $P = 0.064$). Station 4 detected fewer species compared to station 3 ($t = 2.63$, df = 64.1, $P = 0.011$; Table 6-6). The number of species detected among stations 1-3 did not differ ($P > 0.05$). Increasing the number of stations from 1 to 4 stations affected the number of new species on the supplemented count ($F = 513.50$, df = 3, $P < 0.001$). One to four recording stations yielded 60.8%, 80.2%, 92.0% and 100% of the total species detected by 2-hour recordings of 4 stations, respectively. However, the detection rate of new species decreased when adding the second station, and leveled off after that (Figure 6-6). Five out of 6 possible paired reciprocals [e.g., 1 visit - 3 stations vs 3 visits - 1 station) showed that more visits yielded more species than did more stations added to each visit. The overall results differed only marginally, in part because of the lack of a difference between the first paired reciprocals (i.e., 1 visit-2 stations vs 2 stations-1 visit ($S = -9.50$, df = 5, $P = 0.062$), Wilcoxon Signed Rank Test, Figure 6-7].

Detection Probabilities

The pattern of detection probability as a function of recording period differed among species and ranged from 0.17 to 1.00 after 10 minutes of recordings. Bright-capped cisticola, hill myna, moustached barbet, red-whiskered bulbul, and mountain imperial pigeon were detected with great frequencies, and their detection probabilities were 100% after the first 10 minutes of recordings (Figure 6-8;

Table 6-7). Some species (e.g., plain prinia, red-wattled lapwing, yellow-bellied prinia, barred cuckoo dove, and large-billed crow) were detected at moderate frequencies. The detection probabilities gradually increased with longer recording periods. Other species such as stripe-tit babbler, and white-browed scimitar babbler were detected at low frequency and low detection probability in the beginning but the detection probabilities gradually increased over longer recording period. For all species, detection probabilities were greater than 0.8 after 90 minutes of recording.

Number of Stations versus Number of Visits versus Recording Periods

The response surface analysis showed that the linear effects of number of visits, number of stations, and recording-period were important (F = 2745.88, df = 3, $P <$ 0.001), as well as the quadratic effects (F = 64.07, df = 3, $P <$ 0.001). The model fit the data extremely well, explaining 94.8% of cumulative species differences (Figure 6-9). For these 3 variables, this produced the following model:

$$\begin{aligned}\text{Number of species} = {} & 7.713258 + 2.921834(\text{visit}) + 5.741742(\text{station}) + 1.704783(\text{period}) \\ & + 0.049107(\text{visit}^2) - 0.85(\text{station}^2) - 0.098626(\text{period}^2) \\ & + 0.2275(\text{visit*station}) + 0.189773(\text{visit*period}) \\ & + 0.090629(\text{station*period})\end{aligned}$$

Because the response surface analysis resulted in a saddle point, the estimated value does not have a unique optimum. However, based on the model, it suggests that 59.5 species were detected by acoustic method species under the maximum unit effort (5 visits with 4 stations and 120 minutes of recordings). In actually, the acoustic monitoring recorded 60 species.

Discussion

Acoustic Method, Point Counts, and Territory Mapping

After pooling across all three methods, 72 species were identified on the plot. Considering the fact that grassland and secondary growth habitats cover only 5% of the area, the species found inside and around the plot was 20% of the bird list in KhaoYai. The number of species detected by acoustic method was almost 100% more than by territory mapping or unlimited-distance point counts. This was in part due to the observer's limited experience with the songs and calls of these species during the field work. Four out of 5 winter visitors documented in this study (i.e., Asian emerald dove, black-naped oriole, dusky warbler, and Radde's warbler) were recorded by acoustic method. Acoustic method detected many species located in the forest near the edge while birds off the plot were not included by territory mapping. Unlimited-distance point counts and acoustic method were similar because there wasn't a fixed plot boundary. However, the period of monitoring was different. Only 4 point counts (40 minutes total per day) were conducted each morning while 4 acoustic monitoring devices ran for 2 hours each morning (8 hours total per day). One of the advantages of acoustic method was those recordings allowed for repeated listening (Haselmayer and Quinn 2000). Therefore, the unclear songs/calls (e.g., the flurry of activity by most species during the dawn chorus) were listened to carefully and were repeated to verify vocalizations to species.

The similarity index between point counts and acoustic method or between point counts and territory mapping was greater than the similarity between territory mapping and acoustic method. Three species were missed by acoustic method, but were recorded by point counts and territory mapping (i.e., Barn swallow, "a flyover", Eurasian jay, and hair-crested drongo detected by visual observation at the edge of the eco-tone between grassland and forest habitat). Four species (black-headed bulbul, Chestnut-headed bee-eater, crested serpent eagle, and scalet minivet) were missed by point counts and acoustic method, but were noted by territory mapping. These species were detected infrequently or as flyovers. Acoustic method added 24 species to the list. Twenty-one out of 24 were detected at a distance, possibly in the forest edge. The other three species with low amplitude vocalizations, were detected by acoustic method less than 10 times (i.e., chestnut-capped babbler, olive-backed sunbird, and Radde's warbler). From the acoustic results, 85.9 percent of the detected calls and songs were identified to species. If I assumed that the total bird list of the three methods (72) is all of the species in the study plot, then the species missed by acoustic method was 12 species from the tallied counts of unknown sounds (538). The rate of missed detection of new species can be calculated as 12 species divided by 538 or 2.2 percent. This means that for every 100 unknown vocalizations, there were 2 species missed by acoustic method. The % detection in this study seemed reasonable when compared to the study by Lynch (1995). He detected 88% of individual birds or conspecific groups by using unlimited-distance point counts in semi-evergreen tropical forests in Mexico.

Ten-Minute Point Counts versus Ten-Minute Acoustic Method

Unlimited-distance point counts and simultaneous acoustic monitoring at point-count stations were very similar when both methods recorded species regardless of distance within the same time period (10 minutes) and place. The acoustic devices recorded more species, such as collar owlet, brown hawk owl, spotted dove, Asian emerald dove, and coral-billed ground cuckoo than were noted during the point counts, especially at great distance (i.e., > 300-500 m) during the dawn chorus. These non-passerine species tend to have low-frequency calls with less attenuation compared to the songs of most passerines (Catchpole and Slater 1995). The low- frequency calls were either inaudible or overlooked, evidently, because the observer might have been concentrating on other birds (Verner 1985, Verner and Milne 1989). During point counts at dawn, some laughingthrushes, such as black-throated laughingthrush, lesser-necklaced laughingthrush, and white-crested laughingthrush not only drowned out the calls of other birds, but also make it difficult for the observer to identify birds among these species. However, these species and some other species were recognized after repeated listening by acoustic monitoring. This was one of the reasons why the acoustic method detected a lot more vocalizations than the unlimited-distance point counts.

The acoustic method obviously did not perform well for secretive or non-vocal species. Six flyovers were all missed by acoustic methods: Asian palm swift, barn swallow, chestnut-headed bee-eater, Chinese pond heron, scarlet minivet, and crested serpent eagle. Other species such as great barbet, hair-crested drongo, black-headed bulbul, dollarbird, and Eurasian jay were missed by the acoustic method. These species were noted infrequently during territory mapping or point counts. Avian species including bright-capped cisticola, hill myna, red-whiskered bulbul, great coucal, and large-billed crow detected by both point counts and acoustic methods were easily identified by visual and/or aural cues. Some of these species were vocally active and were common in the study area (e.g., moustached barbet, red-wattled lapwing, and mountain imperial pigeon).

Even though acoustic monitoring cannot be as effective as point counts for abundance estimates or recording secretive species and flyovers, acoustic monitoring has some advantages over the point counts such as no requirement for expert field observer, yielding permanent records, and the ability to monitor many sites simultaneously (Haselmayer and Quinn 2000, Hobson et al. 2002). These advantages may be particularly important in the tropical ecosystems where the avian species richness is high and there are very few expert field observers.

Effect of Recording Period and Time of Day

When the recording duration increased, detection probability increased for birds that were far from the point or vocalized infrequently because there was more time to detect inactive birds (Robbins 1981, Verner 1985, Dawson et al. 1995). In this context, 50 minutes of acoustic monitoring detected at least 82 percent of the cumulative species of the 2-hour recordings and did so with only one visit. Using the acoustic methods then, at least a 50-minute recording would provide reasonable efficiency for monitoring birds in tropical grassland. Even though 50-minute recordings did not record all species at a given point, the results should yield enough information for monitoring avian populations.

The mean number of species (unsupplemented counts) detected in 10 minute recordings declined by about 40 percent between 10 minutes and 190 minutes after sunrise. The species detected between 0830 - 0900 decreased significantly (28%) from the previous 30 minutes. Despite declining bird activity levels and changing environmental factors (e.g., greater wind velocity, and lower humidity), which affect the avian detectability as morning progressed, ground temperature is a significant effect on sound transmission in open habitats. Temperature near the ground in the tropical grassland habitat tends to be warmer than the gradient above the ground during a typical sunny day. As a result, wave front of avian vocalizations advancing parallel with the ground is defracted upward. This phenomenon leaves an area of attenuated sound under the wave front called "shadow zone effect" (Catchpole and Slater 1995, Hopp and Morton 1998). Thus, the detectability of birds in the tropical grassland tends to decrease significantly when the ground temperature is increasing. However, in the forest (especially tropical ones), there is no shadow zone effect due to the relatively homogenous air below the canopy (Hopp and Morton 1998). Given the monitoring dates used for this study (April 2002), there appeared to be a significant decrease in detection rates of birds in tropical grassland at Khao Yai. To improve the detection probability, the recording should be started running before or at dawn and stopped no later than two and a half hours after sunrise (Table 6-5).

Effect of Number of Visits and Number of Stations

Based on 10-minute recordings, new species were detected significantly as the number of visits increased from 1 to 5. Species accumulation may likely increase even after 5 visits but no data were available to evaluate this possibility. Four 10-minute visits would allow the detection of at least 88% of species recorded which would provide enough information for bird monitoring. The recording duration can be extended from 10 minutes to 50 minutes. The addition of more stations, within the original plot, would only be appropriate if the stations are far enough (> 250 m) apart to maintain independence of the count stations (Petit et al. 1995).

Detection Probabilities

Detection probabilities vary among species. Vocally active and abundant species tend to have higher estimated detection probabilities (Dawson et al. 1995). These included bright-capped cisticola, hill myna, and moustached barbet. These birds were usually detected 100% within the first 10 minutes. Some species such as 4 species of Prinia (i.e., yellow-bellied prinia, plain prinia, grey-breasted prinia, and rufescent prinia) were occasionally detected and showed significant increase in detection probabilities as recording period increased. My detection probabilities suggested that birds in tropical grassland habitat were mostly detected by 80-minute recordings (detection probabilities greater than 0.8) (Table 6-7). To increase detection probability in some species such as stripe-tit babbler, recording period would need to be increased up to 120 minutes.

Utility of Acoustic Monitoring in Tropical Grassland

The response surface model demonstrated that conducting acoustic surveys for 5 visits with 4 stations and 120-minute recordings can approach the maximum number of species detected (59.4 species). This approach may be used for acoustic monitoring in the tropical grassland habitat. However, if the sampling effort is limited, the combinations among visits, stations, and recording periods can be adjusted according to the response surface analysis. A reasonable effort for conducting acoustic surveys would be 4 days with 3 stations and 80-minute recording periods. These combinations, according to the response surface model, would detect 48 species (81%) and provide enough information for monitoring bird populations in grassland habitat.

Generally, more factors (e.g., the high species richness, the peculiarities in behavior and ecology such as the aggregation of individuals, the temporal dynamic of tropical bird activities among days, seasons, and years [Karr 1981]) affect the census accuracy in the tropical ecosystem than in the temperate ecosystem. The sampling effort may have to be expanded considerably relative to the use of acoustic monitoring in temperate grassland in Fort Campbell. The bottom line for avian acoustic monitoring in the tropical grassland is to know the birds to be studied and design a census protocol according to the purpose of the investigation. Further research is required in order to modify the method for the specific species or specific groups under new conditions and new habitats.

CHAPTER 7

CONCLUSION AND IMPLEMENTION OF AN ACOUSTIC MONITORING PROGRAM

The acoustic protocol was developed to monitor avian communities in five different habitat types within two world zones: temperate grassland habitat in Fort Campbell, Tennessee-Kentucky; temperate oldfield habitat in Freel's Bends, Tennessee; temperate mixed hardwood forest in Cherokee National Forest, Tennessee; tropical hill evergreen forest in Phu Luang Wildlife Sanctuary, Loei Province, Thailand; and tropical grassland in Khao Yai National Park in Nakorn Ratchasima Province, Thailand. The overall design for this research was aimed to develop an acoustic monitoring system and apply monitoring protocols for avian communities in 5 different habitats during the breeding season. Ten visits with 4 recording stations and up to 2-hour recording were conducted in 9-ha plot in each habitat. The effect of recording period, number of visits, and number of stations, and time of morning were investigated to answer these questions: how many visits, how many stations, when to record and how long to record to detect most species present in those areas. To determine the efficiency of the acoustic monitoring comparing to the standard monitoring protocols, unlimited-distance point counts were conducted concurrently with the acoustic monitoring. In addition, species detectability was determined for each species in each habitat to incorporate with the acoustic monitoring protocols. Because there was no replication within the same habitat, the variability of detecting avian communities within the same habitat was not documented. I also did not investigate the environmental factors that may affect acoustic bird monitoring but used the same criteria for weather conditions for all 3 methods (e.g., surveys were not conducted when it was raining, or when there was moderate wind). In this study, observer variability was controlled by using 1 observer for all habitats and methods. Observer variability is known as a potential source of error in avian surveys because of the differences in ability to detect and identify a vocalization to a specific species (e.g., hearing ability and skill) (Rosenstock et al. 2002). Use of acoustic monitoring may limit observer variability by placing similar recording units in the field and limiting the number of observer listening to recorded data.

Species Richness across Temperate and Tropical Habitats

The avian diversity in tropical grassland habitat in Khao Yai, Thialand was greater than the temperate grassland and oldfield habitat in Tennessee even though all 3 habitats were maintained as early successional habitat by fire. Similarly the number of avian species in the tropical hill evergreen forest at Phu Luang was greater than in the temperate mixed hardwood habitat at Cherokee National Forest. The result supports the hypothesis that species richness of birds in the tropics is greater than in the temperate (Primack 2000). In temperate habitats, the oldfield seemed to have more species detected compared to the grassland and mixed hardwood habitat. This was because the oldfield habitat was in later succession than the grassland and more early and mid-successional species were found in this area. Many species were detected in the surrounding habitats off the plot because the acoustic method detected avian species regardless of distance. In four out of 5 habitats, acoustic monitoring detected more species than the unlimited-distance point counts and territory mapping (Figure 7-1). When the similarity index was compared among 3 methods and 5 habitats, it was clearly shown that in temperate habitats, each method provided at least 80% similarity, indicating that any of one sampling methods can be used for monitoring species diversity in those area (Figure 7-2). On the other hand, the similarity index among 3 methods ranged from 65-78% for the tropical hill evergreen habitat and 50-56% for the tropical grassland , thus avian monitoring in the tropics may need multiple sampling methods to detect most species in those areas. Acoustic monitoring detected at least as many species compared to unlimited-distance point count when the 2 methods were conducted simultaneously (Table 7-1). In fact, in tropical settings, acoustic monitoring was significantly better than alternative methods.

Species Detectability

Individual species has unique characteristic and behavior which may affect the detectability of acoustic monitoring. For example, birds with melodic song, such as common yellowthroats and yellow-breasted chat in the temperate grassland habitat were completely detected by acoustic monitoring whereas secretive species with simple and low amplitude vocalizations (such as velvet-fronted nuthatch in tropical hill evergreen forest and ruby-throated hummingbirds in the temperate grassland habitat) were totally missed. The acoustic monitoring did not perform well for non-vocal flyovers such as turkey vulture in the temperate and crested serpent eagle in the tropics. Thus the secretive species and flyovers tended to be biased low when acoustic monitoring was used. On the other hand, some species were detected acoustically at a great distance when the observer was concentrating on the birds in the plot and overlooked the less audible songs and calls during point counts or territory mapping especially during the dawn chorus when many species were singing at the same time and noisy species such as red-whiskered bulbul drew out other species such as barred cuckoo dove and chestnut-headed bee-eater in the tropical grassland habitat.

Worm-eating warbler and pine warbler were a good example to demonstrate the relationship between behavior and habitat attributes. These 2 species have similar song characteristic (trill notes) and about the same frequency range. Worm eating warblers usually feed and sing close to the ground when pine warblers stay in the canopy at all time. Songs of worm-eating warblers transmitted near the ground had more degradation than songs of pine warblers transmitted high above the ground because of the dense ground cover and high volume of tree trunks comparing to the canopy. Thus, pine warbler tended to have greater propagation distance (see Table 4-8 for details).

Time of day was an important factor of species detectabilities. Previous results suggested that most birds were active within the first 4 hours after sunrise but in this study indicated that the earliest morning hours tended to be the best period for recording not only because weather is usually calm but also low temperature and high moisture in the air increase song propagation distances for individual birds. Insect noise, like Cicadas were found to interfere with the recordings considerably after 2 hours of sunrise in the tropical hill evergreen forest, thus acoustic monitoring should be conducted as early as possible. The dawn chorus tended to be a potential problem on counting birds because the flurry of activity by most species confused field observers and made sorting and counting of birds difficult (Bystrak 1981). With acoustic monitoring, repeated listening from the recordings improved the ability to detect overlooked species or unclear vocalizations during the dawn chorus. In this research, some unknown songs and calls were sent to experts for identification, thus, the permanent records can improve the precision and reduce the bias.

The variability among season could not be determined in this research because I only conducted avian monitoring during the breeding season for both temperate and tropical habitats. However it should be noted that the detection probabilities in most species in Cherokee National Forest tended to be consistently lower than those reported by Farnsworth et al. (2002). Logan (1983) indicated that mockingbird breeding males were most vocal during each breeding attempt from pairing and nest building period and declined during the incubation and nestling stages. In this study, for example, one family of tufted titmouse (male, female and fledgings) were detected by point counts, territory mapping and acoustic method inside the plot in temperate mixed hardwood forest habitat. Because the fledgings already left the nest and the breeding male decreased his singing rate, the estimated detection probability was biased low.

Detection probability of birds varies across distance and time. However, the distance between recorders and birds was generally not determinable. In chapter 2-6, I estimated detection probability as a function of recording period from 10-120 minutes in different habitats using Kaplan-Meier product limit estimators. The results showed that 10-minute recordings per visit may be long enough to detect most common species in those area but if the detection probability threshold is 80% of the total number of species present, acoustic monitoring should be conducted for 70-100 minutes per visit. In Chapter 4, the detection probability of individual species across distance was estimated in the mixed hardwood forest habitat using probit analysis. Seven out of 12 species of birds in mixed hardwood at CNF were detected out to 100 m and two passerines (black-throated green warbler and tufted titmouse) were detected beyond 150 m ($P = 0.99$). These results suggest that the acoustic devices were capable of monitoring a 100-m radius plot (3 ha) for most species with high detection probabilities. Stations also needed to be separated by > 250 m to avoid double counting individuals.

System Design, Cost and Areas of Improvement

The acoustic monitoring system was designed and constructed in 2000 based on discussions with personnel at the Cornell Lab of Ornithology. Four individual units were built, comprised of Sennheiser MKH20 omni-directional microphones with 18-volt phantom power supplies, Jensen videocassette recorders (Hi-Fi VCRs) with 12-volt marine batteries, and microphone amplifiers with 9-volt batteries. Recordings were stored on EP 8-hour videocassettes for further analysis. In 2002, the system was redesigned for automated, unattended recording and for better recording quality. Videocassette recorders were replaced by IBM-laptops and 12 volt-marine batteries were used to power all equipment by using power converters and power adaptors (See Figure 7-3 and Figure 7-4 for details). Cost for constructing acoustic system depends on the quality of microphone and the hard drive capacity and other performance of the computer. In this study, cost for one system was around $2,000 because Sennheiser MKH20 omni-directional microphone alone was around $1,100.

Comparing the cost assessment based on this experimental design and analysis, it clearly showed that the cost for acoustic monitoring was higher than territory mapping and point counts (Table 7-2) indicating that the acoustic monitoring should be used when qualified field observers are unavailable and many sites are needed to be monitored simultaneously, or when the study area is inaccessible (e.g., military base). If and when sound-activated mechanisms and species recognition software are developed and applied to diurnal bird monitoring, the amount of time used for analyzing the recordings will reduce, and costs will be comparable to point count or territory mapping analysis.

To improve the system, all components should have smaller size with lower power consumption and should be stored in a weather resistant container. Data storage capacity should be up to 80-120 GB so that the system can run for weeks or even months in the field. Listening to the recordings was time consuming. Initially, I spent 20 hours listening for each 2-hour recording to ensure accuracy and I spent at least 4 hours for every 2-hour recording after I was familiar with the vocalizations (depending on the number of unknown song I detected). To save time for listening, I recommended that the system use a sound-activated mechanism (e.g., the software Avisoft-RECORDER single channel; Raimund Specht, personal communication) for recording sporadic vocalizations. The computer as a recorder will be run automatically each morning and the software will only record as long as the bird vocalizes. Researchers will save time listening to the recordings by using the software, but also save the hard disk space for the next day. However, the applicablity of this technique depends on the specific circumstances based upon the objective of the study.

Implementing Acoustic Monitoring across Temperate and Tropical Habitats

The overall implementations suggested by mix model and response surface were summarized in Table 7-3 and 7-4. Tropical grassland and tropical hill evergreen forest were similar in terms of high species diversity with various songs and calls in the areas sampled. In spite of the resident birds, the breeding and the non-breeding visitors in Khao Yai and Phu Luang were 40% and 26% of the total, respectively. These visitors can be found between October to April. Thus, January to April is preferred for monitoring by any methods (acoustic monitoring, point counts and territory mapping) because of the small quantity of rain. Whereas the suitable period for monitoring breeding birds in the eastern USA starts from mid-May to the end of June and may extend until mid-July for grassland birds.

Developing appropriate census procedures in the tropical habitats seemed to be more complicated to design than in temperate habitats for a variety of reasons. Tropical habitats have a high diversity of species, social systems and behaviors. There also is a lack of knowledge about population trends and a lack of systematic, comparative studies to evaluate census methodology even for standard protocols (point counts and territory mapping) (Karr 1981, Raman 2003). My study was the first attempt to develop an acoustic monitoring protocol for tropical grassland habitat and tropical hill evergreen forest. It was difficult during the study to find references of songs and calls of Asian tropical birds as well as to find the song recognition experts to identify vocalizations to species. To reduce this variation, recording data should be interpreted by a single, trained expert, or automated species recognition software when available. It needs to be clarified that many of suggested standards presented in this research were based on one study site per habitat, thus, will require further investigation and modification as components of acoustic methodology are tested under new conditions or new environments in both temperate and tropical ecosystems.

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APPENDICES

TABLES

CHAPTER 2

Table 2-1. Common and scientific names of birds with AOU code documented by point counts, territory mapping, and acoustic method during June–July, 2000 in grassland habitat at Fort Campbell Military Reservation, Tennessee-Kentucky. Species are listed in alphabetic order.

Common Name	AOU Code	Scientific Name
American crow	AMCR	*Corvus brachyrhynchos*
American goldfinch	AMGO	*Carduelis tristis*
American robin	AMRO	*Turdus migratorius*
Bachman's sparrow	BASP	*Aimophila aestivalis*
Bell's vireo	BEVI	*Vireo bellii*
Blue grosbeak	BLGR	*Guiraca caerulea*
Blue Jay	BLJA	*Cyanocitta cristata*
Blue-gray gnatcatcher	BGGN	*Polioptila caerulea*
Brown thrasher	BRTH	*Toxostoma rufum*
Chimney swift	CHSW	*Chaetura pelagica*
Common yellowthroat	COYE	*Geothlypis trichas*
Dickcissel	DICK	*Spiza americana*
Downy woodpecker	DOWO	*Picoides pubescens*
Eastern bluebird	EABL	*Sialia sialis*
Eastern kingbird	EAKI	*Tyrannus tyrannus*
Eastern meadowlark	EAME	*Sturnella magna*
Eastern towhee	EATO	*Pipilo erythrophthalmus*
Eastern wood-pewee	EAWP	*Contopus virens*
Field sparrow	FISP	*Spizella pusilla*
Great blue heron	GBHE	*Ardea herodias*
Great crested flycatcher	GCFL	*Myiarchus crinitus*
Henslow's sparrow	HESP	*Ammodramus henslowii*
Indigo bunting	INBU	*Passerina cyanea*
Killdeer	KILL	*Charadrius vociferus*
Mourning dove	MODO	*Zenaida macroura*
Northern bobwhite	NOBO	*Colinus virginianus*
Northern cardinal	NOCA	*Cardinalis cardinalis*
Northern mockingbird	NOMO	*Mimus polyglottos*

Table 2-1. Continued.

Common Name	AOU Code	Scientific Name
Northern flicker	YSFL	*Colaptes auratus*
Orchard oriole	OROR	*Icterus spurius*
Pileated woodpecker	PIWO	*Dryocopus pileatus*
Prairie warbler	PRAW	*Dendroica discolor*
Purple martin	PUMA	*Progne subis*
Red-bellied woodpecker	RBWO	*Melanerpes carolinus*
Red-eyed vireo	REVI	*Vireo olivaceus*
Red-shouldered hawk	RSHA	*Buteo lineatus*
Red-tailed hawk	RTHA	*Buteo jamaicensis*
Red-winged blackbird	RWBL	*Agelaius phoeniceus*
Ruby-throated hummingbird	RTHU	*Archilochus colubris*
Summer tanager	SUTA	*Piranga rubra*
Tufted titmouse	ETTI	*Baeolophus bicolor*
White-eyed vireo	WEVI	*Vireo griseus*
Wood thrush	WOTH	*Hylocichla mustelina*
Yellow-billed cuckoo	YBCU	*Coccyzus americanus*
Yellow-breasted chat	YBCH	*Icteria virens*

Table 2-2. Species observed during unlimited-distance point counts, territory mapping, and acoustic method in grassland habitat at Fort Campbell Military Reservation, Tennessee-Kentucky, July 2000.

Species	Unlimited-distance Point Counts	Territory Mapping	Acoustic Method
American crow	+	+	+
American goldfinch	+	+ *	+
American robin	+	-	+
Barn swallow	+	+	-
Bell's vireo	-	-	+
Blue grosbeak	+	+	+
Blue jay	+	+	+
Blue-gray gnatcatcher	+	+	+
Brown-headed cowbird	+	+	+
Carolina wren	+	+	+
Chimney swift	+	+	+
Common yellowthroat	+	+ *	+
Dickcissel	+	+ *	+
Downy woodpecker	+	-	+
Eastern bluebird	+	+	+
Eastern kingbird	+	+	+
Eastern meadowlark	+	-	+
Eastern towhee	+	+	+
Eastern-wood pewee	-	+	+
Field sparrow	+	+ *	+
Great blue heron	+	+	-
Indigo bunting	+	+ *	+
Killdeer	-	+	+
Northern mocking bird	-	-	+
Mourning dove	+	+	+
Northern bobwhite	+	+	+
Northern cardinal	+	+	+
Northern flicker	+	-	+
Orchard oriole	+	+	-
Pileated woodpecker	+	+	+
Prairie warbler	+	+	+
Purple martin	+	+	+
Red-bellied woodpecker	+	+	+
Red-eyed vireo	-	-	+
Red-shouldered hawk	-	-	+
Red-tailed hawk	+	+	-

Table 2-2. Continued.

Species	Unlimited-distance Point Counts	Territory Mapping	Acoustic Method
Red-winged blackbird	-	-	+
Ruby-throated	-	+	-
Summer tanager	+	+	+
Tufted titmouse	+	+	+
White-eyed vireo	+	+	+
Wood thrush	+	+	+
Yellow-billed cuckoo	+	+	+
Yellow-breasted Chat	+	+ *	+
Yellow-throated warbler	+	+	+
Total 45	37	36	40

+ = Presence
- = Absence
* = Territorial species

Table 2-3. Least squares means (LSM), percent detection rate of new species, percent of total, and probabilities of differences of cumulative number of species as functions of increasing 10-minute recording period (n = 480) in grassland habitat at Fort Campbell Military Reserve, Tennessee-Kentucky, July 2000.

Period	LSM [1]	% Detection Rate of New Species	% of Total [2]
10	11.2[a]	60.2	60.2 (28.0)
20	13.5[b]	12.4	72.6 (33.8)
30	14.6[c]	5.9	78.5 (36.5)
40	15.7[cd]	5.9	84.4 (39.2)
50	16.3[cde]	3.8	88.2 (40.8)
60	16.8[cde]	2.2	90.3 (42.0)
70	17.0[de]	1.1	91.4 (42.5)
80	17.4[e]	2.2	93.5 (43.5)
90	17.7[e]	1.6	95.2 (44.2)
100	18.1[e]	2.7	97.8 (45.2)
110	18.4[e]	1.1	98.9 (46.0)
120	18.6[e]	1.1	100.0 (46.5)

[1] Pooled SE = 0.5

[2] % of total indicates percent of all species detected in 2-hour recording. Percent of all species detected on the entire plot by acoustic method is indicated in parentheses.

[abc] Means within columns with no common superscripts differed ($P < 0.05$).

Table 2-4. Least squares means (LSM), percent detection rate of new species, percent of total, and probabilities of differences of cumulative number of species as functions of increasing number of visits from 1-10 visits (*n* = 480) in grassland habitat at Fort Campbell Military Reserve, Tennessee-Kentucky, July 2000.

Number of visits	LSM [1]	% Detection Rate of New Species	% of Total [2]
1	12.2[a]	56.5	56.5 (30.5)
2	15.2[b]	13.9	70.4 (38.0)
3	17.1[c]	8.8	79.5 (42.8)
4	18.3[d]	5.6	84.7 (45.8)
5	19.0[d]	3.2	88.0 (47.5)
6	19.7[e]	3.2	91.2 (49.2)
7	20.3[e]	2.8	94.0 (50.8)
8	20.5[e]	0.9	94.9 (51.2)
9	21.0[e]	2.3	97.2 (52.5)
10	21.6[e]	2.8	100.0 (54.0)

[1] Pooled SE = 0.5

[2] % of total indicates percent of all species detected on 10 of ten-minute-counts. Percent of all species detected on the entire plot by acoustic method is indicated in Parentheses.

[abc] Means within columns with no common superscripts differed ($P < 0.05$)

Table 2-5. Least squares means (LSM) as functions of increasing 30-minute recording period (*n* =480) in grassland habitat at Fort Campbell Military Reserve, Tennessee-Kentucky, July 2000.

Period	**Time after sunrise (minutes)**	**LSM** [1]
0600 - 0630	20 - 50	11.4[b]
0630 - 0700	50 - 80	12.3[b]
0700 - 0730	80 - 110	11.5[a]
0730 - 0800	110 - 140	11.4[a]
0800 - 0830	140 - 170	10.3[c]

[1] Pooled SE = 0.4
[abc] Means within columns with no common superscripts differed ($P < 0.05$)

Table 2-6. Least squares means (LSM) of unsupplemented and supplemented counts), percent detection rate of new species, and differences of cumulative number of species as functions of increasing number of stations from 1 to 4 stations in grassland habitat at Fort Campbell Military Reserves, Tennessee-Kentucky, July 2000.

Number of stations	LSM unsupplemented count[1]	LSM supplemented count[2]	% of Total[3]	% Detection rate of new species
1	12.4[a]	11.0[a]	67.1	67.1
2	13.1[b]	14.0[b]	85.4	18.3
3	12.8[ab]	15.5[c]	94.5	9.1
4	13.3[b]	16.4[d]	100.0	5.5

[1] The number of species detected at each 10-minute increment within each visit and at each station (Pooled SE = 0.3)

[2] The cumulative species detected based on number of station from 1 to 4 (Pooled SE = 0.4)

[3] % of total indicates percent of all species detected at 4 stations within 10-minute counts (supplemented count).

[abcd] Means within columns with no common superscripts differed ($P < 0.05$).

Table 2-7. Probabilities of detecting 22 avian species from 10 minutes to 110 minutes at 4 stations for 10 days in grassland habitat at Fort Campbell Military Reserve, Tennessee-Kentucky, June 2000.

			Probability of detection within (minutes)										
Species name	**Actual sample size**[1]	**Detection Frequency**[2]	**10**	**20**	**30**	**40**	**50**	**60**	**70**	**80**	**90**	**100**	**110**[3]
Indigo bunting	471	0.98	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Yellow-breasted chat	466	0.97	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Common yellowthroat	421	0.88	0.87	0.95	0.97	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
American crow	416	0.87	0.95	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Dickcissel	361	0.75	0.70	0.82	0.90	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Field sparrow	359	0.75	0.62	0.90	0.92	0.95	0.98	1.00	1.00	1.00	1.00	1.00	1.00
Northern bobwhite	336	0.70	0.92	0.95	0.98	0.985	0.98	0.98	0.98	0.98	0.98	0.98	1.00
Tufted titmouse	293	0.61	0.47	0.79	0.82	0.92	0.94	0.97	0.97	0.97	1.00	1.00	1.00
Yellow-billed cuckoo	242	0.50	0.48	0.72	0.80	0.85	0.90	0.90	0.92	0.98	0.98	1.00	1.00
Carolina wren	220	0.46	0.33	0.51	0.69	0.82	0.87	0.90	0.92	0.95	0.97	1.00	1.00
Northern cardinal	201	0.42	0.90	0.90	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00

Table 2-7. Continued.

			Probability of detection within (minutes)										
Species name	Actual sample size[1]	Detection Frequency[2]	10	20	30	40	50	60	70	80	90	100	110[3]
Summer tanager	185	0.39	0.52	0.70	0.79	0.85	0.94	0.97	0.97	0.97	0.97	1.00	1.00
American goldfinch	175	0.36	0.36	0.52	0.55	0.64	0.77	0.81	0.87	0.87	0.90	0.90	0.97
White-eyed vireo	168	0.35	0.38	0.47	0.53	0.74	0.79	0.79	0.82	0.88	0.97	0.97	1.00
Prairie warbler	130	0.27	0.23	0.27	0.27	0.54	0.62	0.77	0.85	0.88	0.92	0.96	1.00
Blue grosbeak	111	0.45	0.47	0.84	0.90	0.95	0.95	0.95	0.95	1.00	1.00	1.00	1.00
Blue-gray gnatcatcher	100	0.21	0.27	0.45	0.50	0.73	0.73	0.73	0.82	0.86	0.91	1.00	1.00
Wood thrush	96	0.20	0.37	0.53	0.63	0.74	0.74	0.74	0.90	0.90	0.95	1.00	1.00
Mourning dove	63	0.13	0.60	0.73	0.73	0.87	0.93	0.93	0.93	0.93	0.93	0.93	1.00
Blue jay	52	0.11	0.14	0.45	0.59	0.77	0.86	0.91	0.91	0.91	0.91	0.91	1.00

Table 2-7. Continued.

			Probability of detection within (minutes)										
Species name	**Actual sample size**[1]	**Detection Frequency**[2]	**10**	**20**	**30**	**40**	**50**	**60**	**70**	**80**	**90**	**100**	**110**[3]
Eastern towhee	39	0.08	0.13	0.33	0.40	0.53	0.60	0.60	0.60	0.60	0.73	0.80	0.80
Eastern bluebird	35	0.07	0.00	0.10	0.15	0.15	0.30	0.40	0.40	0.80	0.90	0.95	1.00

[1] The number of points that the species was detected.
[2] The number of points at which a species was detected divided by the total number of point sampled ($n = 480$).
[3] Detection probabilities after 110-minute recordings for all species equaled to 1.00 because all species analyzed were detected within 2 hours.

CHAPTER 3

Table 3-1. Common and scientific names of birds with AOU code documented by point counts, territory mapping, and acoustic method during June 2000, at Freel's Bend Wildlife Management Area, Oak Ridge, Tennessee. Species are listed in alphabetic order.

Common Name	AOU Code	Scientific Name
American crow	AMCR	*Corvus brachyrhynchos*
American goldfinch	AMGO	*Carduelis tristis*
Barn swallow	BARS	*Hirundo rustica*
Black-crowned night heron	BCNH	*Nycticorax nycticorax*
Blue-gray gnatcatcher	BGGN	*Polioptila caerulea*
Blue grosbeak	BLGR	*Guiraca caerulea*
Blue jay	BLJA	*Cyanocitta cristata*
Brown-headed cowbird	BHCO	*Molothrus ater*
Brown thrasher	BRTH	*Toxostoma rufum*
Canada goose	CAGO	*Branta canadensis*
Carolina chickadee	CACH	*Poecile carolinensis*
Carolina wren	CARW	*Thryothorus ludovicianus*
Chimney swift	CHSW	*Chaetura pelagica*
Common grackle	COGR	*Quiscalus quiscula*
Common yellowthroat	COYE	*Geothlypis trichas*
Cooper's hawk	COHA	*Accipiter cooperii*
Downy woodpecker	DOWO	*Picoides pubescens*
Eastern bluebird	EABL	*Sialia sialis*
Eastern meadowlark	EAME	*Sturnella magna*
Eastern towhee	EATO	*Pipilo erythrophthalmus*
Eastern wood-pewee	EAWP	*Contopus virens*
Field sparrow	FISP	*Spizella pusilla*
Great blue heron	GBHE	*Ardea herodias*
Great crested flycatcher	GCFL	*Myiarchus crinitus*
Hairy woodpecker	HAWO	*Picoides villosus*
Indigo bunting	INBU	*Passerina cyanea*
Killdeer	KILL	*Charadrius vociferus*
Mourning dove	MODO	*Zenaida macroura*
Northern bobwhite	NOBO	*Colinus virginianus*
Northern cardinal	NOCA	*Cardinalis cardinalis*

Table 3-1. Continued.

Common Name	**AOU Code**	**Scientific Name**
Northern flicker	YSFL	*Colaptes auratus*
Orchard oriole	OROR	*Icterus spurius*
Osprey	OSPR	*Pandion haliaetus*
Pileated woodpecker	PIWO	*Dryocopus pileatus*
Prairie warbler	PRAW	*Dendroica discolor*
Purple martin	PUMA	*Progne subis*
Red-bellied woodpecker	RBWO	*Melanerpes carolinus*
Red-eyed vireo	REVI	*Vireo olivaceus*
Red-shouldered hawk	RSHA	*Buteo lineatus*
Red-tailed hawk	RTHA	*Buteo jamaicensis*
Red-winged blackbird	RWBL	*Agelaius phoeniceus*
Ruby-throated hummingbird	RTHU	*Archilochus colubris*
Summer tanager	SUTA	*Piranga rubra*
Tufted titmouse	ETTI	*Baeolophus bicolor*
Turkey vulture	TUVU	*Cathartes aura*
White-breasted nuthatch	WBNU	*Sitta carolinensis*
White-eyed vireo	WEVI	*Vireo griseus*
White-throated sparrow	WTSP	*Zonotrichia albicollis*
Wild turkey	WITU	*Meleagris gallopavo*
Willow flycatcher	WIFL	*Empidonax traillii*
Wood thrush	WOTH	*Hylocichla mustelina*
Yellow-billed cuckoo	YBCU	*Coccyzus americanus*
Yellow-breasted chat	YBCH	*Icteria virens*
Yellow-throated warbler	YTWA	*Dendroica dominica*

Table 3-2. Species observed during point counts, territory mapping, and acoustic method, Freel's Bend Wildlife Management Area, Oak Ridge, Tennessee, June 2000.

Species	**Unlimited-distance Point Counts**	**Territory Mapping**	**Acoustic Method**
American crow	+	+	+
American goldfinch	+	+	+
Barn swallow	+	+	-
Black-crowned night heron	-	+	+
Blue-gray gnatcatcher	+	+	+
Blue grosbeak	+	+*	+
Blue jay	+	+	+
Brown-headed cowbird	+	+	+
Brown thrasher	-	+	-
Canada goose	+	+	+
Carolina chickadee	-	+	+
Carolina wren	+	+	+
Chimney swift	-	+	+
Common grackle	-	+	-
Common yellowthroat	+	+*	+
Cooper's hawk	+	-	-
Downy woodpecker	+	+	+
Eastern bluebird	+	+	+
Eastern meadowlark	+	+	+
Eastern towhee	+	+*	+
Eastern wood-pewee	-	+	+
Field sparrow	+	+*	+
Great blue heron	+	+	+
Great crested flycatcher	-	+	+
Hairy woodpecker	+	+	+
Indigo bunting	+	+*	+
Killdeer	-	-	+
Mourning dove	+	+	+
Northern bobwhite	+	+	+
Northern cardinal	+	+*	+
Northern flicker	-	-	+
Orchard oriole	+	+	+
Osprey	-	+	-
Pileated woodpecker	-	+	+
Prairie warbler	+	+	+
Purple martin	-	-	+
Red-bellied woodpecker	+	+	+

Table 3-2. Continued.

Species	**Unlimited-distance Point Count**	**Territory Mapping**	**Acoustic Method**
Red-eyed vireo	+	+	+
Red-shouldered hawk	+	+	+
Red-tailed hawk	-	+	+
Red-winged blackbird	+	-	+
Ruby-throated	+	+	-
Summer tanager	+	+	+
Tufted titmouse	-	+	+
Turkey vulture	+	+	-
White-breasted nuthatch	-	+	-
White-eyed vireo	+	+*	+
White-throated sparrow	-	-	+
Wild turkey	+	+	-
Willow flycatcher	-	+	-
Wood thrush	-	+	+
Yellow-billed cuckoo	+	+	+
Yellow-breasted chat	+	+*	+
Yellow-throated warbler	+	+	-
Total 54	36	48	43

+ = Presence
- = Absence
* = Territorial species

Table 3-3. Least squares means (LSM), percent of total, and probabilities of differences of cumulative number of species as functions of increasing 10-minute recording period (n = 480) in oldfield habitat at Freel's Bend Wildlife Management Area, Oak Ridge, Tennessee, June 2000.

Period	LSM [1]	% Detection rate of new species	% of Total[2]
10	11.3[a]	56.2	55.7 (28.0)
20	13.7[b]	11.9	68.2 (33.8)
30	15.0[c]	6.5	74.6 (36.5)
40	16.0[d]	5.0	79.6 (39.2)
50	17.0[e]	5.0	84.6 (40.8)
60	17.6[f]	3.0	87.6 (42.0)
70	18.0[g]	2.0	89.6 (42.5)
80	18.5[g]	2.5	92.0 (43.5)
90	18.9[hi]	2.0	94.0 (44.2)
100	19.4[ij]	2.5	96.0 (45.2)
110	19.7[jk]	1.5	97.5 (46.0)
120	20.1[k]	2.0	100.0 (46.5)

[1] Pooled SE = 0.5

[2] % of total indicates percent of all species detected in 2-hour recording. Percent of all species detected on the entire plot by acoustic method is indicated in parentheses.

[abc] Means within columns with no common superscripts differed ($P < 0.05$)

Table 3-4. Least squares means (LSM), percent detection rate of new species, percent of total and differences of cumulative number of species as functions of increasing number of visits (n = 480) in oldfield habitat at Freel's Bend Wildlife Management Area, Oak Ridge, Tennessee, June 2000.

Number of visits	LSM [1]	% Detection rate of new species	% of Total[2]
1	11.7[a]	51.8	51.8 (27.2)
2	14.8[b]	13.7	65.5 (34.4)
3	15.9[c]	4.9	69.9 (36.7)
4	18.4[d]	11.1	81.4 (42.8)
5	19.6[e]	5.3	86.7 (45.6)
6	20.8[f]	5.3	92.0 (48.4)
7	21.5[fg]	3.1	95.1 (50.0)
8	22.0[gh]	2.2	97.3 (51.2)
9	22.1[gh]	0.4	97.8 (51.4)
10	22.6[h]	2.2	100.0 (52.6)

[1] Pooled SE = 0.3

[2] % of total indicates percent of all species detected on 10 visits of ten-minute counts. Percent of all species detected on the entire plot by acoustic method is indicated in parentheses.

[abc] Means within columns with no common superscripts differed ($P < 0.05$)

Table 3-5. Least squares means (LSM) of species detected as functions of increasing 30-minute recording period (n = 480) in old field habitat at Freel's Bend Wildlife Management Area, Oak Ridge, Tennessee, June 2000.

Period	Time after sunrise (minutes)	LSM [1]
0630 - 0700	10 - 40	11.2[a]
0700 - 0730	40 - 70	11.4[a]
0730 - 0800	70 - 100	11.3[a]
0800 - 0830	100 - 130	11.4[a]
0830 - 0900	130 - 160	11.6[a]

[1] Pooled SE = 0.4
[a] Means did not differ ($P > 0.05$)

Table 3-6. Least squares means (LSM) of unsupplemented and supplemented counts and differences of cumulative number of species as functions of increasing number of stations from 1 to 4 stations (n = 480) in oldfield habitat at Freel's Bend Wildlife Management Area, Oak Ridge, Tennessee, June 2000.

Number of stations	LSM unsupplemented count[1]	LSM supplemented count[2]	% of Total[3]	% Detection rate of new species
1	11.3[ab]	11.4[a]	65.1	66.3
2	11.6[ac]	14.3[b]	83.1	16.9
3	11.9[a]	16.1[c]	93.6	10.5
4	11.1[b]	17.2[d]	100.0	6.4

[1] The number of species detected at each 10-minute increment within each visit and at each station (Pooled SE = 0.3)

[2] The cumulative species detected based on number of station from 1 to 4 (Pooled SE = 0.5

[3] % of total indicates percent of all species detected at 4 stations within 10-minute counts (supplemented count).

[abcd] Means within columns with no common superscripts differed ($P < 0.05$)

Table 3-7. Probabilities of detecting 23 species from 10 minutes to 120 minutes at 4 stations for 10 days ($n = 480$) in oldfield habitat at Freel's Bend Wildlife Management Area, Oak Ridge, June 2000.

			Probability of detection within (minutes)										
Species name	**Actual sample size[1]**	**Detection Frequency[2]**	**10**	**20**	**30**	**40**	**50**	**60**	**70**	**80**	**90**	**100**	**110[3]**
Yellow-breasted chat	459	0.98	0.97	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Northern cardinal	443	0.95	0.92	0.97	0.97	0.97	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Eastern towhee	418	0.89	0.87	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Field sparrow	415	0.89	0.87	0.95	0.95	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
American crow	411	0.88	0.90	0.97	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Indigo bunting	368	0.79	0.77	0.90	0.92	0.92	0.95	0.97	0.97	1.00	1.00	1.00	1.00
Carolina wren	352	0.75	0.76	0.89	0.95	0.95	0.95	0.95	0.95	0.98	1.00	1.00	1.00
Northern bobwhite	346	0.74	0.81	0.94	0.94	0.94	0.94	0.94	0.94	0.94	0.94	0.94	1.00
White-eyed vireo	282	0.60	0.67	0.83	0.86	0.89	0.92	1.00	1.00	1.00	1.00	1.00	1.00
Red-bellied woodpecker	269	0.57	0.45	0.71	0.76	0.87	0.95	0.97	0.97	1.00	1.00	1.00	1.00

Table 3-7. Continued.

			Probability of detection within (minutes)										
Species name	**Actual sample size[1]**	**Detection Frequency[2]**	**10**	**20**	**30**	**40**	**50**	**60**	**70**	**80**	**90**	**100**	**110[3]**
Blue jay	239	0.51	0.43	0.68	0.76	0.81	0.89	0.92	0.95	0.95	1.00	1.00	1.00
Common yellowthroat	206	0.44	0.38	0.53	0.62	0.70	0.79	0.88	0.91	0.97	0.97	1.00	1.00
Mourning dove	159	0.34	0.33	0.47	0.64	0.69	0.78	0.89	0.94	0.94	0.97	0.97	0.97
Yellow-billed cuckoo	151	0.32	0.33	0.48	0.67	0.73	0.76	0.76	0.76	0.79	0.85	0.94	0.97
American goldfinch	129	0.28	0.26	0.39	0.55	0.68	0.74	0.77	0.77	0.84	0.90	0.94	1.00
Red-eyed vireo	116	0.25	0.30	0.37	0.56	0.63	0.82	0.82	0.85	0.89	0.93	1.00	1.00
Canada goose	98	0.21	0.46	0.57	0.75	0.82	0.86	0.90	0.90	0.90	0.93	0.93	0.93
Blue grosbeak	92	0.20	0.35	0.52	0.61	0.74	0.83	0.83	0.83	0.87	0.87	0.91	1.00
Brown-headed cowbird	65	0.14	0.33	0.48	0.48	0.57	0.57	0.67	0.71	0.81	0.90	0.95	0.95
Eastern bluebird	47	0.10	0.06	0.44	0.50	0.56	0.69	0.69	0.75	0.81	0.81	0.88	0.94

Table 3-7. Continued.

			Probability of detection within (minutes)										
Species name	**Actual sample size[1]**	**Detection Frequency[2]**	**10**	**20**	**30**	**40**	**50**	**60**	**70**	**80**	**90**	**100**	**110[3]**
Prairie warbler	45	0.10	0.23	0.31	0.31	0.46	0.46	0.62	0.70	0.70	0.77	0.77	1.00
Eastern meadowlark	42	0.09	0.33	0.33	0.33	0.40	0.53	0.53	0.80	0.80	0.87	0.93	0.93
Downy woodpecker	38	0.28	0.33	0.44	0.67	0.78	0.94	0.94	0.94	0.94	0.94	0.94	1.00

[1] The number of points that the species was detected.
[2] The number of points at which a species was detected divided by the total number of point sampled ($n = 480$).
[3] Detection probabilities after 110-minute recordings for all species equaled to 1.00 because all species analyzed were detected within 2 hours.

CHAPTER 4

Table 4-1. Common and scientific names of birds with AOU code documented by point counts, territory mapping, and acoustic method during June–July 2002 in mixed hardwood forest at Cherokee National Forest, Tellico District, Tennessee. Species are listed in alphabetic order.

Common Name	**AOU Code**	**Scientific Name**
American crow	AMCR	*Corvus brachyrhynchos*
American goldfinch	AMGO	*Carduelis tristis*
American robin	AMRO	*Turdus migratorius*
Blue-headed vireo	BHVI	*Vireo solitarius*
Blue jay	BLJA	*Cyanocitta cristata*
Black-throated green warbler	BTBW	*Dendroica virens*
Carolina chickadee	CACH	*Poecile carolinensis*
Carolina wren	CARW	*Thryothorus ludovicianus*
Chimney swift	CHSW	*Chaetura pelagica*
Downy woodpecker	DOWO	*Picoides pubescens*
Eastern phoebe	EAPH	*Sayornis phoebe*
Eastern wood-pewee	EAWP	*Contopus virens*
Eastern towhee	EATO	*Pipilo erythrophthalmus*
Hooded warbler	HOWA	*Wilsonia citrina*
Hairy woodpecker	HAWO	*Picoides villosus*
Indigo bunting	INBU	*Passerina cyanea*
Northern cardinal	NOCA	*Cardinalis cardinalis*
Northern flicker	YSFL	*Colaptes auratus*
Mourning dove	MODO	*Zenaida macroura*
Ovenbird	OVEN	*Seiurus aurocapillus*
Pine warbler	PIWA	*Dendroica pinus*
Pileated woodpecker	PIWO	*Dryocopus pileatus*
Red-bellied woodpecker	RBWO	*Melanerpes carolinus*
Red-eyed vireo	REVI	*Vireo olivaceus*
Red-shouldered hawk	RSHA	*Buteo lineatus*
Red-tailed hawk	RTHA	*Buteo jamaicensis*
Ruby-throated hummingbird	RUHU	*Archilochus colubris*
Scarlet tanager	SCTA	*Piranga olivacea*

Table 4-1. Continued.

Common Name	AOU Code	Scientific Name
Tufted titmouse	ETTI	*Baeolophus bicolor*
White-breasted nuthatch	WBNU	*Sitta carolinensis*
White-eyed vireo	WEVI	*Vireo griseus*
Worm-eating warbler	WEWA	*Helmitheros vermivorus*
Winter wren	WIWR	*Troglodytes troglodytes*
Wood thrush	WOTH	*Hylocichla mustelina*
Yellow-billed cuckoo	YBCU	*Coccyzus americanus*

Table 4-2. Species observed during unlimited-distance point counts, territory mapping, and acoustic method, in mixed hardwood forest habitat at Cherokee National Forest, Tellico District, Tennessee, June-July 2002.

Species	**Unlimited-distance Point Counts**	**Territory Mapping**	**Acoustic Method**
American crow	+	+	+
American goldfinch	+	-	+
American robin	+	-	-
Blue jay	+	+	+
Black-throated green warbler	+	+*	+
Carolina chickadee	+	+*	+
Carolina wren	-	+	+
Chimney swift	-	+	-
Downy woodpecker	+	+	+
Eastern towhee	-	-	+
Eastern phoebe	+	+	+
Eastern wood-pewee	+	+	+
Hooded warbler	+	+	+
Hairy woodpecker	-	-	+
Indigo bunting	+	+*	+
Northern cardinal	-	-	+
Northern flicker	+	+	+
Mourning dove	+	-	+
Ovenbird	+	+*	+
Pine warbler	+	+*	+
Pileated woodpecker	+	+	+
Red-bellied woodpecker	-	-	+
Red-eyed vireo	+	+*	+
Red-shouldered hawk	+	+	+
Red-tailed hawk	-	-	+
Scarlet tanager	+	+	+
Tufted titmouse	+	+	+
White-breasted nuthatch	+	+	+
White-eyed vireo	-	-	+
Worm-eating warbler	+	+	+
Winter wren	+	-	+
Wood thrush	-	+	+
Yellow-billed cuckoo	+	+	+
Total 33	24	23	31

+ = Presence - = Absence * = Territorial species

Table 4-3. Least squares means (LSM), percent detection rate of new species, percent of total, and probabilities of differences of cumulative number of species as functions of increasing 10-minute recording period (n = 384) in mixed hardwood forest habitat at Cherokee National Forest, Tellico District, Tennessee, June-July 2002.

Period	LSM [1]	% Detection rate of new species	% of Total[2]
10	8.2[a]	50.3	50.3 (26.5)
20	10.7[b]	15.3	65.6 (34.5)
30	11.8[c]	6.7	72.4 (38.1)
40	12.9[cd]	6.7	79.1 (41.6)
50	13.5[cde]	3.7	82.8 (43.5)
60	14.2[cde]	4.3	87.1 (45.8)
70	14.6[e]	2.5	89.6 (47.1)
80	15.1[de]	3.1	92.6 (48.7)
90	15.4[e]	1.8	94.5 (49.7)
100	15.8[e]	2.5	97.0 (51.0)
110	16.1[e]	1.8	98.8 (51.9)
120	16.3[e]	1.2	100.0 (52.6)

[1] Pooled SE = 0.4

[2] % of total indicates percent of all species detected in 2-hour recording within 1 visit and 1 station. Percent of all species detected on the entire plot by acoustic method is indicated in parentheses.

[abc] Means within columns with no common superscripts differed ($P < 0.05$).

Table 4-4. Least squares means (LSM), percent detection rate of new species, and differences of cumulative number of species as functions of increasing number of visits from 1–8 visits ($n = 384$) in mixed hardwood forest at Cherokee National Forest, Tellico District, Tennessee, June-July 2002.

Number of visits	LSM [1]	% Detection rate of new species	% of Total[2]
1	8.7[a]	49.4	49.4 (28.1)
2	11.4[b]	15.3	64.8 (36.8)
3	12.9[c]	8.5	73.3 (41.6)
4	14.2[cd]	7.4	80.7 (45.8)
5	15.1[de]	5.1	85.8 (48.7)
6	16.0[e]	5.1	90.9 (51.6)
7	16.8[de]	4.5	95.5 (54.2)
8	17.6[e]	4.5	100.0 (56.8)

[1] Pooled SE = 0.3

[2] % of total indicates percent of all species detected on 8 visits of ten-minute-counts. Percent of all species detected on the entire plot by acoustic method is indicated in parentheses.

[abc] Means within columns with no common superscripts differed ($P < 0.05$)

Table 4-5. Least squares means (LSM) of species detected as functions of increasing 30-minute recording period ($n = 384$) in mixed hardwood forest habitat at Cherokee National Forest, Tellico District, Tennessee, June-July 2002.

Period	Time after sunrise (minutes)	LSM [1]
0700 - 0730	40 - 70	8.7^{a}
0730 - 0800	70 - 100	8.5^{ab}
0800 - 0830	100 - 130	8.0^{bc}
0830 - 0900	130 - 160	7.8^{c}

[1] Pooled SE = 0.2
[abc] Means within columns with no common superscripts differed ($P < 0.05$)

Table 4-6. Least squares means (LSM) of unsupplemented and supplemented counts, percent detection rate of new species, and differences of cumulative number of species as functions of increasing number of stations from 1 to 4 stations (n = 384) in mixed hardwood forest at Cherokee National Forest, Tellico District, Tennessee, June-July 2002.

Number of stations	LSM unsupplemented count [1]	LSM supplemented count [2]	% of Total[3]	% Detection rate of new species
1	8.1^{a}	8.1^{a}	60.4	60.4
2	8.5^{a}	10.7^{b}	80.0	19.4
3	6.9^{b}	12.3^{c}	91.8	11.9
4	8.0^{a}	13.4^{d}	100.0	8.2

[1] The number of species detected at each 10-minute increment within each visit and at each station (Pooled SE = 0.2)

[2] The cumulative species detected based on number of station from 1 to 4 (Pooled SE = 0.3)

[3] % of total indicates percent of all species detected at 4 stations within 10-minute visits (supplemented count).

[abcd] Means within columns with no common superscripts differed ($P < 0.05$).

Table 4-7. Probabilities of detecting 17 avian species from 10 minutes to 120 minutes at 4 stations for 8 days (n = 384) in mixed hardwood forest at Cherokee National Forest, Tellico District, Tennessee, June-July 2002.

			Probability of detection within (minutes)										
Species name	**Actual sample size[1]**	**Detection Frequency[2]**	**10**	**20**	**30**	**40**	**50**	**60**	**70**	**80**	**90**	**100**	**110[3]**
Red-eyed vireo	379	0.99	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Ovenbird	294	0.77	0.74	0.84	0.87	0.90	0.94	0.94	0.94	0.97	0.97	0.97	0.97
Indigo bunting	290	0.76	0.91	0.91	0.91	0.91	0.97	1.00	1.00	1.00	1.00	1.00	1.00
Scarlet tanager	251	0.65	0.68	0.81	0.87	0.94	0.97	0.97	0.97	0.97	0.97	0.97	1.00
American crow	224	0.58	0.59	0.81	0.97	0.97	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Carolina chickadee	223	0.58	0.62	0.75	0.81	0.94	0.97	0.97	0.97	0.97	0.97	0.97	0.97
Worm-eating warbler	182	0.47	0.58	0.65	0.77	0.85	0.85	0.88	0.92	0.96	0.96	0.96	1.00
Yellow-billed cuckoo	155	0.40	0.57	0.73	0.83	0.87	0.90	0.97	0.97	0.97	0.97	0.97	1.00
White-breasted nuthatch	150	0.39	0.40	0.60	0.67	0.67	0.67	0.80	0.83	0.93	0.97	1.00	1.00

Table 4-7. Continued.

Species name	Actual sample size[1]	Detection Frequency[2]	Probability of detection within (minutes)										
			10	20	30	40	50	60	70	80	90	100	110[3]
Black-throated green warbler	141	0.37	0.39	0.52	0.65	0.74	0.78	0.91	1.00	1.00	1.00	1.00	1.00
Pileated woodpecker	141	0.37	0.43	0.80	0.87	0.90	0.93	0.93	0.97	1.00	1.00	1.00	1.00
Downy woodpecker	126	0.33	0.20	0.47	0.50	0.67	0.73	0.80	0.83	0.90	0.93	0.97	0.97
Blue jay	80	0.21	0.25	0.45	0.60	0.70	0.85	0.85	0.95	0.95	0.95	0.95	1.00
Hooded warbler	80	0.21	0.48	0.58	0.58	0.58	0.58	0.58	0.58	0.74	0.74	0.74	0.90
Pine warbler	77	0.20	0.35	0.53	0.65	0.82	0.82	0.82	0.82	0.88	0.94	1.00	1.00
Carolina wren	74	0.19	0.33	0.50	0.61	0.72	0.78	0.89	0.89	0.89	0.94	1.00	1.00
Tufted titmouse	73	0.19	0.22	0.30	0.37	0.48	0.67	0.78	0.78	0.89	0.96	1.00	1.00

[1] The number of points that the species was detected.
[2] The number of points at which a species was detected divided by the total number of point sampled ($n = 384$).
[3] Detection probabilities after 110-minute recordings for all species equaled to 1.00 because all species analyzed were detected within 2 hours.

Table 4-8. Detection ranges and detection probability of 19 species at which singing birds became inaudible to a recording device in the Cherokee National Forest, Tellico District, Tennessee, May-June 2003.

Species	Total Records [a]	Min [b]	Max [c]	$D_{0.01}$ [d]	$D_{0.99}$ [e]	$D_{0.50}$ [f]	%95 CI [g]	Slope [h]
American crow [i]	89	-	> 225	-	-	-	-	-
Black-throated green warbler	44	125	133	166	159	162	j	-0.6765
Blue jay [i]	7	-	> 170	-	-	-	-	-
Carolina Chickadee	32	77	127	193	55	124	103-249	-0.0337
Carolina wren	78	147	165	328	117	222	j	-0.0221
Downy woodpecker	24	77	121	312	51	182	j	-0.0119
Hooded warbler	48	82	113	180	78	129	j	-0.0457
Indigo bunting	92	149	208	291	108	200	179-262	-0.0255
Ovenbird	151	119	228	230	119	174	155-265	-0.0421
Pine warbler	24	103	162	179	102	141	121-309	-0.0604
Pileated woodpecker	48	177	239	480	92	286	j	-0.0120
Red-eyed vireo [i]	214	-	> 188	-	-	-	-	-
Red-shoulder hawk [i]	7	-	> 155	-	-	-	-	-
Scarlet tanager [i]	54	-	> 195	-	-	-	-	-
Tufted titmouse	28	98	186	192	184	188	j	-0.6768
Yellow-billed cuckoo	92	200	233	258	242	250	j	-0.2861
White-brested nuthatch [i]	3	-	> 72	-	-	-	-	-
Wild turkey [i]	7	-	> 175	-	-	-	-	-
Worm-eating warbler	12	78	138	210	26	118	79-201	-0.0252

Table 4-8. Continued.

[a] The total number of songs for which distance was measured.
[b] The minimum distance from which a recording device failed to audibly record an individual vocalization.
[c] The maximum distance from which a recording device was able to audibly record an individual.
[d] The maximum distance that a given species can be detected by acoustic devices with $P = 0.01$.
[e] The minimum distance that a given species are detected with $P = 0.99$.
[f] The distance where one-half of vocalizations of a given species are audible with $P = 0.50$.
[g] Confidence interval at 95% of $D_{0.50}$
[h] Slope of estimated detection probability from logistic regression
[i] Species with detection distances that extended well beyond my sampling distance and species with total records < 10 were not estimated the detection probability
[j] Too few data in some 25-m categories, thus 95% confidence interval could not be calculated.

CHAPTER 5

Table 5-1. Common and scientific names of birds documented by point counts, territory mapping, and acoustic method in hill evergreen forest at Phu Luang Wildlife Sanctuary, Loei province, Thailand, March 2002. Species are listed in alphabetic order.

Common Name	Bird Code	Scientific Name
Asian fairy bluebird	AFBL	*Irena puella*
Asian palm swift	APSW	*Cypsiurus balasinensis*
Banded bay cuckoo	BBCU	*Cacomantis sonneratii*
Bar-backed partridge	BBPA	*Arborophila brunneopectus*
Bar-winged flycatcher-shrike	BWFS	*Hemipus picatus*
Bay woodpecker	BAWO	*Blythipicus pyrrhotis*
Black bulbul	BLBU	*Hypsipetes leucocephalus*
Black-crested bulbul	BCBU	*Pycnonotus melanicterus*
Black-naped monarch	BNMO	*Hypothymis azurea*
Black-throated laughingthrush	BTLA	*Garrulax chinensis*
Black-throated sunbird	BTSU	*Aethopyga saturata*
Blue whistling thrush	BWTH	*Myiophoneus caeruleus*
Blue-eared barbet	BEBA	*Megalaima australis*
Blue-throated barbet	BTBA	*Megalaima asiatica*
Blue-winged minla	BWMI	*Minla cyanouroptera*
Bronzed drongo	BRDR	*Dicrurus arneus*

Table 5-1. Continued.

Common Name	Bird Code	Scientific Name
Buffed-breasted babbler	BBBA	*Trichastoma tickllli*
Chestnut-flanked white-eye	CFWE	*Zosterops erythropleurus*
Chestnut-fronted shrike babbler	CFSB	*Pteruthius aenobarbus*
Collared-scops owl	CSOW	*Otus bakkamoena*
Crested serpent eagle	CSEA	*Spilornis cheela*
Emerald dove	EMDO	*Chalcophas indica*
Eurasian jay	JAY	*Garrulus glandarius*
Eye-browed thrush	EBTH	*Turdus obscurus*
Eye-browed wren babbler	EBWB	*Napothera epilepidota*
Golden babbler	GOBA	*Stachyris chrysaea*
Great barbet	GRBA	*Megalaima virens*
Greater coucal	GRCO	*Centopus sinensis*
Grey-capped woodpecker	GCWO	*Picus canus*
Grey-cheeked fulvetta	GCFU	*Alcippe morrisonia*
Grey-eyed bulbul	GEBU	*Hypsipetes propinguus*
Grey-headed canary flycatcher	GHCF	*Cullicicapa ceylonensis*
Grey-throated babbler	GTBB	*Stachyris nigriceps*
Hair-crested drongo	HCDR	*Dicrurus hottentottus*
Hill blue flycatcher	HBFL	*Cyomis banyumas*

Table 5-1. Continued.

Common Name	**Bird Code**	**Scientific Name**
Hill prinia	HIPR	*Prinia atrogularis*
Indian cuckoo	INCU	*Cuculus micropterus*
Japanese white-eye	JWEY	*Zosterops japonicus*
Large niltava	LANI	*Niltava grandis*
Large scimitar babbler	LSBA	*Pomatorhinus hypoleucos*
Lesser shortwing	LESH	*Brachypteryx leucophrys*
Lesser-racket tailed drongo	LRTD	*Dicrurus remifer*
Little cuckoo dove	LCDO	*Macropygia ruficeps*
Little pied flycatcher	LPFL	*Ficedula westermanni*
Little spiderhunter	LISP	*Arachnothera longirostra*
Mountain bulbul	MOBU	*Hypsipetes mcclellandii*
Mountain imperial pigeon	MIPI	*Ducula badia*
Mountain tailorbird	MOTA	*Orthotomus cuculatus*
Orange-bellied leafbird	OBLE	*Chloropsis hardwickii*
Orange-breasted trogon	OBTR	*Harpactes oreskios*
Puff-throated babbler	PTBA	*Pellorneum ruficeps*
Puff-throated bulbul	PTBU	*Criniger pallidus*
Red-headed trogon	RHTR	*Harpactes erythrocephalus*
Red-billed scimitar babbler	RBSB	*Pomatorhinus ochraceiceps*

Table 5-1. Continued.

Common Name	Bird Code	Scientific Name
Scarlet minivet	SCMI	*Pericrocotus flammeus*
Silver-breasted broadbill	SBBR	*Serilophus lunatus*
Silver-eared mesia	SEME	*Leiothrix argentauris*
Speckled piculet	SPPI	*Picumnus innominatus*
Streaked spiderhunter	STSP	*Arachnothera magna*
Striated bulbul	STBU	*Pycnonotus striatus*
Striped tit babbler	STBA	*Macronous gularis*
Velvet-fronted nuthatch	VFNU	*Sitta frontalis*
White-bellied yuhina	WBYU	*Yuhina zantholeuca*
White-browed scimitar babbler	WBSB	*Pomatorhinus schisticeps*
White-crowned forktail	WCFO	*Enicurus leschenaulti*
White-hooded babbler	WHBA	*Gampsorhynchus rufulus*
White-tailed leaf-warbler	WTLW	*Phylloscopus davisonni*
White-tailed robin	WTRO	*Cinclidium leucurum*
White-throated fantail	WTFA	*Rhipidura albicollis*
Yellow-bellied warbler	YBWA	*Abroscopus supercilliaris*

Table 5-2. Species observed during unlimited-distance point counts, territory mapping, and acoustic method in hill evergreen forest at Phu Luang Wildlife Sanctuary, Loei province, Thailand, March 2002.

Species	Unlimited-Distance Point Counts	Territory Mapping	Acoustic Method
Asian fairy bluebird	+	+	+
Asian palm swift	-	-	+
Banded bay cuckoo	-	+	+
Bar-backed partridge	+	-	+
Bar-winged flycatcher-shrike	-	+	+
Bay woodpecker	+	+	+
Black bulbul	-	-	+
Black-crested bulbul	+	+	+
Black-naped monarch	-	-	+
Black-throated laughingthrush	-	-	+
Black-throated sunbird	+	+	-
Blue whistling thrush	+	-	+
Blue-eared barbet	+	+*	+
Blue-throated barbet	+	+*	+
Blue-winged minla	-	+	-
Bronzed drongo	-	+	+
Buffed-breasted babbler	+	+	+
Chestnut-flanked white-eye	-	+	-
Chestnut-fronted shrike babbler	+	-	+
Collared-scops owl	-	-	+
Crested serpent eagle	+	-	-
Emerald dove	+	-	+
Eurasian jay	+	-	+
Eye-browed thrush	-	+	-
Eye-browed wren babbler	-	+	-
Golden babbler	+	+*	+
Great barbet	+	+*	+

Table 5-2. Continued.

Species	**Unlimited-distance Point Counts**	**Territory Mapping**	**Acoustic Method**
Greater coucal	+	-	+
Grey-capped woodpecker	-	-	+
Grey-cheeked fulvetta	+	+*	+
Grey-eyed bulbul	+	+	+
Grey-headed canary flycatcher	+	+*	+
Grey-throated babbler	+	+*	+
Hair-crested drongo	+	-	+
Hill blue flycatcher	+	+*	+
Hill prinia	-	-	+
Indian cuckoo	+	-	+
Japanese white-eye	+	+	-
Large niltava	+	+*	+
Large scimitar babbler	+	-	+
Lesser shortwing	+	+*	+
Lesser-racket tailed drongo	+	+*	+
Little cuckoo dove	-	-	+
Little pied flycatcher	+	-	-
Little spiderhunter	+	-	+
Mountain bulbul	+	+	+
Mountain imperial pigeon	+	+*	+
Mountain tailorbird	+	+	+
Orange-bellied leafbird	-	+	+
Orange-breasted trogon	+	-	+
Puff-throated babbler	-	-	+
Puff-throated bulbul	+	+*	+
Red-headed trogon	-	+	+
Red-billed scimitar babbler	-	+	+
Scarlet minivet	+	+	+
Silver-breatsed broadbill	-	+	-
Silver-eared mesia	+	+*	+
Speckled nuthatch	-	+	-

Table 5-2. Continued.

Species	Unlimited-distance Point Counts	Territory Mapping	Acoustic Method
Streaked spiderhunter	-	+	+
Striated bulbul	-	+	+
Striped tit babbler	-	-	+
White-hooded babbler	+	+	+
Velvet-fronted nuthatch	-	+	-
white-bellied yuhina	-	+	-
White-browed scimitar babbler	+	+	+
White-crowned forktail	+	+	+
White-tailed leaf-warbler	+	+*	+
White-tailed robin	+	-	+
White-throated fantail	+	+*	+
Yellow-bellied warbler	+	-	+
Total 69	44	45	58

+ = Presence
- = Absence
* = Territorial species

Table 5-3. Least squares means (LSM), percent detection rate of new species, percent of total, and probabilities of differences of cumulative number of species as functions of increasing 10-minute recording period (n = 384) in hill evergreen forest at Phu Luang Wildlife Sanctuary, Loei province, Thailand, March 2002.

Period	LSM [1]	% Detection rate of new species	% of Total [2]
10	11.5^{a}	46.6	46.6 (19.8)
20	14.5^{b}	12.1	58.7 (25.0)
30	16.5^{c}	8.1	66.8 (28.4)
40	18.1^{cd}	6.5	73.3 (31.2)
50	19.3^{de}	4.9	78.1 (33.3)
60	20.1^{efg}	3.2	81.4 (34.6)
70	21.2^{def}	4.5	85.8 (36.6)
80	22.1^{defg}	3.6	89.5 (38.1)
90	22.9^{efg}	3.2	92.7 (39.5)
100	23.7^{efg}	3.2	96.0 (40.9)
110	24.2^{fg}	2.0	98.0 (41.7)
120	24.7^{g}	2.0	100.0 (42.6)

[1] Pooled SE = 0.5

[2] % of total indicates percent of all species detected in 2-hour recording within 1 visit and 1 station. Percent of all species detected on the entire plot by acoustic method is indicated in parentheses.

[abc] Means within columns with no common superscripts differed ($P < 0.05$).

Table 5-4. Least squares means (LSM), percent detection rate of new species, and differences of cumulative number of species as functions of increasing number of visits from 1–8 visits (n = 384) in hill evergreen forest at Phu Luang Wildlife Sanctuary, Loei province, Thailand, March 2002.

Number of visits	LSM [1]	% Detection rate of new species	% of Total [2]
1	9.8[a]	36.6	36.3 (16.9)
2	15.2[b]	20.1	56.7 (26.2)
3	18.9[c]	15.0	70.5 (32.6)
4	20.7[de]	7.3	77.2 (35.7)
5	22.6[d]	7.7	84.3 (39.0)
6	24.0[de]	5.7	89.6 (41.4)
7	25.6[de]	6.5	95.5 (44.1)
8	26.8[e]	4.9	100.0 (46.2)

[1] Pooled SE = 0.3

[2] % of total indicates percent of all species detected on 8 visits of ten-minute counts. Percent of all species detected on the entire plot by acoustic method is indicated in parentheses.

[abc] Means within columns with no common superscripts differed ($P < 0.05$)

Table 5-5. Least squares means (LSM) of species detected as functions of increasing 30-minute recording period (n = 384) in hill evergreen forest at Phu Luang Wildlife Sanctuary, Loei province, Thailand, March 2002.

Period	Time after sunrise (minutes)	LSM [1]
0700 - 0730	30 - 60	10.9[a]
0730 - 0800	60 - 90	10.2[b]
0800 - 0830	90 - 120	9.8[bc]
0830 - 0900	120 - 150	9.3[c]

[1] Pooled SE = 0.3

[abcd] Means within columns with no common superscripts differed ($P < 0.05$).

Table 5-6. Least squares means(LSM) of unsupplemented and supplemented counts, detection rate of new species, and differences of cumulative number of species as functions of increasing number of stations from 1 to 4 stations (n = 384) in hill evergreen forest at Phu Luang Wildlife Sanctuary, Loei province, Thailand, March 2002.

Number of stations	LSM unsupplemented count[1]	LSM supplemented count[2]	% of total[3]	% Detection rate of new species
1	10.3^{a}	10.3^{a}	50.0	38.4
2	9.1^{b}	14.0^{b}	53.8	13.8
3	10.3^{a}	17.4^{c}	84.5	13.8
4	10.3^{a}	20.6^{d}	100.0	13.0

[1] The number of species detected at each 10-minute increment within each visit and at each station (Pooled SE = 0.2)

[2] The cumulative species detected based on number of stations from 1 to 4 (Pooled SE = 0.4)

[3] % of total indicates percent of all species detected at 4 stations within 10-minute counts (supplemented count).

[abcd] Means within columns with no common superscripts differed ($P < 0.05$).

Table 5-7. Probabilities of detecting 26 avian species from 10 minutes to 110 minutes at 4 stations for 8 Days in hill evergreen forest at Phu Luang Wildlife Sanctuary, Loei province, Thailand, March 2002.

			Detection Probabilities within (minutes)										
Species name	**Actual sample size[1]**	**Detection Frequency[2]**	**10**	**20**	**30**	**40**	**50**	**60**	**70**	**80**	**90**	**100**	**110[3]**
Blue-throated barbet	371	0.97	0.97	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Great barbet	341	0.89	0.88	0.94	0.97	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Golden babbler	337	0.88	0.94	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
White-tailed leaf-warbler	299	0.78	0.78	0.84	0.94	0.97	0.97	0.97	0.97	0.97	0.97	0.97	1.00
Grey-eyed bulbul	227	0.59	0.53	0.75	0.84	0.91	0.94	0.97	0.97	0.97	0.97	1.00	1.00
Silver-eared mesia	203	0.53	0.58	0.71	0.87	0.87	0.87	0.81	0.90	0.97	0.97	0.97	0.97
Puff-throated bulbul	169	0.44	0.34	0.62	0.84	0.91	0.96	0.96	0.96	0.94	0.97	0.97	0.97
Lesser-racket tailed drongo	150	0.39	0.39	0.55	0.68	0.81	0.88	0.94	0.97	1.00	1.00	1.00	1.00
White-throated fantail	144	0.38	0.38	0.63	0.80	0.83	0.88	0.88	0.92	0.92	1.00	1.00	1.00

Table 5-7. Continued.

Species name	Actual sample size[1]	Detection Frequency[2]	Detection Probabilities within (minutes) 10	20	30	40	50	60	70	80	90	100	110[3]
Blue-eared barbet	127	0.33	0.53	0.70	0.80	0.87	0.90	0.93	0.93	1.00	1.00	1.00	1.00
Black-crested bulbul	89	0.23	0.00	0.32	0.42	0.47	0.63	0.68	0.74	0.84	0.90	0.90	1.00
Mountain imperial pigeon	86	0.22	0.40	0.64	0.80	0.84	0.92	0.96	1.00	1.00	1.00	1.00	1.00
Buffed-breasted babbler	84	0.22	0.25	0.36	0.46	0.68	0.79	0.79	0.89	0.89	0.93	1.00	1.00
Grey-throated babbler	80	0.21	0.33	0.56	0.61	0.83	0.89	0.94	0.94	0.94	1.00	1.00	1.00
Lesser shortwing	75	0.20	0.41	0.47	0.53	0.65	0.65	0.65	0.71	0.82	0.94	0.94	0.94
Mountain tailorbird	71	0.18	0.50	0.64	0.68	0.68	0.68	0.73	0.78	0.82	1.00	1.00	1.00
Larger scimitar babbler	67	0.17	0.48	0.71	0.76	0.76	0.76	0.76	0.81	0.86	0.90	1.00	1.00
White-browed scimitar babbler	61	0.16	0.09	0.22	0.35	0.40	0.53	0.61	0.78	0.78	0.83	0.87	0.96
White-hooded babbler	60	0.16	0.24	0.47	0.53	0.53	0.65	0.77	0.77	0.82	0.88	1.00	1.00
Grey-cheeked fulvetta	58	0.15	0.29	0.43	0.43	0.57	0.64	0.64	0.64	0.64	0.71	0.93	1.00

Table 5-7. Continued.

			Detection Probabilities within (minutes)										
Species name	**Actual sample size**[1]	**Detection Frequency**[2]	**10**	**20**	**30**	**40**	**50**	**60**	**70**	**80**	**90**	**100**	**110**[3]
Little spiderhunter	57	0.15	0.20	0.50	0.60	0.65	0.70	0.75	0.75	0.90	0.95	0.95	0.95
Red headed trogon	51	0.13	0.38	0.38	0.38	0.56	0.62	0.69	0.75	0.75 0	0.81	0.81	0.94
Hill blue flycatcher	44	0.11	0.30	0.35	0.35	0.40	0.55	0.60	0.65	0.70	0.80	0.90	0.90
Large niltava	42	0.11	0.22	0.44	0.67	0.78	0.78	0.89	0.89	0.89	0.89	1.00	1.00
Bar-backed partridge	34	0.09	0.14	0.14	0.21	0.36	0.50	0.64	0.71	0.93	0.93	0.93	1.00

[1] The number of points that the species was detected.
[2] The number of points at which a species was detected divided by the total number of point sampled (*n* = 384).
[3] Detection probabilities after 110-minute recordings for all species equaled to 1.00 because all species analyzed were detected within 2 hours.

CHAPTER 6

Table 6-1. Common and scientific names of birds documented by point counts, territory mapping, and acoustic method in grassland habitat at KhaoYai National Park, Thailand, April 2002. Species are listed in alphabetic order.

Common Name	Bird Code	Scientific Name
Asian barred owlet	ABOW	*Glaucidium cuculoides*
Asian emerald dove	AEDO	*Chrysococcyx maculatus*
Asian fairy bluebird	AFBL	*Irena puella*
Asian palm swift	APSW	*Cypsiurus balasiensis*
Banded broadbill	BABR	*Eurylaimus javanicus*
Barn swallow	BASW	*Hirundo rustica*
Barred cuckoo dove	BCDO	*Macropygia unchall*
Black-crested bulbul	BCBU	*Pycnonotus melanicterus*
Black-headed bulbul	BHBU	*Pycnonotus atriceps*
Black-naped oriole	BNOR	*Oriolus chinensis*
Black-throated laughingthrush	BTLA	*Garrulax chinensis*
Blue pitta	BLPI	*Pitta cyanea*
Blue-bearded bee-eater	BBBE	*Nyctyornis athertoni*
Blue-eared barbet	BEBA	*Megalaima australis*
Blue-winged leafbird	BWLE	*Chloropsis cochinchinensis*
Bright-capped cisticola	BCCI	*Cisticola exilis*
Brown hawk owl	BHOW	*Ninox scutulata*
Brown shrike	BRSH	*Lanius cristatus*
Chestnut-capped babbler	CCBA	*Timalia pileata*
Chestnut-headed bee-eater	CHBE	*Merops leschenaulti*
Chinese pond heron	CPHE	*Ardeola bacchus*
Collar owlet	COOW	*Glaucidium brodiei*
Collared scops owl	CSOW	*Otus bakkamoena*
Common flameback	COFL	*Dinopium javanense*
Coral-billed ground cuckoo	CBGC	*Carpococcyx renauldi*
Crested serpent eagle	CSEA	*Spilornis cheela*
Dark-necked tailorbird	DNTA	*Orthotomus atrogularis*
Dollarbird	DOLL	*Eurystomus orientalis*

Table 6-1. Continued.

Common Name	Bird Code	Scientific Name
Dusky warbler	DUWA	*Phylloscopus fuscatus*
Eurasian jay	EUJA	*Garrulus glandarius*
Great barbet	GRBA	*Megalaima virens*
Great hornbill	GRHO	*Buceros bicornis*
Greater coucal	GRCO	*Centropus sinensis*
Greater flamback	GRFL	*Chrysocolaptes lucidus*
Greater racket-tailed drongo	GRTD	*Dicrurus paradiseus*
Green magpie	GEMA	*Cissa chinensis*
Green-eared barbet	GEBA	*Megalaima faiostricta*
Grey-breasted prinia	GBPR	*Prinia hodgsonii*
Grey-eyed bulbul	GEBU	*Iole propinqua*
Hair-crested drongo	HCDR	*Dicrurus hottentottus*
Hill myna	HIMY	*Gracula religiosa*
Laced woodpecker	LAWO	*Picus vittatus*
Large-billed crow	LBCR	*Corvus macrorhynchos*
Lesser coucal	LECO	*Centropus bengalensis*
Lesser necklaced laughingthrush	LNLA	*Garrulax monileger*
Lesser racket-tailed drongo	LRTD	*Dicrurus remifer*
Long-tailed broadbill	LTBR	*Psarisomus dalhousiae*
Mountain imperial pigeon	MIPI	*Ducula badia*
Moustached barbet	MOBA	*Megalaima incognita*
Olive-backed sunbird	OBSU	*Nectarinia jugularis*
Orange-breasted trogon	OBTR	*Harpactes oreskios*
Oriental pied hornbill	OPHO	*Anthracoceros albirostris*
Plain crinia	PLPR	*Prinia inornata*
Puff-throated babbler	PTBA	*Pellorneum ruficeps*
Radde's warbler	RAWA	*Phylloscopus schwarzi*
Red junglefowl	REJU	*Gallus gallus*
Red-throated flycatcher	RTFL	*Ficedula parva*
Red-wattled lapwing	RWLA	*Vanellus indicus*
Red-whiskered bulbul	RWBU	*Pycnonotus jocosus*
Rufescent prinia	RUPR	*Prinia rufescens*

Table 6-1. Continued.

Common Name	Bird Code	Scientific Name
Scarlet minivet	SCMI	*Pericrocotus flammeus*
Scaly-breasted partridge	SBPA	*Arborophila chloropus*
Spotted dove	SPDO	*Streptopelia chinensis*
Stripe-throated bulbul	STBU	*Pycnonotus finlaysoni*
Stripe-tit babbler	STBA	*Macronous gularis*
Thick-billed spiderhunter	TBSP	*Arachnothera crassirostris*
White-browed scimitar babbler	WBSB	*Pomatorhinus schisticeps*
White-crested laughingthrush	WCLA	*Garrulax leucolophus*
White-rumped shama	WRSH	*Copsychus malabaricus*
Wreathed hornbill	WRHO	*Aceros undulatus*
Yellow-bellied prinia	YBPR	*Prinia flaviventris*
Yellow-legged button quail	YLBQ	*Turnix tanki*

Table 6-2. Species observed during unlimited-distance point counts, territory mapping, and acoustic method in grassland habitat at KhaoYai National Park, Thailand, April 2002. Species are listed in alphabetic order.

Species	Unlimited-distance Point Counts	Territory Mapping	Acoustic Method
Asian barred owlet	-	-	+
Asian emerald dove	-	-	+
Asian fairy bluebird	+	-	+
Asian palm swift	+	+	-
Banded broadbill	-	-	+
Barn swallow	+	+	-
Barred cuckoo dove	-	-	+
Black-crested bulbul	-	-	+
Black-headed bulbul	-	+	-
Black-naped oriole	-	+	+
Black-throated laughingthrush	-	+	+
Blue pitta	-	-	+
Blue-bearded bee-eater	-	-	+
Blue-eared barbet	-	-	+
Blue-winged leafbird	-	-	+
Bright-capped cisticola	+	+*	+
Brown hawk owl	-	-	+
Brown shrike	-	+	+
Chestnut-capped babbler	-	-	+
Chestnut-headed bee-eater	-	+	-
Chinese pond heron	+	-	-
Collar owlet	+	-	+
Collared scops owl	+	+	+
Common flameback	-	-	+
Coral-billed ground cuckoo	+	-	+
Crested serpent eagle	-	+	-
Dark-necked tailorbird	-	-	+
Dollarbird	-	+	-
Dusky warbler	-	-	+
Eurasian jay	+	+	-

Table 6-2. Continued.

Species	Unlimited-distance Point Counts	Territory Mapping	Acoustic Method
Great barbet	+	-	-
Great hornbill	+	-	+
Greater coucal	+	-	+
Greater flameback	-	+	+
Greater racket-tailed drongo	+	-	+
Green magpie	-	-	+
Green-eared barbet	-	-	+
Grey-breasted prinia	+	+	+
Grey-eyed bulbul	+	-	+
Hair-crested drongo	+	+	-
Hill myna	+	+	+
Laced woodpecker	-	+	+
Large-billed crow	+	+	+
Lesser coucal	-	+	+
Lesser necklaced laughingthrush	-	-	+
Lesser racket-tailed drongo	+	-	-
Long-tailed broadbill	-	-	+
Mountain imperial pigeon	+	+	+
Moustached barbet	+	-	+
Olive-backed sunbird	-	-	+
Orange-breasted trogon	-	-	+
Oriental pied hornbill	+	-	+
Plain prinia	+	+	+
Puff-throated babbler	-	-	+
Radde's warbler	-	-	+
Red junglefowl	+	+	+
Red-throated flylcatcher	-	+	+
Red-wattled lapwing	+	+	+
Red-whiskered bulbul	+	+*	+
Rufescent prinia	+	+	+
Scalet minivet	-	+	-
Scaly-breasted partridge	+	+	+
spotted dove	-	-	+
Stripe-throated bulbul	-	+	+
Stripe-tit babbler	+	-	+

Table 6-2. Continued.

Species	Unlimited-distance Point Counts	Territory Mapping	Acoustic Method
Thick-billed spiderhunter	-	+	+
White-browed scimitar babbler	+	-	+
White-crested laughingthrush	+	-	+
White-rumped shama	-	-	+
Wreathed hornbill	+	+	+
Yellow-bellied prinia	+	+*	+
Yellow-legged button quail	-	-	+
Total 72	33	32	60

Table 6-3. Least squares means (LSM), percent detection rate of new species, percent of total, and probabilities of differences of cumulative number of species as functions of increasing 10-minute recording period (n = 240) in grassland habitat at KhaoYai National Park, Thailand, April 2002.

Period	LSM [1]	% Detection rate of new species	% of Total[2]
10	17.2[a]	54.8	54.8(28.7)
20	21.0[b]	12.1	66.9(35.0)
30	22.9[c]	6.1	72.9(38.2)
40	24.4[cd]	4.8	77.7(40.7)
50	25.7[cde]	4.1	81.8(42.8)
60	26.9[cde]	3.8	85.7(44.8)
70	27.9[cde]	3.2	88.9(46.5)
80	29.1[cde]	3.8	92.7(48.5)
90	30.0[de]	2.9	95.5(50.0)
100	30.8[de]	2.5	98.1(51.3)
110	31.2[e]	1.3	99.4(52.0)
120	31.4[e]	0.6	100.0(52.3)

[1] Pooled SE = 1.1

[2] % of total indicates percent of all species detected in 2-hour recording within 1 visit and 1 station. Percent of all species detected on the entire plot by acoustic method is indicated in parentheses.

[abc] Means within columns with no common superscripts differed ($P < 0.05$).

Table 6-4. Least squares means (LSM), percent detection rate of new species, and differences of cumulative number of species as functions of increasing number of visits from 1–5 visits in grassland habitat at KhaoYai National Park, Thailand, April 2002.

Number of visits	LSM [1]	% Detection rate of new species	% of Total [2]
1	15.2[a]	46.6	46.6(25.3)
2	20.4[b]	16.0	62.6(34.0)
3	25.2[b]	14.7	77.3(42.0)
4	28.8[c]	11.0	88.3(48.0)
5	32.6[c]	11.7	100.0(54.3)

[1] Pooled SE = 0.3

[2] Percent of total number of species, for all species detected on the entire plot by acoustic method (60 species)

[abc] Means within columns with no common superscripts differed ($P < 0.05$)

Table 6-5. Least squares means (LSM) of species detected as functions of increasing 30-minute recording period (n = 240) in grassland habitat at KhaoYai National Park, Thailand, April 2002.

Period	Time after sunrise (minutes)	LSM (±SE)
0600 - 0630	10 – 40	16.8(0.5)[a]
0630 - 0700	40 – 70	16.7(0.4)[a]
0700 - 0730	70 – 100	16.4(0.4)[ab]
0730 - 0800	100 – 130	15.5(0.4[bc]
0800 - 0830	130 – 160	14.4(0.4)[c]
0830 - 0900	160 – 190	10.0(1.0)[d]

[abcd] Means within columns with no common superscripts differed ($P < 0.05$).

Table 6-6. Least squares means (LSM) of unsupplemented and supplemented counts, detection rate of new species, and differences of cumulative number of species as functions of increasing number of stations from 1 to 4 stations (n = 240) in grassland habitat at KhaoYai National Park, Thailand, April 2002.

Number of stations	LSM unsupplemented count[1]	LSM supplemented count[2]	% of total[3]	% Detection rate of new species
1	16.0[ab]	16.0[a]	60.8	60.8
2	15.7[ab]	21.1[b]	80.2	19.4
3	16.5[a]	24.2[c]	92.0	11.8
4	15.4[b]	26.3[d]	100.0	8.0

[1] The number of species detected at each 10-minute increment within each visit and at each station (Pooled SE = 0.4)

[2] The cumulative species detected based on number of station from 1 to 4 (Pooled SE = 0.6)

[3] % of total indicates percent of all species detected at 4 stations within 10-minute counts (supplemented count).

[abcd] Means within columns with no common superscripts differed ($P < 0.05$).

Table 6-7. Probabilities of detecting 24 avian species from 10 minutes to 110 minutes at 4 stations for 5 days in grassland habitat at KhaoYai National Park, Thailand, April 2002.

Species	Actual sample size[1]	Detection Frequency[2]	10	20	30	40	50	60	70	80	90	100	110[3]
Bright-capped cisticola	237	0.99	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Hill myna	228	0.95	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Moustached barbet	221	0.92	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
White-crested laughingthrush	221	0.92	0.85	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Red-whiskered bulbul	213	0.89	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Scaly-breasted partridge	210	0.88	0.90	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Mountain imperial pigeon	205	0.85	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Greater coucal	190	0.79	0.90	0.95	0.95	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Red junglefowl	189	0.79	0.95	0.95	0.95	0.95	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Collar owlet	176	0.73	0.55	0.65	0.85	0.90	0.95	0.95	1.00	1.00	1.00	1.00	1.00

Table 6-7. Continued.

Species	**Actual sample size[1]**	**Detection Frequency[2]**	**10**	**20**	**30**	**40**	**50**	**60**	**70**	**80**	**90**	**100**	**110[3]**
Large-billed crow	153	0.64	0.75	0.85	0.90	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Bared cuckoo dove	151	0.63	0.80	0.95	0.95	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Greater racket-tailed drongo	126	0.52	0.53	0.68	0.90	0.95	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Yellow-bellied prinia	126	0.53	0.50	0.72	0.83	0.83	0.89	0.94	1.00	1.00	1.00	1.00	1.00
Red-wattled lapwing	108	0.45	0.65	0.85	0.85	0.95	0.95	1.00	1.00	1.00	1.00	1.00	1.00
Plain prinia	98	0.41	0.62	0.70	0.77	0.77	0.77	0.85	0.85	1.00	1.00	1.00	1.00
Green-eared barbet	68	0.28	0.45	0.73	0.82	0.82	0.91	0.91	1.00	1.00	1.00	1.00	1.00
Grey-breasted prinia	66	0.28	0.67	0.75	0.75	0.83	0.92	0.92	0.92	1.00	1.00	1.00	1.00
Banded broadbill	65	027	0.67	0.87	0.93	0.93	0.93	0.93	0.93	0.93	1.00	1.00	1.00

Table 6-7. Continued.

Species	Actual sample size[1]	Detection Frequency[2]	10	20	30	40	50	60	70	80	90	100	110[3]
Laced woodpecker	62	0.26	0.28	0.39	0.50	0.56	0.83	0.83	0.94	1.00	1.00	1.00	1.00
Rufescent prinia	61	0.25	0.20	0.80	0.87	0.93	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Stripe-tit babbler	57	0.24	0.33	0.50	0.50	0.50	0.56	0.67	0.72	0.89	0.89	0.89	0.89
White-browed scimitar babbler	42	0.18	0.31	0.46	0.54	0.54	0.54	0.61	0.80	0.92	0.92	1.00	1.00
Oriental pied hornbill	37	0.15	0.50	0.50	0.54	0.58	0.67	0.75	0.75	0.75	1.00	1.00	1.00
Lesser necklaced laughingthrush	31	0.13	0.17	0.42	0.50	0.58	0.67	0.83	0.92	0.92	1.00	1.00	1.00

[1] The number of points that the species was detected.
[2] The number of points at which a species was detected divided by the total number of point sampled (n = 240).
[3] Detection probabilities after 110-minute recordings for all species equaled to 1.00 because all species analyzed were detected within 2 hours.

CHAPTER 7

Table 7-1. Mean number of avian species detected per 10 minutes by unlimited-distance point counts and acoustic monitoring in 5 habitat types

Habitat Type	Unlimited-Distance Point Counts	Acoustic Monitoring
Temperate Grassland	10.98±0.28	11.95±0.35*
Temperate Oldfield	12.39±0.28	12.10±0.30^{ns}
Temperate Mixed Hardwood	6.25±0.27	7.91±0.36*
Tropical Hill Evergreen	9.28±0.38	10.00±0.30*
Tropical Grassland	14.40±0.59	16.45±0.63*

* $= P < 0.05$
^{ns} $= P > 0.05$

Table 7-2. Cost assessment for each avian monitoring method based on 10 visits

Type of Cost	Unlimited-Distance Point Counts		Territory Mapping		Acoustic Monitoring	
	Time (days)	Costs[1] ($)	Time (days)	Costs[1] ($)	Time (days)	Costs[1] ($)
Field work	10	500	10	500	10	500
Analysis	1	50	5	250	25	1,250[2]
Equipment	-	-	-		-	8,000[3]
Total	11	550	15	750		9,750

[1] Labor cost based on $50 per day
[2] Assuming 2.5 hours of listening for every 1-hour recording
[3] Four sets of equipment ($2000 per 1 set)

Table 7-3. Suggested implementation for acoustic monitoring from Mix Models procedure to detect maximum number of avian species presence in 5 habitat types

Habitat Type	Recording Period (minutes)	Number of Visits*	Number of Stations	Time of morning (minutes after sunrise)
Temperate grassland	90	10 (10)	4	50-80
Temperate oldfield	120	10 (10)	4	10-160 [ns]
Temperate mixed hardwood	80	8 (8)	4	≤ 40-100
Tropical Hill evergreen	110	8 (8)	4	≤ 30-60
Tropical grassland	100	5 (5)	4	≤ 10-100

* Number in parentheses indicated total visits used in this analysis

[ns] No significant difference in detecting number of avian species during this period

≤ It is possible that more avian species were detected in the earlier period but no data supported

Table 7-4. Suggested combinations of recording period, number of visits and number of stations for acoustic monitoring from response surface model to detect at least 80% of avian species presence in 5 habitat types

Habitat Type	Recording Period (minutes)	Number of Visits[1]	Number of Stations	Number of species detected[2]
Temperate grassland	50	4 (10)	3	32 (80%)
Temperate oldfield	80	5 (10)	3	37 (86%)
Temperate mixed hardwood	80	6 (8)	4	30 (82%)
Tropical hill evergreen forest	80	3 (8)	4	47 (81%)
Tropical grassland	80	4 (5)	3	48 (81%)

[1] Number in parentheses indicated total visits used in this analysis
[2] Number in the parentheses indicated percent of all avian species detected based on the entire list

FIGURES

CHAPTER 2

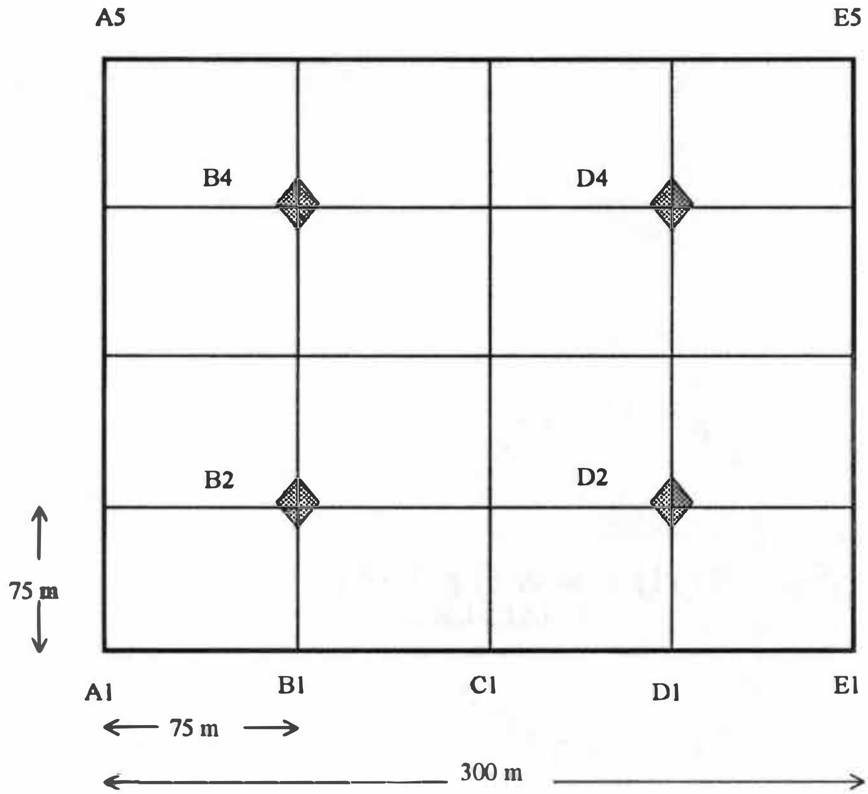


Figure 2-1. Configuration of the study plot to monitor avian species in grassland habitat at Fort Campbell Military Reservation, Tennessee-Kentucky, July 2000. The 4 monitoring stations (◆) were placed at grid intersections with 150 m spacing between each station.

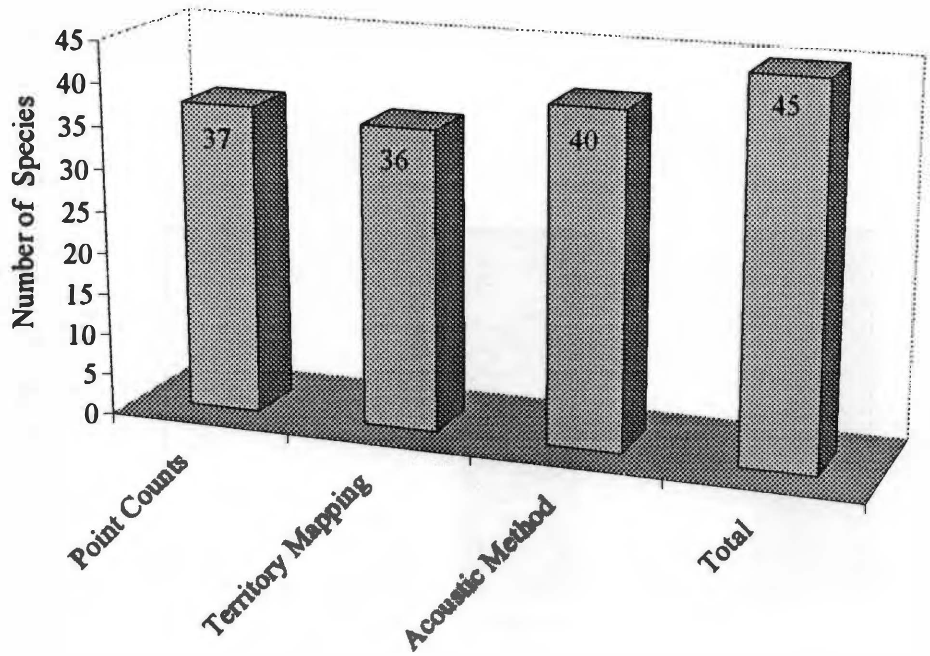


Figure 2-2. Avian species richness based on unlimited-distance point counts, territory mapping, and acoustic method in grassland habitat at Fort Campbell Military Reservation, Tennessee-Kentucky, July 2000.

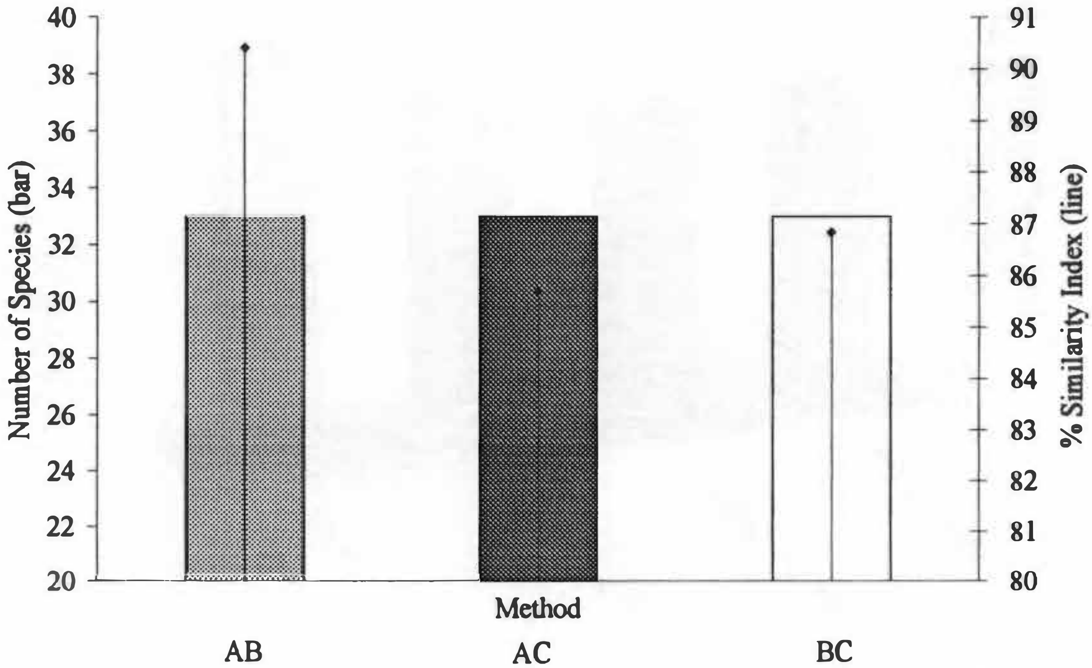


Figure 2-3. Number and percent similarity in species among avian monitoring methods: A) Unlimited-distance point count; B) Territory mapping; C) Acoustic method in grassland habitat at Fort Campbell Military Reservation, Tennessee-Kentucky, July 2000.

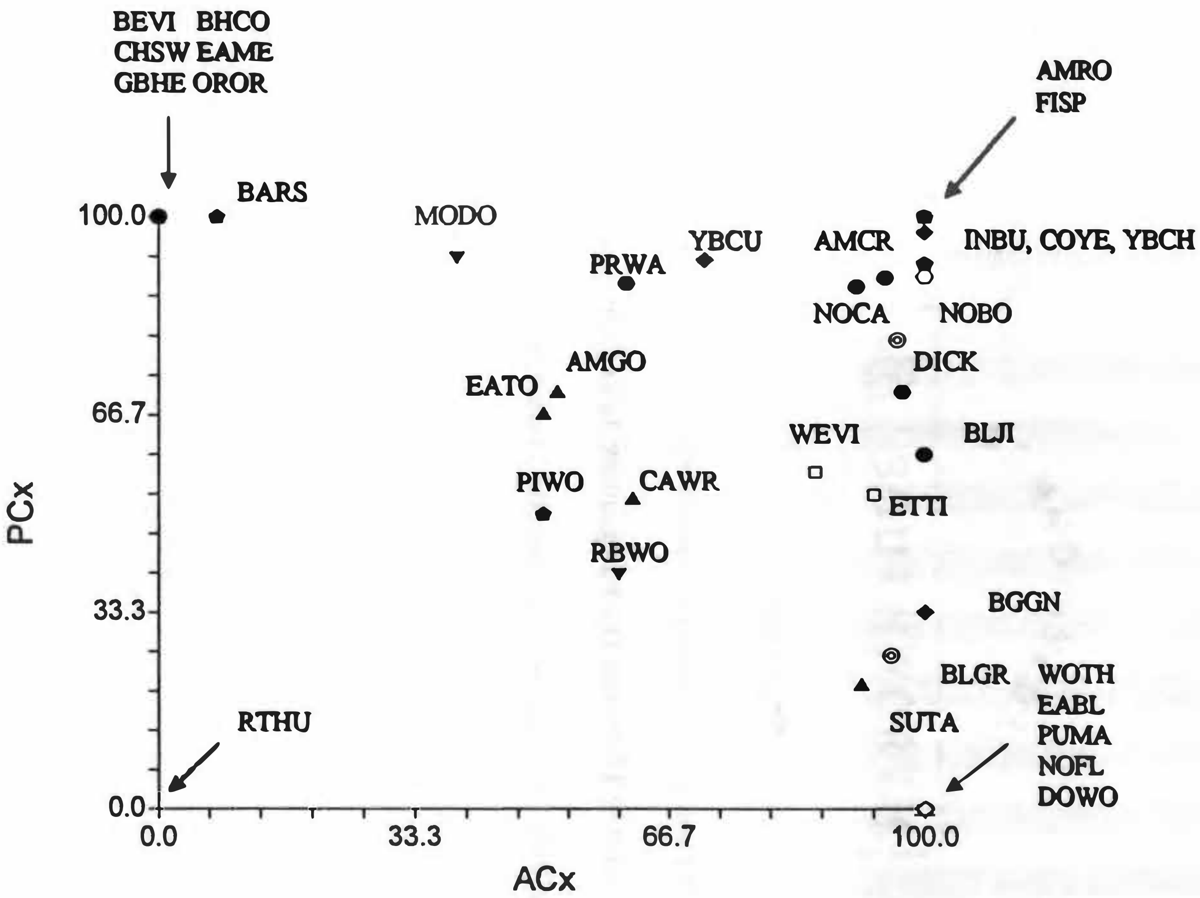


Figure 2-4. Scatter plot of % of avian species detected by unlimited point counts (PCx) and % of avian species detected by acoustic method (ACx) in grassland habitat at Fort Campbell Military Reservation, Tennessee-Kentucky, July 2000. Detected species with records less than 10 were not included in the analysis . Ruby-throated hummingbird missed by these 2 methods was shown at the coordinate 0, 0.

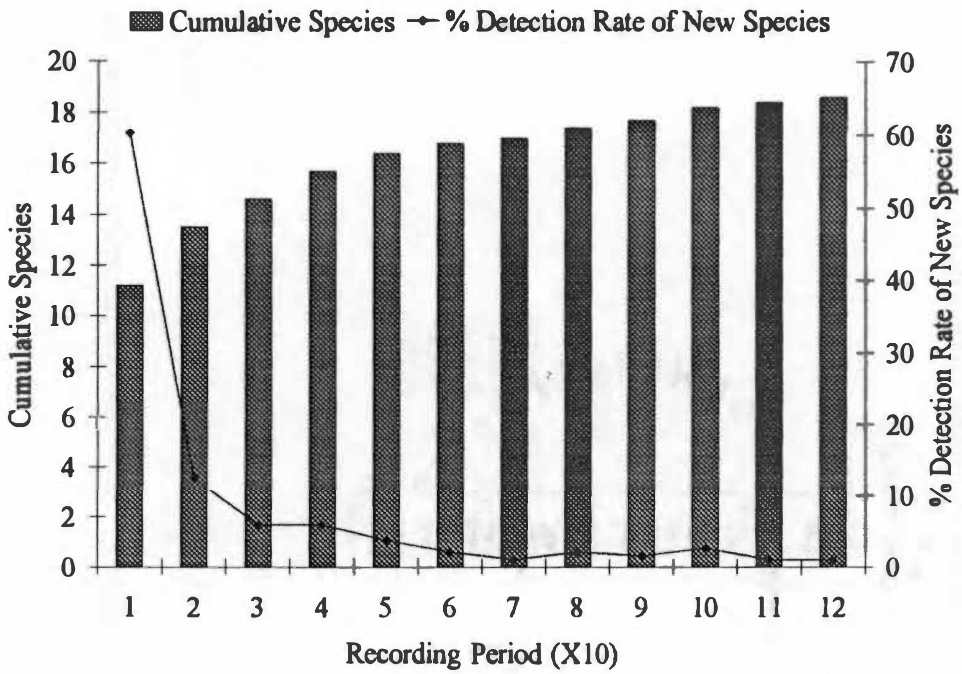


Figure 2-5. Cumulative species and percent detection rate of new species of 2-hour recordings as functions of increasing 10-minute recording intervals to monitor avian species in grassland habitat at Fort Campbell Military Reserve, Tennessee-Kentucky, July 2000.

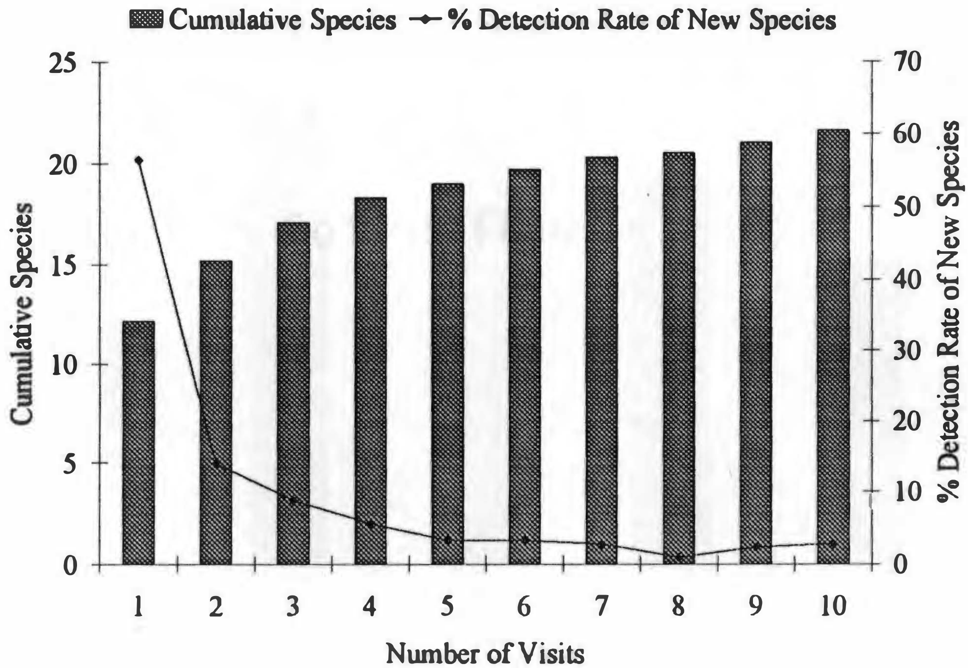


Figure 2-6. Cumulative species and percent detection rate of new species as functions of increasing number of 10-minute visits to monitor avian species in grassland habitat at Fort Campbell Military Reserves, Tennessee-Kentucky, July 2000.

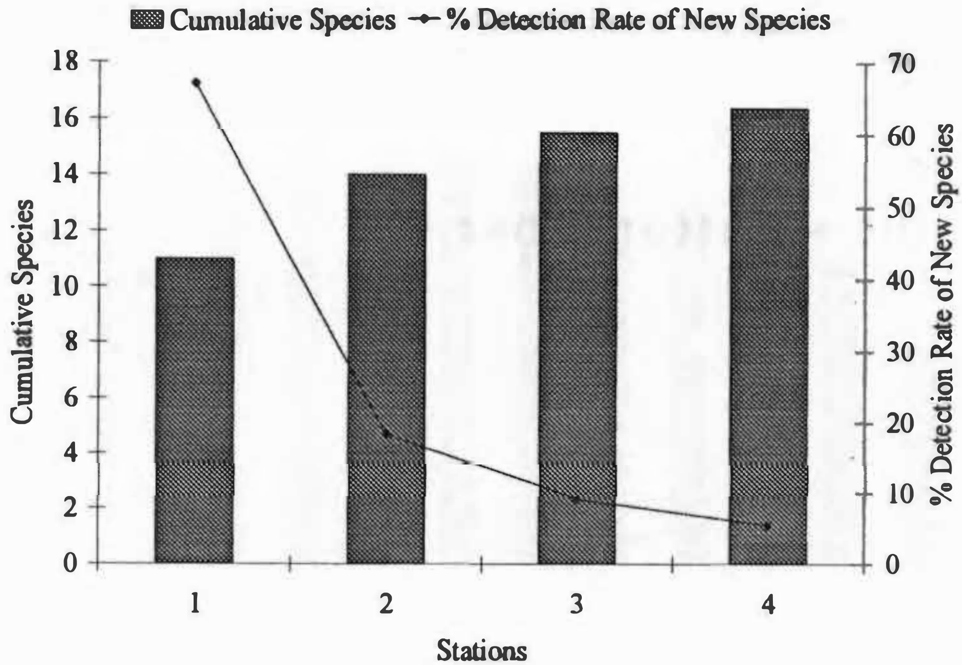


Figure 2-7. Cumulative species and percent detection rate of new species within 10-minute visits as functions of increasing number of stations to monitor avian species in grassland habitat at Fort Campbell Military Reserves, Tennessee-Kentucky, July 2000.

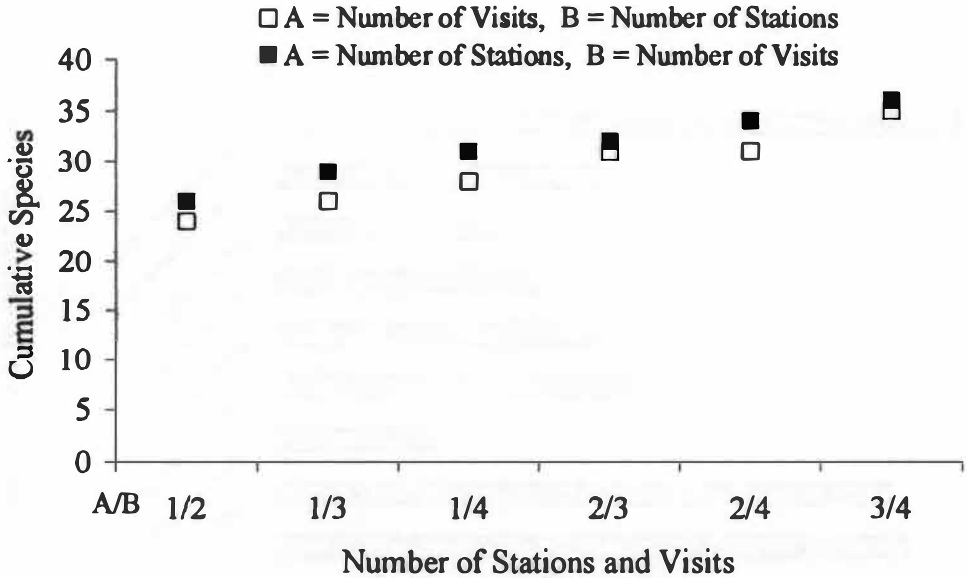


Figure 2-8. Cumulative number of avian species recorded between 6 possible paired reciprocals (e.g., 1 station-2 visits vs. 2 stations-1 visit) of number of stations visited and number of visits to each station in grassland habitat at Fort Campbell Military Reserve, Tennessee-Kentucky, July 2000.

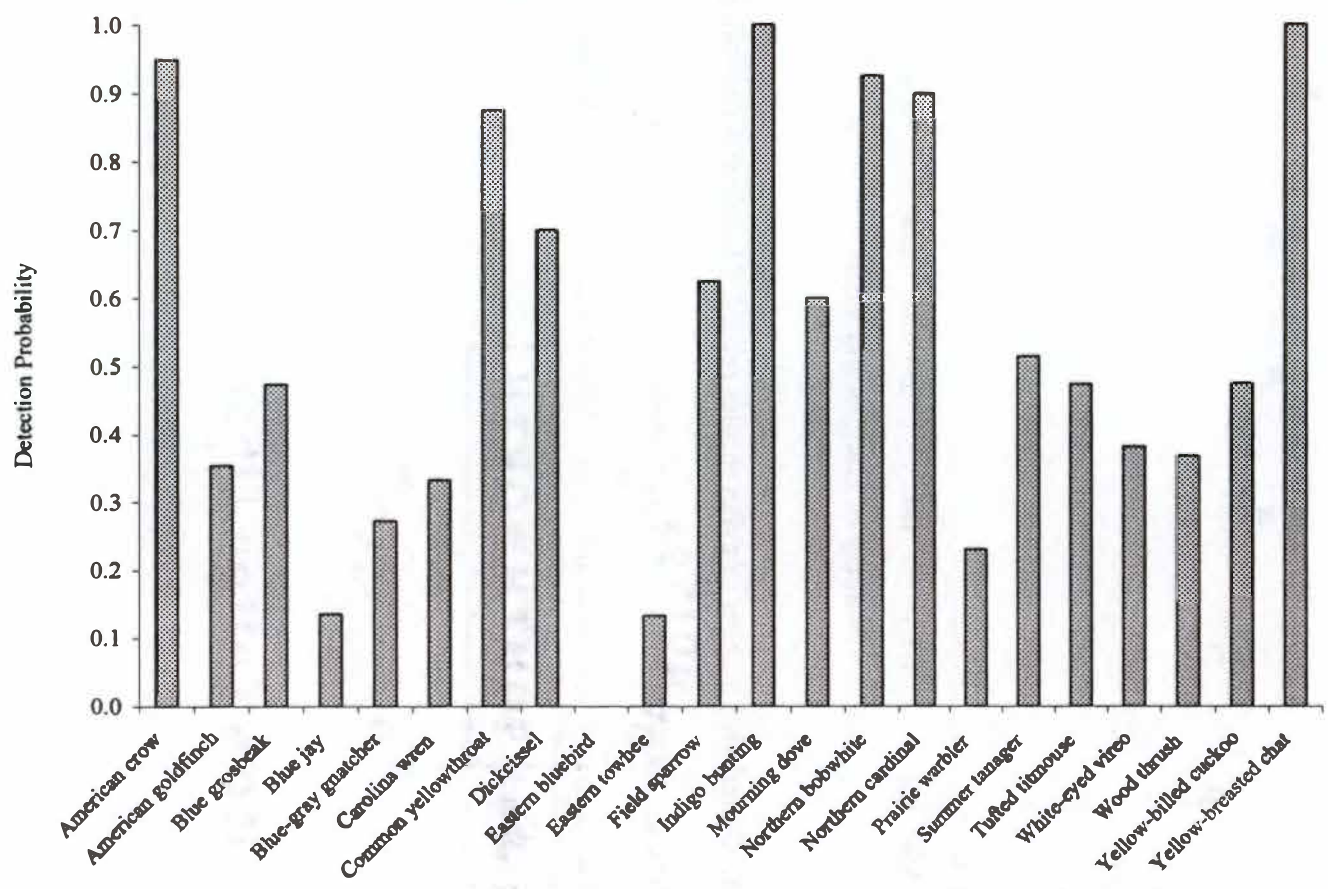


Figure 2-9. Detection probability of 22 avian species (in alphabetic order) within the first 10-minute acoustic recordings in grassland habitat at Fort Campbell Military Reserve, Tennessee-Kentucky, July 2000.

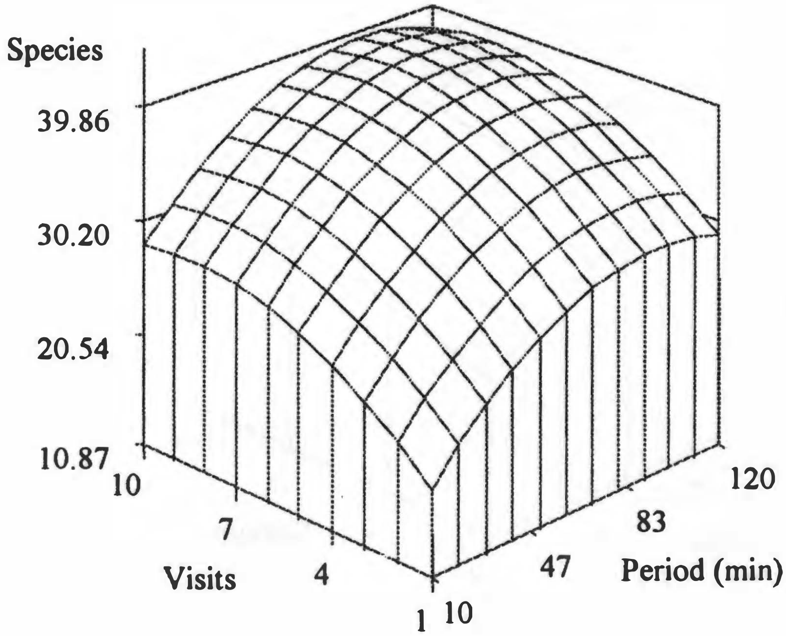


Figure 2-10 (1). Number of avian species detected as a function of number of visits and recording period in grassland habitat at Fort Campbell Military Reserve, Tennessee-Kentucky, July 2000.

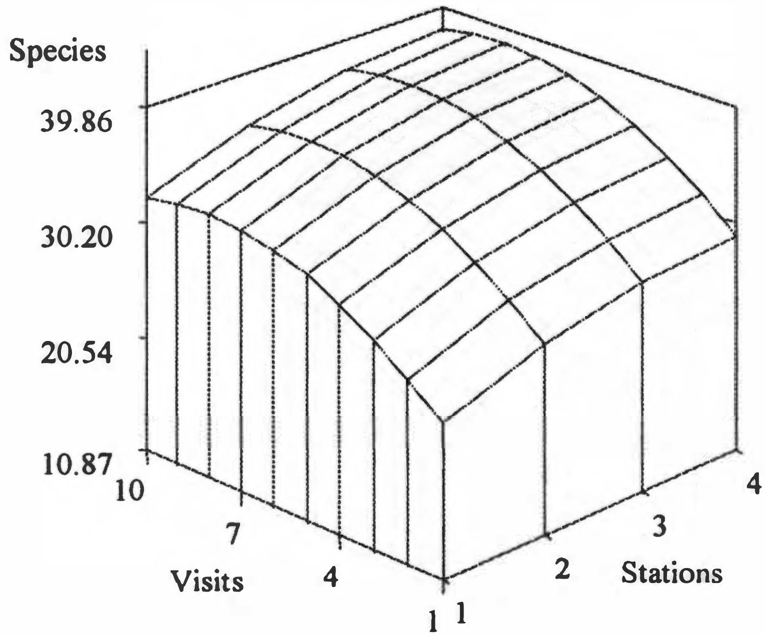


Figure 2-10 (2). Number of avian species detected as a function of number of visits and number of stations in grassland habitat at Fort Campbell Military Reserve, Tennessee-Kentucky, July 2000.

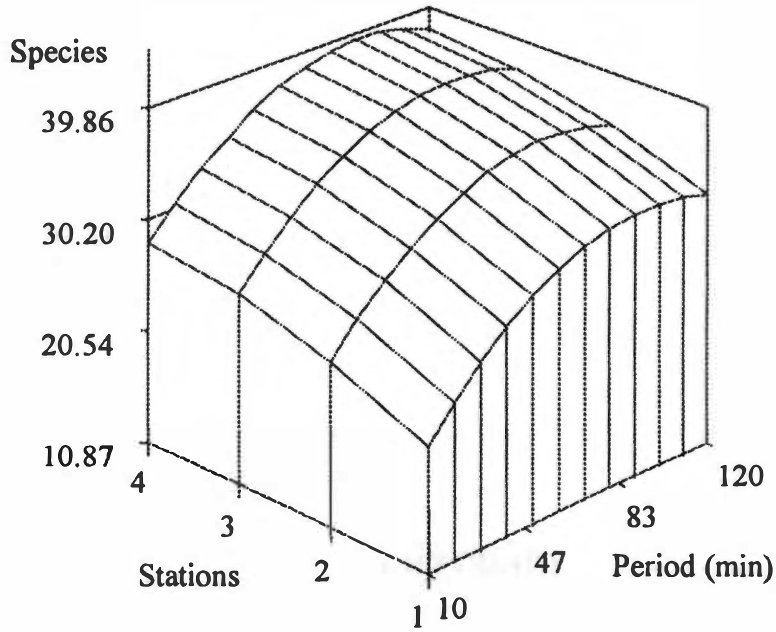


Figure 2-10 (3). Number of avian species detected as a function of number of stations and recording period in grassland habitat at Fort Campbell Military Reserve, Tennessee-Kentucky, July 2000.

CHAPTER 3

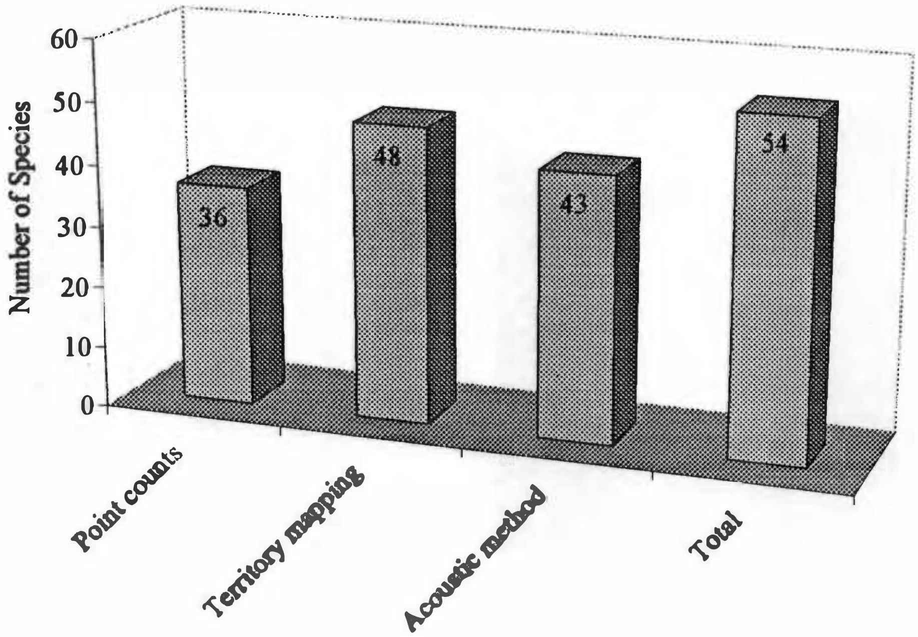


Figure 3-1. Avian species richness based on unlimited-distance point counts, territory mapping, and acoustic method, Freel's Bend Wildlife Management Area, Oak Ridge, Tennessee, June 2000.

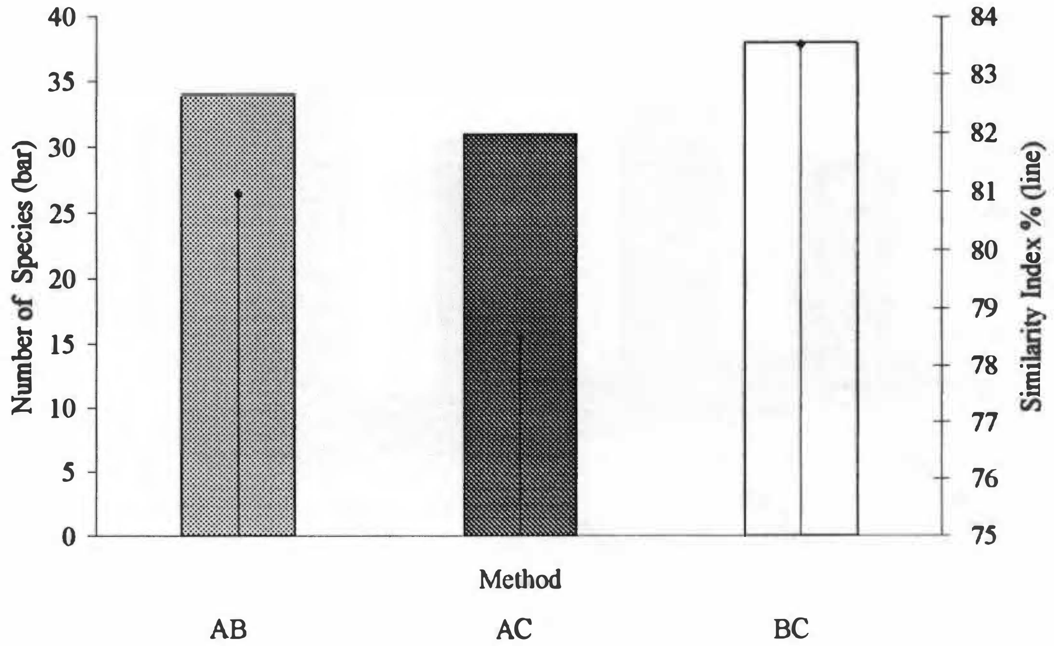


Figure 3-2. Number and percent similarity in species among avian monitoring methods: A) Unlimited-distance point count; B) Territory mapping; C) Acoustic monitoring, Freel's Bend Wildlife Management Area, Oak Ridge, Tennessee, June 2000.

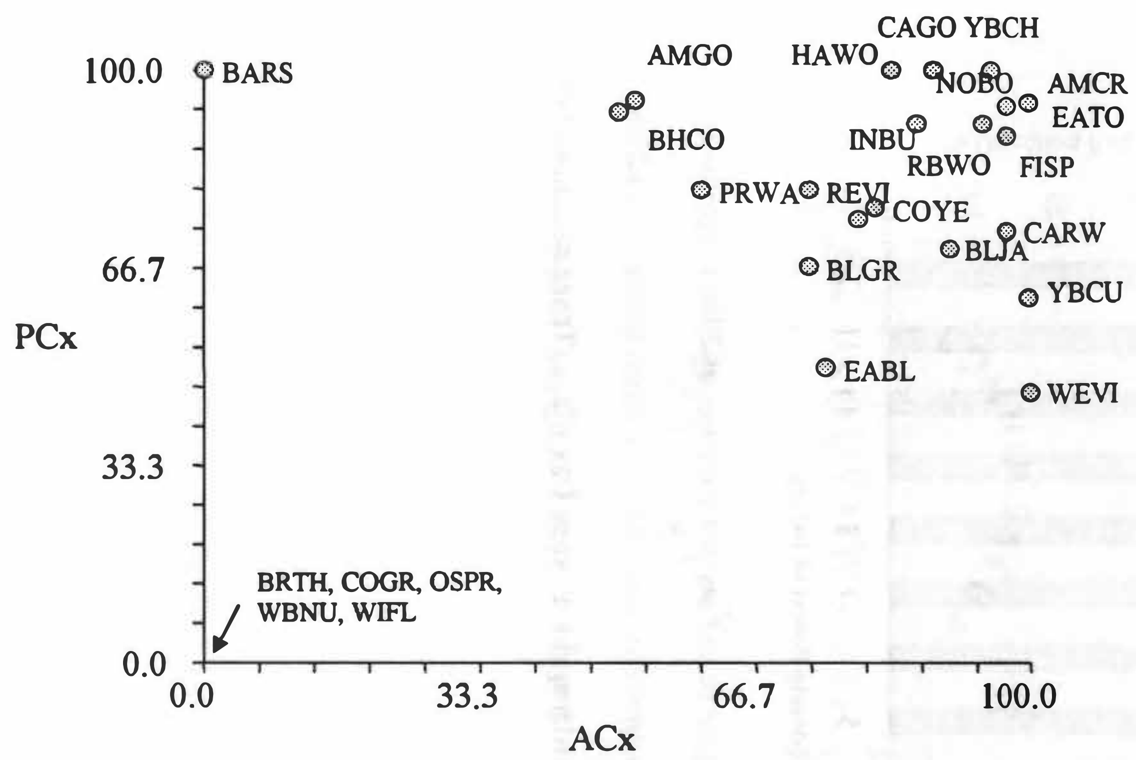


Figure 3-3. Scatter plot of % of avian species detected by point counts (PCx) and % of avian species detected by acoustic method (ACx) at Freel's Bend Wildlife Management Area, Oak Ridge, Tennessee, June 2000. Detected species with records less than 10 were not included in the analysis. Five species missed by these 2 methods were shown at the coordinate 0,0.

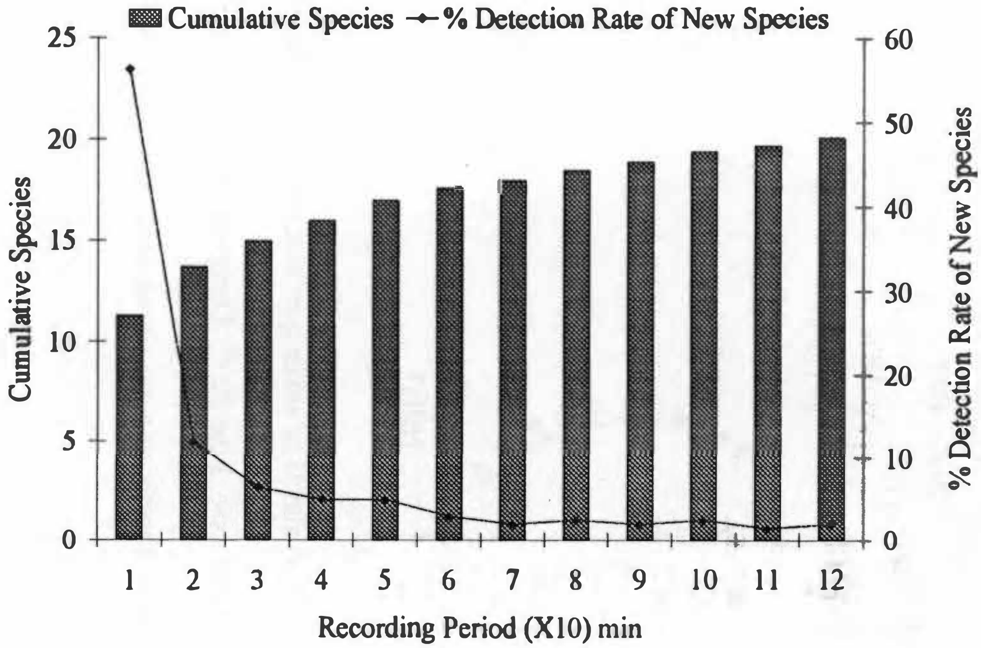


Figure 3-4. Cumulative species curve and percent coverage of 2-hour recordings as functions of increasing 10-minute recording to monitor avian species in oldfield habitat at Freel's Bend Wildlife Management Area, Oak Ridge, Tennessee, June 2000.

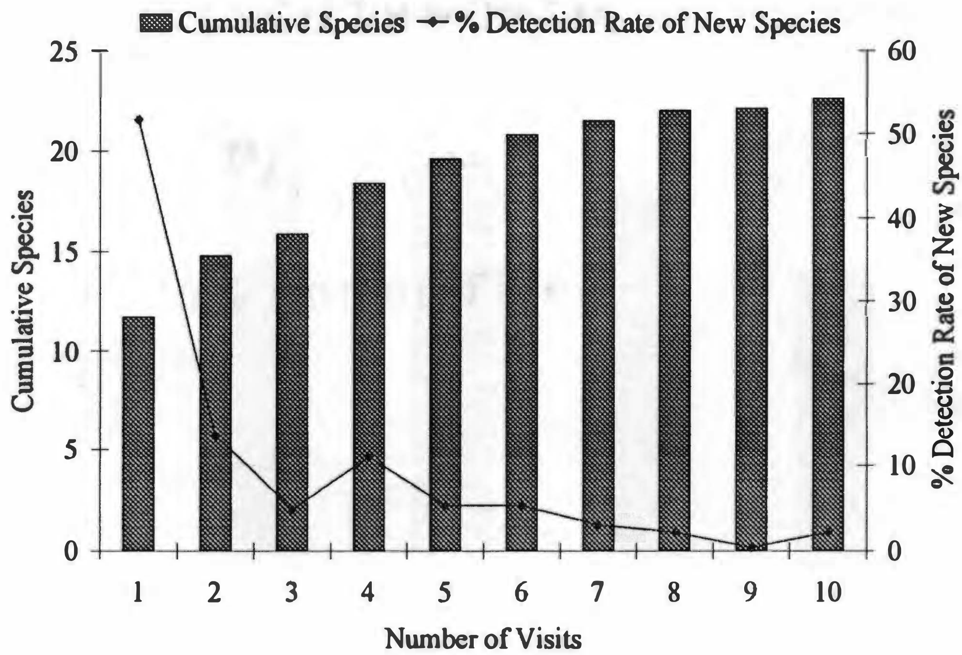


Figure 3-5. Cumulative species and percent detection rate of new species as functions of increasing number of 10-minute visits to monitor avian species in oldfield habitat at Freel's Bend Wildlife Management Area, Oak Ridge, Tennessee, June 2000.

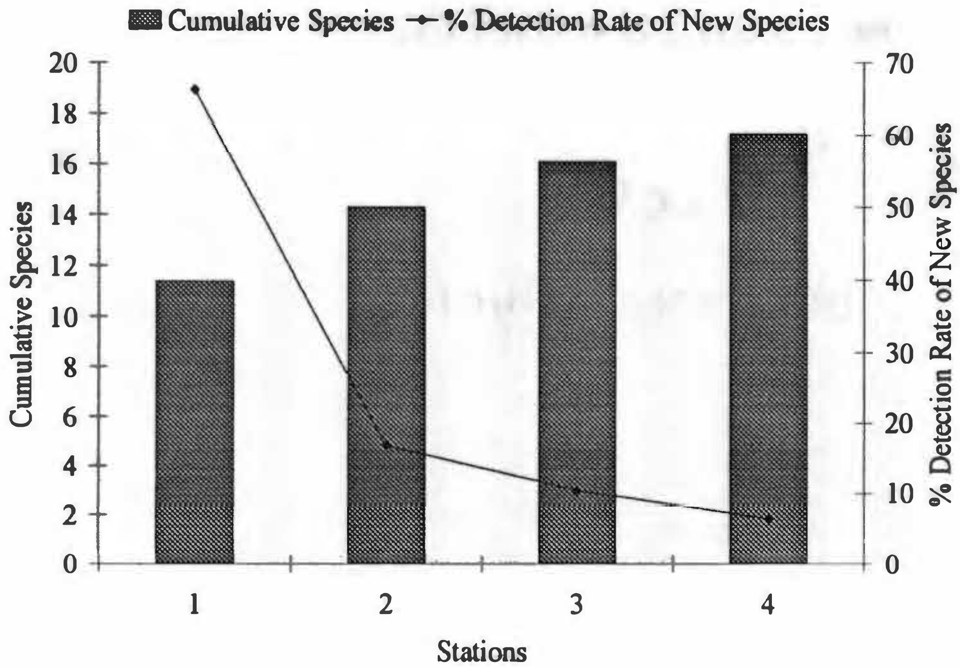


Figure 3-6. Cumulative species and percent detection rate of new species within 10-minute visits as functions of increasing number of stations to monitor avian species in oldfield habitat at Freel's Bend Wildlife Management Area, Oak Ridge, Tennessee, June 2000.

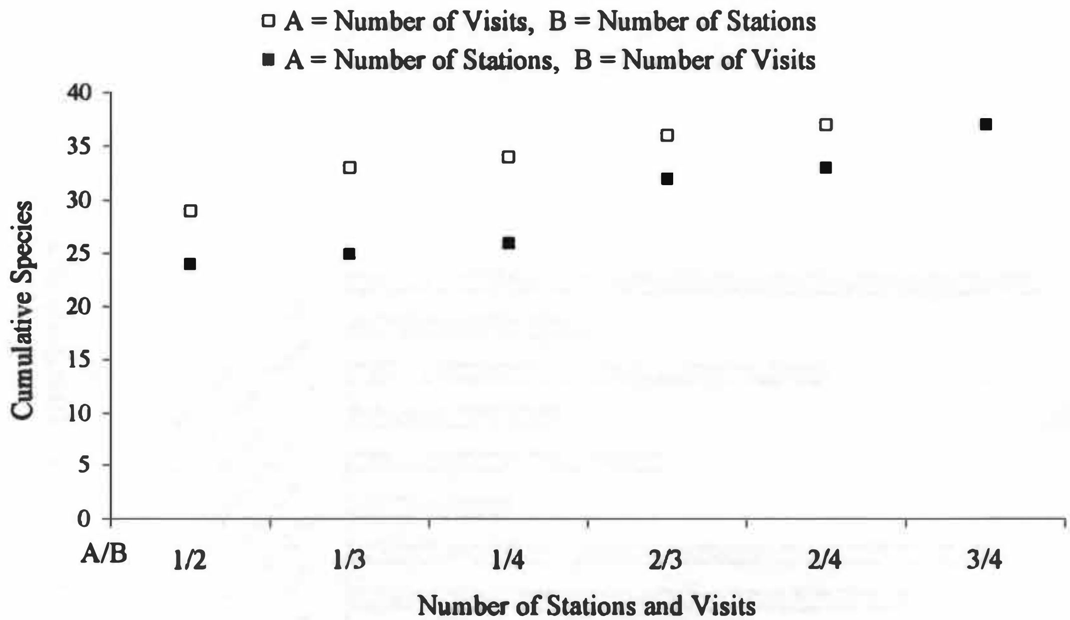


Figure 3-7. Cumulative number of avian species recorded between 6 possible paired reciprocals (e.g., 1 station-2 visits vs. 2 stations-1 visit) of number of stations visited and number of visits to each station in oldfield habitat at Freel's Bend Wildlife Management Area, Oakridge, Tennessee, June 2000.

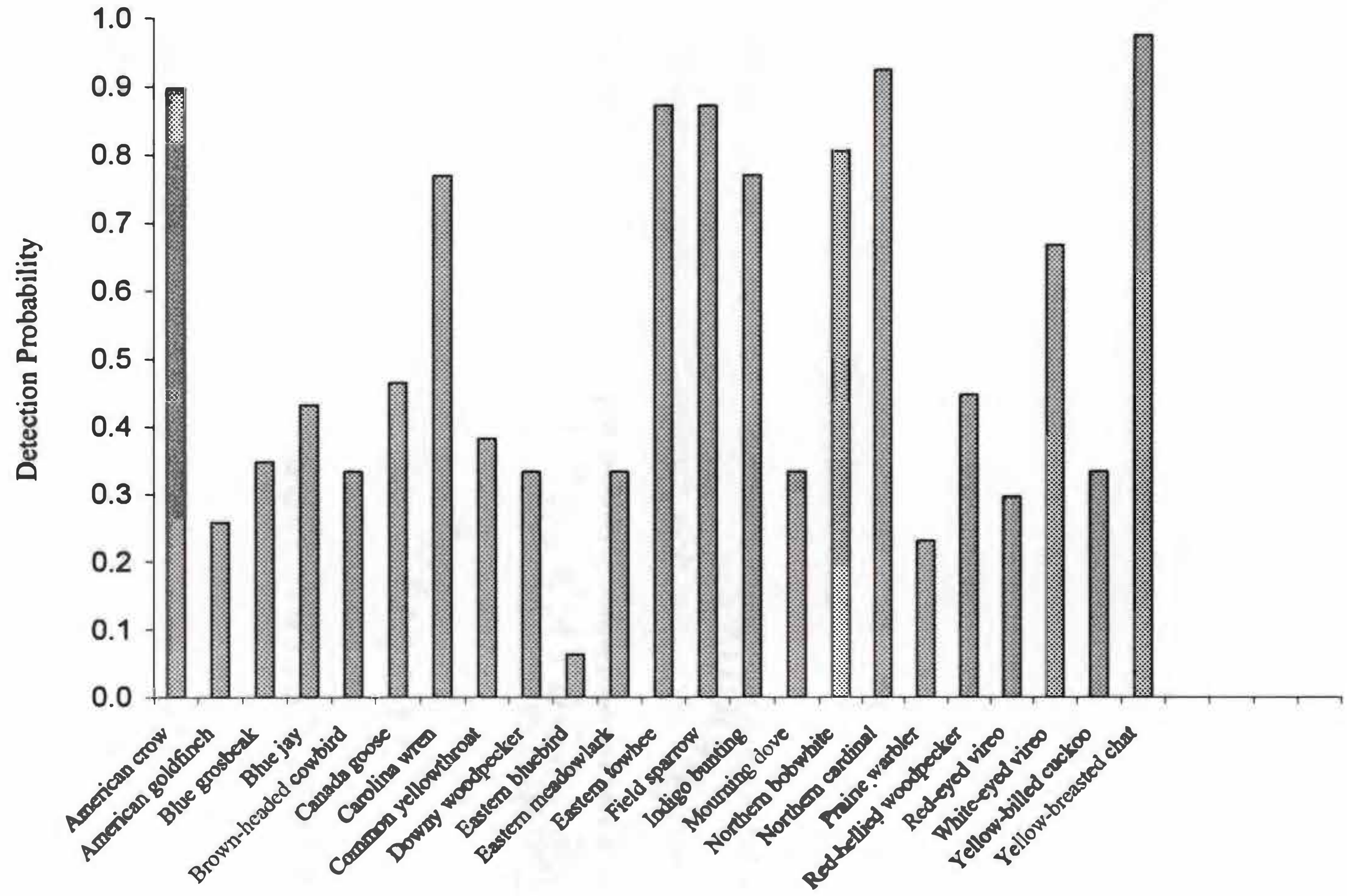


Figure 3-8. Detection probability of 23 avian species (in alphabetic order) within the first 10-minute acoustic recordings in oldfield habitat at Freel's Bend Wildlife Management Area, Oak Ridge, Tennessee, June 2000.

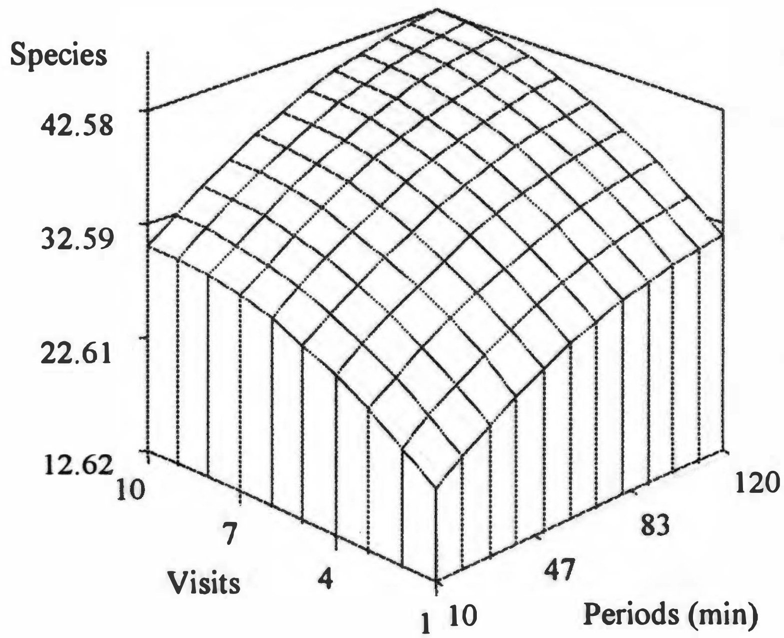


Figure 3-9 (1). Number of avian species detected as a function of number of visits and recording period in oldfield habitat at Freel's Bend Wildlife Management Area, Oak Ridge, Tennessee, June 2000.

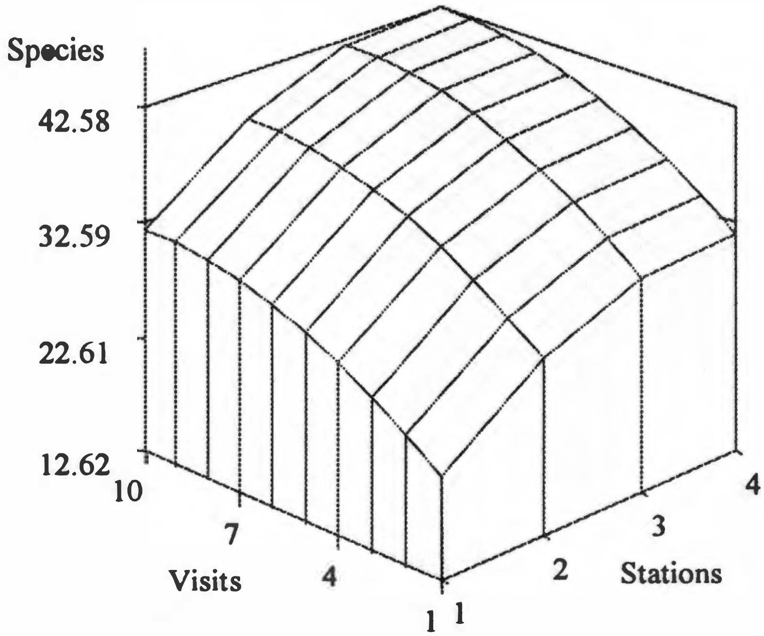


Figure 3-9 (2). Number of avian species detected as a function of number of visits and number of stations in oldfield habitat at Freel's Bend Wildlife Management Area, Oak Ridge, Tennessee, June 2000.

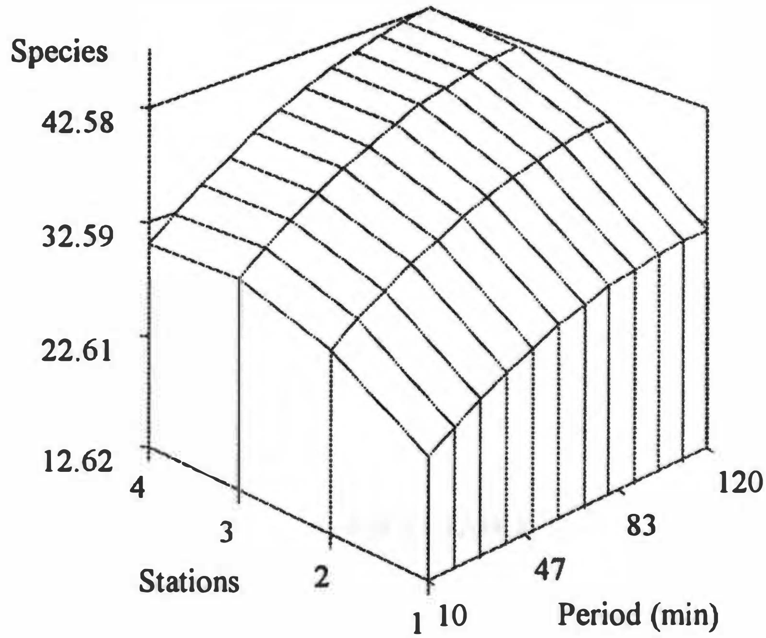


Figure 3-9 (3). Number of avian species detected as a function of number of stations and recording period in oldfield habitat at Freel's Bend Wildlife Management Area, Oak Ridge, Tennessee, July 2000.

CHAPTER 4

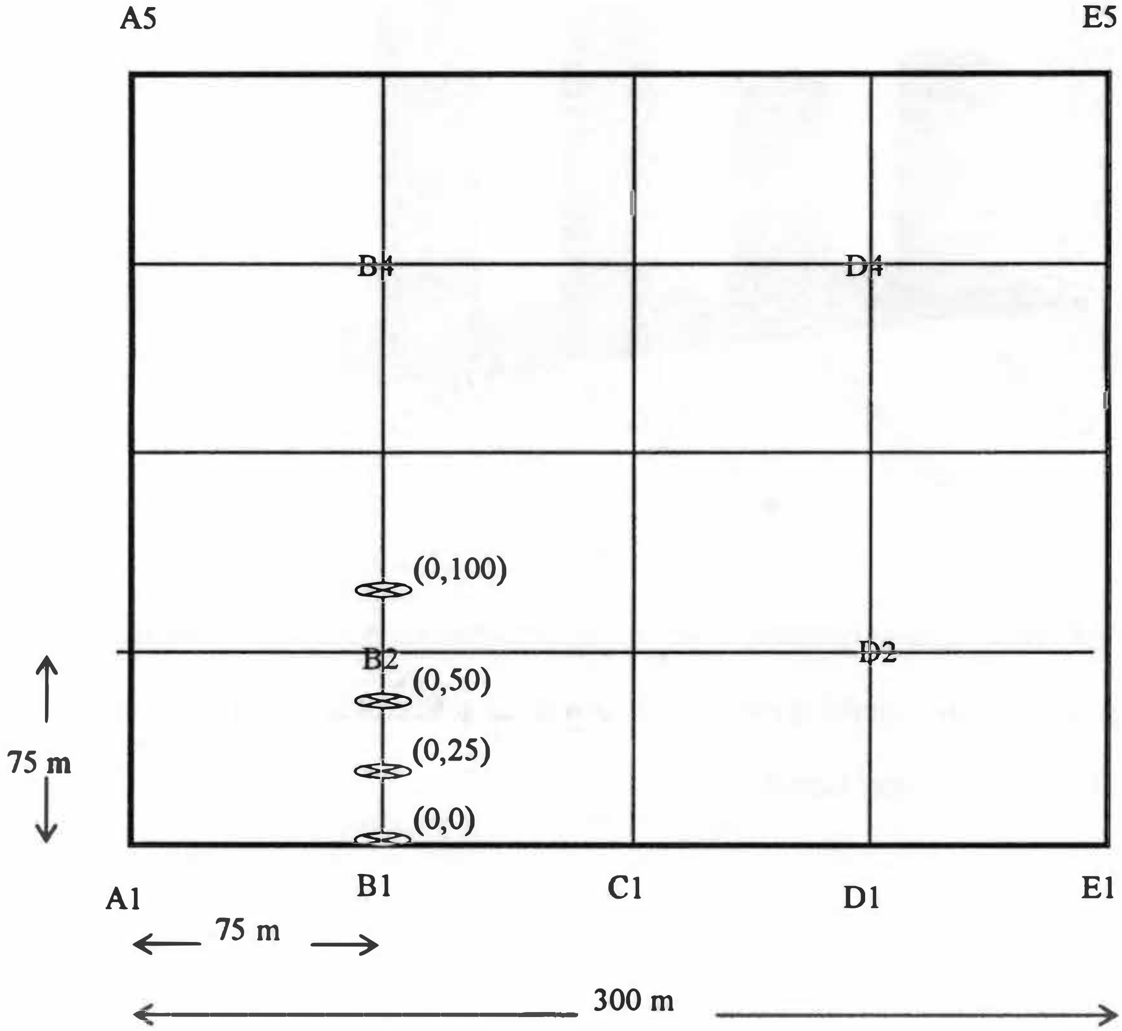


Figure 4-1. Configuration of the study plot to monitor avian species in mixed hardwood forest at Cherokee National Forest,Tellico District, Tennessee. Year 2002, the four recording devices were placed at grid intersections (B2, B4, D2, and D4) with 150 m spacing between each station in 9-ha plot. Year 2003, the four recording devices were placed at grid B with 25-m spacing at coordinate (0,0), (0,25), (0,50), and with 50-m spacing at coordinate (0,100).

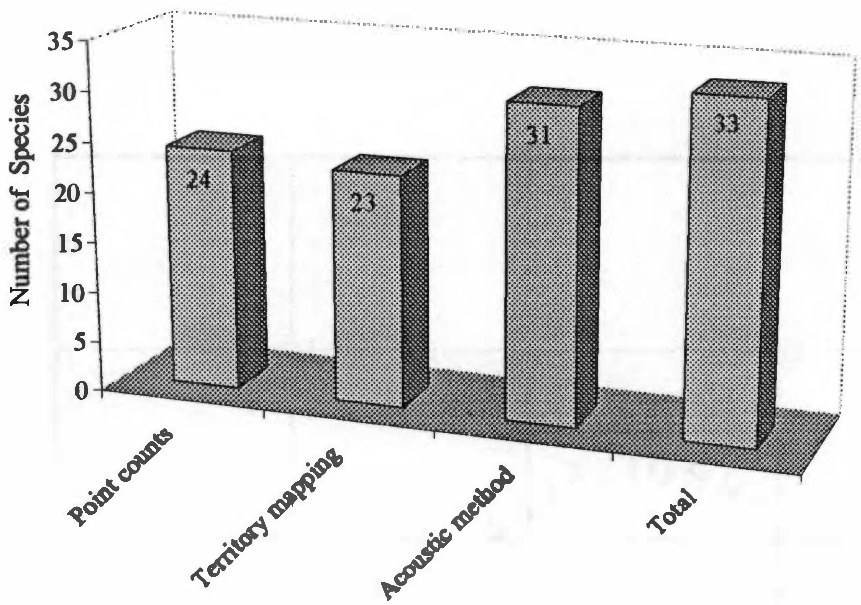


Figure 4-2. Avian species richness based on unlimited-distance point counts, territory mapping, and acoustic method in mixed hardwood forest at Cherokee National Forest, Tellico District, Tennessee, June-July 2002.

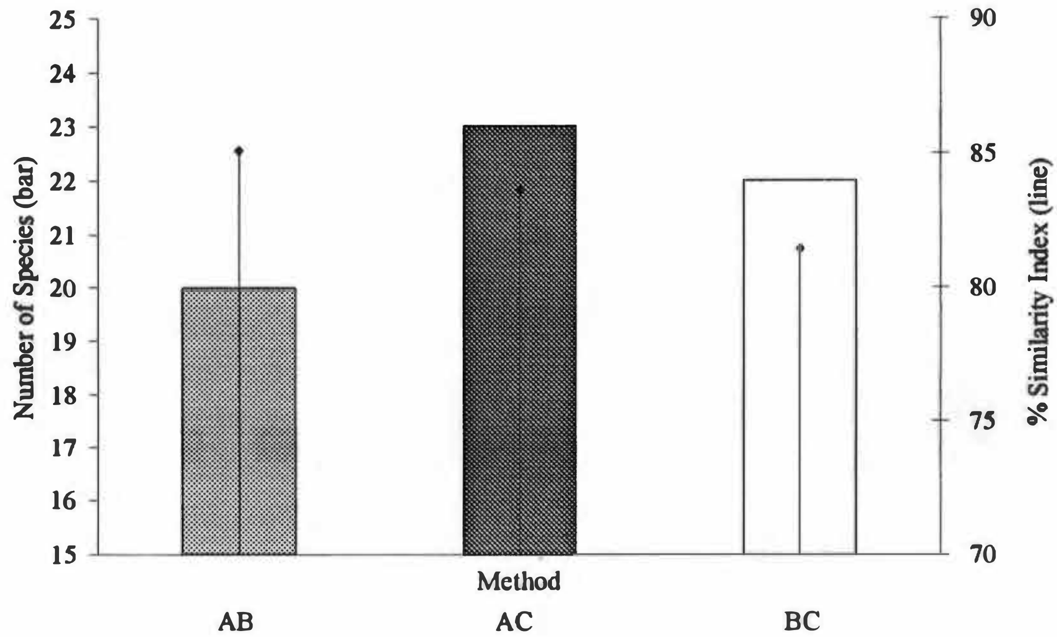


Figure 4-3. Number and percent similarity in species among avian monitoring methods: A) Unlimited-distance point count; B) Territory mapping; C) Acoustic monitoring in mixed hardwood forest at Cherokee National Forest, Tellico District, Tennessee, June-July 2002.

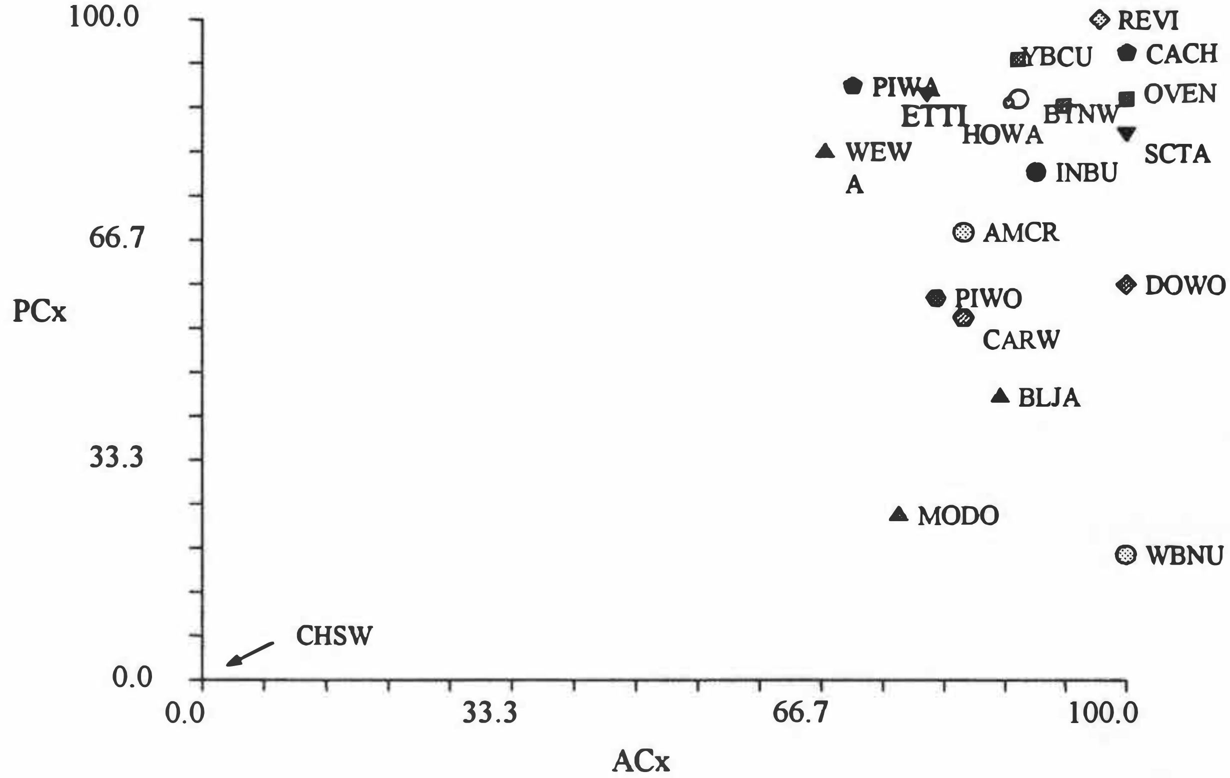


Figure 4-4. Scatter plot of % of avian species detected by unlimited-distance point counts (PCx) and % avian species detected by acoustic method (ACx) in mixed hardwood forest at Cherokee National Forest, Tellico District, Tennessee, June-July, 2002. Species with < 10 observations were not included in the analysis.

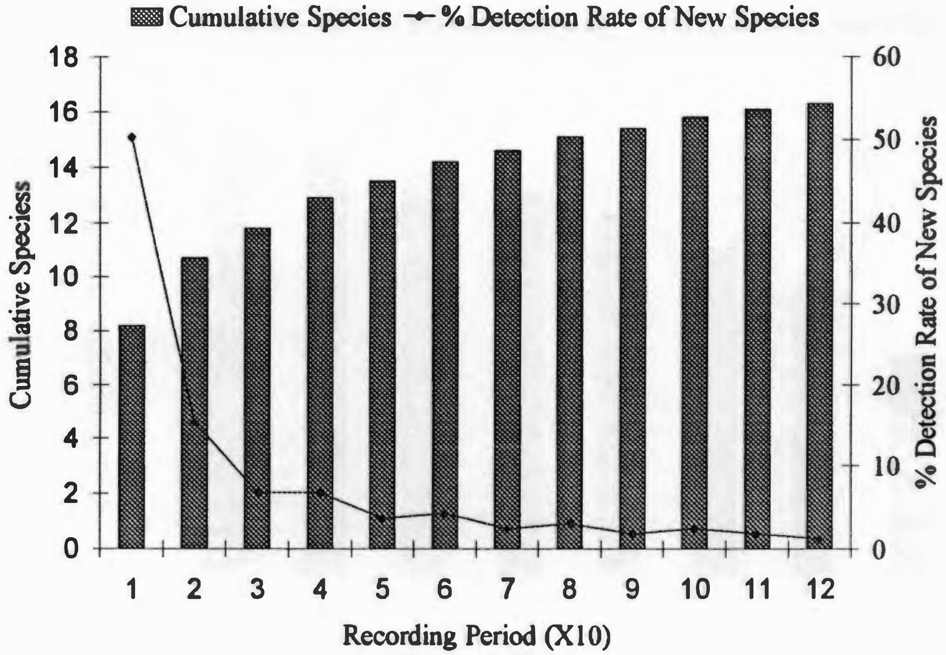


Figure 4-5. Cumulative species curve and percent detection rate of new species of 2-hour recordings as functions of increasing 10-minute recording intervals to monitor avian species in mixed hardwood forest at Cherokee National Forest, Tellico District, Tennessee, June-July 2002.

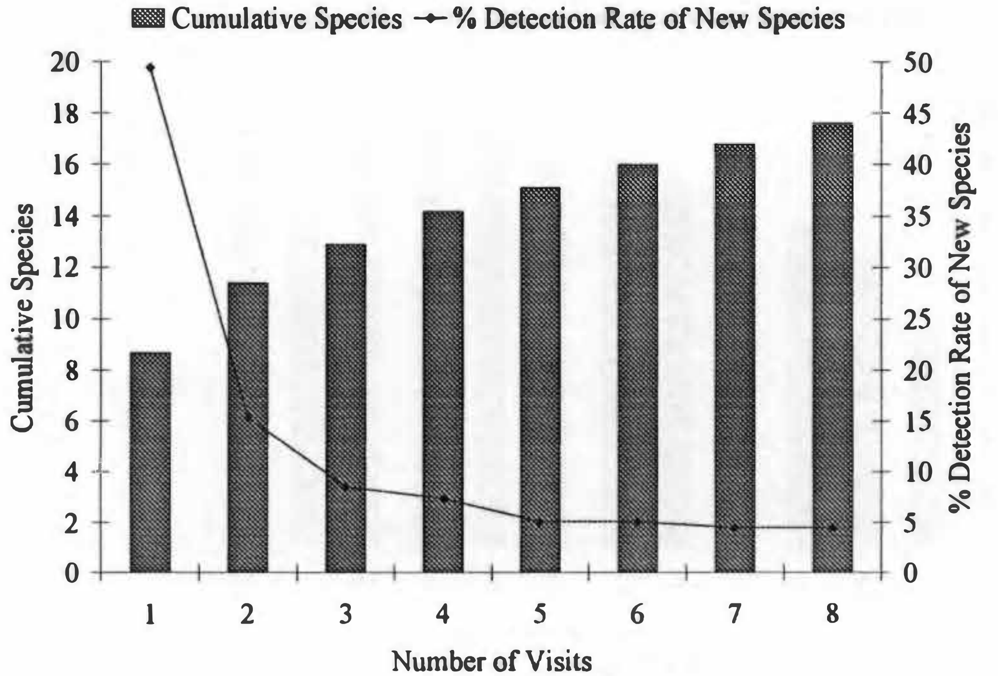


Figure 4-6. Cumulative species and percent detection rate of new species as functions of increasing number of 10-minute visits to monitor avian species in mixed hardwood forest at Cherokee National Forest, Tellico District, Tennessee, June-July 2002.

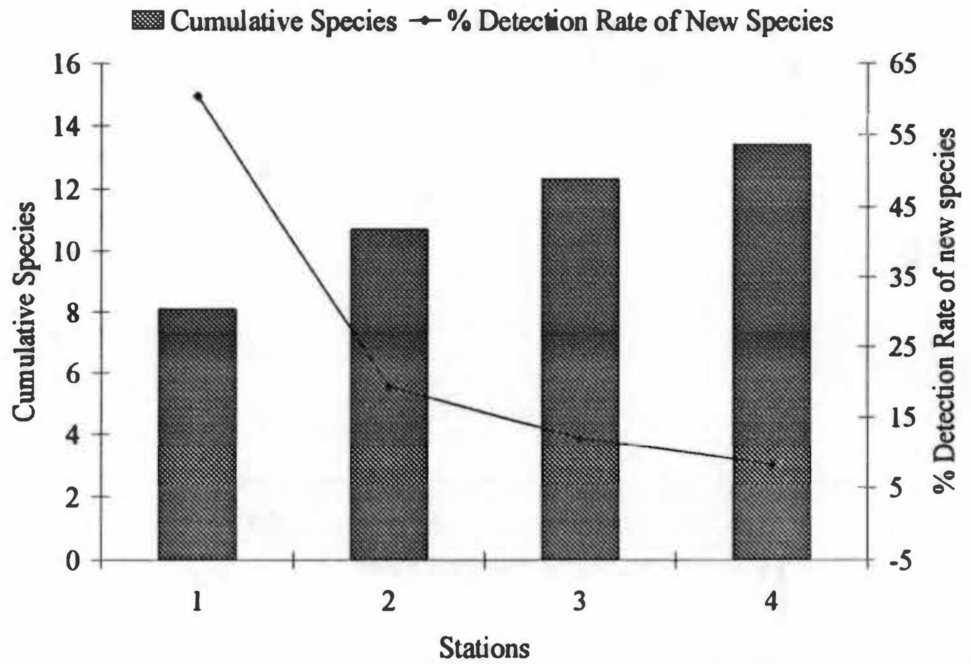


Figure 4-7. Cumulative species and percent detection rate of new species within 10-minute visits as functions of increasing number of stations to monitor avian species in mixed hardwood forest at Cherokee National Forest, Tellico District, Tennessee, June-July 2002.

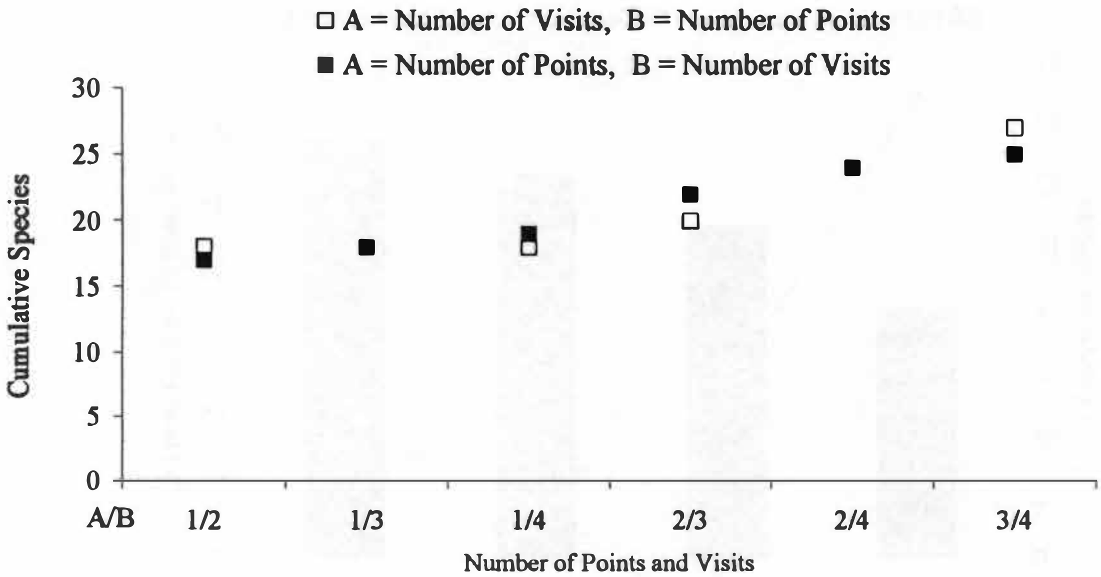


Figure 4-8. Cumulative number of avian species recorded between 6 possible paired reciprocals (e.g., 1 station-2 visits vs. 2 stations-1 visit) of number of stations visited and number of visits to each station in mixed hardwood forest at Cherokee National Forest, Tellico District, Tennessee, June-July 2002.

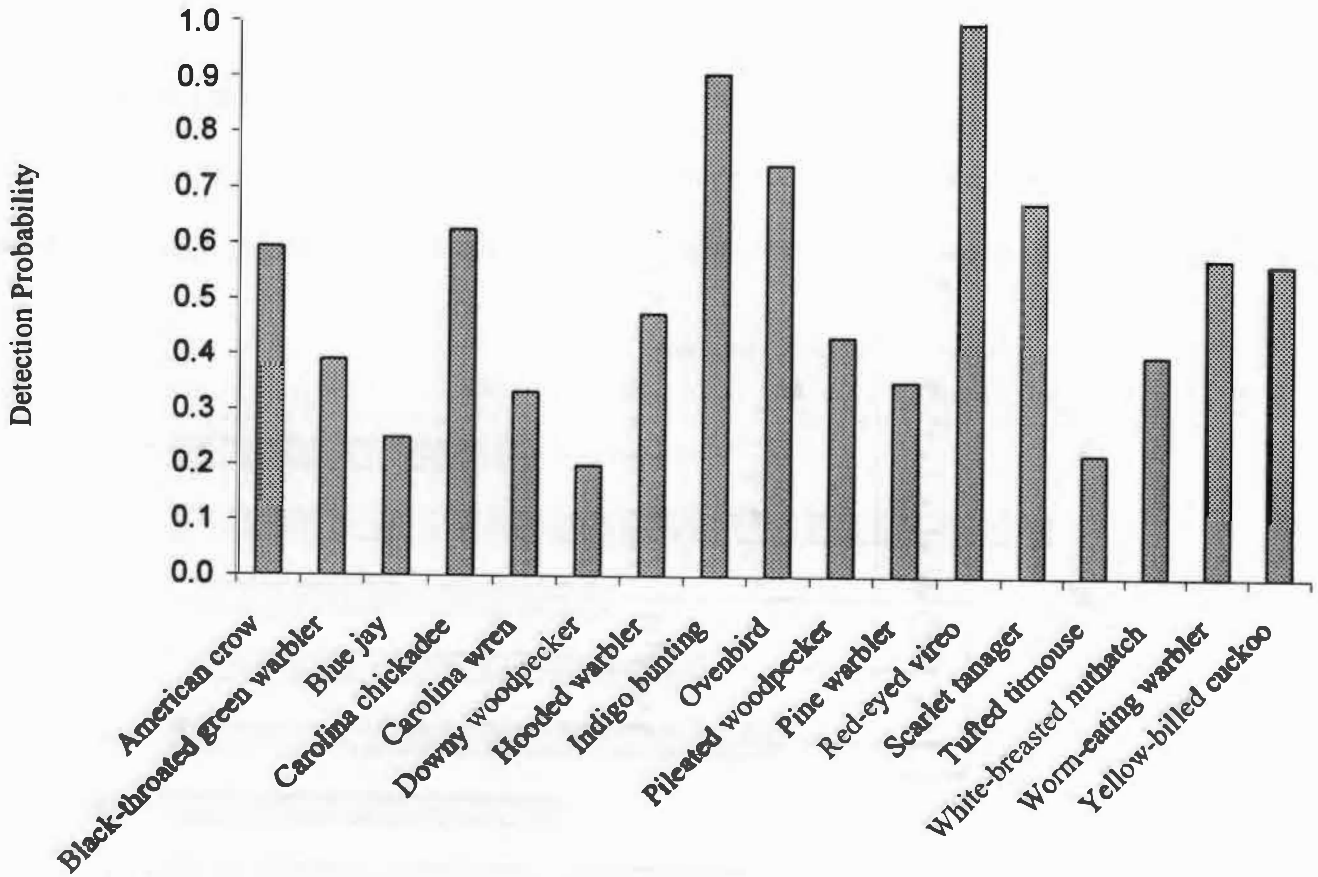


Figure 4-9. Detection probability of avian 17 species (in alphabetic order) within the first 10-minute acoustic recordings in mixed hardwood forest at Cherokee National Forest, Tellico District, June-July 2002.

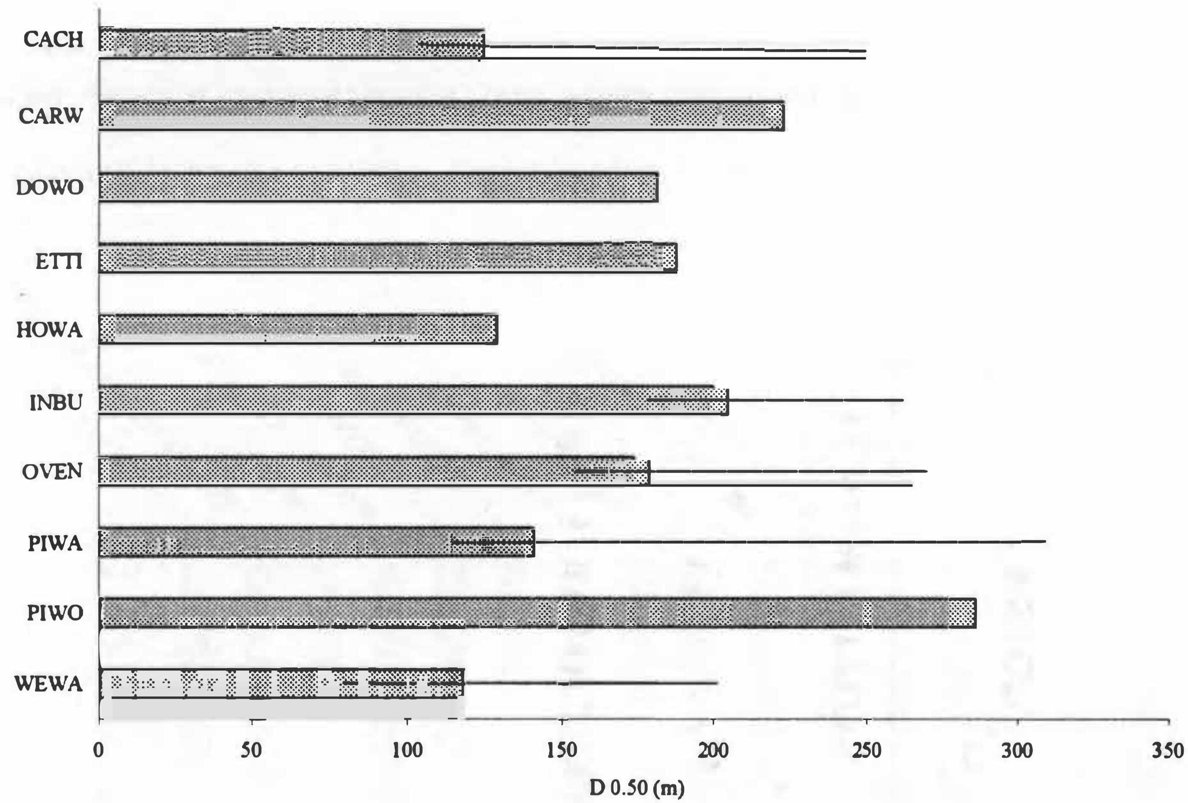


Figure 4-10. Distance, $D_{0.50}$ (m), where one-half of vocalizations of a given species are audible with $P = 0.50$ of 12 species in mixed hardwood forest, Cherokee National Forest, Tellico District. Confidence interval (95%) is indicated by the solid line (See species code in Table 4-1).

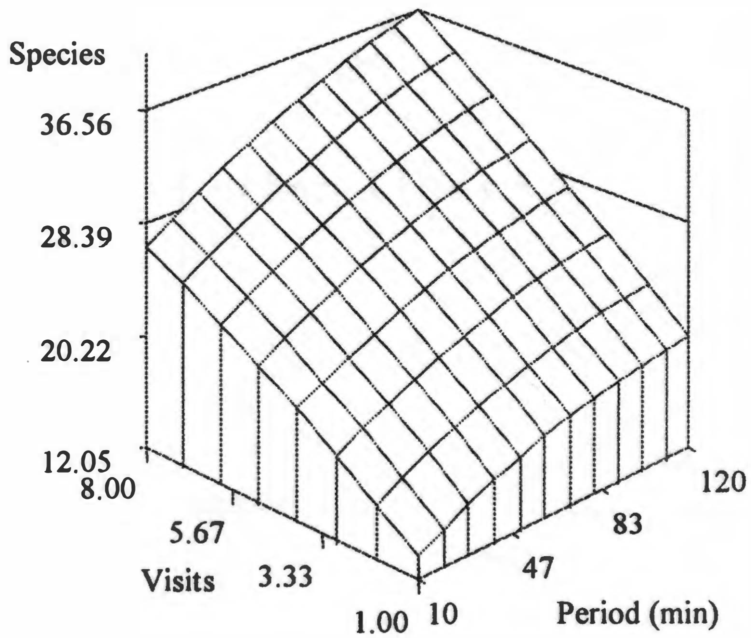


Figure 4-11 (1). Number of avian species detected as a function of number of visits and recording period in mixed hardwood forest at Cherokee National Forest, Tellico District, Tennessee, June–July 2002.

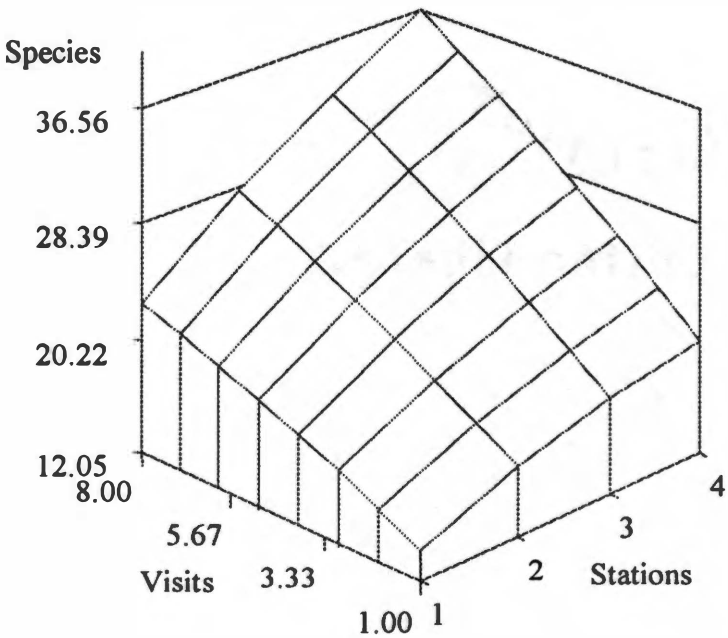


Figure 4-11 (2). Number of avian species detected as a function of number of visits and number of stations in mixed hardwood forest habitat at Cherokee National Forest, Tellico District, Tennessee, June–July 2002.

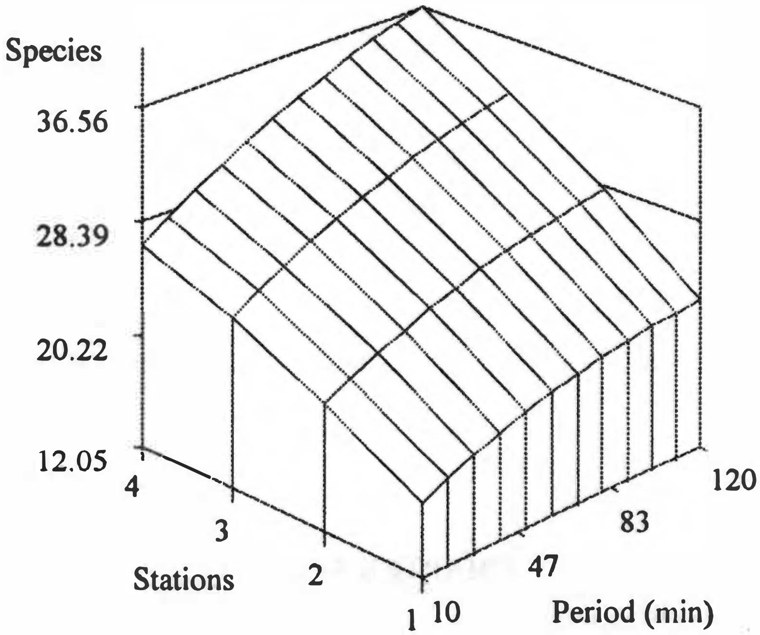


Figure 4-11 (3). Number of avian species detected as a function of number of stations and recording period in mixed hardwood forest at Cherokee National Forest, Tellico District, Tennessee, June–July 2002.

CHAPTER 5

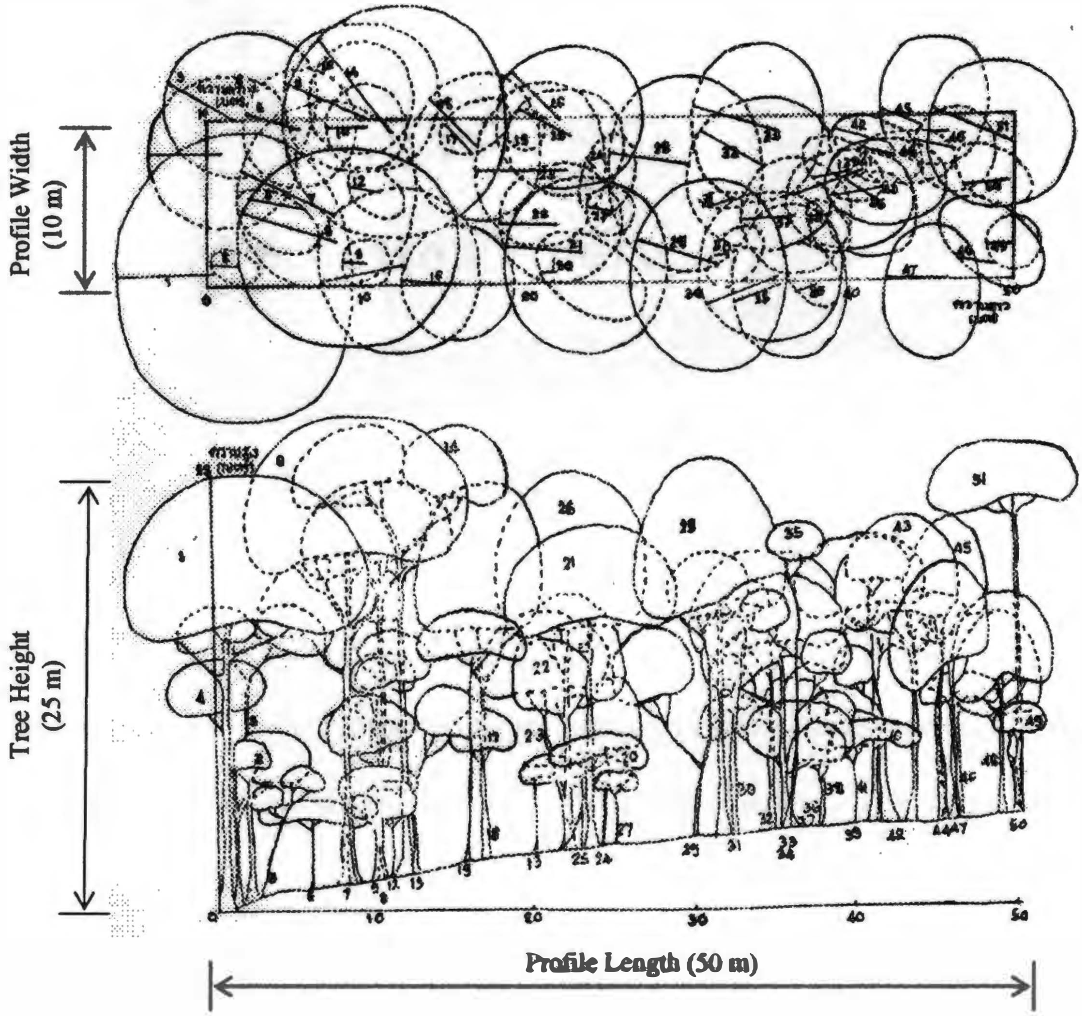


Figure 5-1. Forest structure profile (50 m x 10 m) in hill evergreen forest drawn by Atchara Teerawatananon and Sarawood Sungkaew during the study at Phu Luang Wildlife Sanctuary, Loei province, Thailand, March 2002.

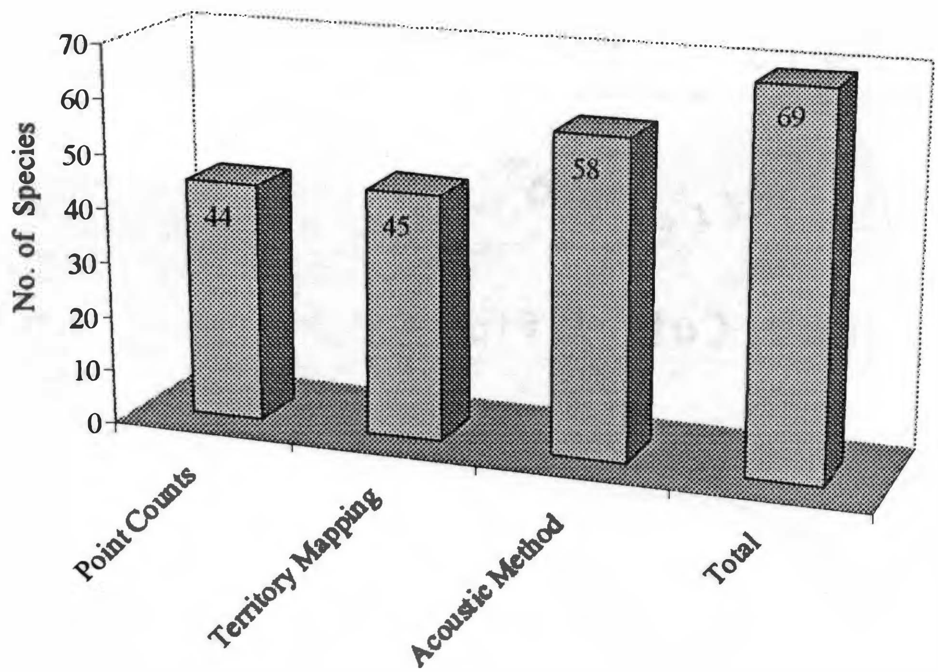


Figure 5-2. Avian species richness based on unlimited-distance point counts, territory mapping, and acoustic method in hill evergreen forest at Phu Luang Wildlife Sanctuary, Loei province, Thailand, March 2002.

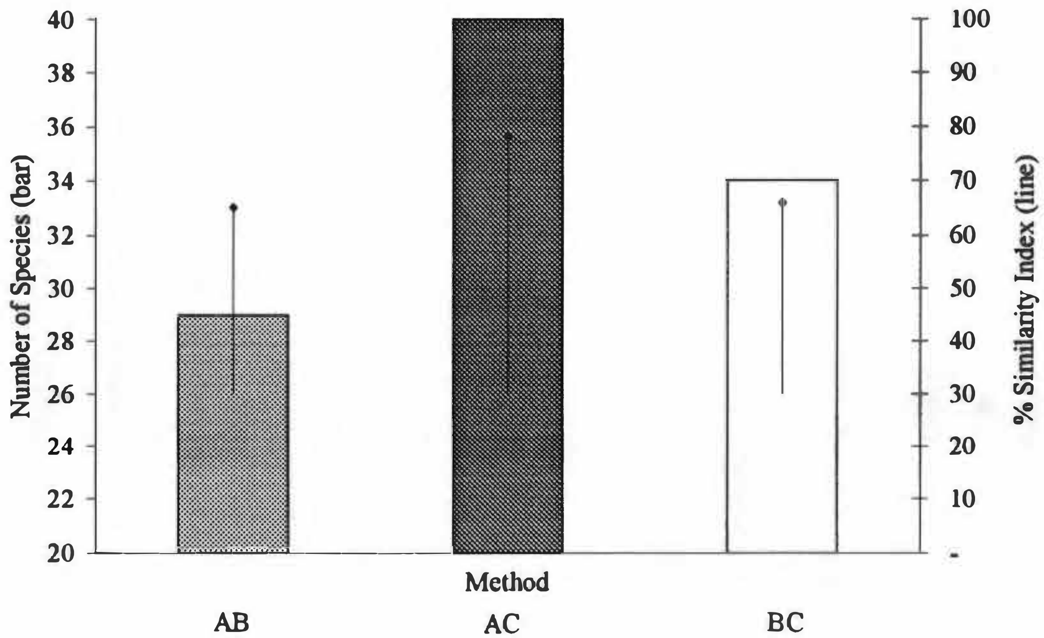


Figure 5-3. Number and percent similarity in species among avian monitoring methods: A) Unlimited-distance point count; B) Territory mapping; C) Acoustic monitoring in hill evergreen forest at Phuluang Wildlife Sanctuary, Loei province, Thailand, March 2002.

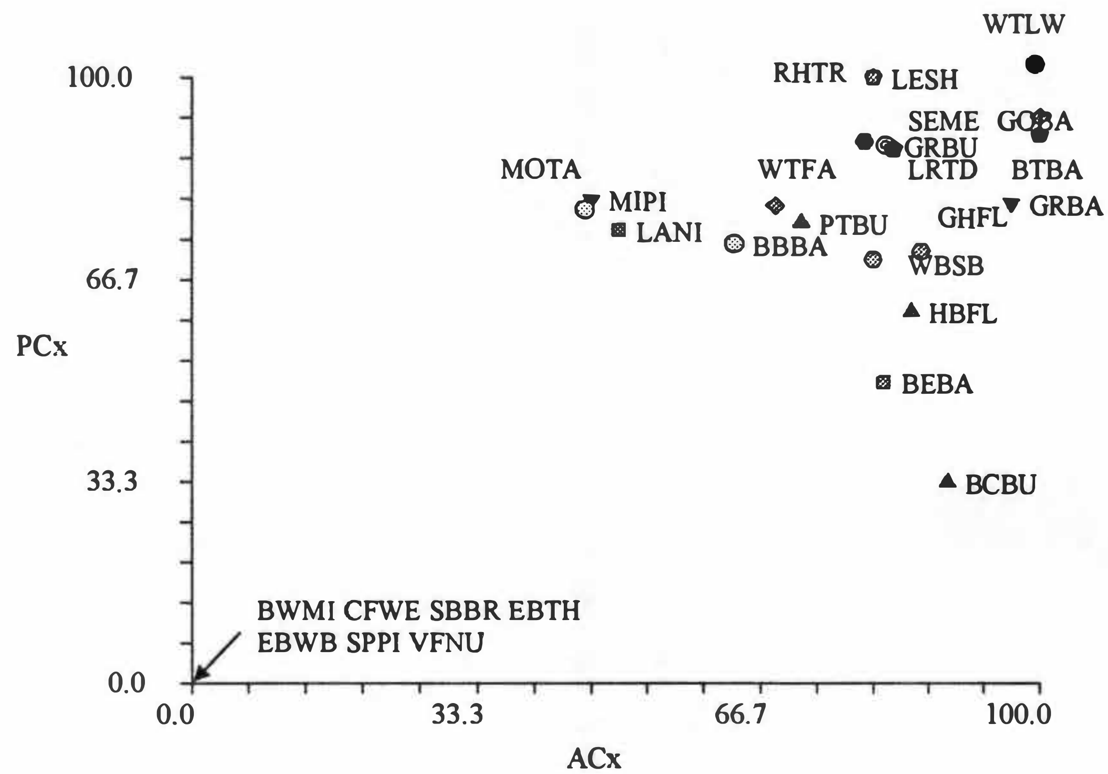


Figure 5-4. Scatter plot of % of avian species detected by unlimited-distance point counts (PCx) and % of avian species detected by acoustic method (ACx) in hill evergreen forest at Phuluang Wildlife Sanctuary, Loei province, Thailand, March 2002. Species with < 10 observations were not included in the analysis. Seven species missed by these 2 methods but detected by territory mapping are shown at the coordinate 0, 0.

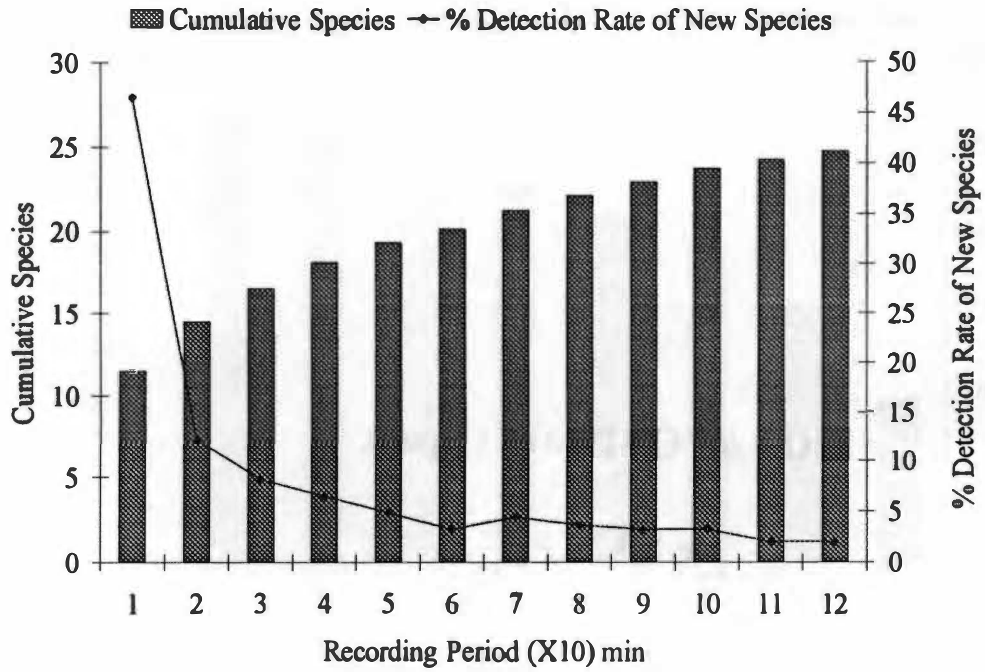


Figure 5-5. Cumulative species and percent detection rate of new species of 2-hour recordings as functions of increasing 10-minute recording intervals to monitor avian species in hill evergreen forest at Phu Luang Wildlife Sanctuary, Loei province, Thailand, March 2002.

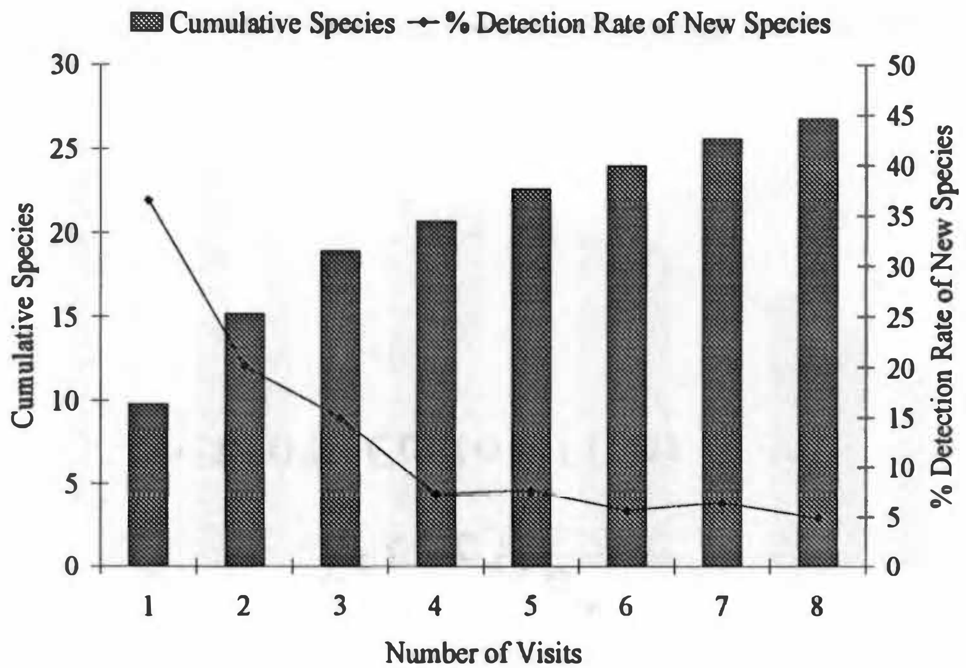


Figure 5-6. Cumulative species and percent detection rate of new species as functions of increasing number of 10-minute visits to monitor avian species in hill evergreen forest at Phu Luang Wildlife Sanctuary, Loei province, Thailand, March 2002.

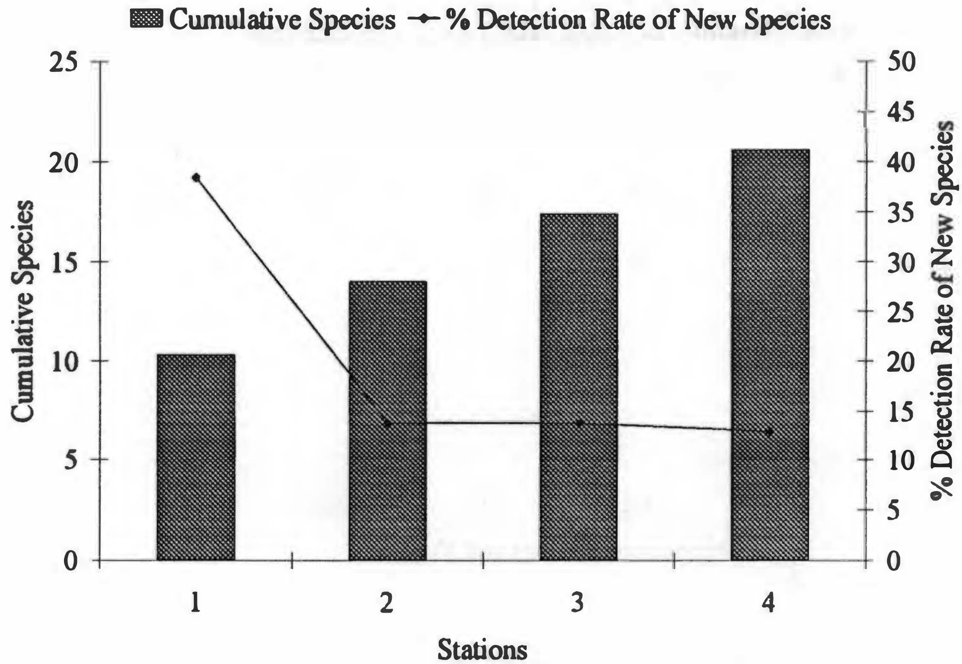


Figure 5-7. Cumulative species and percent detection rate of new species within 10-minute visits as functions of increasing number of stations to monitor avian species in hill evergreen forest at Phu Luang Wildlife Sanctuary, Loei province, Thailand, March 2002.

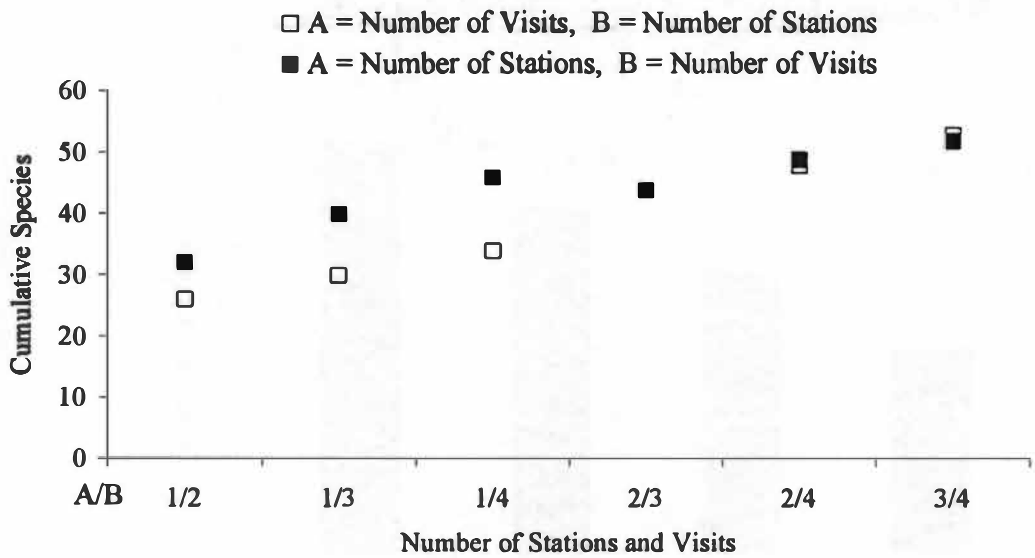


Figure 5-8. Cumulative number of avian species recorded between 6 possible paired reciprocals (e.g., 1 station-2 visits vs. 2 stations-1 visit) of number of stations visited and number of visits to each station in hill evergreen forest at Phu Luang Wildlife Sanctuary, Loei province, Thailand, March 2002.

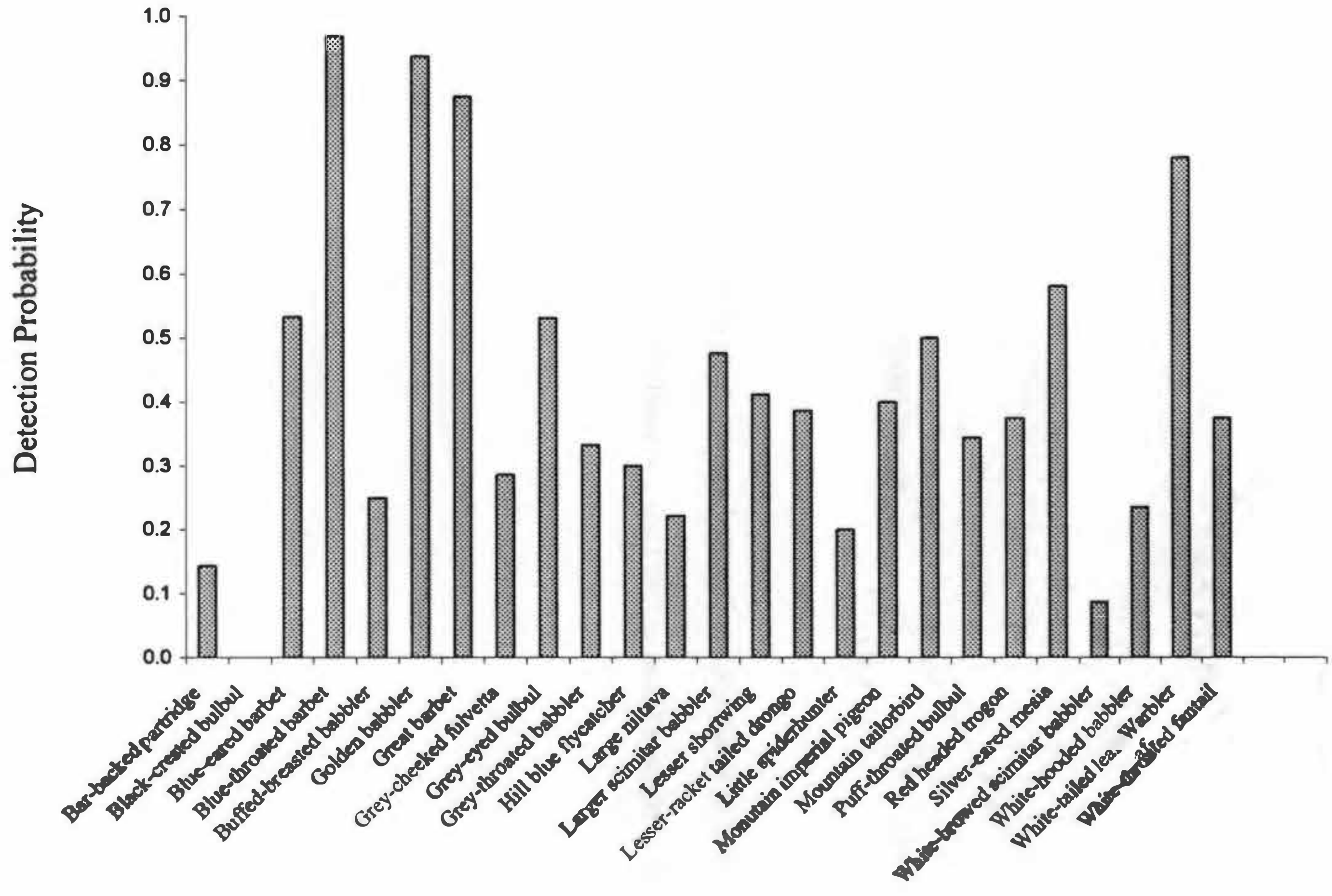


Figure 5-9. Detection probability of 25 avian species (in alphabetic order) within the first 10-minute acoustic recordings in hill evergreen forest at Phu Luang Wildlife Sanctuary, Loei province, Thailand, March 2002.

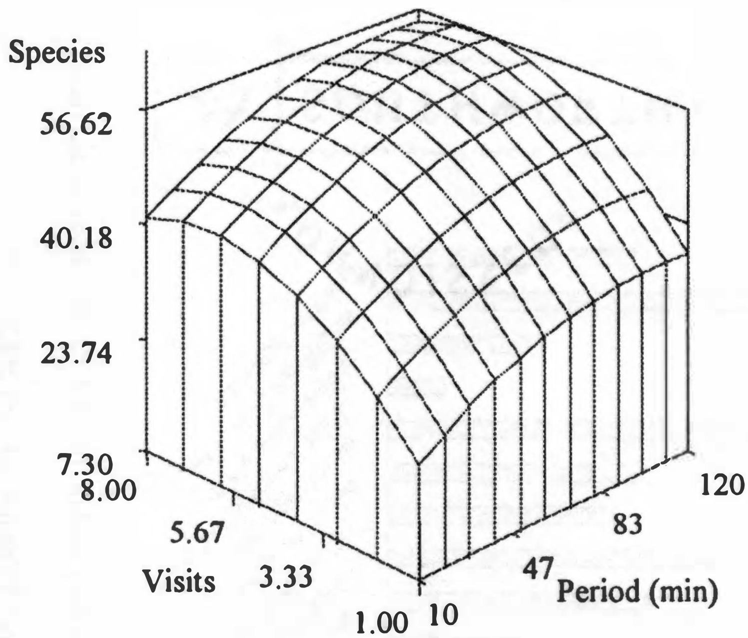


Figure 5-10 (1). Number of avian species detected as a function of number of visits and recording period in hill evergreen forest at Phu Luang Wildlife Sanctuary, Loei province, Thailand, March 2002.

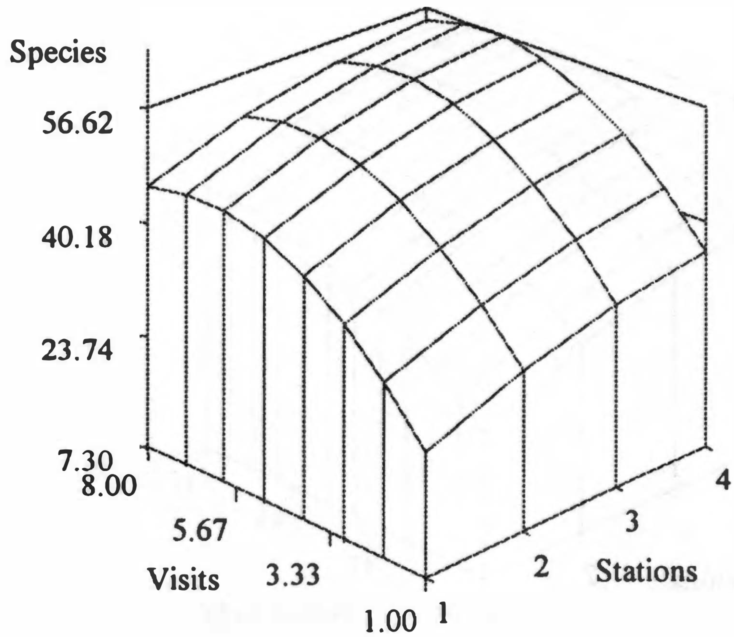


Figure 5-10 (2). Number of avian species detected as a function of number of visits and number of stations in hill evergreen forest at Phu Luang Wildlife Sanctuary, Loei province, Thailand, March 2002.

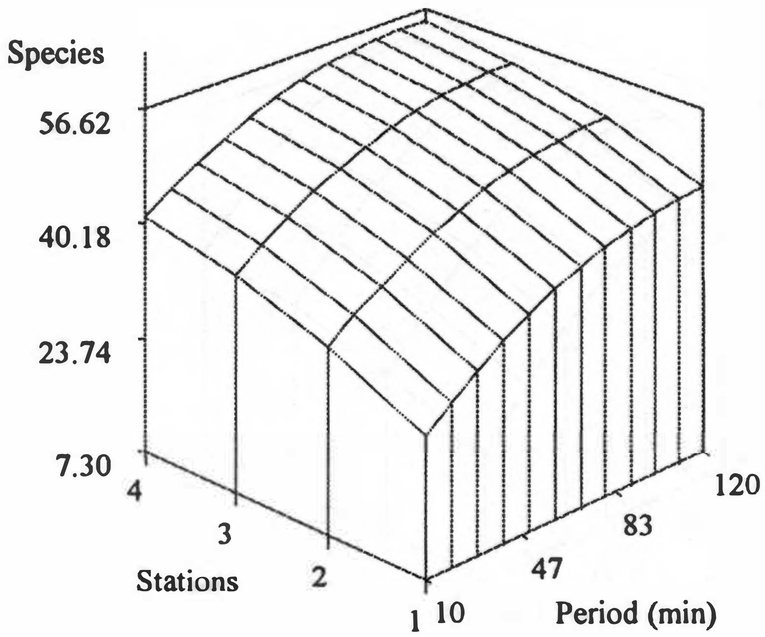


Figure 5-10 (3). Number of avian species detected as a function of number of stations and recording period in hill evergreen forest at Phu Luang Wildlife Sanctuary, Loei province, Thailand, March 2002.

CHAPTER 6

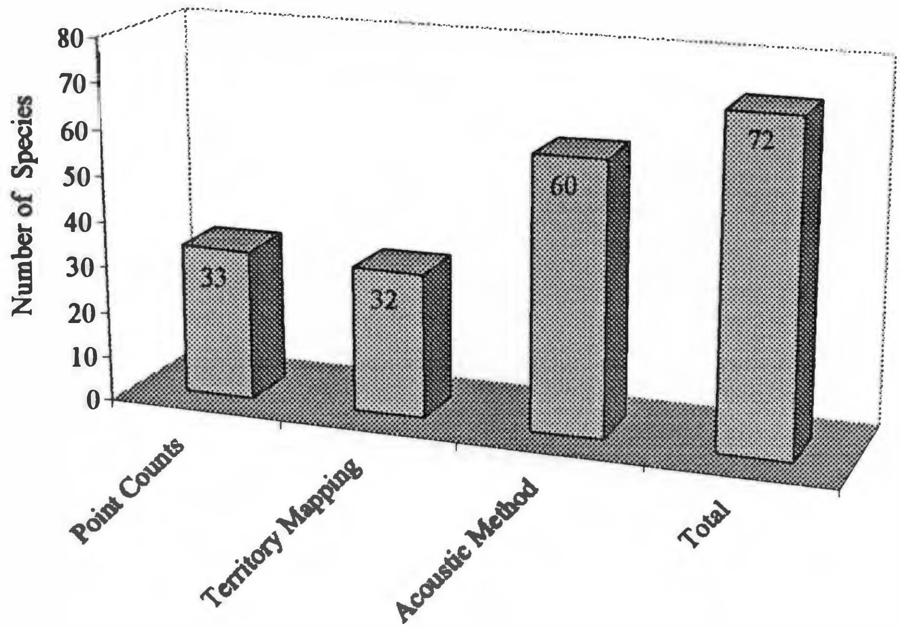


Figure 6-1. Avian species richness based on unlimited-distance point counts, territory mapping, and acoustic method in grassland habitat at KhaoYai National Park, Thailand, April 2002.

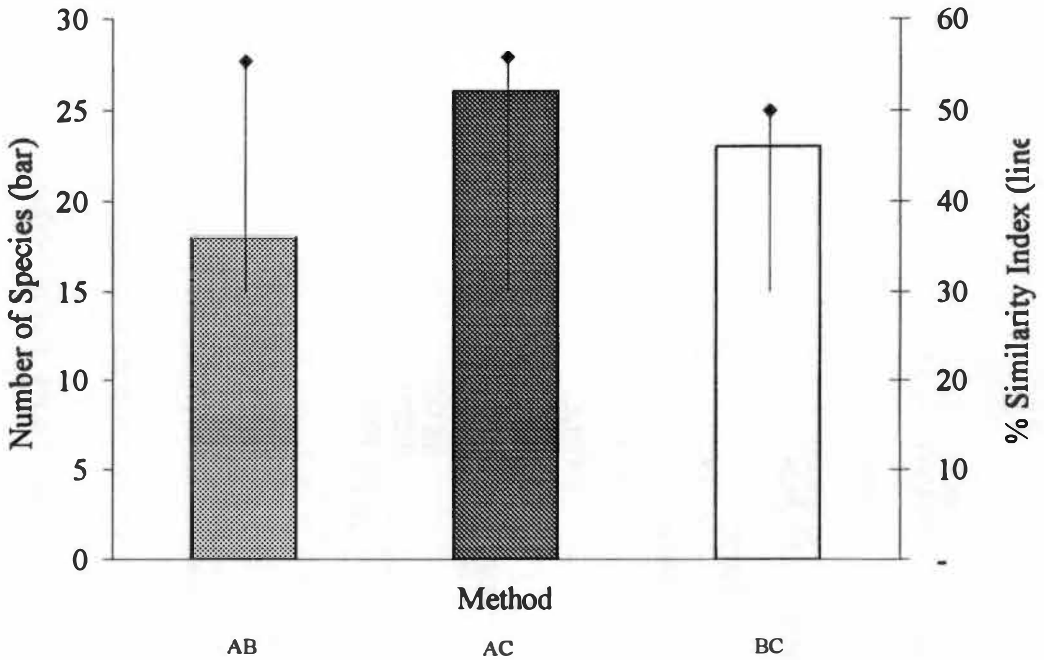


Figure 6-2. Number and percent similarity in species among avian monitoring methods: A) Unlimited-distance point count; B) Territory mapping; C) Acoustic monitoring in grassland habitat at KhaoYai National Park, Thailand, April 2002.

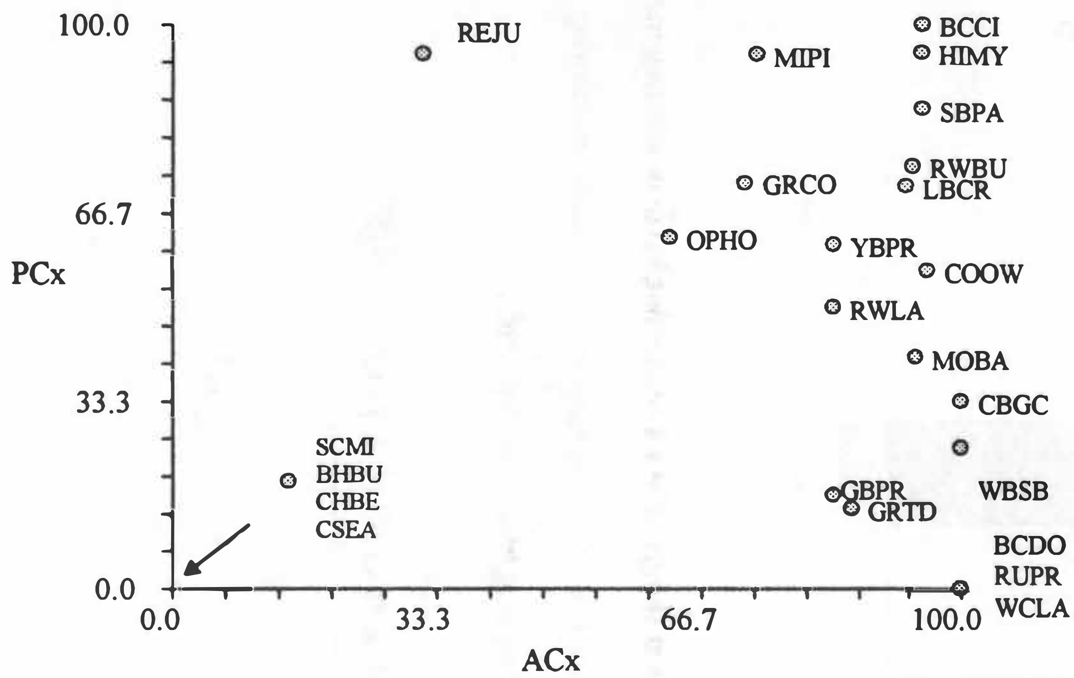


Figure 6-3. Scatter plot of % of avian species detected by unlimited-distance point counts (PCx) and % of avian species detected by acoustic method (ACx) in tropical grassland habitat at Khao Yai National Park, Thailand, April 2002. Detected species with < 5 records were not included in the analysis. Four species missed by these 2 methods were shown at the coordinate 0, 0.

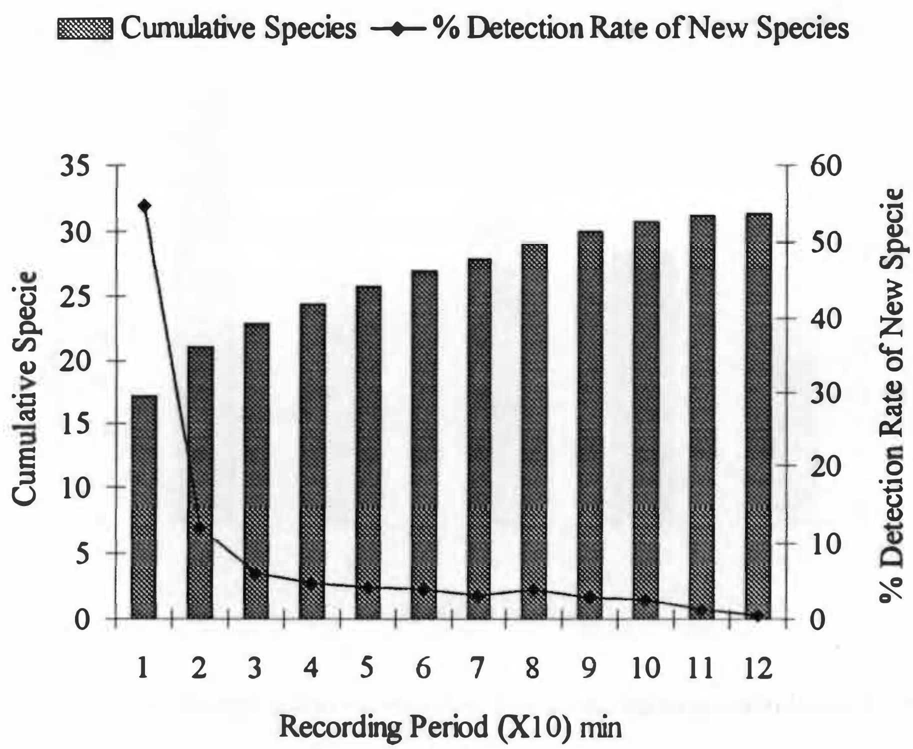


Figure 6-4. Cumulative species curve and percent coverage of 2-hour recordings as functions of increasing 10-minute recording intervals to monitor avian species in grassland habitat at KhaoYai National Park, Thailand, April 2002.

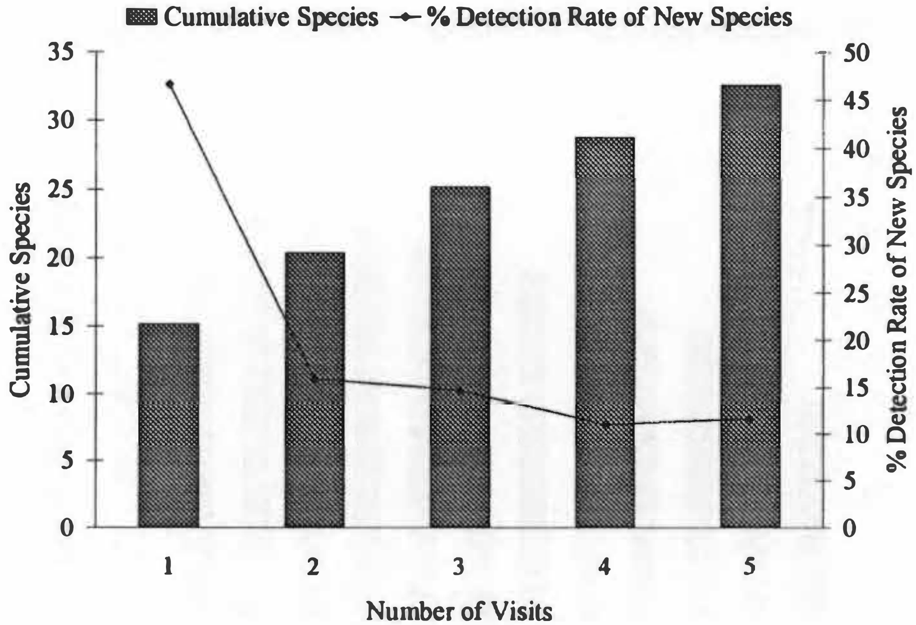


Figure 6-5. Cumulative species curve and percent detection rateof new species of functions of increasing number of 10-minute visits to monitor avian species in grassland habitat at KhaoYai National Park, Thailand, April 2002.

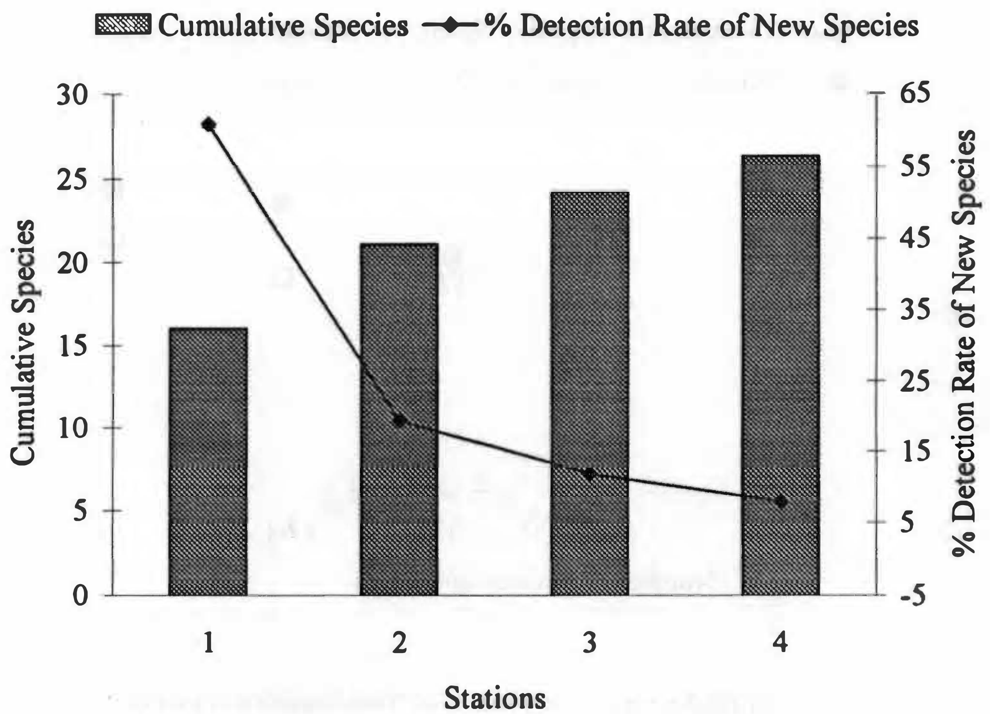


Figure 6-6. Cumulative species and percent detection rate of new species within 10-minute visits as functions of increasing number of stations to monitor avian species in grassland habitat at KhaoYai National Park, Thailand, April 2002.

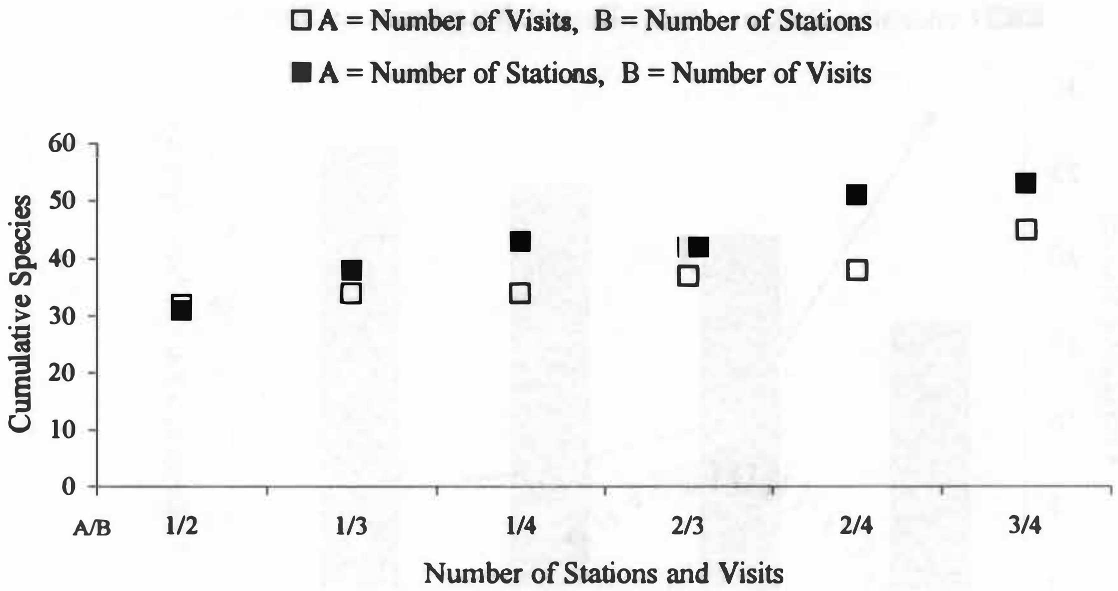


Figure 6-7. Cumulative number of avian species recorded between 6 possible paired reciprocals (e.g., 1 station-2 visits vs. 2 stations-1 visit) of number of stations visited and number of visits to each station in grassland habitat at KhaoYai National Park, Thailand, April 2002.

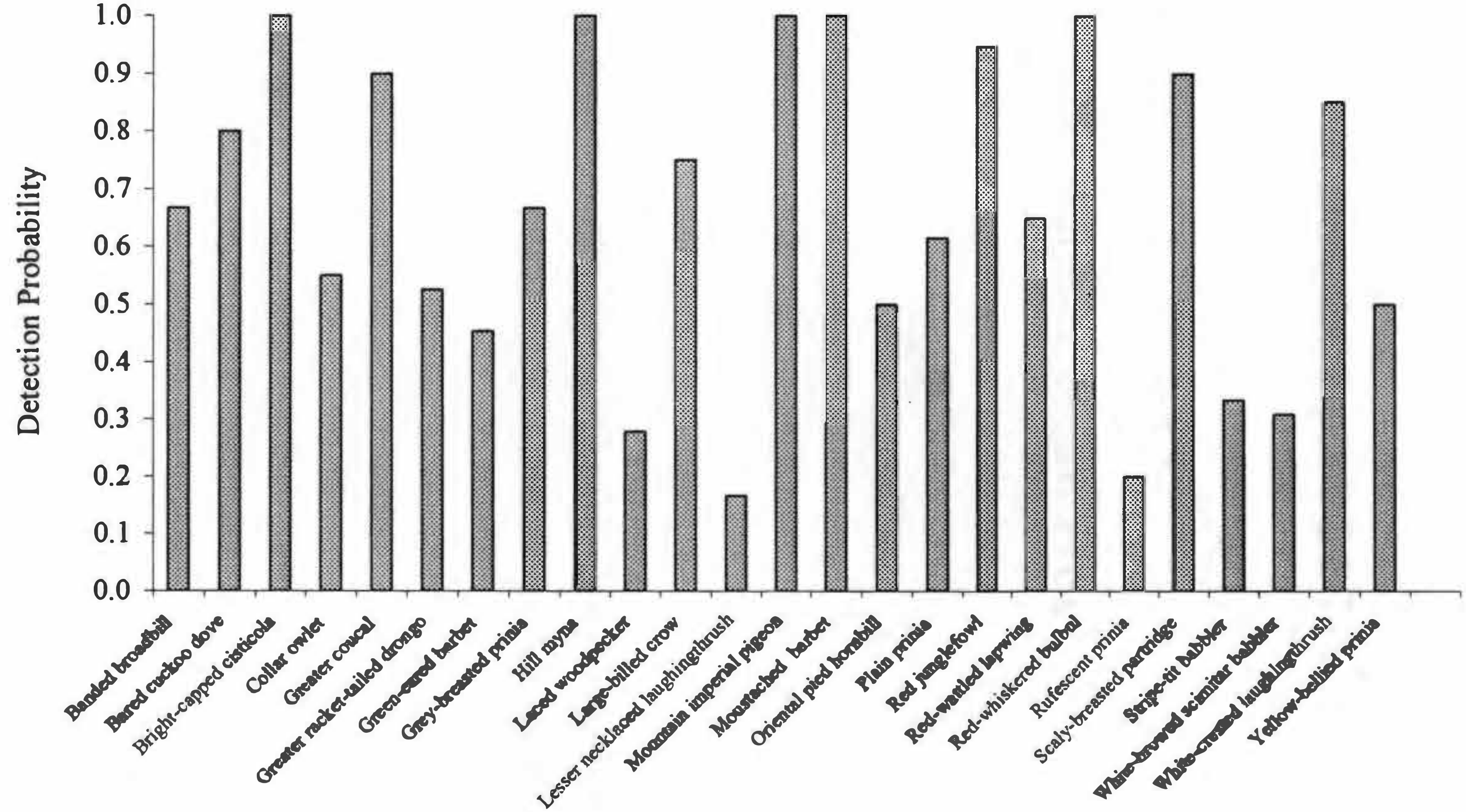


Figure 6-8. Detection probability of avian 25 species (ordered in alphabatic order) within the first 10-minute acoustic recordings in grassland habitat at KhaoYai National Park, Thailand, April 2002.

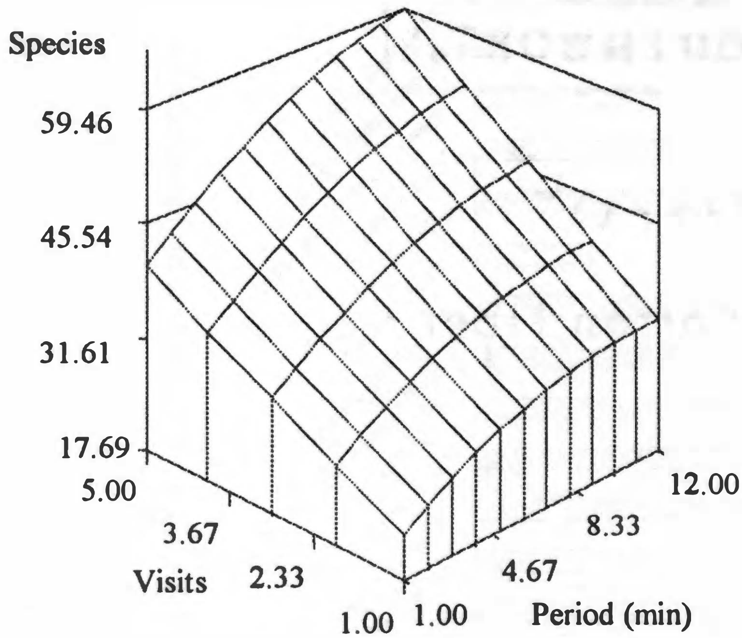


Figure 6-9 (1). Number of avian species detected as a function of number of visits and recording periods in grassland habitat at Khao Yai National Park, Thailand, April 2002.

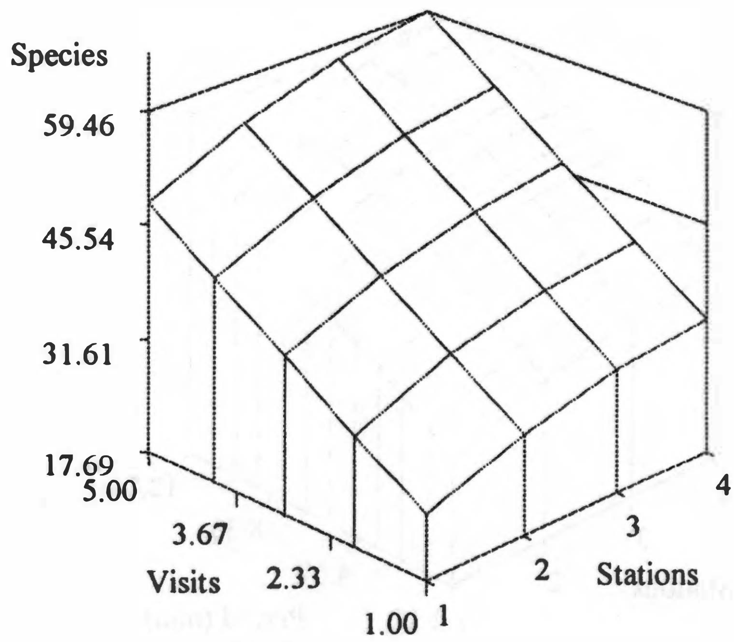


Figure 6-9 (2). Number of avian species detected as a function of number of visits and number of stations in grassland habitat at Khao Yai National Park, Thailand, April 2002.

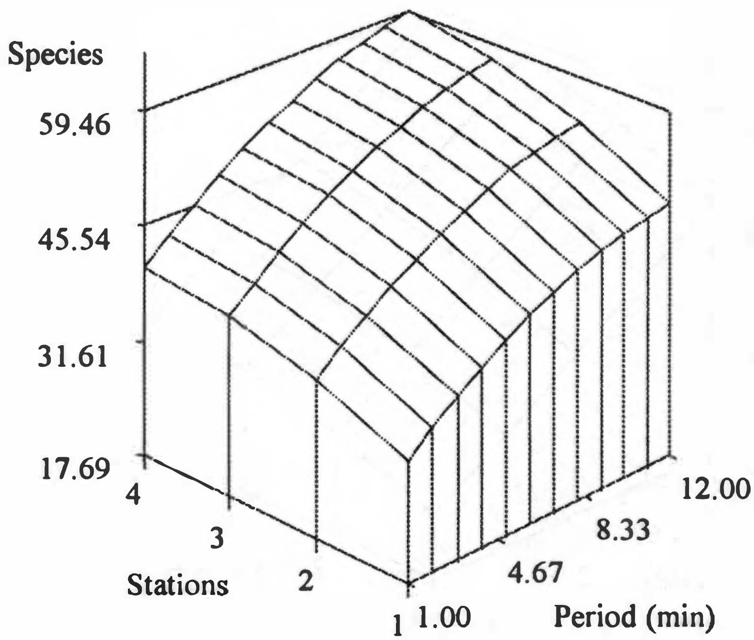


Figure 6-9 (3). Number of avian species detected as a function of number of stations and recording period in grassland habitat at Khao Yai National Park, Thailand, April 2002.

CHAPTER 7

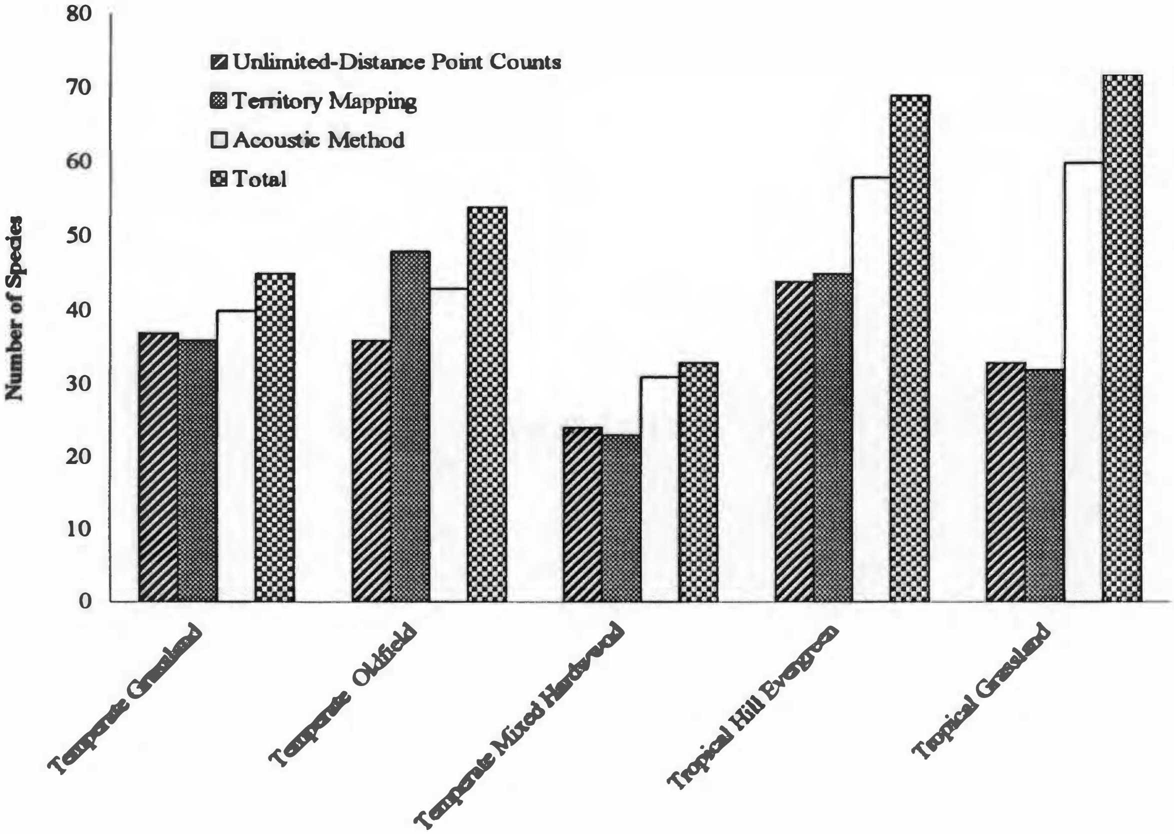


Figure 7-1. Number of avian species detected among 3 monitoring methods in 5 different habitats.

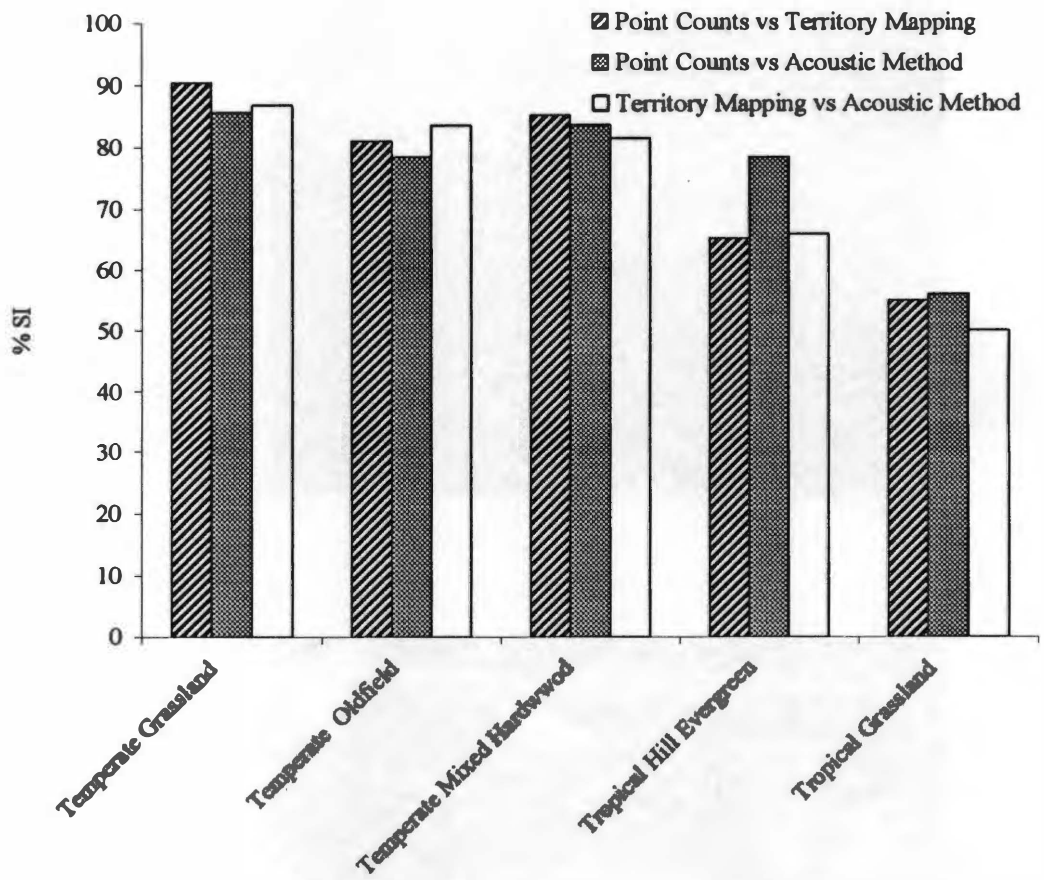
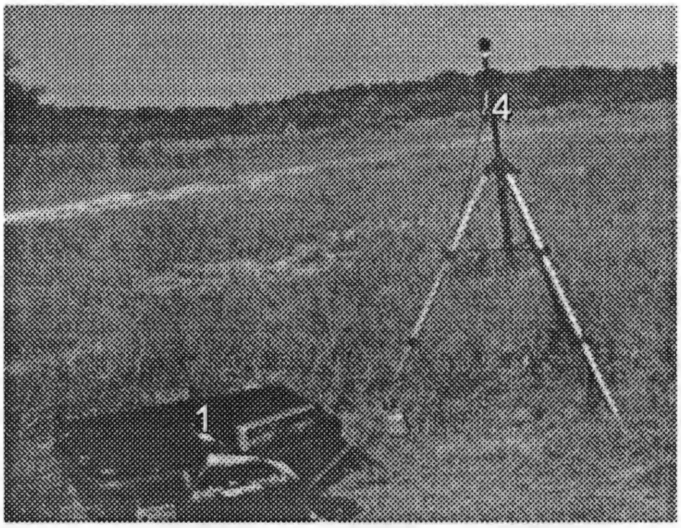
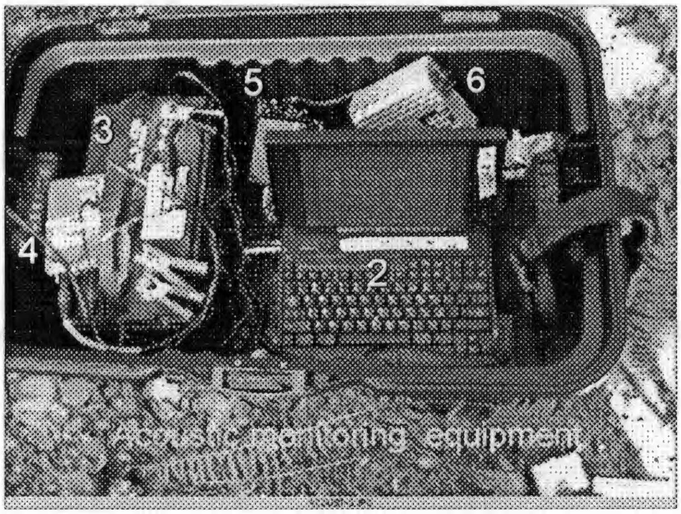


Figure 7-2. Percent similarity index (SI) of avian species among 3 monitoring methods in 5 different habitats.



(A)



(B)

Figure 7-3. (A) The acoustic monitoring system was designed and constructed in 2000 based on discussions with personnel at the Cornell Lab of Ornithology. (B) Videocassette recorder (1) was replaced by IBM Pentium I laptop (2) in 2002. Twelve-volt marine battery (3) was used to power all equipment [laptop, microphone with phantom power (4), amplifier (5)] by using power converter (6).

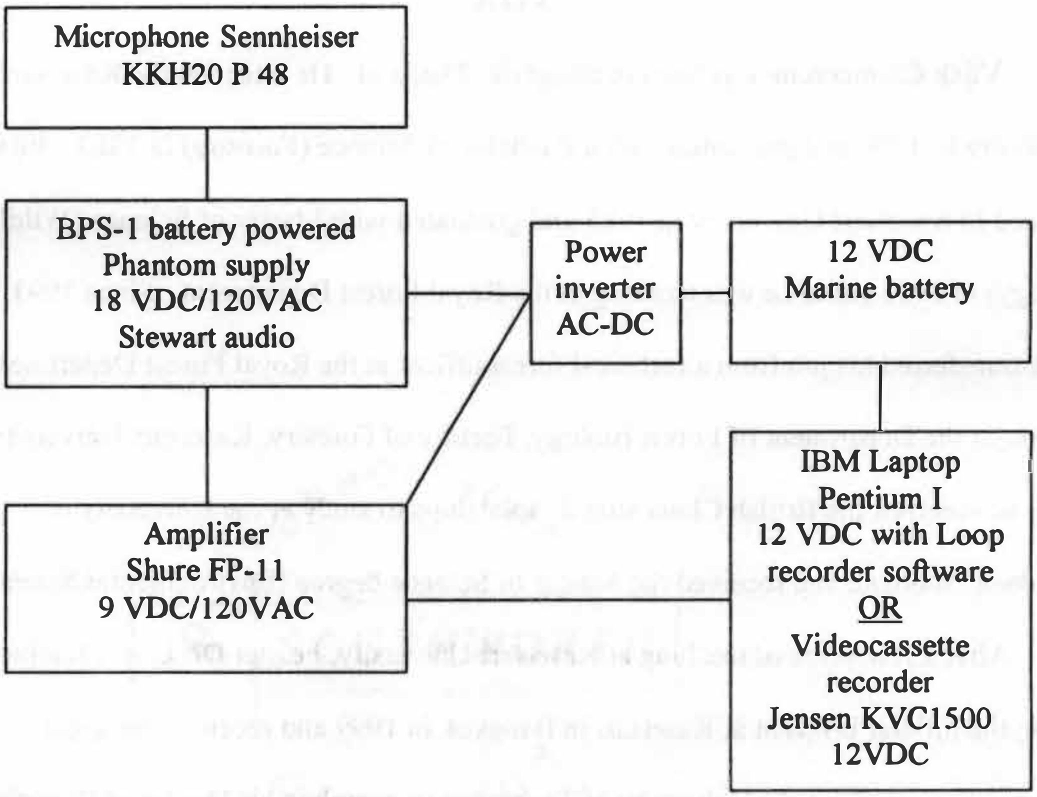


Figure 7-4. Diagram of recording device setup for acoustic monitoring system.

VITA

Vijak Chimchome was born in Bangkok, Thailand. He attended the Kasetsart University in 1979 and graduated with a Bachelor of Science (Forestry) in 1983. Vijak returned to Kasetsart University in 1985 and graduated with Master of Science (Wildlife Biology) in 1991 while he was working at the Royal Forest Department. Since 1993, Vijak transferred his job from a technical forest officer at the Royal Forest Department to a lecturer at the Department of Forest Biology, Faculty of Forestry, Kasetsart University. In 1995, he received the British Chevening Scholarships to study at the University of Aberdeen, Scotland and received the Master of Science degree (Environmental Science) in 1996. After a few years of teaching at Kasetsart University, he met Dr. David Buehler during the official UT visit at Kasetsart in Bangkok in 1999 and received the great opportunity to study at the University of Tennessee to complete his Doctor of Philosophy degree in wildlife Science. Vijak would like to resume his responsibilities in teaching and research and bring back knowledge and experiences to Thai students and Thai people including, government and non-government organizations, with an emphasis on developing more understanding of wildlife biology, ecology and better management practices in Thailand and neighboring countries.