Dr. Keith A. Hobson
Canadian Wildlife Service
115 Perimeter Road
Saskatoon, SK
S7N 0X4
306-975-4102 (office)
306-975-4089 (fax)
Keith.Hobson@ec.gc.ca

Acoustic surveys of birds using electronic recordings: new potential from an omnidirectional microphone system

Keith A. Hobson, Canadian Wildlife Service, 115 Perimeter Road, Saskatoon, SK, Canada, S7N 0X4, Keith.Hobson@ec.gc.ca

Robert S. Rempel, Centre for Northern Forest Ecosystem Research, Ontario Ministry of Natural Resources, 955 Oliver Road, Thunder Bay, ON, Canada, P7B 5E1

Hamilton Greenwood[1], Integrated Resource Management Program, SIAST – Woodland Campus, Box 3003, Prince Albert, SK, Canada, S6V 6G1

Brian Turnbull[1], Integrated Resource Management Program, SIAST – Woodland Campus, Box 3003, Prince Albert, SK, Canada, S6V 6G1

Steven L. Van Wilgenburg, Canadian Wildlife Service, 115 Perimeter Road, Saskatoon, SK, Canada, S7N 0X4

1. Alternate address: River Forks Research Corporation, 2557 McDonald Avenue, Prince Albert, SK, Canada, S6V 2V8

***Abstract*:** Conventional acoustic surveys of avian communities require expert skills that are rare, particularly during the relatively short singing periods of most temperate North American species. We investigated the use of 2 newly developed omnidirectional microphones for field recordings of forest bird communities by comparing richness and abundance of species recorded by field experts and those inferred from simultaneous recordings and later analyzed by the same observers. For bird communities associated with the southern boreal mixedwoods of central Saskatchewan and western Ontario, the acoustic recording technique worked well. Similarity measures for both presence/absence and abundance data ranged from 83% to 97%. The acoustic recording technique, particularly when used in a stereo configuration, can be used to analyze species composition and relative abundance of forest bird communities. Moreover, this approach has numerous advantages including an archived record of point counts, the use of non-expert field staff to collect recordings, and the standardization of field data through time.

***Key words*:** acoustic surveys, forest birds, recording techniques

The survey of bird populations and distributions has involved a remarkably broad variety of techniques that reflect various research objectives, habitats, and species assemblages (reviewed by Ralph and Scott 1981, Bibby et al. 1992). To date, these techniques have typically involved the use of trained observers who rely on both visual and/or auditory cues to record individuals within defined areas during fixed time periods and usually include spot mapping, line transects, or point counts (Ralph and Scott 1981). Point counts in particular are a popular means of surveying birds for population monitoring as well as to understand their habitat associations at local and regional scales (Ralph et al. 1995) and are the basis for the North American Breeding Bird Survey (BBS). With an increasing concern for the effects of anthropogenic changes to landscapes on birds and other wildlife, there is increasing demand for individuals to perform point counts as part of conservation research or environmental impact assessments, particularly in the southern and central boreal forest of North America. This region hosts some of the highest densities of breeding birds on the continent (Smith 1993, Kirk et al. 1996, Cumming et al. 2001). A major portion of the landbase is dominated by forest management agreements or other resource industries (Cummings et al. 1994, Stelfox 1995). Conducting point counts in these areas requires individuals who can identify acoustically as many as 120 species. In our experience, this situation has created a demand for trained individuals that clearly exceeds supply. Because of this, we investigated the use of audio recordings for avian point counts. In particular, we used a newly developed omnidirectional microphone system with exceptional recording performance to see if this could adequately replace a trained observer in the field.

There are a number of potential advantages to using auditory recordings during point counts vs. a trained observer on site. One advantage is extended sampling efforts and increased opportunity to replicate monitoring activities. There is an extremely limited supply of trained observers, particularly for the relatively short breeding season in temperate forests (e.g., essentially the month of June in Canadian boreal forest for Neotropical migrants). The microphone approach does not require trained experts to make the recordings, only to interpret them. A second advantage is control for observer variability. Even among trained observers there can often be significant inter-observer variability based on skill, age, and hearing acuity (Cyr 1981, Raitt 1981, Sauer et al. 1994). The microphone approach would allow all the tapes to be interpreted by a single trained expert and would allow, if necessary, multiple experts to interpret the same tape. A third advantage is long-term quality control. There are practical difficulties associated with maintaining a fixed level of quality of surveys across years or decades, periods corresponding to those of interest for population monitoring studies (Faanes and Bystrak 1981, Sauer et al. 1994, Kendall et al. 1996). Advantages of using archived recordings is that they can be examined by a single trained individual following the breeding season who is not necessarily needed during that season. Such an archived copy could also be examined at any time by several experts, an issue of potential importance for applications to environmental impact assessments. Finally, there are significant cost considerations. We have determined that it costs up to $1,500 more per month to hire an expert in the field when such contracts are available compared with an untrained person who simply makes the recordings. Later interpretation of the recordings can be done following the field season when experts are less in demand and cheaper to hire, or by a single trained researcher conducting the scientific work (and not considered an additional cost).

The use of taped recordings at point counts in boreal forest was investigated previously by Telfer and Farr (1993) who used a directional microphone system. That study established the potential for recordings to monitor bird populations but was hampered by the fact that the trained observer can census in all directions compared to the much more limited scope of the directional microphone. Recently, an omnidirectional microphone with superior sound quality and range was developed by River Forks Research Corporation (Prince Albert, Saskatchewan). Our objectives were to evaluate several aspects of this new recording microphone, including range to which birds could be detected and the degree to which relative abundance of species could be estimated compared to a trained observer. For the purpose of this study, we have considered the number of uniquely identifiable individuals of a species detected per point count by either human observer in the field or from recordings made with the microphones.

Methods

Study Areas

Two independent field crews conducted our study at 2 locations. The first location was the boreal mixedwood forest of central Saskatchewan near the Prince Albert Model Forest at an approximate location of 53°31' N, 106°12' W (Kabzems et al. 1986). Forests in this region are dominated by white spruce (*Picea glauca*) and trembling aspen (*Populus tremuloides*), and to a lesser extent contain balsam poplar (*P. balsamifera*), jack pine (*Pinus banksiana*), white birch (*Betula papyrifera*), and black spruce (*Picea mariana*). Stands used in this study were either mature aspen-dominated softwoods or aspen-white spruce-dominated mixedwoods. The shrub layer in the study area was variable in density and composition, with beaked hazelnut (*Corylus cornuta*), green alder (*Alnus viridis crispa*), red-osier dogwood (*Cornus stolonifera*), trembling aspen, and white spruce saplings being the most common species. The second location was also boreal mixedwood forest located in northwestern Ontario (48^{o}50' N, 89^{o} 15'W). The sample plots in this region were dominated by black spruce and trembling aspen, and to a lesser extent jack pine, white birch, balsam fir, and white spruce. The shrub layer was also variable in density and composition, with most sites containing green or speckled alder (*A. incana rugosa*), and to a lesser extent beaked hazel and mountain maple (*Acer spicatum*).

The microphone

The microphone was developed by River Forks Research Corporation by creating a new technology that combines the acoustic properties of a pressure zone microphone and an acoustic transformer. Sensitivity is increased by sound being reflected from a hard surface, creating a zone of increased sound pressure. The microphone also acts as an acoustic transformer by having sound enter a large aperture and then compressing it into a smaller area, increasing sound pressure and thereby gain. Both techniques amplify sound mechanically, and thereby avoid distortions due to electronic amplification. The CVX microphones have been configured in a variety of ways. In our Saskatchewan study area, we used a single omnidirectional microphone (the CVX-360) as a monaural pick-up (Figure 1a). In contrast, the system used in our northern Ontario study area incorporated a pair of directional microphones (CVX-180s) to achieve stereo separation of the acoustic signals (Figure 1b). The CVX-180s represent a modification of the CVX-360, so that each microphone collects sound over a 180° angle. In field configuration, the 2 microphones are aligned so that each is collecting from opposite directions. This effectively yields a signal from the full 360° radius, while maintaining many of the acoustic properties of the omnidirectional model but gaining stereo separation.

The CVX-360 omnidirectional microphone utilizes a sensitive microphone element that is placed parallel to a hard waterproof reflective surface, which is located within the throat of an open acoustic guide (Figure 2). Sound enters a relatively wide mouth and it is guided and compressed as the cross sectional surface area of the wave-guide decreases (Figure 2). This causes a progressively greater mechanical gain in sound energy or sound pressure levels as the sound wave approaches the microphone element at the center of the curvature. A similar acoustic guide was historically used as an ear horn for hearing-impaired patients in the late 19th century, but the closed nature of the early ear horns resulted in reflected sound and distortions of sound quality. One of the significant advances with this new technology is a solution to the problem of sound distortion. RFRC found that by placing the microphone element in an open chamber, parallel to the direction in which the sound waves are traveling, a pressure zone is created that lacks distortion due to the reflective patterns typical of a closed housing. The result of these combined effects is a microphone capable of recording sounds in all directions (i.e., omnidirectional), with virtually no sound distortion, and that exceeds the acoustic range (quietest to loudest detectable noises) of a 0.6 m parabolic microphone.

Power sources for the microphone system are flexible. During field work for this study, we used 24V phantom power supply in standard configuration. RFRC now supplies microphones with an 18V power supply (essentially a rechargeable motorcycle battery) or two 9V batteries. The 18V power supply can also be used to power an accompanying mini-disc or DAT recorder. The microphones are weather resistant to conditions beyond when a point count would normally be called off due to adverse weather and have been tested by RFRC for shock resistance in a 4 m drop test.

The microphone system can be easily handled by one individual in the field and weighs 2.83 kg without the tripod.

Response distance

To evaluate the effective recording distance, or "detectability" of forest songbirds, we conducted a controlled field experiment at our Saskatchewan study area. The acoustic gain or sensitivity of the CVX-360 is a function of the physical size of the acoustic guides with greater diameters being more sensitive than smaller diameters, and the electronic attenuation (reduction) of the sound levels received. We evaluated the sensitivity of the 28-cm microphone by replaying digital recordings of territorial calls or songs of Swainson's thrush (*Catharus ustulatus*), golden-crowned kinglet (*Regulus satrapa*), white-throated sparrow (*Zonotrichia albicollis*), black-and-white warbler (*Mniotilta varia*), and common (yellow-shafted) flicker (*Colaptes auratus*). We performed this experiment in a moderately dense trembling aspen /balsam poplar stand and a denser, more mature mixedwood or white spruce /trembling aspen stand. We also used a custom built stepped-attenuator to determine if we could effectively restrict the range of the radial pick-up of the CVX-360 to a particular habitat type and avian guild.

Study blocks were set-up along a 2-lane gravel road which bisected relatively uniform blocks of the boreal forest approximately 12 km west of MacDowall, Saskatchewan. The sound levels were adjusted to levels that were judged to be equivalent to normal calling volumes by 2 experienced birders and maintained by periodically checking the Sound Pressure Level (SPL) at source using an Audio Control Industrial Real-Time-Analysis meter (model SA-3050a). The CVX-360 microphones and recording units were established perpendicular to the transmitting signals at distances of 50, 100, and 150 m into the forest stand. Recordings were only made when wind speed was < 10 km/hr. The microphones were mounted on tripods at a height of 1 m and were connected to a custom built attenuator with 3 levels of attenuation. Level I was without attenuation. Level II (6 dB reduction) and III (10 dB reduction) had progressively greater levels of attenuation. At the 3 levels of attenuation, the calls of each species were recorded in both habitat types. A minimum of 2 territorial calls for each species were recorded at each distance. Mean level below tone was used in this analysis. These trials were conducted 25-29 September 1999 to minimize any chance of recording resident birds.

A built-in tone-generator was established in the attenuation equipment built for this experiment. The function of the tone-generator was to enable the researchers to measure a standard sound level against which the playback of avian territorial calls would be measured. This single frequency tone was always triggered and recorded immediately before the territorial call, and the sound levels are presented as the number of decibels (dB) “below-tone”, as measured through the acoustic software analysis tool Soundforge Version 4 (Sonic Foundry, Inc., Madison, WI).

Observer-instrument comparisons

We conducted comparisons between recordings made from the CVX system and those made simultaneously in the field by trained observers in both the Saskatchewan and Ontario study sites. In both study areas, the same observer who conducted the field trial was asked to later identify and enumerate birds from the simultaneous recording, and the 2 results were compared. The evaluation was a blind test, in that the recordings were numbered and reordered, so the observer would not know the location where the recording was made. This set of trials was conducted using both BBS roadside (3 min) and within-stand (10 min) point counts as described below. All within-stand point counts were conducted according to Indice Ponctuel d'Abondance (IPA) point count technique (Blondel et al. 1970). Within-stand point counts were 250 m apart. All trials were performed without attenuation on the microphone systems, hence an unlimited recording distance.

At our Saskatchewan study site, 4 within-stand point counts were conducted in boreal mixedwood forest by a single observer. Simultaneous recordings made using a single CVX-360 (monaural) microphone system were later analyzed by the same observer. This observer and recording system were also used to collect data from 18 (3 min) BBS-style point counts separated by a minimum of 400 m. Data from Saskatchewan were treated on a presence/absence basis, counting the number of stations at which a species was encountered in each of the field and recorded observations.

All data from our western Ontario study area were collected by a single observer. The same protocols for 10 min within-stand point counts as used in Saskatchewan were used at the Ontario study area, where 51 point counts were conducted. However, in Ontario, we used 2 CVX-180 microphones separated by < 1 m to produce a stereo recording, instead of the monaural recordings obtained in Saskatchewan. The stereo configuration used at this site allowed the observer to estimate the number of individuals of a given species at each point count, based on the direction the call came from (e.g., left vs. right) and any temporal separation between multiple calls. Data from Ontario were analyzed on both a presence/absence and abundance at each station basis.

Statistical analysis

Community similarity measures were obtained by comparing the overall species complement and abundance patterns between field- and recording-based observations. We used Quantan Software (Brower et al. 1997) to calculate several different community similarity indices. Indices differed in their relative emphasis of the importance of species complement vs. abundance. Species similarity measures were likewise obtained by comparing species abundance patterns between field- and recording-based observations. Differences in abundance estimates from field observations and simultaneous stereo recordings from 51 point counts in Ontario were evaluated for each of the 10 most abundant species using a 2-tailed Student's *t*-test for paired samples (df = 50 for all comparisons). A sequential Bonferroni correction for multiple comparisons was applied to the *t*-tests to avoid Type I errors due to performing the test for each of the 10 species (Rice 1989). An initial significance level of $p = 0.05$ was selected to assess statistical significance. The effect of habitat type on detectability of playback songs was tested by comparing "level below-tone" between habitat types using the Mann-Whitney U-test with the data pooled across species.

Results

Radial distance sensitivity

Our original objective for this element of the study was to establish the average distance to which the CVX would record bird songs, and to determine if a specific attenuation setting was appropriate for forest bird surveys. Similar to the human ear, at all

CVX attenuation settings, yellow-shafted flicker, Swainson's thrush, and white-throated sparrow were heard up to 150 m (Figure 3, levels beyond 150 m not shown). In contrast, the songs of golden-crowned kinglet and black-and-white warbler were especially difficult to discern with the human ear at 100-150 m under calm conditions in either stand type, and we were able to only obtain trace recordings with the CVX beyond 100 m.

The detectability of playback calls appeared to be little effected by habitat type (Figure 3). No significant differences were detected between habitats for any of the attenuation settings (Mann-Whitney U, $p > 0.05$). Furthermore, between aspen and mixedwood stands the calls of each species showed similar patterns of decline in "level below-tone" with distance (Figure 3). In general, calls or songs were more easily detected in mixedwood stands, but not significantly so.

Monaural point counts

Point counts conducted in the field according to BBS roadside protocols produced very similar results to those obtained using a later analysis of the simultaneous CVX recording (Table 1). We examined similarity between recordings and field data using several indices of similarity. For BBS data in Saskatchewan, similarity ranged from 85 to 96% (Table 2). For point counts conducted in the forest with longer durations we examined similarity based on the number of stations at which each species was detected (i.e., the actual encounters) and found good agreement (Table 3) with similarity indices ranging between 83 and 97% (Table 2). For both BBS data and within-stand point counts, fewer species were detected in the field by observers than by recordings (Tables 1 and 3).

Stereo point counts

Point counts conducted in Ontario using a stereo microphone configuration were examined according to number of stops where a species was encountered (presence/absence), and according to the total abundance of individuals across all point counts (i.e., the sum of the number of individuals detected at all point counts). Similarity measures for both encounter and abundance data ranged from 83 to 97% (Tables 2 and 3). For the 10 most abundant species examined, we found strong agreement between recordings and field data (Figure 4).

Abundance estimates between field observations and recordings were also similar, and none of the abundance estimates for the 10 most abundant species were statistically different using sequential Bonferroni corrections. If Bonferroni corrections were not used, only 3 species were significantly more abundant in field estimates than estimates from recordings (df = 50 for all tests; CSWA, $t = 2.58$; $p = 0.013$; SWTH, $t = 2.40$; $p = 0.020$; and VEER, $t = 2.54$; $p = 0.014$). Estimates of abundance were similar between field and recording for almost all species (Table 3), and no discernible trend in song/call pitch, frequency, or life history seem readily apparent for those species that differed.

Discussion

Our field trials using the CVX-360 omnidirectional microphone and digital recording equipment indicate that, for a number of survey objectives, this system provides a viable alternative to expert observer recording in the field. This approach to avian surveys may thus allow a significant increase in field coverage since it frees researchers of the need for expert recorders during the relatively short breeding season typical of temperate areas. If skilled observers were not required for all field work, it could make much more intensive sampling feasible (Haselmayer and Quinn 2000). This information is timely because of the widely recognized need for new and improved monitoring techniques and expanded surveys, especially in boreal forest and other more remote areas (Downes et al. 2000).

The obvious advantages to using the omnidirectional microphone system include the opportunity to hire non-experts to make the field recordings according to set protocols of count duration, location, and weather conditions. Another major advantage is that a permanent digital record is made available for the scrutiny of several experts and if these recordings were archived through time, the same interpreter can be used to evaluate population trends. Thus, it should be possible to control the confounding factors of inter-observer bias, changes in observer, or observer ability over time (Cyr 1981, Kendall et al. 1996) for both short- and long-term studies. The permanent recordings allow observations to be challenged, and the approach allows the researcher to both control and measure components of inter-observer variability. These are important changes that enhance the reliability of interpretations made from bird-song observations. Additionally, the sensitivity of the microphone allows observers with deteriorating hearing to detect species that they could not otherwise hear in the field. In particular, high frequency and/or quiet species such as brown creeper were detected by observers on recordings but not in the field (personal observation and data presented herein).

Our initial concerns in using this methodology involved the possible inability to control or evaluate the distance over which recordings were made and the general problem of not being able to determine relative abundance estimates for each species. We reasoned that the expert charged with deciphering the digital recordings would have difficulty estimating the distance at which birds were singing. This would be a particular disadvantage if it were important to associate birds with a specific forest stand or other discrete habitat type. However, such problems with distance estimation also occur with observers in the field (Scott et al. 1981), and there appears to be no easy solution to this issue. Nevertheless, we were encouraged with our tests of the distances over which specific species songs or calls could be detected. Detection distance was of course related to species (Schieck 1997), and it was not surprising that species such as the yellow-shafted flicker could be heard in the field and on recordings up to 250 m from the source. For quieter species, such as the golden-crowned kinglet and black-and-white warbler, the recording appeared extremely similar to the field observer's threshold. We have demonstrated that it should be possible using electronic attenuation to reduce the sensitivity of the CVX microphone system to provide a customized recording system for a particular suite of species. However, for our purposes, we found that an unattenuated 28-cm microphone system came reasonably close to approximating the human ear. An advantage of a digital recording of bird songs is that they can be examined using sonograph software so that song attenuation could be measured and distance estimated by comparing to empirical data, and field data can be readily backed-up to a hard drive on a PC.

Censuses requiring only presence/absence information (Bart and Klosiewski 1989) certainly can be conducted readily using the recording approach. Other studies that aim to test for differences in number of birds among study areas, habitat types, or among years may similarly not require absolute abundance of individuals and species at a given point as long as differences in means reflect differences in actual numbers (Petit et al. 1995, Drapeau et al. 1999). Other applications are more sensitive to count accuracy and include examining relationships between bird patterns of occurrence or relative abundance and habitat characteristics at patch or landscape scales (reviewed by Drapeau et al. 1999). In these cases, study design can ameliorate inaccuracies associated with recording technique, e.g., increasing count duration or the number of counts conducted at a single point over the season. In our study, the problem of estimating relative abundance did not appear to be as serious as we had expected. Even with the monaural system, BBS-style or within-stand point count data as recorded using the CVX microphone were quite close to those obtained using the field observer. In fact, community similarity measures did not differ between the 2 techniques in 2 different habitat types. Relative abundance estimates were possible using a stereo system, and we recommend that this configuration be used for routine survey work. Abundance estimates from recordings were similar to field observations for most species. However, many species normally detected visually, particularly rare species or species that call infrequently, are likely underestimated by recordings (Haselmayer and Quinn 2000). Future studies should address how missing visual detections and rarity alter abundance estimates for such species. Another potential solution to determining absolute numbers of individuals recorded is through sonographic analysis of songs that are known to differ among individuals within species (Falls 1982). This, however, would likely only be feasible on a limited basis.

An important consideration in recommending the use of a high-quality omnidirectional microphone system over an expert field recorder is cost. Currently, the stereo (twin microphone) system with appropriate associated hardware is of the order of $1,640 (US). To this one could add a high quality recording system and portable battery recharging unit for $800 bringing the total expenditure to about $2440. As we have stated, the potential direct saving of hiring a field assistant to simply collect recorded data can be as much as

$1,500 for the month-long recording period typical of north-temperate regions of North America. We find it unnecessary to hire an expert to then decipher these recordings since we are capable of doing this with existing staff. So, our costs can be recovered within two years of operation. If we were to hire an expert in the non-field season, we would pay that individual on an hourly basis to listen to the tapes and to record species and approximate number of individuals heard. The overall cost will then depend on the number of hours of recordings and not on any time or accommodation costs in the field. We anticipate that the observer could decipher 40 min of tape/hr or 4 10-min point counts. For an hourly wage of $20/hr, 60 hrs of work or 240 10-min point counts corresponds to $1200. This corresponds to a saving of $300 per year to be applied to the initial cost of the unit. Running fewer point counts than this per person during the field season is more likely due to poor weather, etc. and might be reduced dramatically based on study design and distance traveled between stations. Running fewer counts will result in a greater direct subsidy of the purchase of the equipment after accounting for costs of hiring an interpreter of the recordings.

Overall, where extensive coverage is important and where field expertise is rare, the electronic recording of songbird communities using an omnidirectional microphone system with an acoustic guide such as those used here, represents a considerable advance over the limitations presented by requiring an expert in the field during the short survey periods typical of temperate regions. For the delineation of bird communities and their monitoring, this approach works sufficiently well to facilitate the much needed increase in point-count surveys required to answer pressing ecological and conservation issues.

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Table 1. Comparison of encounters (number of sample points where a species was recorded in the field by an observer) between field data and data determined from simultaneous recordings. Recordings were made according to BBS roadside protocols in Saskatchewan. The same field observer later analyzed the recordings.

Species	Scientific name	AOU code	Observed in field	From recordings
Common loon	Gavia immer	COLO	1	1
Canada goose	Branta canadensis	CAGO	6	5
American bittern	Botaurus lentiginosus	AMBI		1
Ruffed grouse	Bonasa umbellus	RUGR	2	8
Yellow-bellied sapsucker	Sphyrapicus varius	YBSA	1	1
Eastern kingbird	Tyrannus tyrannus	EAKI	1	1
Alder flycatcher	Empidonax alnorum	ALFL	1	2
Least flycatcher	Empidonax minimus	LEFL	6	5
Gray jay	Perisoreus canadensis	GRAJ		2
Common raven	Corvus corax	CORA	2	2
American crow	Corvus brachyrhynchos	AMCR		1
Brown-headed cowbird	Molothrus ater	BHCO	1	1
Pine siskin	Carduelis pinus	PISI	3	2
White-throated sparrow	Zonotrichia albicolis	WTSP	12	9
Chipping sparrow	Spizella passerina	CHSP	2	2
Rose-breasted grosbeak	Pheucticus ludovicianus	RBGR	5	3
Red-eyed vireo	Vireo olivaceus	REVI	16	14
Blue-headed vireo	Vireo solitarius	BHVI	1	1
Black-and-white warbler	Mniotilta varia	BAWW	2	3
Nashville warbler	Vermivora ruficapilla	NAWA	1	2

Yellow warbler	Dendroica petechia	YWAR	1	1
Magnolia warbler	Dendroica magnolia	MAWA	3	2
Chestnut-sided warbler	Dendroica pensylvanica	CSWA	3	2
Blackburnian warbler	Dendroica fusca	BLBW	2	2
Ovenbird	Seiurus aurocapillus	OVEN	18	16
Connecticut warbler	Oporornis agilis	CONW	8	6
Common yellowthroat	Geothlypis trichas	COYE	1	1
American redstart	Setophaga ruticilla	AMRE	5	4
Brown creeper	Certhia americana	BRCR		1
Ruby-crowned kinglet	Regulis calendula	RCKI	1	2
Hermit thrush	Catharus guttatus	HETH	4	3
American robin	Turdus migratorius	AMRO	1	2
Total no. of species			28	32
No. of sample points			18	18

Table 2. Comparison of community similarity indices between field data and data determined from simultaneous recordings. The BBS-style stops were 3-min counts using a monaural system, the Saskatchewan point counts were 10-min duration also using a monaural system, and the Ontario data were 10-min point counts using a stereo recording configuration. In the Ontario data, encounters refers to number of sites where species were detected and abundance refers to number of individuals per species. The same field observer later analyzed the recordings.

	BBS data	Point count data		
	Saskatchewan	Saskatchewan	Ontario	
			Encounters	Abundance
Data pairs	32	20	53	53
No. species identified in field and on recordings	28,32	19,20	51,46	51,46
Jaccard coefficient	0.88	0.95	0.83	0.83
Sorensen coefficient	0.93	0.97	0.91	0.91
Percent similarity	0.85	0.85	0.86	0.87
Stander index	0.96	0.95	0.97	0.97

Table 3. Comparison of encounters and total abundance between field data and data determined from simultaneous recordings. Recordings were made according to forest point count protocols (see Methods). Encounters refers to number of sites where a species was detected and abundance refers to the number of individuals per species. The same field observer later analyzed the recordings.

Species	Scientific name	AOU code	Saskatchewan Encounters		Ontario Encounters		Ontario Abundance	
			Field	Recording	Field	Recording	Field	Recording
Common snipe	*Gallinago gallinago*	COSN			1		1	
Ruffed grouse	*Bonasa umbellus*	RUGR			8		8	
Hairy woodpecker	*Picoides villosus*	HAWO			3	1	3	1
Downy woodpecker	*Picoides pubescens*	DOWO			1		1	
Yellow-bellied sapsucker	*Sphyrapicus varius*	YBSA	1	1	6	3	6	4
Pileated woodpecker	*Dryocopus pileatus*	PIWO			1	1	1	1
Northern flicker	*Colaptes auratus*	NOFL			1	3	2	3
Olive-sided flycatcher	*Contopus cooperi*	OSFL			2	3	2	3
Yellow-bellied flycatcher	*Empidonax flaviventris*	YBFL			13	10	15	12
Alder flycatcher	*Empidonax alnorum*	ALFL			10	11	19	17
Least flycatcher	*Empidonax minimus*	LEFL			3	4	5	5
Blue jay	*Cyanocitta cristata*	BLJA			8	5	11	6
Gray jay	*Perisoreus canadensis*	GRAJ	2	1	3	2	4	3
Red-winged blackbird	*Agelaius phoeniceus*	RWBL				1		1
Evening grosbeak	*Coccothraustes vespertinus*	EVGR	2	1	6	9	6	10
Purple finch	*Carpodacus purpureus*	PUFI	1	1	2	2	2	2
Pine siskin	*Carduelis pinus*	PISI	4	4	1	2	1	2
White-throated sparrow	*Zonotrichia albicolis*	WTSP			29	33	47	56
Chipping sparrow	*Spizella passerina*	CHSP	2	2	7	8	11	8
Slate-colored junco	*Junco hyemalis*	SCJU			3	3	3	3

Song sparrow	*Melospiza melodia*	SOSP			3	3	3	3
Rose-breasted grosbeak	*Pheucticus ludovicianus*	RBGR			1		1	
Red-eyed vireo	*Vireo olivaceus*	REVI		2	25	28	32	35
Blue-headed vireo	*Vireo solitarius*	BHVI	3	2	13	10	13	11
Black-and-white warbler	*Mniotilta varia*	BAWW			9	12	10	12
Nashville warbler	*Vermivora ruficapilla*	NAWA			31	32	50	51
Tennessee warbler	*Vermivora peregrina*	TEWA	3	4	5	4	5	5
Northern parula	*Parula americana*	NOPA			4	3	4	3
Cape May warbler	*Dendroica tigrina*	CMWA	3	4	1		1	
Yellow warbler	*Dendroica petechia*	YWAR			1	1	1	1
Black-throated blue warbler	*Dendroica caerulescens*	BTBW			4	3	5	3
Yellow-rumped warbler	*Dendroica coronata*	YRWA	2	2	22	19	27	20
Magnolia warbler	*Dendroica magnolia*	MAWA			19	19	23	23
Chestnut-sided warbler	*Dendroica pensylvanica*	CSWA			12	6	24	12
Bay-breasted warbler	*Dendroica castanea*	BBWA	4	4	2		2	
Blackburnian warbler	*Dendroica fusca*	BLBW	3	2	5	5	5	5
Black-throated green warbler	*Dendroica virens*	BTNW			10	7	15	9
Ovenbird	*Seiurus aurocapillus*	OVEN	4	4	26	26	48	41
Mourning warbler	*Oporornis philadelphia*	MOWA			8	11	11	18
Common yellowthroat	*Geothlypis trichas*	COYE			4	3	4	3
Canada warbler	*Wilsonia canadensis*	CAWA			2	1	2	1
American redstart	*Setophaga ruticilla*	AMRE			6	13	6	13
Winter wren	*Troglodytes troglodytes*	WIWR			17	16	18	18
Brown creeper	*Certhia americana*	BRCR	1	1		3		3
Red-breasted nuthatch	*Sitta canadensis*	RBNU	1	2	3	6	4	7
Black-capped chickadee	*Parus atricapillus*	BCCH			7	8	8	8
Boreal chickadee	*Parus hudsonicus*	BOCH			1		1	
Golden-crowned kinglet	*Regulus satrapa*	GCKI	1	1	17	17	19	19
Ruby-crowned kinglet	*Regulis calendula*	RCKI	4	3	10	10	14	14
Veery	*Catharus fuscescens*	VEER			14	8	24	12

Swainson's thrush	*Catharus ustulatus*	SWTH	2	3	23	13	28	16
Hermit thrush	*Catharus guttatus*	HETH			14	16	17	18
American robin	*Turdus migratorius*	AMRO	1	1	20	15	26	20
Total no. of species			19	20	51	46	51	46
No. of sample points			4	4	51	51	51	51

Figure Captions

Figure 1. Field configuration of the recording equipment: (a) monaural configuration using a single 360^o CVX microphone and (b) using a stereo configuration with two 180^o CVX microphones.

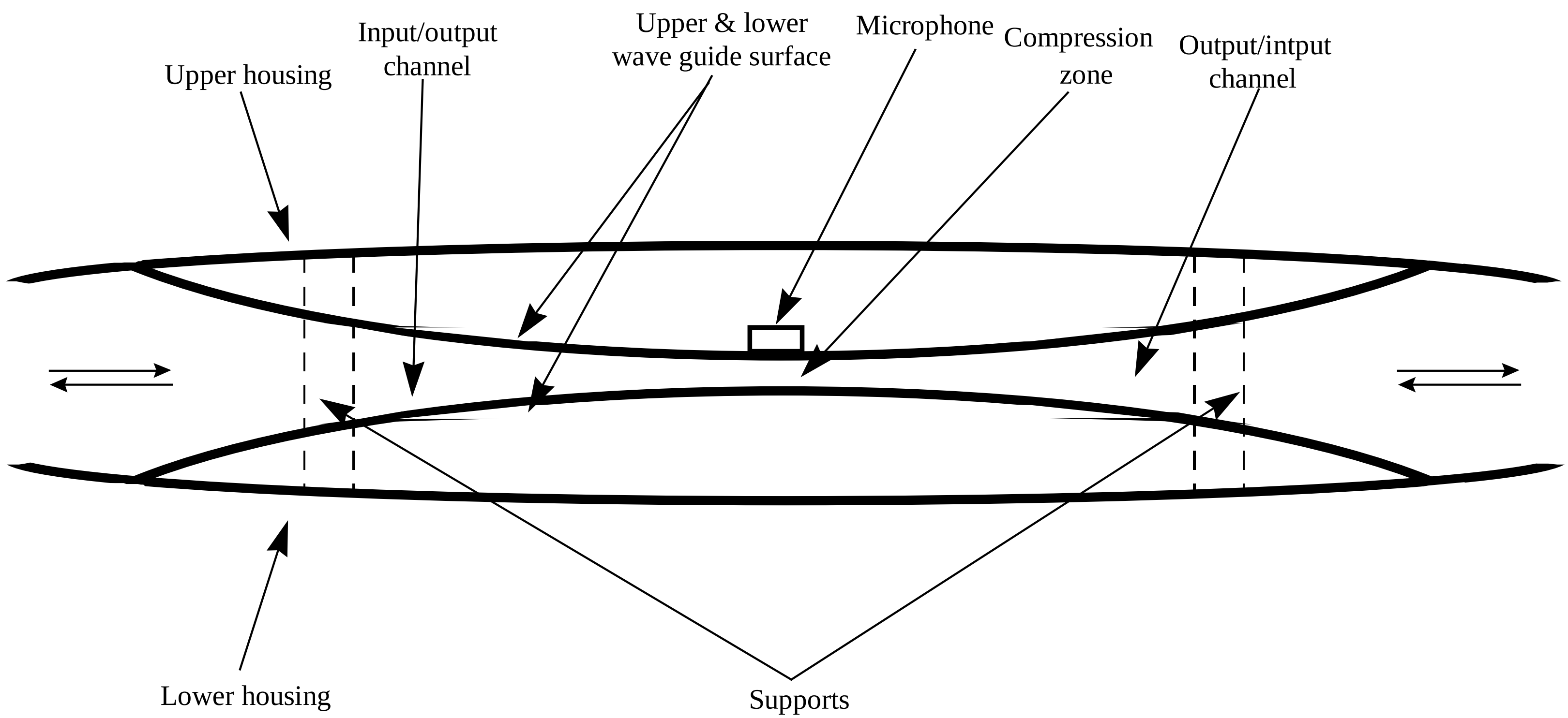
Figure 2. Schematic diagram of the CVX omnidirectional microphone system.

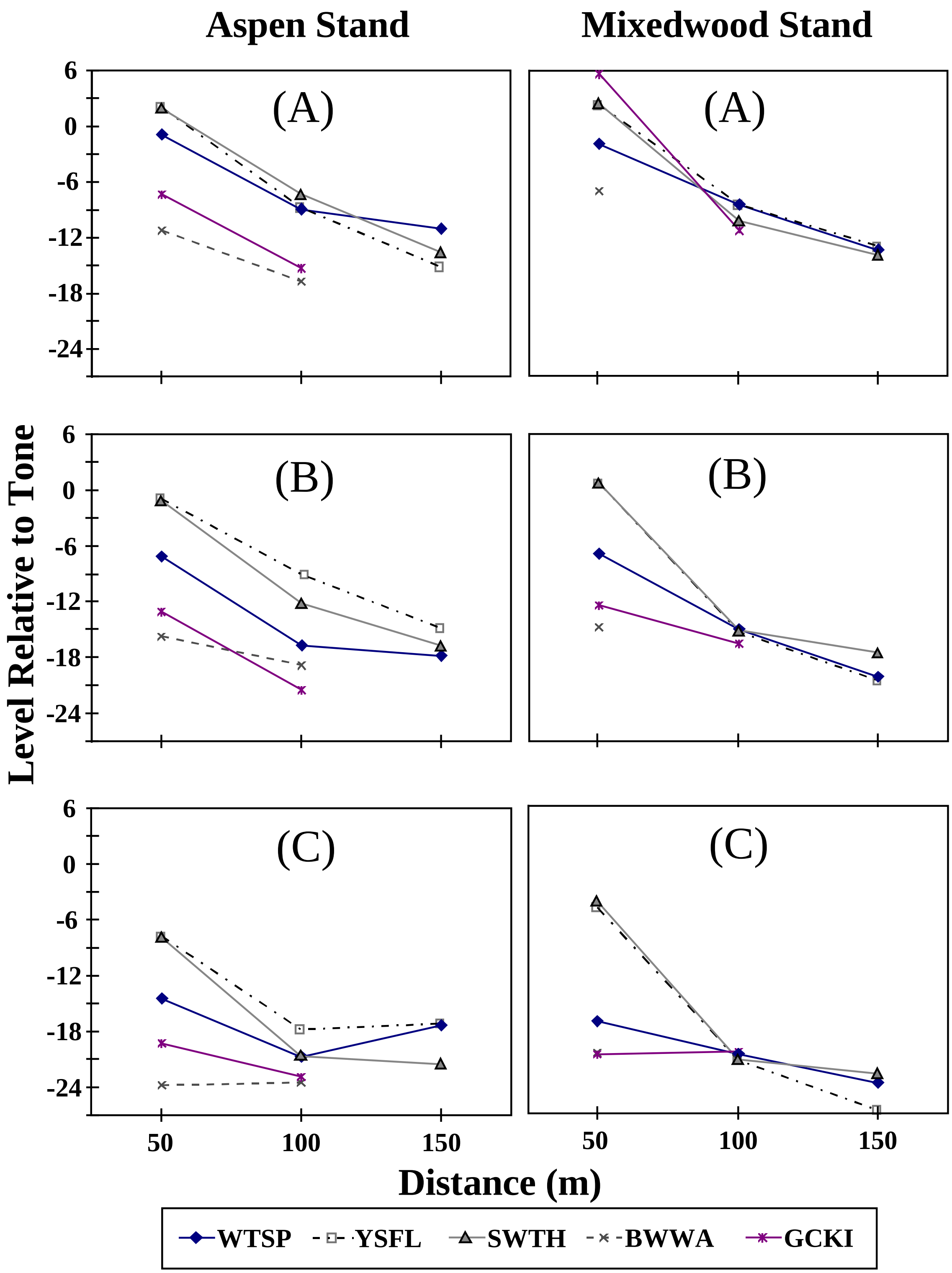
Figure 3. Results of field attenuation trials (Saskatchewan) in aspen and mixedwood forest using a 28-cm diameter CVX omnidirectional microphone. The y-axis shows the deviation in decibels between the recording and a known tone recorded at source. Trials show response for (a) unattenuated, and 2 levels of attenuation (b and c) for 5 species common to our study areas. Each point represents a single datum.

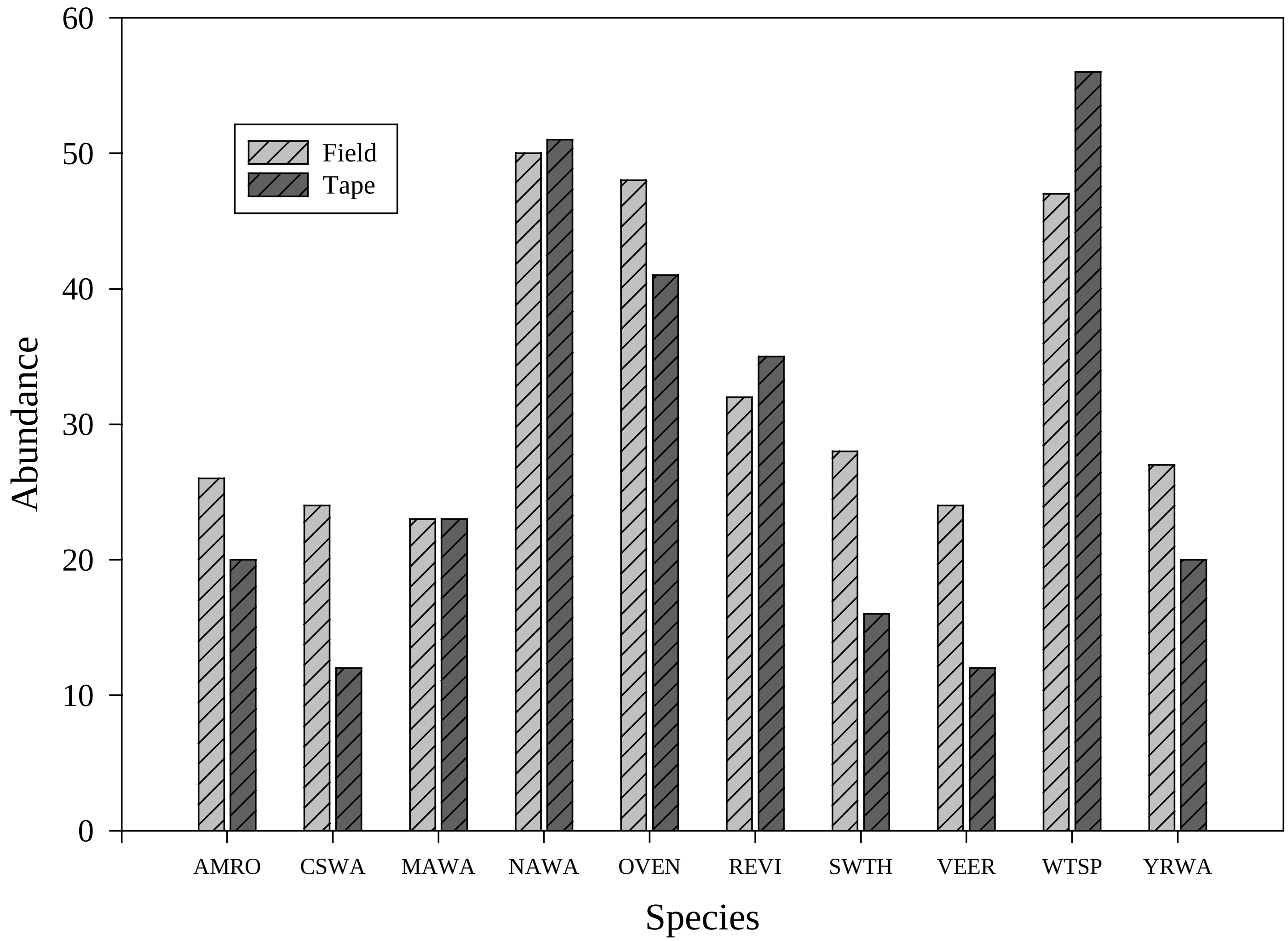
Figure 4. Abundance estimates from field observations and tape recordings for the 10 most numerous species encountered in the field at Ontario study sites from 51 point count stations.

A

B


Upper housing
Input/output
channel
Upper & lower
wave guide surface
Microphone
Compression
zone
Output/intput
channel
Lower housing
Supports


Aspen Stand
Mixedwood Stand
(A)
(A)
(B)
(B)
(C)
(C)
Level Relative to Tone
6
0
-6
-12
-18
-24
50
100
150
Distance (m)
WTSP
YSFL
SWTH
BWWA
GCKI



60
50
40
30
20
10
0
Abundance
Field
Tape
AMRO
CSWA
MAWA
NAWA
OVEN
REVI
SWTH
VEER
WTSP
YRWA
Species