Journal of Field Ornithology

J. Field Ornithol. 80(1):42–50, 2009 DOI: 10.1111/j.1557-9263.2009.00204.x

Comparison of manual and automated methods for identifying target sounds in audio recordings of Pileated, Pale-billed, and putative Ivory-billed woodpeckers

Kyle A. Swiston[1] and Daniel J. Mennill

Department of Biological Sciences, 401 Sunset Avenue, Biology Building, University of Windsor, Windsor, Ontario, N9B3P4, Canada

Received 15 June 2008; accepted 29 September 2008

ABSTRACT. Although offering many benefits over manual recording and survey techniques for avian field studies, automated sound recording systems produce large datasets that must be carefully examined to locate sounds of interest. We compared two methods for locating target sounds in continuous sound recordings: (1) a manual method using computer software to provide a visual representation of the recording as a sound spectrogram and (2) an automated method using sound analysis software preprogrammed to identify specific target sounds. For both methods, we examined the time required to process a 24-h recording, scanning accuracy, and scanning comprehensiveness using four different target sounds of Pileated Woodpeckers (*Dryocopus pileatus*), Pale-billed Woodpeckers (*Campephilus guatemalensis*), and putative Ivory-billed Woodpeckers (*Campehilus principalis*). We collected recordings from the bottomland forests of Florida and the Neotropical dry forests of Costa Rica, and compared manual versus automated cross-correlation scanning techniques. The automated scanning method required less time to process sound recordings, but made more false positive identifications and was less comprehensive than the manual method, identifying significantly fewer target sounds. Although the automated scanning method offers a fast and economic alternative to traditional manual efforts, our results indicate that manual scanning is best for studies requiring an accurate account of temporal patterns in call frequency and for those involving birds with low vocalization rates.

RESUMEN. **Una comparación de métodos manuales y automatizados para la identificación de sonidos clave en grabaciones de *Dryocopus pileatus*, *Campephilus guatemalensis* y supuestos individuos de *C. principalis***

Aunque ofrecen muchos beneficios mayores a las de la grabación manual y técnicas de muestreo al realizar estudios de aves en el campo, los sistemas automatizados de grabación de sonidos producen una base grande de datos que necesita ser examinada cuidadosamente para localizar los sonidos de interés. Comparamos dos métodos para localizar sonidos clave en grabaciones continuos de sonido: (1) un método manual usando un programa computacional para proveer una representación visual de la grabación en forma de un espectrograma de sonido, y (2) un método automatizado usando un programa de análisis de sonido preprogramado para identificar sonidos claves específicos. Para los dos métodos, examinamos el tiempo requerido para procesar una grabación de 24 horas, la precisión de escaneo y la comprensión de escaneo usando cuatro diferentes sonidos claves de *Dryocopus pileatus*, *Campephilus guatemalensis* y supuestos individuos de *C. principalis*. Colectamos grabaciones de bosques de baja elevaciones de Florida y de bosques secos Neotropicales de Costa Rica y comparamos técnicas de escaneo de correlación cruzada manuales vs. automatizadas. El método de escaneo automatizado requirió de menos tiempo de procesamiento de las grabaciones de sonido pero hizo más identificaciones positivas falsas y fue menos comprensivo que el método manual, identificando significativamente menos sonidos clave. Aunque el método de escaneo automatizado ofrece una alternativa rápida y económica a métodos manuales tradicionales, nuestros resultados indican que el método de escaneo manual es la mejor para estudios que requieren de resultados precisos de los patrones temporales en la frecuencia de llamadas y para estudios de especies con bajos ritmos de vocalización.

Key words: automated recording, bird song, *Campephilus*, *Dryocopus*, rare birds, sound detection

Automated sound recording systems have been used in a number of studies across a diverse array of taxa, including birds (Burt and Vehrencamp 2005, Mennill et al. 2006, Tremain et al. 2008). Recently, investigators have compared the use of automated recording systems for conducting population and species surveys to traditional survey methods (Penman et al. 2005, Rempel et al. 2005, Acevedo and Villanueva-Rivera 2006, Gunzburger 2007). Acoustic recording systems offer several benefits over manual surveying techniques for

---

[1] Corresponding author. Email: kswiston@gmail.com

monitoring wildlife, including (1) extended sampling periods (Peterson and Dorcas 1994, Acevedo and Villanueva-Rivera 2006), (2) the ability to survey several areas simultaneously (Peterson and Dorcas 1994), (3) a permanent survey record that can be evaluated by multiple independent sources (Bridges and Dorcas 2000, Rempel et al. 2005), (4) accurate examination of temporal and interspecific variation in acoustic behavior (Peterson and Dorcas 1994, Bridges and Dorcas 2000), and (5) less disruption of the behavior of the individuals being surveyed (Bridges and Dorcas 2000). There are also, however, drawbacks to using automated recordings systems. Distinguishing between conspecifics can be difficult in species that lack individually distinctive vocalizations, and automated recorders generate massive volumes of acoustic data that can be problematic to both store and analyze (Rempel et al. 2005).

To locate sounds of interest in recordings collected using an automated recording system, recordings can be either scanned manually using computer software that provides a visual representation of the recordings as sound spectrograms or automated sound analysis software preprogrammed to identify specific target sounds can be used. Although spectrograms have long been used to analyze sounds (Potter et al. 1947, Thorpe 1961), the use of sound recognition software for automated sound scanning is a more recent development. Such software has been used to identify an assortment of animal calls and sounds with varying degrees of success (Niezrecki et al. 2003, Chesmore and Ohya 2004, Brandes et al. 2006, Roch et al. 2007, Somervuo et al. 2006). The use of sound recognition software is particularly attractive in studies involving automated recording systems because manually scanning the large datasets these devices produce can be arduous. An accurate and comprehensive automated sound scanning method would greatly reduce the time required to scan through large acoustic datasets.

Perhaps the highest profile use of automated sound recording systems has been the application of this technology for monitoring forests in Arkansas and Florida for the presence of Ivory-billed Woodpeckers (*Campephilus principalis*). Once a widespread resident of mature bottomland forests in southeastern North America, the Ivory-billed Woodpecker was widely believed to have been driven to extinction in the latter half of the 20th century (Jackson 2002) until an announcement of its rediscovery was made in Arkansas in 2005 (Fitzpatrick et al. 2005). This announcement encouraged a number of researchers and bird enthusiasts to search for Ivory-billed Woodpeckers in other areas of their former range. One such search was conducted along the Choctawhatchee River in the Florida Panhandle between 2006 and 2008 after a purported Ivory-billed Woodpecker was sighted in the area in May 2005 (Hill et al. 2006). As part of this search, between 2006 and 2008 we captured 56,000 h of audio recording using automated recording systems along the Choctawhatchee River. To date, approximately 45,000 h of these recordings have been manually scanned for putative Ivory-billed Woodpecker sounds.

We scanned recordings collected using automated recording systems along the Choctawhatchee River, Florida, and in Santa Rosa National Park, Costa Rica, using two scanning methods, a traditional manual scanning method and an automated scanning method using cross-correlation-based sound recognition software. We scanned these recordings for four target sounds: the double-knock drum of Pale-billed Woodpeckers (*Campephilus guatemalensis*), the double-knock drum and "kent" call of Ivory-billed Woodpeckers, and the cackle call of Pileated Woodpeckers (*Dryocopus pileatus*; Fig. 1). Costa Rican Pale-billed Woodpeckers were selected because they produce a double-knock drum similar to that of other *Campephilus* woodpeckers, including Ivory-billed Woodpeckers (Jackson 2002). For both methods, we compared the time required to process a 24-h sound recording, the accuracy with which annotated sounds were identified, and the comprehensiveness of the scans. We examined the suitability of using the automated sound scanning method rather than manual scanning when attempting to isolate sounds of interest from large recording datasets, particularly those generated by automated recordings systems in a natural environment.

METHODS

Sound recordings. Recordings of Pileated Woodpeckers and putative Ivory-billed Woodpeckers were collected along the Choctawhatchee River in the Florida Panhandle (30°37′N, 85°55′W) during 2006

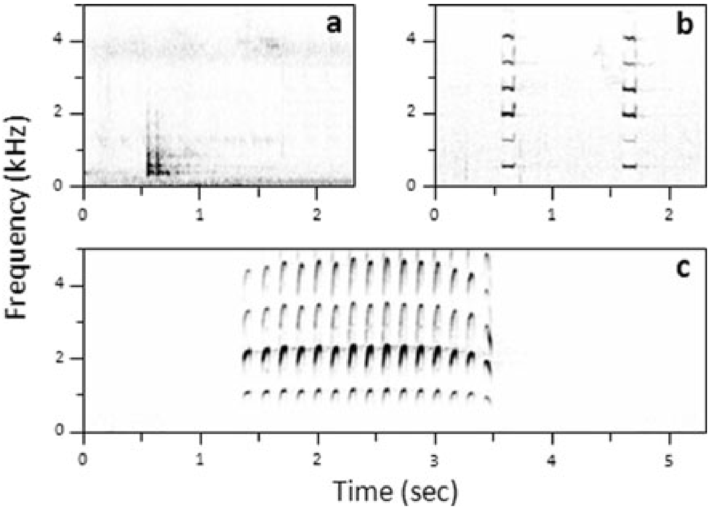

Fig. 1. Sound spectrograms of the target sounds that were searched for in continuous audio recordings made using automated recorders in Florida and Costa Rica: (a) Pale-billed Woodpecker double knock, (b) Ivory-billed Woodpecker "kent" calls (recorded by Allen and Kellogg in 1935), and (c) Pileated Woodpecker cackle call. In the absence of confirmed recordings of the Ivory-billed Woodpecker double knock, Pale-billed Woodpecker double knocks recorded in Costa Rica were used as template sounds to search for Ivory-billed Woodpecker double knocks in Florida recordings.

and 2007 (see Hill et al. 2006). Recordings of Pale-billed Woodpeckers were collected in Santa Rosa National Park, Guanacaste, Costa Rica (10°40′N, 85°30′W), during 2006. All recordings were collected using automated recording systems (or "listening stations") that collected audio data 24 h a day. Listening stations in Florida consisted of a digital recorder (Marantz PMD670) connected to an omni-directional microphone (Sennheiser ME62/K6) and were powered by a sealed, lead-acid battery. In Florida, sounds were recorded onto 3 GB Hitachi Microdrive cards and 4 GB Seagate CompactFlash Photo hard drives as MP3 files at 44.1 kHz, 16-bit, 160 kbps. In Costa Rica, listening stations consisted of a recorder (Marantz PMD660) connected to an omni-directional microphone, and sounds were recorded onto 3 GB Hitachi Microdrive cards as MP3 files at 44.1 kHz, 16-bit, 64 kbps. A more detailed description of listening station design is provided by Hill et al. (2006). All recordings were split into hour-long segments and converted to 44.1 kHz, 16-bit WAV files before scanning

Manual scanning. During 2006 and 2007, sound analysts ($N = 21$) manually scanned 39, 570 h of audio recordings collected in Florida for putative Ivory-billed Woodpecker double knocks and "kent" calls using Syrinx-PC sound analysis software (J. Burt, Seattle, WA). Sound spectrograms viewed in Syrinx-PC were limited to a frequency range of 0–4000 Hz (a frequency range where double knocks and "kent" calls are readily detectible) and had a transform size of 512. Viewing 75 s of recording at a time, sound analysts inspected the displayed spectrogram for sounds resembling those of Ivory-billed Woodpecker double knocks and "kent" calls before moving to the next segment. Examples of *Campephilus* woodpecker double knocks and a historical recording of Ivory-bill Woodpecker "kent" calls recorded by Allen and Kellogg in 1935 (see Allen and Kellogg 1937) were included on the sound analysts' monitors as references. When a putative Ivory-billed Woodpecker sound was identified, sound analysts noted it using Syrinx-PC's annotation tool. This procedure was repeated until the entire sound recording had been scanned and all sounds of interest annotated. We checked all annotations and discarded any sounds that were poor matches for Ivory-billed Woodpecker sounds. All remaining putative double knock and "kent" calls of Ivory-billed Woodpeckers were independently ranked in quality using a process detailed by Hill et al. (2006)

Prior to scanning the Florida recordings, the scanning abilities of sound analysis technicians were tested using two 24-h recordings into which examples of both historic "kent" calls and *Campephilus* double knocks were inserted at known times. These sounds varied in loudness and signal-to-noise ratio in an effort to simulate the range in quality of sounds collected by automated listening stations. Only technicians able to identify an average of 90% of the target sounds in both recordings were retained to scan for putative Ivory-billed Woodpecker sounds.

A subset of $N = 105$-d-long audio recordings (2709 h) made in Florida in 2006 were scanned for the calls and drums of Pileated Woodpeckers using the scanning method described above. All Pileated Woodpecker cackle calls were annotated as described by Tremain et al. (2008), and we reviewed all annotated Pileated Woodpecker sounds for accuracy.

From October to December 2006, recordings (665 h) made in Santa Rosa National Park in 2006 were scanned for the double knocks of Pale-billed Woodpecker by novice sound analysts. Scanning these recordings served as a training session for technicians who then scanned recordings made along the Choctawhatchee River in 2007 for putative Ivory-bill Woodpecker sounds. We reviewed all annotations of Pale-billed Woodpecker double knocks for accuracy.

Automated scanning. Automated scanning was conducted using the Data Template Detector of XBAT (Harold Figueroa, Ithaca, NY), an open-source application written for MATLAB R2006a (MathWorks Inc., Natick, MA). The Data Template Detector searches for and identifies target sounds that match one or more preset sound templates to a specified correlation threshold. For all automated scans in our study, the correlation threshold was set to 0.4. This level was chosen after conducting a comprehensive series of trials where we scanned the same recording using different correlation thresholds; threshold values under 0.4 dramatically increased the number of sounds falsely identified as target sounds, whereas threshold values over 0.4 returned too few target sounds. Sounds that matched a template sound were automatically annotated by XBAT, and annotation lists were displayed at the end of the automated scanning process. We reviewed these annotation lists manually to ensure accuracy. Although it is possible to search for multiple target sounds concurrently using XBAT, all automated scanning sessions were programmed to search for a single sound type. MATLAB and the XBAT application were run in the Windows XP operating system on two Dell Optiplex GX620 computers. Each computer contained a 3.0 GHz Pentium 4 central processing unit and 512 MB RAM.

To evaluate the utility of the template sounds chosen for the automated scanning procedure, we conducted a preliminary analysis. For each target sound type, a number of nonoverlapped, exemplar sounds with a high signal-to-noise ratio were selected as potential template sounds. Four examples of each target sound type were ultimately chosen as templates based on their combined ability to identify at least 90% of the target sounds in arbitrarily chosen test recordings. These test recordings, created for each sound type, contained 20 target sounds taken from both focal recordings of individual birds and from listening station recordings. Focal recordings were made using a directional microphone. Because there are no known historically recorded examples of Ivory-billed Woodpecker double knocks and because the double knocks of many *Campephilus* species are similar in structure, the same template sounds used to scan for the double knocks of Pale-billed Woodpeckers were used to scan for putative double knocks of Ivory-billed Woodpeckers. For the "kent" calls of Ivory-billed Woodpeckers, two calls recorded by Allen and Kellogg (1937) and two discussed by Hill et al. (2006) were used as templates.

We automatically scanned 60-d-long recordings for each target sound type except the double knock of Pale-billed Woodpeckers (32-d-long recordings were available). The 60 d of recording automatically scanned for Pileated Woodpecker cackle calls were randomly chosen from a total of 105 d that had been manually scanned. Because manual searches identified putative double knocks and "kent" calls of Ivory-billed Woodpeckers infrequently (Hill et al. 2006), 10-d-long recordings, each containing four or more putative sounds, were included among the recordings automatically scanned for each Ivory-billed Woodpecker sound type. The remaining 50 recordings were selected randomly from a total of 39,570 h that had previously been manually scanned for Ivory-billed Woodpecker sounds.

Comparing methods. Overall, 212-d-long audio recordings were scanned using both the manual and automated methods. For each scanning method, we noted the total time required to process a 24-h sound recording, the accuracy in correctly identifying annotated sounds, and whether or not all target sounds were actually annotated

The total time required to process a 24-h recording was defined as the time taken to initially scan the recording, either manually using Syrinx-PC or automatically using XBAT's Data Template Detector, plus the time needed to review the annotations generated. Because recordings varied in duration from 17.2 to 29 h (mean = 23.8 h), all processing times were standardized for a recording length of 24 h by multiplying the actual processing time of a recording by 24 and dividing the resulting product by the length of the recording (in hours).

Two measures of sound identification accuracy were taken. For all recordings, the number of false positive identifications made using each scanning method was recorded. Additionally, for recordings with at least one annotation, a scanning accuracy percentage was calculated as the number of correctly annotated sounds (true positive annotations) divided by the total number of annotations made for the recording (both true positive and false positive annotations). Because their status is controversial (Jackson 2006), some caution must be taken when identifying putative Ivory-billed Woodpecker sounds. However, to examine the accuracy of annotations marked as the "kent" calls or double knocks of Ivory-billed Woodpeckers, we had to differentiate between true and false target sounds. Thus, we assumed that sounds matching those described for Ivory-billed Woodpeckers were actually Ivory-billed Woodpecker sounds. The process by which putative "kent" calls and double knocks were assessed as possible Ivory-billed Woodpecker sounds is described by Hill et al. (2006).

Scanning comprehensiveness was measured as the number of correctly identified sounds annotated by each scanning method over the total number of target sounds in a recording, with the total number of target sounds in a recording defined as the number of target sounds identified by one scanning method plus any additional target sounds found solely by the second scanning method. Scanning comprehensiveness was only measured for recordings with at least one target sound.

Statistical analyses. All analyses were conducted using SPSS 15.0 (SPSS Inc., Chicago, IL). For the two scanning methods, we compared total processing time, number of false positives, scanning accuracy, and scanning comprehensiveness using Wilcoxon paired-comparison signed rank tests. All tests were conducted at the $\alpha = 0.05$ level, and all values are reported as mean ± 1 SD.

RESULTS

Processing time. For all four target sounds, processing time (initial scan time plus annotation review time) for 24-h recordings was significantly shorter using the automated scanning method (Table 1). However, reviewing annotation lists generated by the automated method took longer than by the manual method for all target sounds except the Pileated Woodpecker cackle call (Pale-billed Woodpecker double knock: $z = 3.5$, $P < 0.001$; Ivory-billed Woodpecker double knock: $z = 4.0$, $P < 0.001$; Ivory-billed Woodpecker "kent" call: $z = 6.3$, $P < 0.001$; Fig. 2).

Table 1. Time required to scan and review a 24-h sound file for one of four target sounds using automated and manual scanning methods.

Target sound	Automated[a]	Manual[a]	z^b	P
Pale-billed Woodpecker double knock	28.7 ± 12.1	137.9 ± 29.7	4.9	<0.001
Ivory-billed Woodpecker double knock	19.3 ± 2.7	71.5 ± 22.2	6.7	<0.001
Ivory-billed Woodpecker "kent" call	33.8 ± 13.9	68.2 ± 20.6	6.4	<0.001
Pileated Woodpecker cackle call	42.5 ± 12.8	69.4 ± 19.6	6.3	<0.001

[a] Times reported in minutes as mean ± 1 SD.

[b] Wilcoxon paired-comparison signed-rank test.

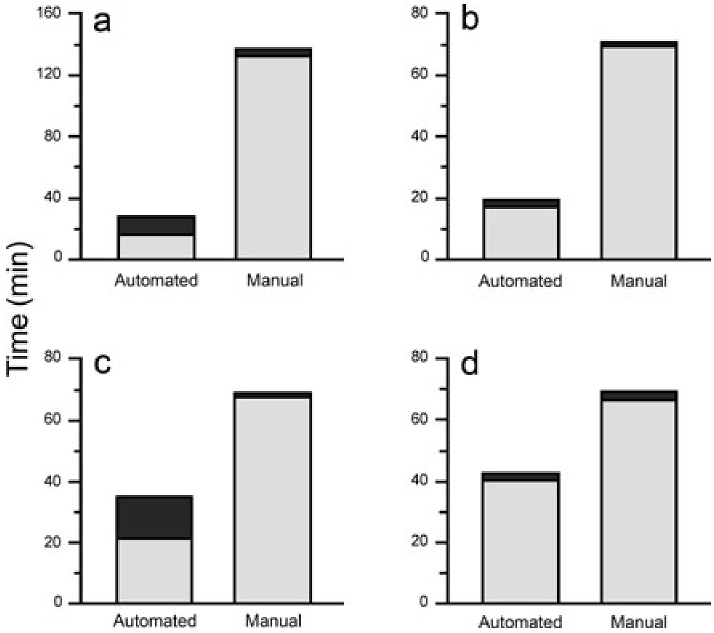

Fig. 2. Mean time required to initially scan (light grey) and review annotations (black) of a 24-h recording for one of four target sounds: (a) Pale-billed Woodpecker double knock, (b) Ivory-billed Woodpecker double knock, (c) Ivory-billed Woodpecker "kent" call, and (d) Pileated Woodpecker cackle call.

Scanning accuracy. For all four target sounds, significantly more false positive identifications were made by the automated scanning method than the manual scanning method (Table 2). For recordings with one or more annotated sounds (32 automated and 23 manual scans for Pale-billed Woodpecker double knocks, 57 automated and 18 manual scans for Ivory-billed Woodpecker double knocks, 55 automated and 21 manual scans for Ivory-billed Woodpecker "kent" calls, and 42 automated and 60 manual scans for Pileated Woodpecker cackle calls), the proportion of sounds correctly identified by the automated scanning method was significantly lower for all target sounds, including Pale-billed Woodpecker double knocks (automated 3.0 ± 8.6% correct, manual 66.2 ± 39.2% correct, $z = 3.8$, $P < 0.001$), Ivory-billed Woodpecker double knocks (automated 1.5 ± 7.6% correct, manual 37.6 ± 42.9% correct, $z = 2.8$, $P = 0.005$), Ivory-billed Woodpecker "kent" calls (automated 0.4 ± 1.0% correct, manual 40.9 ± 43.5% correct, $z = 3.2$, $P = 0.001$), and Pileated Woodpecker cackle calls (automated 60.6 ± 42.1% correct, manual 100 ± 0% correct, $z = 4.2$, $P < 0.001$)

Scanning comprehensiveness. Scanning comprehensiveness was calculated for

Table 2. Mean number of false positive identifications (per sound file) made by both scanning methods while searching for one of four target sound types.

Target sound	Automated[a]	Manual[a]	z^b	P
Pale-billed Woodpecker double knock	269.0 ± 279.1	3.5 ± 7.2	4.9	<0.001
Ivory-billed Woodpecker double knock	94.0 ± 176.3	1.2 ± 3.3	6.4	<0.001
Ivory-billed Woodpecker "kent" call	447.1 ± 536.2	3.3 ± 8.7	6.0	<0.001
Pileated Woodpecker cackle call	48.9 ± 269.6	0.0 ± 0.0	4.2	<0.001

[a] Values reported as mean ± 1 SD.

[b] Wilcoxon paired-comparison signed-rank test.

Table 3. Mean scanning comprehensiveness for both scanning methods for four target sound types. For each scanning method, comprehensiveness was measured as the number of target sounds annotated divided by the total number of target sounds present in a recording.

Target sound	Automated[a]	Manual[a]	z[b]	P
Pale-billed Woodpecker double knock	0.24 ± 0.35	0.99 ± 0.02	3.9	<0.001
Ivory-billed Woodpecker double knock	0.08 ± 0.14	1.0 ± 0.0	2.9	0.004
Ivory-billed Woodpecker "kent" call	0.56 ± 0.31	0.92 ± 0.27	2.3	0.023
Pileated Woodpecker cackle call	0.17 ± 0.23	1.0 ± 0.001	6.7	<0.001

[a] Values reported as mean ± 1 SD.

[b] Wilcoxon paired-comparison signed-rank test.

day-long recordings with at least one target sound. Of recordings scanned for their respective target sounds, 19 included one or more Pale-billed Woodpecker double knocks, 10 contained at least one putative Ivory-billed Woodpecker double knock, 14 contained putative Ivory-billed Woodpecker "kent" calls, and 60 contained Pileated Woodpecker cackle calls. The automated scanning method was significantly less comprehensive than the manual method, identifying fewer target sounds for all four target sounds (Table 3)

DISCUSSION

We found that scanning recordings for the sounds of Pale-billed, Pileated, and Ivory-billed woodpeckers using cross-correlation based automated sound recognition software (XBAT) was faster than scanning the same recordings manually. However, the automated scanning method returned more false positive identifications and missed more target sounds than the manual scanning method.

Processing time. Scan time using the automated method was influenced by the duration of the template sounds. For example, automated scanning for double knocks of both Pale-billed and Ivory-billed woodpeckers used template sounds averaging 0.08 s in duration, and mean completion time for these scans was 17 min. In contrast, automated scanning for the cackle calls of Pileated Woodpeckers used template sounds averaging 1.7 s in duration and mean completion time was 40 min. Selecting longer duration templates increases the time required for XBAT's Data Template Detector to scan and annotate a recording. If the target sound is long, part of the sound can be used as a template to reduce scan time, provided that the component is sufficiently stereotyped. Although we did not test this in our study, computer specifications may also influence the speed of the automated scanning process

Manual scanning speeds are influenced by the experience level of the sound analyst and the number of target sounds in a recording, with less experienced analysts generally scanning more slowly. In our study, recordings with the double knocks of Pale-billed Woodpeckers were scanned by technicians with less than 20 h of experience who had never heard a double knock in a natural setting. As a result, scanning times for these recordings were longer than those for recordings with the other three target sounds. In our study, most of the recordings scanned contained no more than a few dozen target sounds. However, individuals in some bird species call hundreds of times an hour and in chorusing species, several individuals may call simultaneously (Catchpole and Slater 1995). Because Syrinx-PC requires that annotation boxes be individually drawn and typed, recordings with numerous target sounds would likely take longer to manually scan than those with fewer sounds, such as the recordings in our study.

The time required to review annotation lists generated by either scanning method was dependent on the number of sounds annotated. Although the automated scanning process required longer annotation review times, it also annotated significantly more sounds (most of which were falsely identified).

Scanning accuracy. Automated scanning was less accurate than the manual method both in correctly annotating sounds and in the number of false positive identifications. More false positive identifications occurred when scanning for acoustically simple double knock or "kent" calls of Ivory-billed Woodpecker than when scanning for the more complex "cackle" call of Pileated Woodpeckers. Humans are better able to discriminate between similar sounds and consider a sound's context. For instance, many sounds misclassified as Pale-billed Woodpecker double knocks were calls of Blue-crowned Motmots (*Momotus momota*) that also have two amplitude peaks, but bear little resemblance to a double knock to the human ear. Sounds generated by wind, rain, and microphone static were also commonly misclassified as either *Campephilus* woodpecker double knocks or Ivory-billed Woodpecker "kent" calls

More time could have been spent developing a set of template sounds better able to discriminate between sounds of interest and those commonly misclassified as target sounds, but this would require a pilot study to identify the sounds most commonly misclassified. The number of false positives returned by XBAT's Data Template Detector was also influenced by the correlation threshold value used. A high correlation threshold value will reduce the number of false positive annotations, but make it more likely that individual target sounds will fail to meet the correlation threshold required for annotation.

Scanning comprehensiveness. The automated scanning method missed significantly more target sounds for all four target sound types, with most sounds missed being low volume, having a low signal-to-noise ratio, or overlapped by other sounds. Human sound analysts are better able to discriminate between signals of interest and background noise, making them less likely to miss faint or overlapped sounds and more comprehensive in identifying target sounds in a recording. As mentioned above, it is possible to set XBAT's Data Template detector to identify more target sounds by using a lower correlation threshold, but this increases the number of false positive identifications and the time required to review the annotation file. For example, when deciding on our correlation threshold, five recordings were scanned for Pale-billed Woodpecker double knocks using the Data Template detector with a correlation threshold of 0.3. In all five recordings, 5000–45,000 sounds were annotated. With a correlation threshold of 0.4, the maximum number of annotations was 947. With large numbers of annotations, the time required to review the results is longer than the time required to scan and review the same file manually, eliminating any benefit of using the automated method

Conclusions.

XBAT's Data Template detector provides a fast and economic alternative to manual scanning of large sound files, but at the cost of scanning comprehensiveness. With the automated scanning method, only initiation of the Data Template detector and subsequent review of sounds annotated during scans require human input. Discounting the time needed to create sound templates, load sound files, and initiate the Data Template detector for each recording, automatically scanning 60-d-long recordings (1468 h) for Pileated Woodpecker cackle calls took about 2.5 h. Manually scanning the same recordings took approximately 69.2 h. This does not take into account the time required for XBAT to complete its automated scan, but this time can be reduced by scanning on multiple computers simultaneously.

The major drawback of the automated scanning method tested was its low scanning comprehensiveness. Although manual scanning is more labor intensive, trained sound analysts achieve close to 100% scanning comprehensiveness and misclassify few sounds in the process. The automated scanning process was better at identifying more complex sounds in our study. As such, automated cross-correlation scanning methods may be best suited for studies targeting complex, highly stereotyped bird songs or calls.

Ultimately, the cross-correlation based automated scanning method used in this study is well suited for studies that do not require the identification of every target sound in a recording, such as presence–absence species surveys of vociferous birds. However, when an accurate account of daily or seasonal patterns in call frequency is important, or for studies of birds with low vocalization rates, traditional manual scanning efforts appear to be the best option at present, despite being more costly.

ACKNOWLEDGMENTS

We thank the Bioacoustics Research Program at the Cornell Lab of Ornithology and J. Burt for their support and technical assistance. For field and laboratory assistance, we are deeply indebted to G. Hill, B. Rolek, T. Hicks, S. Tremain, K. Odom, J. Stahl, E. Bailey, S. Baldo, C. Bustos, K. Cogliati, M. Deneau, B. Falica, J. Goettel,

E. Green, L. Hand, H. Hennin, T. Howlett, S. Lippold, A. Mistakidis, J. Mouland, A. Osmun, K. Rieveley, S. Tremblay, K. Winger, and S. Yavno. For funding, we thank the Natural Sciences and Engineering Research Council of Canada (NSERC), Pelee Island Winery, University of Windsor, Canada's Foundation for Innovation, the Ontario government, Nokuse Plantation Conservation Initiative, Northwest Florida Water Management District, Florida Fish and Wildlife Conservation Commission, and the U.S. Fish and Wildlife Service.

LITERATURE CITED

Acevedo, M. A., and L. J. Villanueva-Rivera. 2006. Using automated digital recording systems as effective tools for the monitoring of birds and amphibians. Wildlife Society Bulletin 34: 211–214.

Allen, A. A., and P. P. Kellogg. 1937. Recent observations on the Ivory-billed Woodpecker. Auk 54: 164–184.

Brandes, T. S., P. Naskrecki, and H. K. Figueroa. 2006. Using image processing to detect and classify narrow-band cricket and frog calls. Journal of the Acoustical Society of America 120: 2950–2957.

Bridges, A. S., and M. E. Dorcas. 2000. Temporal variation in anuran calling behavior: Implications for surveys and monitoring programs. Copeia 2000: 587–592.

Burt, J. M., and S. L. Vehrencamp. 2005. Dawn chorus as an interactive communication network. In: Animal communication networks (P. K. McGregor, ed.), pp. 320–343. Cambridge University Press, New York.

Catchpole, C. K., and P. J. B. Slater. 1995. Bird song: biological themes and variations. Cambridge University Press, Cambridge, UK.

Chesmore, E. D., and E. Ohya. 2004. Automated identification of field-recorded songs of four British grasshoppers using bioacoustic signal recognition. Bulletin of Entomological Research 94: 319–330.

Fitzpatrick, J. W., M. Lammertink, M. D. Luneau Jr., T. W. Gallagher, B. R. Harrison, G. M. Sparling, K. V. Rosenberg, R. W. Rohrbaugh, E. C. H. Swarthout, P. H. Wrege, S. B. Swarthout, M. S. Dantzker, R. A. Charif, T. R. Barksdale, J. V. Remsen Jr., S. D. Simon, and D. Zollner. 2005. Ivory-billed Woodpecker (*Campephilus principalis*) persists in continental North America. Science 308: 1460–1462.

Gunzburger, M. S. 2007. Evaluation of seven aquatic sampling methods for amphibians and other aquatic fauna. Applied Herpetology 4: 47–63.

Hill, G. E., D. J. Mennill, B. W. Rolek, T. L. Hicks, and K. A. Swiston. 2006. Evidence suggesting that Ivory-billed Woodpeckers (*Campephilus principalis*) exist in Florida. Avian Conservation and Ecology 1:2. Available at: http://www.ace-eco.org//vol1/iss3/art2/; (Accessed 2 June 2008).

Jackson, J. A. 2002. Ivory-billed Woodpecker (*Campephilus principalis*). In: The birds of North America, no. 711 (A. Poole, and F. Gill, eds.). The Birds of North America Inc., Philadelphia, PA.

———. 2006. Ivory-billed Woodpecker (*Campephilus principalis*): hope, and the interfaces of science, conservation, and politics. Auk 123: 1–15.

Mennill, D. J., J. M. Burt, K. M. Fristrup, and S. L. Vehrencamp. 2006. Accuracy of an acoustic location system for monitoring the position of duetting tropical songbirds. Journal of the Acoustical Society of America 119: 2832–2839.

Niezrecki, C., R. Phillips, and M. Meyer. 2003. Acoustic detection of manatee vocalizations. Journal of the Acoustical Society of America 114: 1640–1647.

Penman, T. D., F. L. Lemckert, and M. J. Mahony. 2005. A cost-benefit analysis of automated call recorders. Applied Herpetology 2: 389–400.

Peterson, C. R., and M. E. Dorcas. 1994. Automated data acquisition. In: Measuring and monitoring biological diversity—standard methods for amphibians (W. Heyer, R. W. McDiarmid, M. Donnelly, and L. Hayek, eds.), pp. 47–57. Smithsonian Institution Press, Washington, D.C.

Potter, R. K., G. A. Kopp, and H. C. Green. 1947. Visible speech. Van Nostrand, New York.

Rempel, R. S., K. A. Hobson, G. Holborn, S. L. Van Wilgenburg, and J. Elliot. 2005. Bioacoustic monitoring of forest songbirds: interpreter variability and effects of configuration and digital processing methods in the laboratory. Journal of Field Ornithology 76: 1–11.

Roch, M. A., M. S. Soldevilla, J. C. Burtenshaw, E. E. Henderson, and J. A. Hildebrand. 2007. Gaussian mixture model classification of odontocetes in the Southern California Bight and the Gulf of California. Journal of the Acoustical Society of America 121: 1737–1748.

Somervuo, P., A. Harma, and S. Fagerlund. 2006. Parametric representations of bird sounds for automatic species recognition. IEEE Transactions in Speech and Audio Processing 14: 2252–2263.

Thorpe, W. H. 1961. Bird song. Cambridge University Press, Cambridge, UK.

Tremain, S. B., K. A. Swiston, and D. J. Mennill. 2008. Seasonal variation in acoustic signals of Pileated Woodpeckers (*Dryocopus pileatus*). Wilson Journal of Ornithology 120: 499–504.