

A COMPARISON OF ACOUSTIC MONITORING METHODS FOR COMMON
ANURANS OF THE NORTHEASTERN UNITED STATES

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ABSTRACT

Anurans are often the focus of monitoring, so it is important that the best methods be chosen to meet the needs of a particular program. Some have begun to use autonomous recording units (ARUs) which can collect audio data for extended periods of time with little maintenance and at sites where traditional call surveys might be difficult. Another new method is use of computer software that automatically identifies calls of different species, allowing for data spanning large areas or long periods of time to be processed more expediently. Although these technologies offer many benefits, with increased automation comes increased error. Several different variables affect errors in detection, but we examined four in this study: ARU type, method of species identification, focal species, and background noise. We collected higher and lower quality audio data with two different types of ARUs at wetland sites in Vermont and New York. We identified calls on these recordings with the tradition method of human identification as well as with the software package Song Scope which automatically identifies calls. Results were compared to the calls known to be on the recordings in order to find instances where species were incorrectly identified (false positives) and where species were missed (false negatives). We performed a logistic regression in order to determine the effects of ARU type, species identification method, and focal species, as well as variables associated with background noise on the rates of these two kinds of error. The results showed a significant three-way interaction between ARU type, species identification method, and focal species. The detection of some species saw a large increase in error when using automatic species identification (as high as a 40% increase in the likeliness of an error) versus human identification, while others, like *A. americanus* were less effected (less than a 10% increase). For most species there was little difference in error between the two recording units, but for *L. clamitans* detections made by the automatic species identification software, there was 10% more probability of error when using lower quality ARU rather than a higher quality commercial one. We also found main effects of the background noise produced by traffic and rain, as well as the effect of how many individuals were calling. This indicates that all variables must be considered when choosing a monitoring method.

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CHAPTER 1: LITERATURE REVIEW

WILDLIFE MONITORING

Wildlife monitoring is a research activity which is often difficult to perform well, but when successful, can provide invaluable information for a variety of purposes. Generally speaking, the purpose of monitoring is to detect changes in the state of a system over time. When applied to the study of wildlife, monitoring is used to keep track of populations or communities of species over time, often in order to assess the effects of management practices (Yoccoz et al. 2001). Monitoring may be done on many different scales, but there has been growing interest in large-scale, multiple species monitoring efforts which are both effective and increasingly feasible due to the implementation of new technology (Manley et al. 2004). By collecting simple presence/absence data, it is possible to generate data sets spanning larger areas and longer time periods than with more intensive studies focused on only one or a few species. This is important if researchers hope to monitor the effects of large scale influences such as anthropogenic alteration of the landscape and climate change (Manley et al. 2004, Sauer and Knutson 2008).

Along with this increase in number and scale of monitoring programs has come concern about the quality of the data collected and its ultimate use to complete specific program goals. Many critics have cited problems such as a lack of explicitly defined objectives, failure to analyze data in a timely manner, and a failure to account for the increased error inherent in monitoring larger areas with heterogeneous detectability

(Gibbs et al. 1999, Field et al. 2007, Sauer and Knutson 2008). In response there has been a call for increase accountability and a new body of research aimed at remedying these problems.

Detectability

Successful monitoring hinges on the ability of a study to accurately detect change in the variable of interest (Gibbs et al. 1999, Field et al. 2007). There are many decisions when setting up a monitoring program that help to accomplish this goal. For example, the number and location of sites, the number of surveys conducted at each site, and the method used, are all factors in whether or not the data collected reflects the state of the system with an acceptable degree of accuracy and precision (Gibbs et al. 1999). In wildlife monitoring, the variable of interest is often the number of individuals or number of species. One of the problems then is that species are not always detected even when they are present, and may be misidentified. This is the problem of imperfect detectability (MacKenzie et al. 2002). There are two types of error associated with imperfect detectability; Type I errors (false positives) occur when a species is not present but is recorded as present and Type II errors (false negatives) occur when a species is present but is not detected. Both kinds of error interfere with the ability to accurately measure populations and increase bias, and therefore must be minimized and controlled (MacKenzie et al. 2002, Miller et al. 2011). Even relatively low numbers of false negatives and false positives have been shown to bias estimates (Tyre et al. 2003). Among other things, detectability is a result of characteristics of the species of interest,

biotic and abiotic factors, the method used, and the skill of the person carrying out the survey.

Tradeoffs

Of course it is not possible to conduct an unlimited number of surveys over the entire area of study with a method chosen solely for its accuracy and precision. The reality of creating a monitoring program is that there are limitations on the money, time, and personnel available to meet the project goals. These tradeoffs result in a need for careful decision making about what study design is able to detect change efficiently. Structured decision making is composed of a set of tools that are currently being developed and used to guide the decision making process. These tools systematically break down the components of a decision and analyze possible alternatives in terms of how they meet specific objectives to determine the best choice (Lyons et al. 2008). However, these tools are only effective when there is information available about each choice and its consequences. In the case of number of sites and surveys, it is generally a simple case of more is better to reduce bias (Tyre et al. 2003), however when choosing a method (especially when some methods are relatively new) the choice becomes much more complex and a researcher may not have all of the information necessary to make the best choice for their program. It is therefore important to conduct method comparison studies so that future researchers may make informed decisions that lead to monitoring programs that are effective.

ANURANS

Why Monitor Anurans?

For more than 50 years, scientists have been aware of a marked decline in amphibian populations throughout the world, with several species threatened or already extinct (Alford et al. 2001). To date, causes of amphibian declines have been linked to a number of factors, including habitat fragmentation (Knutson et al. 1999), road mortality (Carr and Fahrig 2001), disease (Skerratt et al. 2007), pollution and pesticides (Bridges and Semlitsch 2000, Davidson et al. 2002), and the effects of climate change (Blaustein et al. 2001). There is also a growing body of research which indicates that multiple factors are at play at once (Kiesecker et al. 2001, Blaustein and Kiesecker 2002, Burrowes et al. 2004). Among the hardest hit by these changes are amphibians of the order Anura, which include frogs and toads (Knutson et al. 1999, Funk et al. 2005, Skerratt et al. 2007).

Due to the large scale nature of the potential factors responsible for these declines, and the variety of species threatened, Anurans are a good candidate for large-scale multiple species monitoring. Already, they are a common focus of monitoring programs in the United States and around the world. These programs face the same tradeoffs discussed above, and there are now many new methods being developed which add even more complexity to the decision making process. With these challenges in mind, it is clear that it is important to conduct further research to increasing the effectiveness of anuran monitoring programs.

Anuran Natural History

The order Anura is the taxonomic group of amphibians that contains the frogs and toads, which are characterized by their long hind legs, smooth permeable skin, amphibious life cycle, and lack of a tail as adults (Stebbins and Cohen 1995). Their permeable skin and need for both freshwater and terrestrial habitats for completion of their life cycle makes them especially vulnerable to habitat degradation. There are over 4000 species of anurans found across the globe (Stebbins and Cohen 1995).

Decline and extinction of members of this group have far reaching implications for the ecosystems in which they are found. Frogs and toads are important both as a prey and predatory species within the food chains of the ecosystems in which they occur. In many freshwater wetland habitats, they are the predominant vertebrate consumer of invertebrates. As such, their removal is likely to result in large population increases of these invertebrates, which include insects considered to be nuisance species or disease carriers for humans (Stebbins and Cohen 1995). Monitoring of Anurans is thus important for the sake of the health of both natural and human communities who rely on them.

Anuran Acoustic Communication

One trait that sets Anurans apart from other amphibians is their almost universal use of acoustic communication for the purposes of finding a mate. During the breeding season males produce an advertisement call in order to communicate their fitness and location to potential mates (Ryan 2001). The calls are vocalizations produced by inflating the lungs and pushing air in vocal sacs located on the throat or neck. These calls are unique to each species and therefore be taken advantage of as a reliable means of

species identification. The calls of different Anuran species tend to occupy different frequencies, so that there is less overlap when two or more species are calling at the same time (Gerhardt 1994). The calls of anurans are usually a repetitive series of simple calls, with little regional variation. As ectotherms, however, their calls are affected by temperature, with colder temperatures usually associated with lower frequencies and fewer repetitions of calls (Gerhardt and Huber 2002). Breeding behavior, including calling, is generally carried out in the spring and summer months, with different peak calling times for different species. Additionally, some species are explosive breeders and only call in large numbers for only a short time period, while others will call over the course of months. There are also differences in the temporal pattern of calling in response to factors such as time of day, temperature, other species calling, and the presence of predators (Ryan 2001).

Chorusing is a behavior where acoustically calling individuals aggregate and call at the same time (Gerhardt and Huber 2002). The reason for this is thought to be simply that they are gathered together at areas where resources are concentrated during times that are optimal for breeding. This is also an explanation for different species calling from the same wetland habitat at the same time. Chorusing increases competition for both heterospecific and conspecific males to be heard, and can also be a challenge for a researcher attempting to identify all the species calling. While this may make it more difficult for females to locate a specific caller as well, it has the benefit of making the individual harder to locate for predators which may take advantage of the vocalization to find a meal (Gerhardt and Huber 2002).

Anurans will engage in other kinds of vocalizations as well, but these are heard much less often and are not broadcast in the same way that advertisement calls are. Some examples are the ‘release call’ that some males use when accidentally engaged in amplexus with another male, to let them know they have made a mistake. There are also aggressive calls that may be exchanged between territorial males (Ryan 2001).

Focal Species

In this study we focused on the most common Anurans in the Northeast in order to obtain a large enough data set for analysis. The four focal species were the Spring Peeper (*Pseudacris crucifer*), American Bullfrog (*Anaxyrus americanus*), Green Frog (*Lithobates clamitans*), and Gray Treefrog (*Hyla versicolor*).

Pseudacris crucifer is a relatively small Anuran (1 to 1.5 inches long), varying in color from light to dark brown, with a characteristic “x” mark on its back. Their calls can be described as a series of ‘peeps’ repeated up to 1.5 times per second (Wells, 2001) and is around 3 kHz (Parris 2002). They tend to call in large choruses which sound to some like jingle bells.

Anaxyrus americanus is one of two toad species found in northern New England (the other being *Anaxyrus fowleri* or the Fowler’s Toad). Unlike frog species they have dry and bumpy skin with a white underside covered in black specks. Their call is a long trill that can last up to 15 seconds and is around 1.5 to 2 kHz (Howard and Young 1998).

Lithobates clamitans has a somewhat variable appearance, but is generally mottled green and brown and an adult is between 2.5 to 3.5 inches long (Andrews 2005). The call is often compared to the plucking of a loose banjo string and is a single ‘plunk’

repeated less frequently than the other frogs and toads in this study. The dominant frequency is also lower at around 1 kHz (Bee et al. 2001).

Lastly, *Hyla versicolor* is from 1 to 2 inches long and has a gray and light green pattern that looks much like 'lichen' on its back (Andrews 2005). They have a loud, short trill with dominant call frequencies at both about 1 and 2 kHz (Gerhardt and Doherty 1988). They often call from the trees rather than by or in the water as other species do (Andrews 2005).

Figure 1. shows estimates of the calling times and dates of these Anurans in Vermont according to reports sent in to the Vermont Reptile and Amphibian Atlas (Andrews 2005). *Pseudacris crucifer* begin calling in mid-March, peak at around May 1st, and continue calling into late to late July. *Anaxyrus americanus* begin calling later, in the beginning of April, peak at around May 1st as well, and also continue calling into mid-July. Both *Hyla versicolor* and *Lithobates clamitans* begin calling around the middle of April and end at the beginning of August, however, *H. versicolor* peak early in June, while *L. clamitans* peak in early July.

ACOUSTIC MONITORING

There are many methods of monitoring change in anuran populations and communities (visual counts of individuals and egg masses, trapping using drift nets, and many more) but due to their breeding call behavior, one of the most commonly used methods is acoustic monitoring (Heyer et al. 1994). This method of detecting the species and number of individuals by the sound of their calls has been used by scientists for many

decades and is still one of the most popular methods today (Dorcas et al. 2009). The calls of a species are unique and relatively easy to learn, which means that even relatively inexperienced listeners can be trained to identify calls. Now, with the advent of recording devices and the speedy rise of computing technology, there are new ways to supplement or replace this age old method of anuran monitoring.

Traditional Methods of Acoustic Monitoring

Usually referred to simply as a frog and toad call survey, this technique has been used for scientific monitoring efforts as early as the 1950s and is still the most commonly used methods of monitoring anurans (Dorcas et al. 2009). It is used by several well-known monitoring programs around the world and by programs here in the United States, such as the USGS North American Amphibian Monitoring Program (NAAMP). For several years NAAMP has employed volunteers to perform call surveys along roadsides to generate a country-wide multispecies dataset (Weir et al. 2005). In general, the method consists of a human surveyor going out into the field and listening for frog and toad calls for a 5 or 10 minute period. The surveyor then records the species heard and the time and location they were heard at. They may also record abundance based on some call index of the number of individuals heard calling (Dorcas et al. 2009). Studies have shown that this method can produce reliable presence/absence data (Genet and Sargent 2003, Nelson and Graves 2004, Weir et al. 2005), especially with common species (Crouch and Paton 2002). However, for more rare species, or for species that call sporadically, this method may not be as effective (Dorcas et al. 2009).

Abiotic factors such as weather, temperature, and anthropogenic noise as well as biotic factors such as the presence of a predator (or even the surveyor themselves) also greatly affect the calling behavior of anurans so that they may or may not be calling when a survey is taking place (Weir et al. 2005, Saenz et al. 2006). Even if these factors do not stop the frogs from calling, they may keep the surveyor from hearing them due to noisy conditions like heavy rain, traffic noise, or wind. The NAAMP protocol and other programs seek to counteract this by setting rules about the conditions that indicate a survey should be abandoned. However, not all of the factors determining the probability of calling are known, and there is always the chance that a species is present but silent. There is also disagreement over the adequate length of a survey, time, and the number of surveys needed over a season in order to detect the majority of species present (Bridges and Dorcas 2000, Crouch and Paton 2002, Pierce and Gutzwiller 2004).

Another problem is inter-observer variation and variation for a single observer at different points in time. Observers vary from one another in the amount of errors they make depending on their skill and individual observers even vary from survey to survey or even over the course of a survey (Lotz and Allen 2007). Studies have shown that this variation is especially true for estimates of abundance because individual frogs in a chorus are difficult to count and estimate are somewhat subjective (Genet and Sargent 2003). The biggest problem with these errors is that they are relatively unknown unless observers work in pairs and compare their surveys, or if surveys are recorded and replayed to determine errors in detection made by a human surveyor.

Automation in Monitoring: Recording

With the advent of digital recorders a few decades ago came the ability to supplement call surveys with recordings of the calls for later review. Recording is a method that has been used for several years, especially for bird point count studies (Parker 1991). Having a recorded copy allows for repeated play back of the calls during the course of a survey so that detections can be verified. Several studies have used this method to check the accuracy of human observers (Genet and Sargent 2003, Rempel et al. 2005, Lotz and Allen 2007).

Increasingly recorders are being used not only to supplement or assess traditional call surveys, but to replace them completely. Several different models of autonomous recording units (ARUs) have been developed to be installed at a survey site and left there to record autonomously with no human present (Acevedo and Villanueva-Rivera 2006, Agranat 2007, Dorcas et al. 2009). Recorders are weather proof and are able to record at predetermined times. They may be able to stay in the field for month at a time with human interference needed only to change batteries and to collect data. This allows for recording on a flexible schedule, with longer and more repeated surveying than would be possible with human observers. Also, by recording for long periods of time it is possible to determine the best conditions and time periods for sampling (Steelman and Dorcas 2010, Shearin et al. 2012). This method is especially useful in remote locations (Peterson and Dorcas 1992), detection of rare species , and for surveying large areas with few personnel (Dorcas et al. 2009). However, it is not as effective for more quietly calling species which are more difficult to capture with the microphone than with the

human ear (Hsu et al. 2005). The recording technique has been used successful for a range of species, including Anurans, and in addition to creating your own ARU, there are now commercially available recorders (Agranat 2007). Excitingly, recording surveys also allows the use computer programs to help identify species or even identify species completely autonomously.

Automation in Monitoring: Species Identification

In many ways, computers have revolutionized the way we do science. Have a digital copy of a call survey means that it may now be viewed and manipulated using a computer. Earlier technology allowed for the viewing of calls in the form of a spectrogram which could be created by converting sound into an analog signal representation (Altes 1980). Viewing sounds in this way was helpful for picking out calls visually as well as acoustically. In addition, by the creating a digital copy of the sound, there was a huge increase in the ability to view, manipulate, and even automate the process of detecting the calls of different species.

Manually listening through surveys is time consuming and it takes even more time when stopping and replaying the recording to make certain of detections. This method certainly allows for a reduction in detection errors, but the cost in time may be prohibitive, especially for large multispecies monitoring efforts. Recently there have been several computer software programs that have been designed to automatically detect species by their sounds (Agranat 2009). Generally they work by being given the parameters of a call of interest and then searching through the recording for similar sounds. This method has been used for the purposes of speech recognition for many

years (Juang and Rabiner 1991), and is now making its way into the field of wildlife monitoring. Amphibians are a good candidate for this method due to their fairly simple and repetitive calls, and success has been had with this method (Waddle et al. 2009). However, though the software is catching up, there is still increased error when computers automatically identify species than when a human surveyor makes identifications (Agranat 2009, Waddle et al. 2009).

Automatic Identification using Hidden Markov Models

There are several software programs which use different methods of automatic identification of sounds. One which has been used in several studies and is available for commercial use is Song Scope by Wildlife Acoustics, Inc. which uses Hidden Markov Models in order to make identifications (Agranat 2007, Waddle et al. 2009). Hidden Markov Models (HMM) have been used for decades in human speech recognition and have only relatively recently been adapted for use in recognizing animal vocalizations (Juang and Rabiner 1991). In the simplest terms, this is a statistical method that breaks down a signal (in this case a sound) into several component parts called model ‘states’, and compares them to other signals in order to assess how closely they match (Rabiner 1989).

In Song Scope, a human user compiles a set of examples of a call of interest and then uses the software to create a single ‘recognizer’ that incorporates all of the calls. The recognizer is an HMM which breaks the sound down into several ‘states’ that included time and frequency information about that part of the sound. More complex sounds would have more states than a simple sound. Song Scope then uses an algorithm

to detect signals within an audio recording and comparing each one to the recognizer that was built. The result is a list of potential calls that are similar to the recognizer, along with statistics on how closely they match (Agranat 2009).

File Formats

Once audio data is recorded, it can be stored in a number of formats. Some formats compress the data to allow for more storage, but in doing so they eliminate some of the information stored. The WAV file format is uncompressed and therefore takes up a lot of space, but it is lossless meaning that it includes all of the audio information collected by the microphone (Brandenburg 1999). MP3 is an example of a compressed and lossy file format. Some of the audio information is deleted in order to conserve space. This format conserves audio information especially at the range of human hearing and eliminates audio information in the higher and lower ranges where it makes little difference to a human listener (Brandenburg 1999). This is why music is often stored in this file format. Now that storage is relatively cheap, recordings for wildlife monitoring are made with WAV or other uncompressed formats, though some studies have shown that for human listeners, MP3 format is just as good (Rempel et al. 2005). Storing in MP3 allows for ARUs to be left for longer periods of time since the audio files take up less space and more can be recorded before the ARUs memory is full. Whether this lower quality file makes a difference for automatic computer identification has yet to be seen as most has been done in WAV format to date (Dorcas et al. 2009).

CHOOSING A METHOD

As we can see, for large scale presence/absence monitoring of anurans, the choice of method may not always be obvious. Automation is monitoring in only likely to increase in the future, and as technology gets better it is tempting to simply choose this new and more efficient method over older methods, even when these method might suffice or even be more effective. On the other hand, many researchers may stick to the more traditional methods due to their tried and true nature, even though automation could really allow for a much more effective monitoring program. The best choices, however, are made by taking into account the specific needs of a program and choosing a method that best suits those needs. This means research into the tradeoffs of each method must be performed to make information available about the benefits and costs of each method. Some of these tradeoffs are discussed below.

Bias

Bias refers to whether the estimates from a study are actually close to the true values for the population of interest (Yoccoz et al. 2001). Imperfect detectability is one of the main sources of bias when monitoring wildlife, and while lower when humans perform species identification, it is harder to verify and account for when there is no recording to accompany the surveys. In general, human identification still tends to be more accurate, but automatic identification software is catching up fast (Agranat 2009). There is also the possibility that while humans make less errors on the whole, that automatic identification may be on par or even better at detecting certain species or under

certain conditions. This interaction of method and species or method and recording environment has yet to be fully investigated.

Precision

Since data collected is only from a sample of the whole population you wish to make inferences about, there is uncertainty about the estimates obtained. Precision refers to the amount of uncertainty (Yoccoz et al. 2001). One of the ways to obtain higher precision is to increase the number of sites and surveys. While using volunteers for traditional call surveys means that more area can be covered, ARUs have the advantage of being able to stay out in the field for months and record many more surveys and at many more sites than would be possible for a person. Another advantage is with automation there is less variation from survey to survey. Different observers vary in their ability to detect species and their attention may wane over the course of a survey or a night or surveys. Short of mechanical failure, recording units and the computer software are always performing tasks in the same way.

Costs

With the program budget as a ubiquitous constraint, there are costs associated with all methods that must be considered as well. There is the monetary cost of either paying field technicians (or costs associated with volunteer recruitment and training) or buying ARUs. Commercial ARUs may be costly so making your own units might be a better choice if possible, though these are not as tried and tested as commercial units. In either case there will be the additional cost of data storage for the large digital recording

files generated by the units. The cost of for automatic identification software is high as well, though some programs have free trials versions.

There are also time costs to consider, especially since timely analysis of the data is stressed as one of the keys to a successful program. As mentioned before it is time consuming for a human to perform call surveys or to listen to recorded surveys in real time. Automatic identification cuts down on this time, at the cost of an increase in error as discussed above.

Choice of acoustic monitoring methods for anurans is a perfect example of how these factors play in to designing a monitoring program. A program must have clear objectives in order to choose a monitoring method that is most appropriate for its goals. Every method comes with its own benefits and drawbacks in terms of cost, time, and the types and amount of error associated with it. With these tradeoffs in mind, it is easy to see why a method must be chosen carefully in order to make a program a success.

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CHAPTER 2: A COMPARISON OF ACOUSTIC MONITORING METHODS FOR COMMON ANURANS OF THE NORTHEASTERN UNITED STATES

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INTRODUCTION

The purpose of monitoring wildlife populations is to detect changes in populations of species over time, often in order to better understand population dynamics or to assess the effects of management practices (Yoccoz et al. 2001). Anurans have been the focus of a large number of monitoring programs both in the United States and around the world due to their rapid wide-spread population decline (Alford et al. 2001). Many programs monitor anurans through the unique breeding calls which males emit in order to attract a mate (Dorcas et al. 2009). This technique has been employed for many years and is used by several well-known monitoring programs, such as the USGS North American Amphibian Monitoring Program (NAAMP) which employs volunteers to perform frog and toad call surveys across the country (Weir and Mossman 2005).

Traditional call surveys, in which a human observer is sent out into the field to listen for different species of anurans, have been practiced for decades (Dorcas et al. 2009). This method is low on material costs and has been shown to work well for collecting presence/absence data (Genet and Sargent 2003, Nelson and Graves 2004, Weir et al. 2005). However it is relatively high in time cost. Additionally, the rate of error can be difficult to ascertain because different observers have varying levels of experience and even different hearing capabilities which may yield biased estimates (Crouch and Paton 2002, Genet and Sargent 2003, Lotz and Allen 2007). Another problem is that species may be present but not calling during the relatively short period which marks the official survey. Finally, many abiotic and biotic factors including

temperature, weather, and sometimes even the presence of the observer may affect calling behavior (Bridges and Dorcas 2000, Saenz et al. 2006).

Audio recordings made in place of human surveys are one possible way to counteract these drawbacks. The utility of audio recording for wildlife monitoring is widely documented, both as a complement to traditional field methods (Peterson and Dorcas 1992) and as a method of data collection on its own (Acevedo and Villanueva-Rivera 2006, Agranat 2007, Dorcas et al. 2009). Autonomous recording units (ARUs) are weatherproofed and highly programmable so they may record on a schedule for long periods of time with very little maintenance (Peterson and Dorcas 1992). This makes it possible to sample at sites over long periods of time, increasing the likelihood of detecting species that might not be calling when an observer is present (Dorcas et al. 2009). Recording during or in place of human surveys allows re-examination and re-analysis of the audio data in order to achieve a higher degree of accuracy.

Yet another choice researchers have is to create their own ARU or purchase a commercially available unit. Cheaper units can be home-made using off-the-shelf digital recorders and widely available, simple electronic components for only a few hundred dollars (Peterson and Dorcas 1992). They may also be set to record in more compact digital formats like MP3, which requires less storage space. However, these inexpensive off-the shelf recorders generally record lower quality audio due to fewer or poorer quality microphones. Also, recording in MP3 format, while producing smaller audio files, results in some loss of audio information. This is not the case for large uncompressed

audio formats like WAV, which are typically used in high quality ARUs (Dorcas et al. 2009).

With a digital copy of a call survey, spectrograms (visual representations of the acoustic information) can be used to scan data more closely for calls of the species of interest (Altes 1980). In addition, software is now available that allows researchers to quantitatively characterize target sounds made by a species of interest, enabling computers to automatically scan through hours of audio recordings and find similar sounds (Agranat 2009). This means that both collecting and analyzing surveys can be highly automated, allowing for the fast processing needed for large-scale data sets. These new methods are not without their short-comings though. Recorders may not be able to detect more quietly calling species (Hsu et al. 2005) and commercially available units can be expensive. Also, it is unknown if recordings from higher quality versus lower quality ARUs affects species identification capabilities of humans or these new computer software programs.

Reducing bias and increasing precision of a population estimator, such as species abundance or occupancy rate, are hallmark goals in designing any monitoring program (Yoccoz et al. 2001). The potential for errors in detection and identification exists for all methods (human surveys and recordings) and may increase the bias of monitoring estimates. Errors include false negatives (a species is present but remains undetected) as well as false positives (a species is not present but is incorrectly detected). Such errors have been found to have a much greater effect on the interpretation of monitoring data than previously assumed (Tyre et al. 2003).

With all of the different options available for monitoring anurans by their calls, the question is not which method is best, but which method is best suited to a particular monitoring program. A certain program may need to focus on keeping costs low, another might focus on minimizing false negatives, and yet another might need a high amount of automation for speedy processing. The call characteristics of a certain species might make it more easily detected by a particular method, or one method may be better than the others at detecting species in a location with a higher volume of background noise. Given these multiple considerations, a decision analysis framework (Belton and Stewart 2002, Mendoza and Martins 2006) can be used to allow researchers to evaluate alternatives (such as recording method and identification method) with respect to multiple, competing objectives (such as minimizing error rates while also minimizing cost).

In this study, we collected acoustic recordings of four anuran species at 10 sites in the Northeastern U. S. with the goal of assessing detection error for two alternative types of ARU and four methods of species identification. We also assessed how calling intensity and background noise affected detection error in order to understand the complexities of the soundscape in which a method must work.

Our objectives were to: (1) Compare detection outcomes (false positive, false negative, true positive, and true negative) for 5 minute call surveys using two different recorders (Olympus and Song Meter) and four different species identification methods (traditional human call surveys and completely automated computer identification utilizing 3 different settings) for the detection of four Anuran species (*H. versicolor*, *P.*

crucifer, *A. americanus*, and *L. clamitans*); and (2) For surveys in which species are present, determine how the number of species present and their call index affects error rates.

METHODS

Study Sites

Ten survey sites were located at three state and national parks in Vermont and New York (Figure 2). We chose sites near freshwater habitats such as a wetland or pond which had previously documented anuran calling activity. Sites were located at least 300 meters apart to avoid recording frogs at one site which were also audible at another site. Marsh-Billings-Rockefeller National Historical Park (4 sites) is a 220 hectare park located in Woodstock, VT. The property ranges from approximately 200 to 450 meters in elevation and is primarily dominated by northern hardwood forest, but also contains 13 hectares of open hay fields (Faccio 2001). Gifford Woods State Park (2 sites) is a 5 hectare park located in Killington, VT directly adjacent to the Green Mountain National Forest. The park is at an approximate elevation of 480 meters, and is unique in containing a large area of relatively undisturbed old hardwood forest. Saratoga National Historical Park (4 sites) is located in Stillwater, NY. The park consists of approximately 1,100 hectares, including 320 acres of managed grassland (Cook et al. 2012).

Focal Species

The focal anurans for this study are some of the most common in Vermont and New York: spring peeper (*Pseudacris crucifer*), green frog (*Lithobates clamitans*),

American toad (*Anaxyrus americanus*), and grey treefrog (*Hyla versicolor*). *P. crucifer* is a relatively small Anuran with a characteristic “x” mark on its back. Its calls can be described as a series of ‘peeps’ repeated up to 1.5 times per second (Wells, 2001) at a frequency of around 3 kHz (Parris 2002). They tend to call in large choruses which sound to some like jingle bells. *Anaxyrus americanus* is a toad whose call is a long trill that can last up to 15 seconds at a frequency of around 1.5 to 2 kHz (Howard and Young 1998). *Lithobates clamitans* is generally mottled green and brown with a call that is a ‘plunk’ often compared to the plucking of a loose banjo string. The dominant frequency is also at around 1 kHz (Bee et al. 2001). Lastly, *Hyla versicolor* has a gray and light green ‘lichen’-like pattern on its back (Andrews 2005) and has a loud, short trill with dominant call frequencies at both about 1 and 2 kHz (Gerhardt and Doherty 1988).

Breeding for *P. crucifer* begins in mid-March, peaks at around May 1st, and continues into late July. *A. americanus* begins calling later, in the beginning of April, peaks around May 1st as well, and also continues calling into mid-July. Both *H. versicolor* and *L. clamitans* begin calling around the middle of April and end at the beginning of August, however, *H. versicolor* peaks early in June, while *L. clamitans* peaks in early July (Figure 1; Andrews 2005).

Field and Recording Methods

Recordings were collected from May 1st to July 1st in 2010, which coincided with the peak calling times for the focal anuran species. At each site, we recorded anuran calls concurrently with two ARU units: (1) Wildlife Acoustics® Song Meter SM1 and (2) a homemade recording unit that used an Olympus® voice recorder (Table 1, Appendix A,

and Appendix B). The Song Meter unit had a weatherproof outer case with two weatherproofed omni-directional microphones which faced in opposite directions at the top of the unit (Appendix B). We recorded in WAV format for increased quality of the audio data, and powered the unit with a 12v battery attached by a cord to the base of the unit (see also <http://www.wildlifeacoustics.com/>).

The second type of recording unit was a home-made autonomous recording unit that used a DM-420 Olympus digital voice recorder as the recording component (Table 1 and Appendix A). The Olympus recorder, an SD card reader, and a battery pack were placed inside a weatherproof Pelican Case® which was modified for this purpose. We built an external omni-directional microphone which attached to the bottom of the unit and could be hung from a branch. The unit was operated using the built-in features of the Olympus recorder which allowed for a choice of data storage types and a function to set the timing of recordings. We recorded in MP3 format for increased data storage capability (see Appendix B for full details on deploying and maintaining both recording units).

At each site, both units were affixed to a tree at approximately 5 feet above the ground and with an unobstructed view of the wetland or body of water at that site. All units were set to record continuously, and the batteries and SD cards of each unit were exchanged every 2 weeks.

Sites were visited by C. Brauer every two weeks to record data that would normally be collected during a traditional call survey (during the time from dusk to midnight). These measurements were adapted from the NAAMP frog survey protocol

and included temperature, weather conditions, and a wind and noise index estimate (see Appendix B for codes). After these data were collected, a 5 minute survey was marked on the recording by loudly announcing “start survey” and “stop survey.” Two consecutive 5 minute survey periods were marked at each site visit. This procedure was carried out every two weeks for a total of 5 visits per site, resulting in a total of N=100 surveys (10 sites * 2 surveys per visit * 5 visits). However, recordings for 13 surveys were corrupted (see below), and thus 87 surveys were analyzed.

Species Identification Methods

For each 5 minute survey recorded by each ARU, we examined the data in depth in an effort to correctly identify every species present or absent in the audio data. Each minute of each survey on each recording unit was viewed as a spectrogram using Song Scope® software (Wildlife Acoustics) and concurrently evaluated with audio in order to be sure of identifications. This examination of the recordings was meant to create a set of data which were very likely to be the most accurate, and therefore the standard to which the other methods are compared. Thus, this “gold standard” dataset consisted of $4 \text{ species} / \text{min} * 5 \text{ minutes} / \text{survey} * 87 \text{ surveys} = 1,740$ records, in which each record contained a 0 if the species was truly absent and a 1 if the species was truly present for any given minute in any given survey. In addition, if a species was present, we recorded a calling index from 1 to 3 indicating the range from an individual caller (call index = 1) to a full chorus of the species (call index=3). We also recorded information about background noise across the 5 minute survey. The major sources of noise were rain (for which each survey was given a 1 for rain present or 0 for rain absent)

and traffic (number of cars heard during a survey: 0, 1, 2). Given this “gold standard” of species known to be present on the audio recordings, we assessed the false positive, false negatives, true positive, and true negative rates of recorded target species for each recording method (Song Meter and Olympus) analyzed with four alternative identification methods (traditional human call survey and three completely automated computer identification templates). Each of these identification methods is described next.

Human Identification Method

First, we simulated the process by which humans would visit a site and conduct a survey in person. In the lab, and prior to any other work with the recordings, C. Brauer listened to each survey with no stops and no aid from computer software to visualize or augment the recording. For each minute of the survey, she recorded the species of frogs heard calling along with a calling index number from 1 to 3 indicating the range from an individual caller (call index=1) to a full chorus of the species (call index=3). Throughout the survey, the volume of playback was kept at a comfortable listening level, and was not turned up or down in order to aid in hearing more distant calls.

Computer Identification Method

For each of the four species, we created three alternative “recognizers” in Song Scope, a bioacoustics analysis tool developed by Wildlife Acoustics, Inc. Song Scope can be used to create recognizers from sample files in WAV format. The audio data for the Song Meter units was recorded in WAC format, which is a lossless compression format specific to Wildlife Acoustics, Inc (Agranat 2009). Before analysis, these files

were converted to WAV files using the free WAC to WAV software available from Wildlife Acoustics, Inc. The Olympus ARUs recorded audio data in the lossy MP3 format, and were converted to WAV format using the free RealPlayer converter software available for download online (RealNetwork, Inc.).

We used Song Scope to develop recognizers for each species based on an input library of example calls. The sounds for creating the recognizer were collected from either professional recordings (Elliot 2004) or were verified calls recorded by the NPS Southeast Coast Network at various parks in their region. Figure 3 illustrates a sound file in Song Scope, where the top panel provides the call in waveform (sound amplitude), and the bottom panel shows the corresponding spectrogram. Users annotate known calls, and these calls are used to create a recognizer. In Song Scope, recognizers are created by a method that uses a Hidden Markov Model (HMM) to determine the frequency states within a call as well as the sequence of states that make up the entire call. We used between 26 and 156 example calls to construct one recognizer for each species (Table 2). The number of HMM states varied from 6 (*H. versicolor*) to 26 (*L. clamitans*), and cross-training accuracy ranged from 73% - 83% (see Table 2, Recognizer Performance Statistics).

One recognizer was developed for each species, but three different settings were used when we used Song Scope to automatically scan the recordings and identify sounds (Table 2). Every detection made by the software is assigned a ‘quality’ and ‘score’ which measure how closely the detected sound matches the recognizer (from 0 to 100). The ‘quality’ relates to the number of HMM states in a sound as compared to the recognizer

(the more closely the number of states match the higher the ‘quality’), while the ‘score’ is a normalized probability of how closely a sound matches all of the HMM states that make up the recognizer (a higher probability results in a higher ‘score’). Simply put, a high quality means a high score is more likely to be a correct match (Agranat 2009). In order to run the software, a minimum value for these two statistics must be set in order to determine a cutoff for how similar a sound must be to the recognizer in order to be included in the list of detections. A lower setting for these values results in many more detections accepted and reported, resulting in a low false negative rate (few actual calls are missed), but a relatively high false positive rate (many calls are not actually the species the recognizer was set to detect). On the other hand, high cutoff values for the ‘quality’ and ‘score’ result in fewer calls detected, with fewer false positives (incorrect detections), but more false negatives (true calls of the species that were not detected because their correlation with the recognizer was too low).

For each species, we ran its unique recognizer three times with low, medium, and high settings for the quality and score cutoff (called SS1, SS2, and SS3 respectively; Table 2) in order to assess the effect of these settings on error rates. These cutoff values for quality and score were species specific. Each audio file recording containing a 5 minute survey was opened, a recognizer was selected, a quality and score setting (SS1, SS2, or SS3) was chosen, and the automatic detector was run. The result was a list of sounds found within the data that matched the recognizer, along with their associated ‘quality’ and ‘score.’

Every minute of every survey was analyzed with all four methods of species identification (human, SS1, SS2, and SS3). The result was four sets of presence and absence data for each of the focal species in every minute of every survey recorded by each ARU.

Data Analysis

We compared the detections for each recording method and species identification method (8 combinations) with the “gold standard” dataset ($N = 1,740$ records). Each record in the gold standard dataset was then used to classify each outcome as 1 of 4 types: (1) If the species was actually present and was detected, the outcome was a true positive; (2) if the species was present and not detected by a method, it was considered a false negative; (3) if the species was not present and was not detected it was considered a true negative, and (4) if the species was not present but was detected it was recorded as a false positive. These four outcomes were used as response variables for analysis. The resulting dataset consisted of 1,740 records for each recording method ($n = 2$) and identification method ($n = 4$) combination ($N = 8 \times 1,740 = 13,920$ records). A single record indicated the species detected, the true presence or absence of that species, and the resultant classification of the outcome.

Objective 1. We used a multinomial logistic regression model to assess detection rates (false positive, true positive, false negative, true negative) as a function of several independent variables: recording method, the species identification method, the species being detected, the interactions between these three variables, and the presence of rain and traffic background noise. All analyses were conducted using SAS (SAS Institute,

Inc.) with the procedure, PROC SURVEYLOGISTIC, which uses maximum likelihood methods to fit multinomial regression models for discrete response data, and allows estimation of parameters when data are clustered (our observations were clustered by site and date). This procedure fit the model, assessed the significance of effects, and then we were able to calculate the predicted probabilities of each outcome based on the model fit.

Objective 2. For surveys in which a species was calling (truly present), we evaluated how ‘call index’ and ‘number of species calling’ affected two types of outcomes: present and detected (true positives) and present but undetected (false negatives). We used PROC LOGISTIC in SAS to evaluate the rates of false negatives as a function of recording method, species identification method, species, call index, and number of species calling. As with objective 1, we used site and date as a clustering variable to account for the fact that observations within a survey were not independent, and two surveys were conducted in the same night for a given site. Because there were very few false negatives or positives when humans were used as an ID method (< 1% of each kind of error was made), we did not include them in the analysis for this objective.

RESULTS

Of the 100 surveys, 13 were corrupted due to SD card failure in the field, resulting in 87 total surveys for analysis. Across these 87 surveys, the “gold standard” method was used to determine the presence or absence of each of the four species in each minute of the survey. The result was 1,740 records, of which 586 were presences and 1,154 were absences. Overall, *P. crucifer* was present most frequently (recorded in 279

different minutes), followed by *L. clamitans* (150 minutes), *H. versicolor* (117 minutes), and *A. americanus* (40 minutes; Figure 4). Of the five visits to our sites, the first visit was the only one during which all four species were recorded (Figure 4). *A. americanus* peaked early in the season, while *L. clamitans* increased as the season progressed (Figure 4). *P. crucifer* and *H. versicolor* remain relatively constant throughout until the end of our survey time period (Figure 4). The calling patterns documented from recordings generally mirrored the temporal calling patterns documented by Andrews (2005; Figure 1).

The comparison of the gold standard presence and absence data to the detections made by each recorder/species identification combination resulted in 13,920 records, of which 1,021 were false negatives, 1,423 were false positives, 7,809 were true negatives, and 3,667 were true positives (Table 3). Overall there were some similarities and differences in the frequency of the four possible outcomes when broken down by recording method, species identification method, and species (Table 3). First, there was little difference in outcome frequencies between the two ARUs. Second, the identification methods varied substantially in their outcome rates. There were 1021 total false negative records; only 4% of these were human identification errors and 60% were associated with computer identification method Song Scope 3 (Table 3). There were 1423 false positive records; only 2% of these were human identification errors and 66% were associated with computer identification method Song Scope 1 (Table 3). The differences between the Song Scope recognizers were expected because we intentionally varied the settings; the SS1 setting minimized false negatives, while the SS3 setting

minimized false positives and SS2 had intermediate settings (Table 2). Finally, across species, *A. americanus* had the lowest frequency of both kinds of error (3% of the total false negatives among species, and 9% of the total false positive records among species). *L. clamitans* had the highest error rates (51% of all false negative records and 29% of all false positive records, Table 3).

Objective 1. Effects of Recording Method, Species Identification Method, Species, Vehicles, and Rain on Outcome Classification Rates. The multinomial logistic regression model was highly significant compared to a model with no covariates (Table 4; -2LogL Intercept Model = 30642; -2LogL Intercept and Covariate Model = 23357; Likelihood Ratio Chi Square = 7489; df = 102; $p < 0.0001$). The results of the analysis of effects (Table 4) show that there is a strong ($p < 0.0001$) three-way interaction between the variables recorder, ID method, and species as well as a marginally significant main effects of rain ($p = 0.059$) and cars ($p = 0.063$), indicating that all of these variables affect the classification rates (true positive, true negative, false positive, false negative). As such, the classification rates are unique for each recording method, ID method, species, and survey condition. Maximum likelihood parameter estimates and their standard errors are provided in Table 5 (see Appendix D for converted probabilities). We used effect coding as our coding scheme (Table 8).

Given the unique outcome classification rates, Figure 5 shows the probability of each of the four outcomes for each of the 32 possible combinations of recorder, species ID, and focal species. The left column of Figure 5 depicts results recorded with Olympus ARUs, while the right column of Figure 5 depicts results recorded with Song Meter

ARUs. The first row of charts in Figure 5 depict results when the identification method was a human; the second, third, and fourth rows in Figure 5 depict the results for the three computer-mediated species identification settings. Within each graph the four outcome rates are shown for each of the four focal species. Due to the significant interactions, results from each combination of recording method, ID method, and species must be evaluated separately.

Within Species Differences in Error Rates

For *H. versicolor*, the results showed little difference between the two recorders (no more than a 1% difference in error regardless of the species identification method). The increase in error rates between human and Song Scope identification methods was stark with error rates jumping from under 1% for human identification to between 20% to 40% total error for the different Song Scope recognizer settings (Figure 5 c-h). The same tradeoff existed with error in SS1 made up mostly false positives (36% to 38% for Olympus and Song Meter, respectively), and SS3 made up of primarily false negatives (18% to 17%), but overall error was higher for SS1, whereas for some other species it was roughly the same for all Song Scope recognizer settings.

The results for *P. crucifer* also showed little difference in the probability of a false positive or false negative between Olympus and Song Meter recording units. There was only a 2.6% or less difference in error rates between recorders for any given ID method. For both recorders, there was a large increase in the probability of an error when using Song Scope for identification versus human identification. With human identification, both false negative and false positive rates were negligible (Figure 5 a-b). However, for

the three different Song Scope settings, the total amount of error ranged between 20-25% (Figure 5 c-h). Total error remained roughly the same, but the SS1 errors were composed mostly of false positives (24% to 25% on Olympus and Song Meter recordings, respectively), while the SS3 errors consisted of mostly false negatives (23.6% to 23.9%), with SS2 falling in between.

A. americanus showed the least probability of overall error, with no more than 10% combined error for any recorder or identification method combination. Like *P. crucifer* and *H. versicolor*, there is very little difference between recording units (around 1% on average), but there is much less of an effect of species identification method. False positives only ranged as high as 10% for SS1 and the overall error rate for SS3 is only 3% in total (Figure 5 a-h). This species showed both the least effect of automatic species identification versus human identification as well as the smallest trade off in the types of error between SS1 and SS3.

L. clamitans had the highest overall error rate, and these errors are by far most likely when Song Scope is used to identify calls. With human identification, however, there was roughly the same amount of error as with the other species (less than 4% total for the Olympus recordings and less than 2% for the Song Meter recordings). Unlike the other species, *L. clamitans* showed a significant difference in false positive error rates between recording units, particularly when SS1 was employed as the method of identification. There was about a 35% probability of false positives when SS1 was used on Olympus recordings and about a 26% probability when SS1 was used on Song Meter recordings. This trend decreased with SS2 and SS3, which have a lower difference in

false positive error rates (6% and less than 1% respectively) between the different recording units (Figure 5 c-h). The lowest false positive error rates for this species occurred with Song Meter recordings and SS3 identification. Like *P. crucifer* and *H. versicolor*, this species had a high tradeoff for false positives and negatives when using automatic identification, and of all the species, *L. clamitans* was the most affected by recording method.

Between Species Differences in Error Rates

Across all recording methods, identification methods, and species, the rate of false positive errors ranged from 0% to close to 40%, while false negative errors ranged between 0% and 34% (Figure 6). Human identification resulted in the lowest likelihood of false positives for all species, with the species most prone to error, *L. clamitans*, still having < 5% error. In Figure 6, the human identification results are clustered together tightly below 5% probability for both false positive and false negative error. When using Song Scope for identification, there was a much larger range in how accurately species were identified. Likewise, for SS3 (which was designed to minimize false positives), there was close to 0% probability of false positives for all species (Figure 6). For *A. americanus* the resulting vulnerability to false negatives for SS3 is minimal (less than 3%). The tradeoff for *P. crucifer*, *H. versicolor*, and *L. clamitans* is much more significant with 18%, 24%, and nearly 35% respectively (Figure 6). Likewise for SS1 (which is optimized for false negatives) there was a lower probability for false negatives, but the values ranged much more than they do for the false positives of SS3. Most of the species had under a 5% probability of a false negative, but *L. clamitans* had a rate of

10%, indicating that even with false negatives minimized, it still proved difficult for the Song Meter recognizer to detect the calls of this species. Again there was an increase in the probability of false positives in response to false negatives being minimized in SS1, with *H. versicolor* showing the greatest tradeoff, with close to a 40% error rate.

For most of the species the two recorders (depicted in light and dark gray) are within a few percentage points of each other. However, as discussed previously, the false positive probabilities for *L. clamitans* were significantly different, especially when detection was done by SS1. As expected, the values for the probabilities of error for SS2 fell in between those for SS1 and SS3 (Figure 6).

Effects of Rain and Cars on Detection Outcomes

There was a small main effect of both rain and cars on the detection outcome (Table 4 and Table 5 coefficients, the reference category for classification is ‘true negative’). Analysis indicated there was a marginally significant effect of rain on the probability of a false positive or false negative outcome. When you adjust for the other variables in the model, the odds ratio estimate for a false positive was 0.575 (95% confidence interval = 0.366 – 0.905) when there was no rain versus when rain was present. This indicates that there was a decreased chance of a false positive when it was not raining (and thus an increase in false positives when it was raining). This result was expected in that the sound of rain has itself been cited as possible source of false positives and in general makes it more difficult to correctly identify species (Weir and Mossman 2005). Interestingly, the odds ratio for false negatives when there is no rain versus when there is rain is 2.2 (95% confidence interval = 0.872 – 5.659). This indicates that false

negatives increased when there was no rain and decreased when rain was present. One possible explanation is that frogs are known to call more often when it is raining or has just rained (Bridges and Dorcas 2000), and thus there were simply more opportunities to hear a species calling when it was raining than when it was not.

The analysis of effects also indicated that noise caused by cars was marginally significant (Table 4); however, the maximum likelihood estimates were not significant for any of the four possible outcomes. The lowest ($p = 0.1$) was for the effect of cars on the probability of a false positive outcome. When we adjust for all of the other variables in the model, the odds ratio for a false positive outcome is 1.6 (95% confidence interval = 0.687 – 3.817) when there are no cars when compared to cases where 2 cars passed by during a survey minute. This indicated that there was an increase in the odds of a false positive outcome when there were no cars passing by. This result was unexpected and is difficult to interpret, but it is notable that we performed many tests which increases the likelihood of a significant result by chance alone. There were also many incidences where no cars passed by, some where one passed, and only a few where two cars passed by during a minute of a survey.

Objective 2. Effects of Call Index and the Number of Species Calling on Outcome Classification Rates.

For survey minutes where anurans were known to be calling, we assessed the effect of the number of species calling and the call index on classification rates by the Song Scope recognizers. The logistic regression model indicated that call index affected the true positive and false negative error rates (-2 Log Likelihood Intercept Model =

4168; -2 Log Likelihood Intercept + Covariate Model = 2778; Likelihood Ratio Chi Square = 1442. $P < 0.001$; Table 6). We did not include human identification methods in this analysis because the extremely low error rates ($<1\%$) resulted in a failed model convergence.

When we adjust for all of the other variables in the analysis, the odds ratio for a false negative is 7.643 (95% confidence interval = 2.766 – 21.12) when a species is calling at a call index of 1 versus a call index of 3 (full chorus). This indicates that when there are fewer individuals calling, the odds of a false negative are increased. This result is also expected, since a larger number of calling individuals would mean a larger number of possible calls may be heard and correctly identified. The number of species calling did not affect the probability of false negatives (-0.2955, SE = 0.36, Wald Chi Square = 0.663, $P = 0.4155$).

DISCUSSION

Automation in monitoring makes it possible to perform large-scale monitoring projects which would not have been possible even a decade ago. Increasingly methods like autonomous recording devices and automatic species identification are being used to acoustically monitor bats (Adams et al. 2010), birds (Agranat 2007), cetaceans (Mellinger et al. 2007), and insects (Chesmore and Ohya 2004). These new technologies come with a tradeoff of accuracy in detection in order to monitor more sites, but they allow researchers to conduct surveys at times and in places that would be inconvenient for a human surveyor (Dorcas et al. 2009). Our study paints a fuller picture of both the type

and amount of error associated with these different methods, and documents the dependence of the error rate on the species being detected, the method of species detection, and specific settings used for automated detection.

No one approach is best for all species in all conditions. For example *P. crucifer*, *H. versicolor*, and *A. americanus* all had little difference in error rates between recording units, and thus would all likely be unaffected by choosing to use a lower quality home-made recorder. In addition, *A. americanus* was detected with very low error even with completely automated computer identification and could likely be monitored successfully this way. This is likely due to a combination of the calling behavior of this species, and the acoustic characteristics of the calls themselves. For humans, other studies have also shown *A. americanus* to have a low frequency of detection error (Lotz and Allen 2007). *A. americanus* is an explosive breeder (Ryan 2001), meaning that a large number of individuals call together over the course of only a few weeks. We documented a relationship between calling index and detection outcomes that indicated that when more individuals were calling, there was a decrease in the likelihood of a false negative error. Since this species is calling only for a short period of time, it tends to call in chorus, thereby increasing its chances of detection. The acoustic qualities of the call of *A. americanus* also make it more likely for a correct detection to occur. The call is a very long trill, a single one of which can last for up to 15 seconds, and may be repeated for many hours without stop (Howard and Young 1998). This allows for a longer amount of time during which detection may occur. In addition, the call falls somewhere in the middle in terms of its frequency (around 2 kHz) when

compared to other species, which may be helpful for automatic detection. Species with higher frequency calls like *P. crucifer* may be more likely to be confused with birds and insects which also tend to call at higher frequencies (Waddle et al. 2009). Lower frequency calls, on the other hand, might be more prone to masking by low frequency noise like wind and traffic.

L. clamitans appears to be a species for which automatic detection is more difficult. Again the reasons may be related to the calling behavior and acoustic characteristics of individuals. *L. clamitans* calls for a longer period of time during the summer, which may have the result of fewer individuals calling at once, and our data confirms that this species most often has a call index of 2 or lower. The call itself is much shorter than that of the other species, often lasting less than a second with a dominant frequency of around 1kHz which might make it more susceptible to low frequency noise. A cursory review of recordings where errors were made revealed that many short percussive sounds, such as splashes, cracking twigs, and unidentified thumps, were misidentified as green frog calls. This does not necessarily mean that *L. clamitans* is unsuitable as a species for automatic detection. Software could be either set with a low threshold for detection, in which case it would need to be checked by a human surveyor to determine which calls were true positives, or the threshold for detection could be set very high and the recording units deployed for longer or more frequent surveys in order to insure that at least some calls are detected.

The effects of call characteristics on the error rate for different recording and identification methods is likely to carry over to the acoustic monitoring of other taxa as

well. Our study builds on a body of literature that demonstrates different rates of detection error for different species of birds (Marcarini et al. 2008), insects (Ganchev and Potamitis 2007) and cetaceans (Mellinger et al. 2007).

Evaluating and Accounting for Error

In terms of monitoring, the challenge is not the rate of error, but failure to account for these errors when establishing the monitoring program and analyzing the resulting data. Knowing the potential for different kinds of error allows managers to take precautions like including a human reviewer to confirm a subset of detections or modeling error into the analysis. Managers can choose to minimize true positives or false negatives, or find a middle ground that optimizes the error rates. These decisions will ultimately affect the bias and precision of monitoring estimates.

For example, *P. crucifer* and *H. versicolor* both clearly demonstrate the tradeoff that exists for computer identification of species, whereby minimizing one type of error results in a vulnerability to the other type. This tradeoff has been noted by others (Agranat 2009, Waddle et al. 2009) and does not mean that automatic identification should be avoided, but that this method can be used as long as error is accounted for. Both species call frequently, and even with a certain rate of error, there are likely to be a good number of correct identifications even though some are incorrect and some were missed. The ability to optimize for one type of error or the other means that there is flexibility for meeting different objectives by simply changing the settings of the software used. If a rare species is the subject of detection, it would likely be best to optimize for true positives so that the species isn't missed. Consequently, many more false positives

will be recorded but false negatives can often be brought down to the same low level as it would be with a human listener who would take far longer to survey recordings in real time. On the other hand, if a species is more common like those we focused on in our study, the recognizer can be optimized to limit false positives. This means that though many calls will be missed, there is a high likelihood that at least some will be detected and a species can be confidently recorded as present at a site with almost no human interference at all.

Since the number of surveys and their length is more flexible with automation, there can be an increase in sampling to help balance the lower accuracy of a given detection by increasing the possibility of capturing more calls. MacKenzie and Royle (2005) have suggestions for decisions regarding survey effort for rare or common species that have higher or lower rates of detectability for use in occupancy modeling. In general they suggest that for a rare species there be less intensive surveys conducted at more sites, and with common species there be more intensive surveys of fewer sites (Mackenzie and Royle 2005).

The Potential for a Structured Decision Making Approach

A monitoring program may have multiple objectives, but hallmark goals include obtaining parameter estimates that are both precise and unbiased. The benefit of automation in monitoring is the ability to survey more locations more frequently, and for longer amounts of time. However, there are trade-offs in detection rates and identification methods, as well as time and funding constraints. This problem lends itself well to a structured decision making (SDM) approach. SDM consists of a set of decision making

tools that allow the user to evaluate a set of alternative actions, such as human versus ARU monitoring, based on how well they meet particular goals (Clemens 1996). This approach has been gaining popularity for use in wildlife management decision-making (Nichols and Williams 2006). There is an increasing demand for accountability in monitoring (Sauer and Knutson 2008) which may be addressed by the use of these tools as well.

As our study shows, deciding what method to use for anuran acoustic monitoring is far from straight forward. The relationship between species and method, as well as the effects of background noise and call index, are all factors that can be incorporated into the decision by using one or more tools of SDM. This method could also take into account factors not assessed in this study such as the cost of each of these methods (monetarily, in time, and in personnel). Then each method alternative can be assessed in terms of how it affects the objectives and constraints of a monitoring program. In this way the complexity of the question of what method is most likely to succeed can be taken fully into account in a systematic and defensible way.

Caveats of this Study

In this study, we identified species on recordings made in the field with autonomous recording units over a ten week period. We focused analyses on a small subset of the recorded data: two, 5 minute surveys at designated times collected every two weeks which may have missed species calling at times other than when the surveys took place and thus introduce another form of false negative error. There are several places where errors in detectability may enter into a study like ours. The first level at

which there is the potential to miss detecting a species acoustically depends on whether or not the species is calling. Species may be present but silent, and research has been done to determine the timing and conditions that are most likely to correspond to calling behavior in anurans (Steelman and Dorcas 2010). Future analyses on error rates could be undertaken to assess how error rates change as a function of time of day/night or day within the breeding season.

The next possibility for a false negative is when a species is calling, but is either too quiet or too distant from the ARU to be recorded. We did not test the range of our units, but we suspect that they picked up somewhat less than a human observer. Just as there are differences in the hearing capabilities of human surveyors, there may be differences in the amount of area surveyed between recorders, especially homemade units which are less standardized.

In addition, the human identification method for this study was conducted by a single person (C. Brauer) in an office setting, and as discussed earlier, there is likely to be variation in error rates between different observers and in different listening environments.

Studies have shown though, that misidentification is more prevalent for certain species when similar sounding calls exist in the soundscape, such as Northern leopard frog vs. pickerel frog (not included in our study) and American Toad vs. Fowler's Toad, *Anaxyrus fowlerii*, (American toad was included in our study, but Fowler's Toad was not). For example in our study we found that when using Song Scope, *H. versicolor* was sometimes misidentified as *A. americanus* (though strangely not the other way around).

This presents a challenge that might not be found in a location where these two species do not coincide. Waddle et al. (2009) documented confusion between *L. clamitans* calls with the calls of birds. These problems can be addressed by limiting or changing the time of day when surveys are performed, and by taking note of what species are often confused with one another and analyzing surveys containing both of them more carefully. Thus, our results apply to our particular soundscape, and may not be transferrable to other systems.

For automatic species identification, our analysis was performed only with Song Scope automatic identification software, but we feel that the trends of false positive/false negative tradeoff and a difference in error rate between species with varying calling characteristics and behaviors would likely hold true for other automated methods as well. However, error rates also depend on the quality of the recognizers themselves. Our recognizers performed well according to diagnostic statistics generated by the software (Table 2) and seem comparable to those found by other studies using Song Scope (Waddle et al. 2009). However, building a recognizer is an iterative process that involves continuous trial and error tweaking of the settings as more is learned about what calls are not detected or misidentified and why.

Conclusion

Over time, the technology used to automate species detection is likely to improve, and the gap between the ability of humans and computers to identify sounds may narrow. It is likely to be a long time though, before computers are able to detect every species with the accuracy that a trained human surveyor is capable of. Therefore it is still

important to consider the tradeoffs when choosing a method of acoustic monitoring, and to be able to account for the consequent rates of error that come with that choice. Now, more than ever before, it is of utmost importance to be able to obtain accurate monitoring data in order to detect range shifts, phenology changes, and to make population estimates for species like anurans as they respond to the barrage of changes in their environment and we attempt to manage them effectively and responsibly.

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Table 1. Physical and electronic specifications for the Olympus and Song Meter ARUs.

Specifications	ARU	
	Olympus DM-420	Song Scope SM1
Measurements (L x W x H)	8.12" x 6.56" x 3.56" (20.6 x 16.7 x 9.0cm)	8.4" x 7.1" x 2.4" (21.3 x 18.0 x 6.0cm)
Enclosure	Pelican Case (copolymer polypropylene)	IP 66/67, NEMA-4 (weatherproof)
Microphone	Omnidirectional, - 40 ± 3 dB	Omnidirectional, -35 ± 4dB
Recording Formats	Linear PCM, MP3, WMA	WAV (16-bit PCB) or WAC (proprietary Song Scope format)
Recording Power Input	D-cell battery, 2.4 V, 9-11 amps	Internal 4 D-size batteries or external power adapter for 6 or 12V battery
Sample Rates	Linear PCM 44.1, 48 kHz MP3 128, 192, 256, 320 kbps	4, 8, 16, 22.05, 24, 32, 44.01 and 48kHz
Storage	1 micro SD flash card slots	2 SD/SDHC/SDIO flash card slots

Table 2. Details and settings for the four focal species recognizers created in Song Scope.

Recognizer Settings	H. versicolor			P. crucifer			A. americanus			L. clamitans		
	SS1	SS2	SS3	SS1	SS2	SS3	SS1	SS2	SS3	SS1	SS2	SS3
Quality Minimum	30	32	35	20	30	40	10	12	15	50	60	70
Score Minimum	30	40	55	35	40	65	15	20	20	50	60	70
Sample Rate	11025			11025			11025			11025		
Maximum Complexity	30			35			32			32		
Maximum Resolution	6			8			8			8		
FFT Size	128			128			128			128		
FFT Overlap	1/2			1/2			1/2			1/2		
Frequency Minimum	24			26			12			3		
Frequency Range	11			14			14			40		
Amplitude Gain (dB)	0			0			0			0		
Background Filter	1s			1s			1s			1s		
Maximum Syllable	45			20			100			140		
Maximum Syllable Gap	30			160			850			160		
Maximum Song	1000			200			11500			500		
Dynamic Range	15			10			18			15		
Recognizer Performance Statistics												
Performance in Cross Training	83.13 ± 3.38%			75.43 ± 6.61%			83.91 ± 4.19%			73.12 ± 5.71%		
Performance in Total Training	80.16 ± 4.15%			74.40 ± 8.84%			84.01 ± 4.30%			73.12 ± 6.42%		
Model States	14			16			22			26		
State Usage	9 ± 3			3 ± 2			10 ± 5			7 ± 4		
Feature Vector	6			8			8			8		
Mean Symbols	72 ± 23			5 ± 3			453 ± 281			13 ± 8		
Syllable Types	4			6			8			3		
Mean Duration of Syllable	0.61 ± 0.18s			0.15 ± 0.06s			8.67 ± 3.90s			0.12 ± 0.06s		
Sources for Annotations	Lang Elliott; Walter Knapp			Lang Elliott; Walter Knapp; SECN field recordings from :			Lang Elliott; Walter Knapp			Lang Elliott; Walter Knapp; SECN field recordings from:		
				CUIS 2009; TIMU 2010						KEMO 2009, OCMU 2009		
Number of Annotations Used	26			117			41			156		

Table 3. Frequency and percentage of each detection outcome (false negative, false positive, true negative, and true positive) for each recorder, method, and species.

Outcome	Recorder Method			ID Method					Species			
	Olympus	Song Meter	Total	Human	Song Scope 1	Song Scope 2	Song Scope 3	Total	H. versicolor	P. crucifer	A. americanus	L. clancitans
False -	508 (50%)	513 (50%)	1021	38 (4%)	126 (12%)	247 (24%)	610 (60%)	1021	193 (19%)	274 (27%)	31 (3%)	523 (51%)
False +	731 (51%)	692 (49%)	1360	22 (2%)	943 (66%)	431 (30%)	27 (2%)	1423	502 (35%)	392 (28%)	123 (9%)	406 (29%)
True -	3885 (50%)	3924 (50%)	7809	2286 (29%)	1365 (17%)	1877 (24%)	2281 (29%)	7809	2042 (26%)	856 (11%)	3037 (39%)	1874 (24%)
True +	1836 (50%)	1831 (50%)	3667	1134 (31%)	1046 (29%)	925 (25%)	562 (15%)	3631	743 (20%)	1958 (53%)	289 (8%)	677 (18%)

Table 4. Analysis of effects showing a significant main effect of cars and rain and a three-way interaction between recording method, species identification method, and species.

Effect	DF	Chi-Square	Pr > Chi-Square
Species ID Method	9	3933.0427	<.0001
Recording Method	3	264.1551	<.0001
Species ID Method * Recording Method	9	648.0772	<.0001
Species	9	215.3128	<.0001
Species ID Method * Species	27	6213.8906	<.0001
Recording Method * Species	9	1584.591	<.0001
Species ID Method * Recording Method * Species	27	6338.063	<.0001
Cars	6	11.9562	0.0630
Rain	3	7.4409	0.0591

Table 4. Analysis of maximum likelihood estimates for each variable and interaction in the model with both presence and absence data.

Recording Method	ID Method	Species	Cars	Rain	Outcome	DF	Estimate	Standard Error	Chi-Square	Pr
.	.	.	.	.	False +	1	-5.102	0.1551	1082.0	<.0001
.	.	.	.	.	False -	1	-4.446	0.2973	223.6	<.0001
.	.	.	.	.	True +	1	-0.857	0.1874	20.9	<.0001
.	Human	.	.	.	False +	1	-7.084	0.1683	1771.0	<.0001
.	Human	.	.	.	False -	1	-6.154	0.1758	1225.1	<.0001
.	Human	.	.	.	True +	1	0.065	0.0511	1.6	0.1993
.	SS1	.	.	.	False +	1	4.795	0.1110	1867.7	<.0001
.	SS1	.	.	.	False -	1	1.623	0.1226	175.4	<.0001
.	SS1	.	.	.	True +	1	0.700	0.0518	182.8	<.0001
.	SS2	.	.	.	False +	1	3.410	0.0897	1446.6	<.0001
.	SS2	.	.	.	False -	1	1.919	0.0817	552.0	<.0001
.	SS2	.	.	.	True +	1	0.072	0.0254	8.1	0.0043
Olympus	.	.	.	.	False +	1	-0.730	0.0822	78.9	<.0001
Olympus	.	.	.	.	False -	1	0.813	0.0573	201.8	<.0001
Olympus	.	.	.	.	True +	1	0.010	0.0162	0.4	0.5213
Olympus	Human	.	.	.	False +	1	-0.810	0.1594	25.8	<.0001
Olympus	Human	.	.	.	False -	1	2.684	0.1116	578.2	<.0001
Olympus	Human	.	.	.	True +	1	-0.031	0.0179	3.0	0.0825
Olympus	SS1	.	.	.	False +	1	0.750	0.0838	80.0	<.0001
Olympus	SS1	.	.	.	False -	1	-0.945	0.0989	91.2	<.0001
Olympus	SS1	.	.	.	True +	1	0.0089	0.0323	0.0	0.7807
Olympus	SS2	.	.	.	False +	1	0.796	0.0759	110.1	<.0001
Olympus	SS2	.	.	.	False -	1	-0.860	0.0589	213.2	<.0001
Olympus	SS2	.	.	.	True +	1	0.014	0.0179	0.6	0.4164
.	.	H. versicolor	.	.	False +	1	0.543	0.2025	7.1	0.0073
.	.	H. versicolor	.	.	False -	1	-0.221	0.3223	0.4	0.4916
.	.	H. versicolor	.	.	True +	1	-0.117	0.2165	0.2	0.5884
.	.	P. crucifer	.	.	False +	1	0.286	0.1561	3.3	0.0667
.	.	P. crucifer	.	.	False -	1	1.130	0.3051	13.7	0.0002
.	.	P. crucifer	.	.	True +	1	1.887	0.1998	89.1	<.0001
.	.	A. americanus	.	.	False +	1	-1.922	0.1950	97.2	<.0001
.	.	A. americanus	.	.	False -	1	-3.579	0.3856	86.1	<.0001
.	.	A. americanus	.	.	True +	1	-1.447	0.3122	21.5	<.0001
.	Human	H. versicolor	.	.	False +	1	0.462	0.3521	1.7	0.1891
.	Human	H. versicolor	.	.	False -	1	-0.238	0.2655	0.8	0.3689
.	Human	H. versicolor	.	.	True +	1	-0.045	0.0663	0.4	0.4825
.	Human	P. crucifer	.	.	False +	1	2.099	0.2473	72.0	<.0001
.	Human	P. crucifer	.	.	False -	1	-0.557	0.1749	10.1	0.0014
.	Human	P. crucifer	.	.	True +	1	-0.425	0.0607	49.1	<.0001
.	Human	A. americanus	.	.	False +	1	-3.411	0.2342	212.2	<.0001
.	Human	A. americanus	.	.	False -	1	-3.750	0.3584	109.4	<.0001
.	Human	A. americanus	.	.	True +	1	0.0021	0.0583	0.0	0.9710
.	SS1	H. versicolor	.	.	False +	1	-0.228	0.1920	1.4	0.2338
.	SS1	H. versicolor	.	.	False -	1	0.170	0.2130	0.6	0.4229
.	SS1	H. versicolor	.	.	True +	1	-0.035	0.0742	0.2	0.6290
.	SS1	P. crucifer	.	.	False +	1	1.073	0.1463	53.8	<.0001
.	SS1	P. crucifer	.	.	False -	1	0.536	0.2117	6.4	0.0112
.	SS1	P. crucifer	.	.	True +	1	0.306	0.1090	7.9	0.0049
.	SS1	A. americanus	.	.	False +	1	0.080	0.1369	0.3	0.5555
.	SS1	A. americanus	.	.	False -	1	0.697	0.3024	5.3	0.0211
.	SS1	A. americanus	.	.	True +	1	-0.554	0.0540	105.2	<.0001
.	SS2	H. versicolor	.	.	False +	1	-0.020	0.1896	0.0	0.9126
.	SS2	H. versicolor	.	.	False -	1	-0.311	0.1363	5.2	0.0224
.	SS2	H. versicolor	.	.	True +	1	0.125	0.0540	5.5	0.0188
.	SS2	P. crucifer	.	.	False +	1	1.049	0.1284	66.7	<.0001
.	SS2	P. crucifer	.	.	False -	1	-0.037	0.0993	0.1	0.7077
.	SS2	P. crucifer	.	.	True +	1	0.043	0.0485	0.8	0.3700
.	SS2	A. americanus	.	.	False +	1	0.030	0.1420	0.0	0.8324
.	SS2	A. americanus	.	.	False -	1	1.747	0.1450	145.2	<.0001
.	SS2	A. americanus	.	.	True +	1	-0.138	0.0378	13.4	0.0002
Olympus	.	H. versicolor	.	.	False +	1	-0.784	0.1861	17.7	<.0001
Olympus	.	H. versicolor	.	.	False -	1	0.850	0.1078	62.3	<.0001
Olympus	.	H. versicolor	.	.	True +	1	-0.035	0.0219	2.6	0.1022
Olympus	.	P. crucifer	.	.	False +	1	-2.735	0.1053	674.4	<.0001
Olympus	.	P. crucifer	.	.	False -	1	0.863	0.1026	70.8	<.0001
Olympus	.	P. crucifer	.	.	True +	1	-0.069	0.0301	5.3	0.0204
Olympus	.	A. americanus	.	.	False +	1	0.899	0.1150	61.2	<.0001
Olympus	.	A. americanus	.	.	False -	1	-1.003	0.0836	143.9	<.0001
Olympus	.	A. americanus	.	.	True +	1	0.018	0.0209	0.7	0.3713
Olympus	Human	H. versicolor	.	.	False +	1	-3.664	0.3403	115.9	<.0001
Olympus	Human	H. versicolor	.	.	False -	1	2.158	0.2264	90.8	<.0001
Olympus	Human	H. versicolor	.	.	True +	1	0.036	0.0228	2.5	0.1129
Olympus	Human	P. crucifer	.	.	False +	1	-2.694	0.2602	107.2	<.0001
Olympus	Human	P. crucifer	.	.	False -	1	2.760	0.2172	161.4	<.0001
Olympus	Human	P. crucifer	.	.	True +	1	0.039	0.0353	1.2	0.2587
Olympus	Human	A. americanus	.	.	False +	1	0.640	0.1820	12.3	0.0004
Olympus	Human	A. americanus	.	.	False -	1	-2.494	0.1412	312.1	<.0001
Olympus	Human	A. americanus	.	.	True +	1	0.0019	0.0242	0.0	0.9359
Olympus	SS1	H. versicolor	.	.	False +	1	0.712	0.1822	15.3	<.0001
Olympus	SS1	H. versicolor	.	.	False -	1	-0.697	0.1207	33.4	<.0001
Olympus	SS1	H. versicolor	.	.	True +	1	0.0037	0.0352	0.0	0.9149
Olympus	SS1	P. crucifer	.	.	False +	1	2.536	0.1444	308.2	<.0001
Olympus	SS1	P. crucifer	.	.	False -	1	-1.011	0.1207	70.2	<.0001
Olympus	SS1	P. crucifer	.	.	True +	1	-0.059	0.0723	0.6	0.4101
Olympus	SS1	A. americanus	.	.	False +	1	-0.882	0.1254	49.4	<.0001
Olympus	SS1	A. americanus	.	.	False -	1	0.792	0.2069	14.6	<.0001
Olympus	SS1	A. americanus	.	.	True +	1	0.0030	0.0370	0.0	0.9350
Olympus	SS2	H. versicolor	.	.	False +	1	0.700	0.1576	19.7	<.0001
Olympus	SS2	H. versicolor	.	.	False -	1	-0.696	0.1204	33.4	<.0001
Olympus	SS2	H. versicolor	.	.	True +	1	0.0076	0.0213	0.1	0.7189
Olympus	SS2	P. crucifer	.	.	False +	1	2.550	0.1150	491.7	<.0001
Olympus	SS2	P. crucifer	.	.	False -	1	-0.929	0.1027	81.8	<.0001
Olympus	SS2	P. crucifer	.	.	True +	1	0.0008	0.0275	0.0	0.9747
Olympus	SS2	A. americanus	.	.	False +	1	-0.880	0.1248	49.6	<.0001
Olympus	SS2	A. americanus	.	.	False -	1	0.884	0.0924	91.6	<.0001
Olympus	SS2	A. americanus	.	.	True +	1	-0.011	0.0209	0.3	0.5736
Olympus	SS2	A. americanus	.	.	False +	1	0.311	0.1482	4.4	0.0354
.	.	.	Cars (0)	.	False +	1	-0.097	0.2638	0.1	0.7120
.	.	.	Cars (0)	.	True +	1	-0.220	0.1801	1.4	0.2211
.	.	.	Cars (1)	.	False +	1	-0.141	0.1115	1.6	0.2042
.	.	.	Cars (1)	.	False -	1	-0.073	0.1535	0.2	0.6338
.	.	.	Cars (1)	.	True +	1	-0.025	0.1259	0.0	0.8380
.	.	.	.	Rain (0)	False +	1	-0.276	0.0930	8.8	0.0030
.	.	.	.	Rain (0)	False -	1	0.399	0.1701	5.5	0.0190
.	.	.	.	Rain (0)	True +	1	0.180	0.1502	1.4	0.2293

Table 5. Analysis of effects showing the significant main effects of species identification method, species, call index, and a significant interaction between species and species ID method for presence-only data.

Effect	DF	Chi-Square	Pr > Chi-Square
Species ID Method	2	156.478	<.0001
Recording Method	1	2.7239	0.0989
Species ID Method * Recording Method	2	0.7151	0.6994
Species	3	6.5977	0.0859
Species ID Method * Species	6	118.854	<.0001
Recording Method * Species	3	3.4961	0.3213
Species ID Method * Recording Method * Species	6	6.1236	0.4095
Call Index	2	25.1936	<.0001
Number of Species Calling	1	0.663	0.4155

Table 6. Analysis of maximum likelihood estimates for each variable and interaction in the model with presence-only data.

Recording Method	ID Method	Species	Call Index	Num Species Calling	DF	Estimate	Standard Error	Chi-Square	Pr
.	.	.	.	.	1	-1.6377	0.4815	11.5686	0.0007
.	.	.	.	.	1	-1.4136	0.0927	232.4417	<.0001
.	SS1	.	.	.	1	-0.3182	0.0868	13.4302	0.0002
.	SS2	.	.	.	1	-0.1164	0.0727	2.5613	0.1095
Olympus	.	.	.	.	1	-0.0527	0.1073	0.2409	0.6236
Olympus	SS1	.	.	.	1	0.0397	0.0571	0.4831	0.487
Olympus	SS2	.	.	.	1	-0.2113	0.3737	0.3197	0.5718
.	.	H. versicolor	.	.	1	-0.7112	0.2692	6.9807	0.0082
.	.	P. crucifer	.	.	1	0.1087	0.4644	0.0548	0.8149
.	.	A. americanus	.	.	1	0.1611	0.1951	0.682	0.4089
.	SS1	H. versicolor	.	.	1	-0.6299	0.1543	16.675	<.0001
.	SS1	P. crucifer	.	.	1	-0.1511	0.2229	0.4595	0.4979
.	SS1	A. americanus	.	.	1	-0.095	0.1547	0.3768	0.5393
.	SS2	H. versicolor	.	.	1	0.2643	0.2263	1.3648	0.2427
.	SS2	P. crucifer	.	.	1	0.7266	0.1474	24.306	<.0001
.	SS2	A. americanus	.	.	1	0.2053	0.1092	3.537	0.06
Olympus	.	H. versicolor	.	.	1	-0.0124	0.1384	0.008	0.9289
Olympus	.	P. crucifer	.	.	1	-0.1759	0.1182	2.2139	0.1368
Olympus	.	A. americanus	.	.	1	0.0208	0.1442	0.0209	0.8851
Olympus	SS1	H. versicolor	.	.	1	0.0124	0.0772	0.0259	0.8722
Olympus	SS1	P. crucifer	.	.	1	-0.1162	0.1522	0.5826	0.4453
Olympus	SS1	A. americanus	.	.	1	0.0106	0.0751	0.02	0.8875
Olympus	SS2	H. versicolor	.	.	1	-0.0149	0.2038	0.0053	0.9419
Olympus	SS2	P. crucifer	.	.	1	0.0545	0.0993	0.3005	0.5836
Olympus	SS2	A. americanus	.	.	1	1.5293	0.2283	44.8859	<.0001
.	.	.	Call Index 1	.	1	-0.6145	0.3104	3.9194	0.0477
.	.	.	Call Index 2	.	1	0.0539	0.1703	0.1003	0.7514
.	.	.	.	Number of Species Calling	1				

Table 8. Effects Coding used for coding the variables in the Analysis of Effects

Class	Level	Effect Coding		
Recording Method	Olympus	1		
	Song Meter	-1		
ID Method	Human	1	0	0
	Song Scope 1	0	1	0
	Song Scope 2	0	0	1
	Song Scope 3	-1	-1	-1
Species	H. versicolor	1	0	0
	P. crucifer	0	1	0
	A. americanus	0	0	1
	L. clamitans	-1	-1	-1
Cars	0 Cars	1	0	
	1 Car	0	1	
	2 Cars	-1	-1	
Rain	No	1		
	Yes	-1		

Figure Legends

1. Graph of the calling times and dates for anurans in Vermont. Reproduced from the Vermont Reptile and Amphibian Atlas (Andrews 2005).
2. Map of the three National and State Parks where study sites were located.
3. Song Scope interface showing the annotation of known calls to be used in recognizer creation.
4. Graph of the total number of minutes each species was verified as present during each of the five visits to the study sites.
5. Probability of each detection outcome by ARU, species ID method, and species. The first column shows results for Olympus units while the second shows results for the SM1. The first row shows detections made using the human method then Song Scope 1, 2, and 3. Within each graph the bars represent each of the four focal species.
6. Graphs depicting the probabilities of each outcome (false negative, false positive, true negative, true positive) for each of the possible combinations of recorder, species identification method, and focal species.

Figure 1.

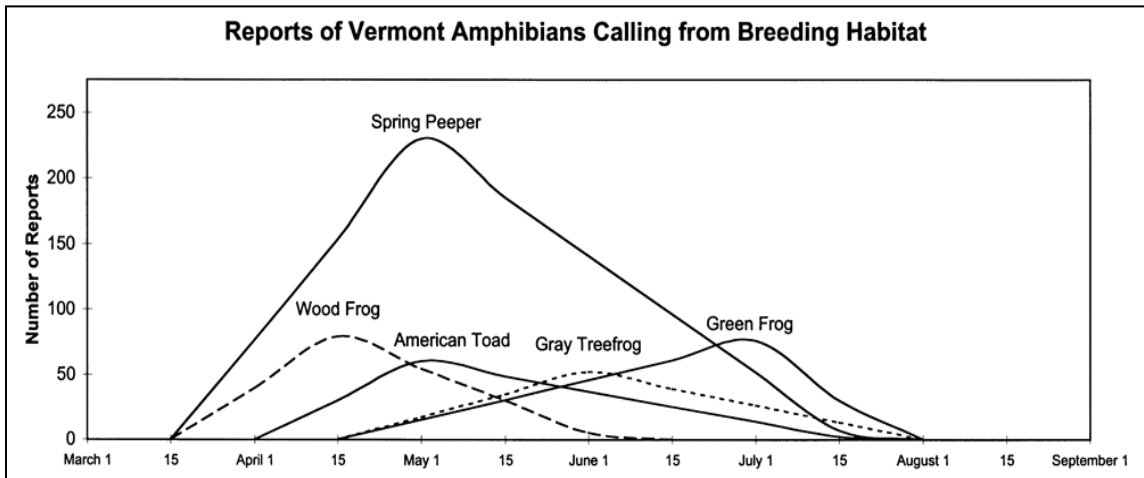


Figure 2.



Figure 3.

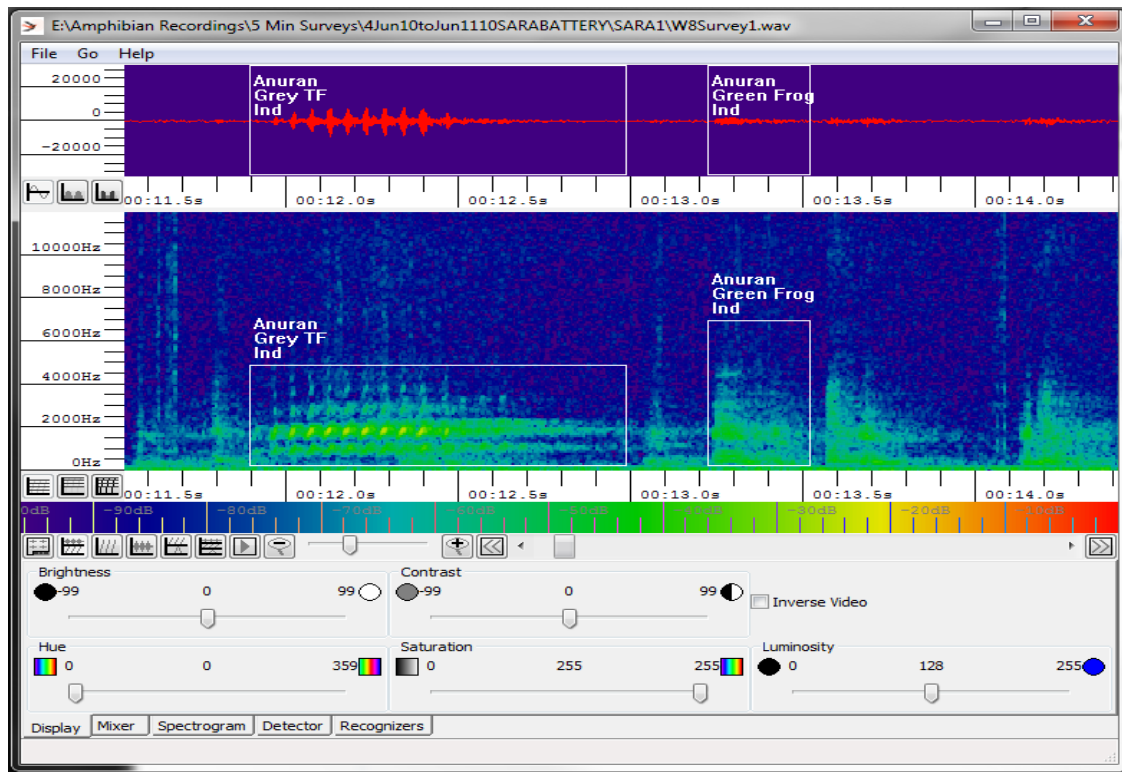


Figure 4.

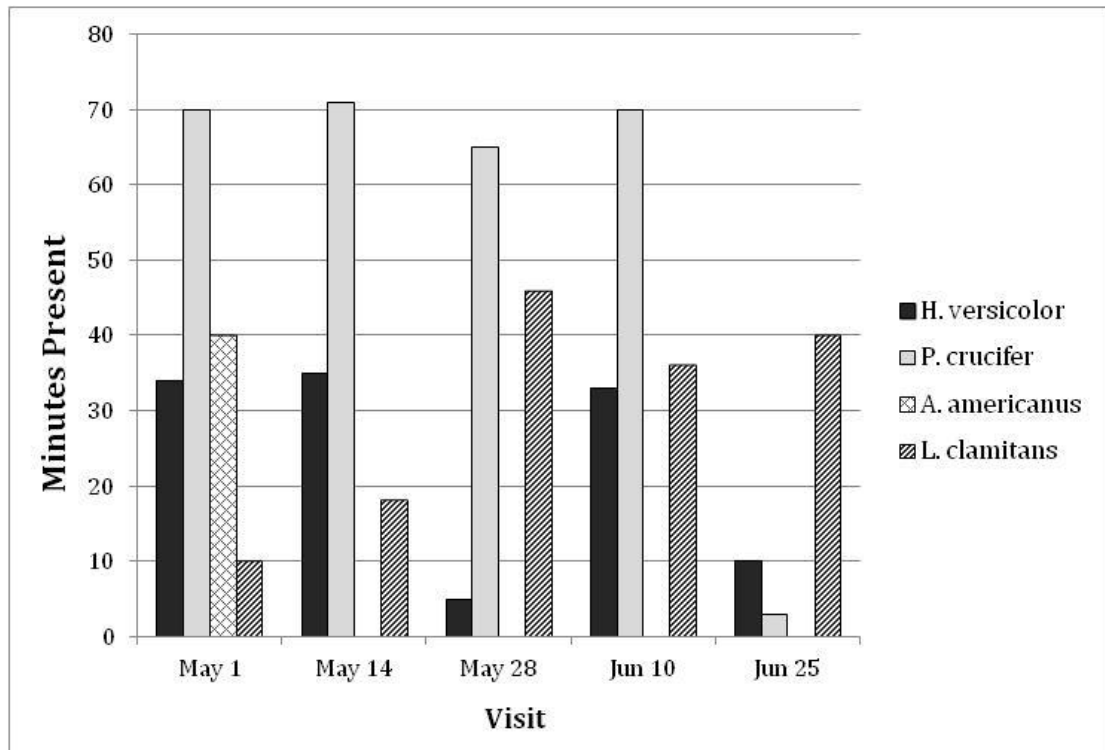


Figure 5.

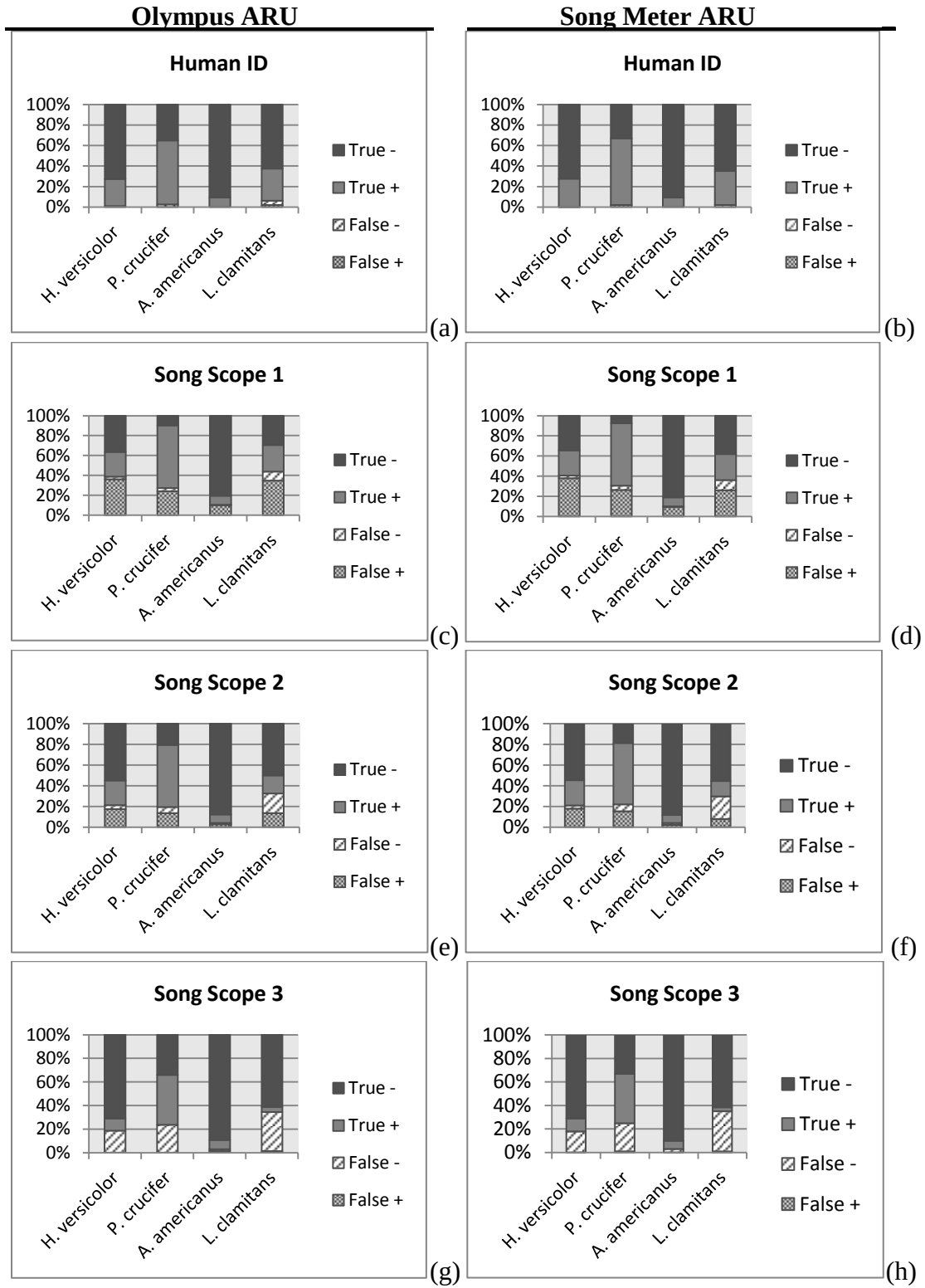
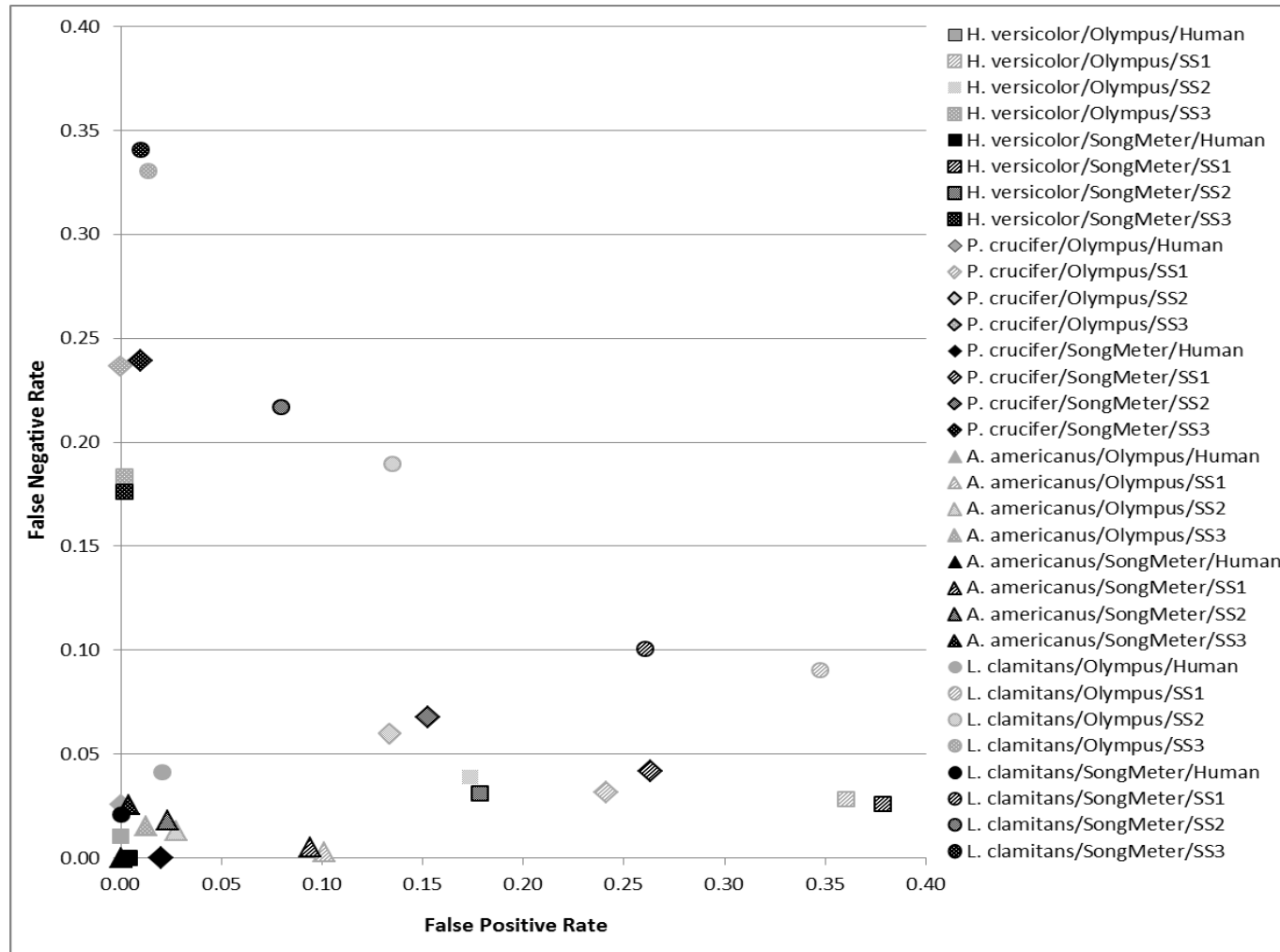


Figure 6.



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APPENDICES

Appendix A: Building an Autonomous Recording Unit Based on the Olympus DM 420 Digital Voice Recorder

Written by:

Jonathan Katz
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In collaboration with
The National Park Service Northeast Temperate Network
Draft 1
January 7, 2011

Electronic Materials:

Qty Needed	Description	Suggested source	Item #	URL	Estimated Cost ¹
1	Olympus DM-420 Digital Voice Recorder	Amazon.com	B002JTX87W	http://www.amazon.com/gp/offer-listing/B002JTX87W/ref=olp_sss_new?ie=UTF8&shipPromoFilter=1&sort=sjp&me=&seller=&condition=new	\$113.36
2	Battery Holders, Snaps & Contacts 2 D W8 24AWG LDS	Mouser	12BH121A-GR	http://mouser.com/ProductDetail/Eagle-Plastic-Devices/12BH121A-GR/?qs=sGAEpiMZZMupurftu7GC%252bdUGrKbfC93ebWmxALtW%3d	\$2.62
2	Microphones OMNIDIRECT 6x3.4mm, 70-20kHz Electret	Mouser	254-ECM640-RO	http://mouser.com/ProductDetail/Kobitone/254-ECM640-RO/?qs=sGAEpiMZZMsYQxPYEnGVuKl2oUawXrSZjuYNZ7QPDw%3d	\$4.98
1 ²	Communication / Instrumentation Cable 2C 24AWG SHIELD, 100'	Mouser	602-2400C-100	http://mouser.com/ProductDetail/Alpha-Wire/2400C-SL005/?qs=sGAEpiMZZMs6%252bU7AAQG5bpaGUIY64uY2lQNJ9eOBQ0%3d	\$3.55
2	Phone Connectors PHONE 3.5MM MONO	Mouser	171-PA3191-1-E	http://www.mouser.com/ProductDetail/Kobiconn/171-PA3191-1-E/?qs=sGAEpiMZZMw0W4pxf2HIV5p4QQjbolli%2fHMMWap7ApBA%3d	\$1.42
1	Phone Connectors 3.5MM MONO JACK HOR	Mouser	502-35RAPC2AH3	http://www.mouser.com/ProductDetail/Switchcraft/35RAPC2AH3/?qs=tCUFd3%252b19IP5bD6uJku1Jg%3d%3d	\$1.75
1	1120NF Guard Box Protector Watertight Case without Foam (Black)	B&H Photo	PE1120B	http://www.bhphotovideo.com/c/product/150620-REG/Pelican_1120_001_110_1120_Case_without_Foam.html	\$17.95
1	32GB microSDHC Memory Card	B&H Photo	TRMSDC32GB	http://www.bhphotovideo.com/c/product/738454-REG/Transcend_TS32GUSDHC2_32GB_microSDHC_Card.html	\$72.63
1 ³	32GB SDHC Memory card	B&H Photo	KSDHC432GB	http://www.bhphotovideo.com/c/product/592772-REG/Kingston_SD4_32GB_32GB_SDHC_Memory_Card.html	\$66.95
1 ³	microSD to SD adapter	Ameri-Rack Technology, Inc	PA-TFC1	http://www.ably.com.tw/pdt/viewpdt.asp?absp=3&cat=OTHERS	\$24.35
4	MAHA PowerEx 1.2V 1100mAh D Cell NiMH Batteries	Zbattery.com	MH-2D110	http://www.zbattery.com/MAHA-PowerEx-1.2V-1100mAh-D-Cell-NiMH-Batteries-2-Card	\$50.70

¹ Costs are for the quantity needed for one recording unit. In many cases, costs per recording unit can be reduced by buying in bulk.

² Usually sold as a full roll rather than as bulk wire, but only 4'-10' is used in one recorder (see note in microphone construction section).

³ Optional; purchase for media storage if microSD cards are undesirable or unavailable.

Additional Materials (May Be Purchased Locally):

6" 18 gauge black wire	7" x 4.5" Lauan or similar 1/4"
6" 18 gauge red wire	Lightweight plywood (oak or birch are more eco-friendly than lauan); MDF, HDF, or Homosote are not recommended
2x 3/8" dowel cut to 1 5/8" length	
1 brass thumb tack	5" length of 2"x2" wood
1 brass screw #4 x 1/2"	7/32" steel rod cut to 6" length
8 screws #6 x 1/4"	Heat shrink tubing or electrical tape
Solder	28" of 1" wide double-sided Velcro strap
3 deck screws, 1 1/4"	8" plastic dish
3x 4" cable ties	1/2" wire mesh or hardware cloth
Waterproof glue	6.5" x 10.5" Faux fur

Tools Required

Soldering iron	Volt/ohm meter
Diagonal pliers	Sewing machine or needle and thread
Needle nose pliers	Ball Peen Hammer
Wire stripper	Hacksaw
Phillips #2 screwdriver	
Electric drill	
7/32" Drill bit	
5/32" Drill bit	
1/8" Drill bit	
1/16" Drill bit	

Prepare the pelican case:

Drill a 7/32" hole through both long ribs on the hinge side of the box. Place the hole at least 1/8" from all edges; centering the hole 5/8" from the end of the rib and 1/4" from the side should provide sufficient support. Pass the steel rod through the hole and use the ball peen hammer to mushroom both ends so it cannot slip back out of the hole. Only a small amount of mushrooming is necessary to keep the rod in place. This preparation will provide an anchor for fastening the case to a tree or other support.

**Prepare the recorder support:**

Insert two deck screws through the lauan into the 2x2, fastening the length of 2x2 to the lower left corner of the lauan and leaving 1/8" along the left margin. Cut a 2.5" length of Velcro strap in half (lengthwise, to form 1/2" wide straps) and use a small screw to fasten one end of each Velcro strap to the 2x2 support 3/4" from the top on the left and right sides. Repeat this and fasten two more straps 3/4" from the bottom on both sides.

**Prepare the battery holder:**

Stack two battery holders end to end, both with the wire leads pointing down. Pass the leads from the top holder through the lower holder so that the leads of both emerge from the lower holder. Cut two segments of Velcro strap 9" long and place one segment behind each battery holder so that it can loop around the front to secure the batteries in place. Use two screws in each holder to fasten each battery holder to the lauan back plate, allowing a 1/4" margin between the edge of the holders and the edge of the 2x2 that is already screwed to the back plate. Use the wire cutters to trim the leads so they are the same length, and use the wire strippers to remove 3/4" of insulation. Twist the two red leads together. Twist the two black leads together. Strip 3/4" from the two lengths of 18 gauge wire and solder them to the respective colored leads. If using shrink fit tubing to insulate connections, slip a 1.25" length onto each lead

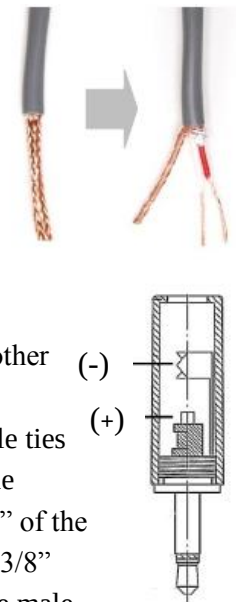


(covering the junction) and heat it with the soldering iron to shrink it. Strip $\frac{1}{2}$ " of insulation from the free end of the extended leads, twist the stranded wire of each lead into a coherent element, and make a 90 degree bend in the exposed wires. Solder the red lead to the brass screw by placing the 90 degree bend immediately below the head of the screw. Solder the black wire to the brass tack in the same fashion. Cut the dowel into two $1\frac{5}{8}$ " pieces to match the size of an AAA battery. In the center of one end of a dowel piece insert the brass screw by holding the screw steady with a screwdriver and twisting the dowel in. In the center of an end of the other dowel push in the brass tack. Insert the dowels into the recording units as they are oriented in the Picture to the right. Insert four D batteries into the battery holders, and check that the recording unit powers on.



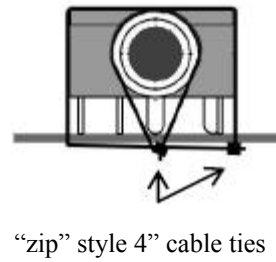
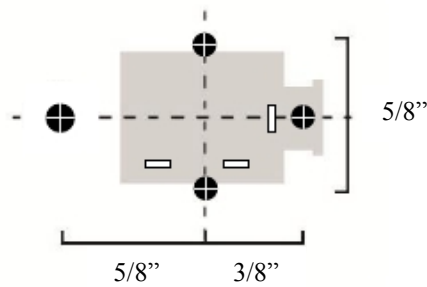
Prepare the internal audio connector:

Cut a 13" section of shielded audio cable. Strip back 1" of the outer insulation and tease the shield open so it may be twisted into a lead (image at right). Strip back $\frac{3}{8}$ " of each audio conductor. Orient the pelican case with the hinge on the right, and the lid in front. Drill a $\frac{5}{32}$ " hole in the bottom center of the Pelican case and pass 2" of audio cable through. Solder the red conductor to the (+) terminal of the female phono jack and the black conductor and shield to the (-) terminal. Drill three $\frac{1}{8}$ " holes in the Pelican case in a triangle beneath where the phono jack will sit, one under the threaded barrel and one to either side (see pattern below). Pass a 4" cable tie through the side holes and loop another



through the hole beneath the barrel (see drawing below right). Use the cable ties to pull the phono jack tight against the Pelican case. On the other end of the audio cable slide the male phono plug housing onto the cable. Strip back 1" of the outer insulation and the shield, isolate the shield into a lead, and strip back $\frac{3}{8}$ " of each audio conductor. Solder the red conductor to the (+) terminal of the male phono plug and the black conductor and shield to the (-) terminal. Assemble the housing over the connections. Seal the holes where the audio connector exits the Pelican case with waterproof glue and allow to dry. Use the ohm meter to test for connectivity between the tip of the phono plug and ground; there should be none.

Hole pattern in Pelican Case floor:

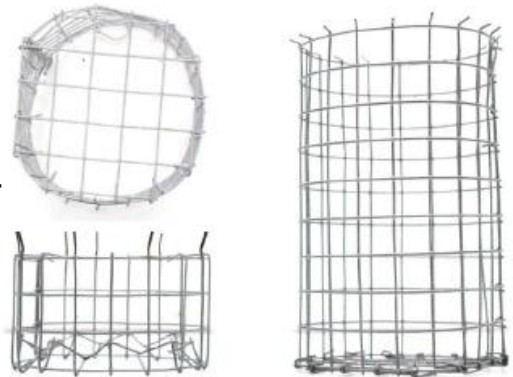


Prepare the windscreen shell:

Cut a rectangle of hardware cloth 9.5" x 5.5". Trim one of the 5.5" edges flat, and leave "tails" on the other 5.5" edge. Trim the 9.5" edges in the same way. Cut a separate square of hardware cloth 3" x 3". Bend the rectangle into a cylinder 3" in diameter and 5" tall; bend the cylinder so that the resulting circular strands of the mesh are on the outside of the straight strands so that the cage will easily slip onto the holder. Use needle-nosed pliers to bend the wire tails around the mating edge to lock the edges in place. Trim the square piece of hardware cloth so it is roughly a circle 3" in diameter, leaving as many open wire tails as possible at the edge. Place it at the bottom of the cylinder and bend the wire tails to hold it in place. Make sure that no wires protrude outside of the cage so that the windscreen cloth can be slipped over it without snagging.



Cut a rectangle of faux fur 10.5" x 6.5". With the faux fur on the inside, fold the fabric in half so that the two 6.5" ends are together. Use the sewing machine to make a rectangular pouch by sewing along one 6.5" edge and one 5.25" edge, leaving the other 5.25" edge open. Turn the pouch right-side out and slip it over the wire cage. Cut a second rectangle of hardware cloth 9" x 2.5"; this will be the windscreen shell holder. Again, leave the tails attached to one of each length edge and trim the other edges so they are flat. Bend the rectangle into a cylinder 3" in diameter; this time bend it so that the resulting circular wires are inside the straight wires. Use the needle-nose pliers to bend the top row of wire (on the finished edge) inwards, so that the larger cylinder can slip over it. Bend every other wire tail on the unfinished edge 90 degrees toward the center of the shape, leaving every other wire tail straight.





The microphone housing is connected to the (-) pole! Take care to prevent short circuits!

There is a lot of flexibility in how long the cable to the microphone could be. Given the high impedance of the microphones, the cable will act as a resistor and attenuate high frequencies. Shorter lengths of cable are therefore more desirable, but 4' is recommended and lengths up to 8' should be acceptable. Cut a length of microphone cable and push 8" of it through the center hole in the plate, with the short tail on the cupped side of the plate. Strip back 1.5" of the outer insulation and the shield and cut the shield flush with the end of the outer insulation. Strip back 1" of insulation from each audio conductor but do not twist into a coherent strand yet. Insulate the back housing of the microphones with a single layer of electrical tape; this will help prevent short circuits to the microphone housing.

Begin assembly by twisting the 1/4" of wire nearest to the insulation, then insert the proper (+) or (-) pin into the strands (+) to red, (-) to white or black depending on your wire). Twist another 3/8" of wire, and then add the second microphone. Finish twisting. Lay out both microphones and the audio cable on a table and solder the microphones to the wire. Use a thin layer of waterproof glue to insulate and stabilize the connections. Avoid applying glue to the fabric face of the microphones. When the glue dries, snugly wrap a cable tie around the audio cable 2.5" above the microphone. This will keep the plate from slipping down the cable. On the opposite end of the audio cable slide the housing for the male audio connector onto the wire. Strip back 1" of the outer insulation and the shield. Strip 1/4" of insulation from each audio conductor. Solder the red wire to the (+) terminal of the phono plug and the black wire and shield to the (-) terminal. Assemble the housing to the phono plug. Use the ohm meter to test for connectivity between the tip of the phono plug and ground; if connectivity is detected, the source of the short circuit must be found and fixed before use.

Final Assembly:

Slide the plastic plate down the microphone wire until it stops on the cable tie. Push the wire tails of the windscreen shell holder through the holes in the plate and bend them down with pliers. Slide the windscreen shell onto the holder; it should fit snugly and stay in place without additional fasteners. Drill a hole in the back of the Pelican case behind where the 2x2 will rest. Place the lauan back board into the Pelican case behind the audio connector and fix the back board in place by screwing from the back of the Pelican case into the 2x2 board with the deck screw. Tighten the screw so that it seals against the plastic Pelican case.



In the photo above, the recorder is shown with a brown micro SD to SD adapter lying on the control buttons. This adapter is an option if micro SD cards are not available in the capacity desired while SD cards are. In 2010 32GB micro SD cards are available for less than \$70 and a 32GB SD card plus adapter costs \$95 (\$67+\$28). We observed that while the adapter made access for card changes easy, occasionally the recorder would not recognize that a new card had been inserted into the adapter and many minutes were spent power-cycling the unit attempting to reboot.

Plug the audio connector into the top of the recording unit. Strap the recording unit to the 2x2 board with the Velcro straps. Plug the microphone into the female phone plug on the outside of the Pelican case and power on the recorder. Test the microphone for function. If multiple recorders are deployed it may be worth testing all microphones in a controlled manner to verify that all are similarly sensitive. If the recorders will be deployed in areas with traffic, use one or two locks with at least a $\frac{3}{4}$ " shackle to secure the door closed. Observe that the recorder will function with only two batteries installed if they are installed side-by-side within the same battery holder. Using only two batteries will reduce the run time by 50%.

Specifications:

Exterior: High impact structural copolymer polypropylene
 Exterior Dimensions: 8.12 x 6.56 x 3.56" (20.6 x 16.7 x 9.0cm) (LxWxH)
 Microphone Cable Length: Variable
 Microphone Cable Shielded: Yes
 Microphone Impedance: 2.2 K Ohms
 Microphone Directional Properties: Omnidirectional
 Microphone Operating Voltage: 2 V
 Microphone Sensitivity: -40 dB +/- 3 dB
 Recording Formats: Linear PCM, MP3, WMA
 Recording Input Level: [Mic Sense]:[Middle] -60 dBv
 Recording Input Impedance: 2.2 k Ω
 Recording Power Input: D-cell battery, 2.4 V, 9-11 amps
 Recorder Operating Temperature: 0°C - 42°C / 32°F - 107.7° F
 Recorder Overall Frequency Response: See table below
 Recorder Plug In Power: 0.8 V - 2.5V

Overall frequency response

I During recording or playback mode:

Linear PCM format

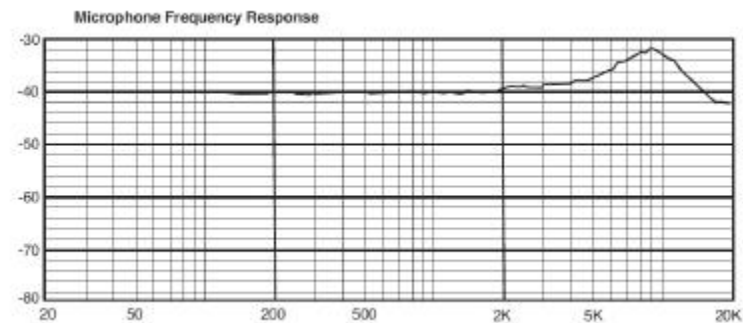
Recording mode	Overall frequency response
48 kHz	40 Hz to 23 kHz
44.1 kHz	40 Hz to 21 kHz

MP3 format

Recording mode	Overall frequency response
320 kbps	40 Hz to 20 kHz
256 kbps	40 Hz to 20 kHz
192 kbps	40 Hz to 19 kHz
128 kbps	40 Hz to 17 kHz

WMA format

Recording mode	Overall frequency response
ST XQ	40 Hz to 19 kHz
ST HQ	40 Hz to 16 kHz
ST SP	40 Hz to 9 kHz
HQ	40 Hz to 13 kHz
SP	40 Hz to 8 kHz
LP	40 Hz to 3 kHz



Maximum recording time per file

I Linear PCM format:

48 kHz	3h.
44.1 kHz	3h.20min.

I MP3 format:

320kbps	29h.40min.
256kbps	37h.10min.
192kbps	49h.40min.
128kbps	74h.30min.

■ WMA format:

ST XQ	26h.40min.
ST HQ	26h.40min.
ST SP	53h.40min.
HQ	26h.40min.
SP	53h.40min.
LP	148h.40min.

Maximum Recording Times Based on Storage Media

Linear PCM Format:

Recording Mode	8GB micro SD Card	16GB micro SD Card	32GB micro SD Card
48 kHz	11 h	22 h	44 h
44.1 kHz	12 h	24 h	36 h

MP3 Format:

Recording Mode	8GB micro SD Card	16GB micro SD Card	32GB micro SD Card
320 kbps	54 h	108 h	216 h
256 kbps	68 h	132 h	264 h
192 kbps	90 h	180 h	360 h
128 kbps	136 h	272 h	544 h

WMA Format:

Recording Mode	8GB micro SD Card	16GB micro SD Card	32GB micro SD Card
ST XQ	132 h	264 h	528 h
ST HQ	266 h	532 h	1064 h
ST SP	532 h	1068 h	2136 h
HQ	532 h	1068 h	2136 h
SP	1048 h	2096 h	4192 h
LP	2084 h	4168 h	8336 h

Guide to Battery Life with NiMH Batteries

Recording Mode	2 D-cell Batteries	4 D-cell Batteries
PCM 48kHz	145 h	290 h
MP3 128kbps	159 h	318 h
ST XQ	159 h	318 h
LP	203 h	406 h

**Appendix B: Deployment and Maintenance of Autonomous Recording Units For
the Olympus Recorder-based Unit and the Wildlife Acoustics Song Meter**

Written by:

Corinne Brauer and Jon Katz
University of Vermont/VTCFWRU
In collaboration with
The National Park Service Northeast Temperate Network
Draft 2
March 16th, 2011

Deployment of an Olympus ARU

The Olympus ARU:



The Olympus Recorder:



Before you go into the field:

Calibration of Units

Methods are being developed for procedures to calibrate units before going into the field. This is to ensure microphone recording quality and uniformity.

Ex: Play back low and high frequency test sounds, using dB meter to ensure a specified volume at 1 m and 10 m. Record these sounds at those distances, and determine how closely mics meet a recorded dB value. Note the difference and don't use the mic if it is particularly poor (a large difference in the recorded dB value and actual value). This would be important for ensuring that a network of mics is always surveying the same basic area, and that swapping out a mic in the event of equipment failure and the like will not impact results.

Setting Date and Time

The time and date in the recording unit may be set in advance and synchronized among units using the Olympus Sonority Software which is included with the recorder. Connect the Olympus ARU to your computer using the USB cable included with the device. Set your computer time to match the time with the official US time at <http://www.time.gov/timezone.cgi?Eastern/d/-5/java>, and then open Olympus Sonority. In the [Device] menu select [Synchronize Date/Time] and press OK. After disconnecting the recorder from the computer be sure to set the unit to 24 Hour time by pressing and holding the OK button for two seconds, opening the [Device Menu] and selecting [Time & Date], and then pressing the 'podcast' button once.

Setting the ID

The recorder ID can also be customized by selecting [Transmit User ID] in the [Device] menu; the first four characters of the user ID will appear as a prefix to each file recorded by the device. Out naming convention was to assign each site a unique number in addition to a 4 letter code which stood for the location or park of deployment. For example, Olympus ARU deployed at site number 4 at Saratoga National Historic Site would be given an ID of SARA4.

Preparing Units

You may also wish to camouflage the units using brown and green spray paint before deployment. Additionally you may want to number units to match the ID set above and write or affix a sticker with identification of the organization deploying the units and with a request not to tamper with units. See example to the right:

Property of National Park Service Northeast Temperate Network
Please Do Not Disturb
For information call (555) 656-3011

Installation

Supplies and Tools:

Olympus ARU with microphones

4-6 Plastic cable ties 14" long (cabletiesplus.com item # CP-14-120-B)

2 Packets of desiccant (amazon.com item # B0038N30OY)

4' length of 3/32" vinyl-coated steel cable and a 1/8" cable clamp

Brass lock with 3/4" shackle (taylorsecurity .com item# No. 4120KA)

Knife/diagonal pliers to trim cable ties

5/16" socket/nut driver or adjustable wrench to tighten cable clamp

For items listed above with no source ask at your local hardware store or Lowes/Home Depot.

Procedure:

To install the recorder in the field, select a location with a tree or post that is between 10 cm (4") and 30 cm (12") diameter. The tree should have a sturdy branch 1 to 2 m (4'-7') above the ground from which to hang the microphone. If using a post you will have to improvise microphone placement.

Hang the microphone by wrapping the wire over and around the branch several times, winding the jack towards the trunk of the tree. The microphone may hang any feasible distance from the trunk and will ideally be above deer browse height. The microphone is inside a windscreen made of wire mesh and faux-fur. The microphone can be visually inspected by holding the base (the plate) as close to the windscreen as possible and gently and slowly rocking the windscreen while pulling it directly off the base. It may help to adjust your grip on the base and the windscreen several times by rotating the base.



Each ARU is enclosed in a Pelican case, with a 3.5mm (1/8") mic input jack on the bottom. Pull the case tight against a tree or post by using two chains of plastic cable ties. The cable ties pass through the handle on the left side of the case and the steel bar on the

right side of the case. Install an upper chain and a lower chain. In addition to the plastic cable ties, optionally install a length of vinyl covered steel rope through the same points, around the tree, and then fasten it with a cable clamp for security.

Once the ARU is firmly attached to the tree, plug the microphone into the jack on the bottom. Arrange the wire so that it falls as close to the trunk as possible, descends below the mic input jack, and then loops once before plugging into the jack. The hanging loop will serve to allow water to drip off the wire before it enters the input jack. The Pelican case is watertight, but the input jack is still exposed.

Setting up 24/7 Recording on an Olympus ARU

Turn on the recorder by sliding the on button (behind the stop button) down and holding for a few seconds.

If not done ahead of time, set the time and date as close as possible to the official US time at <http://www.time.gov/timezone.cgi?Eastern/d/-5/java>. Set the unit to 24 Hour time by pressing the left soft-key. Press and release the OK button when done. Press and hold the OK button for two seconds to open the main menu.

Scroll down to the [**Rec Menu**] (microphone icon) and **press OK**.

Highlight the [**Timer Rec**] option and **press OK**.

Highlight [**Preset 1**] and **press OK**.

In [**On/Off**] select **ON**, **press OK**.

Set the [**Day**] to [**Everyday**] and **press OK**.

In [**Time**] set the start time to ~ 5 minutes from the current time. Set the stop time to 8 hours from the start time and press OK. **Record the start time on your datasheet.**

Set the [**Rec Mode**] to **MP3, 128 kbps** and press OK.

In the [**Folder**] option select [**micro SD**] card (if using an SD card the recorder sees it as a micro SD card, since that is the slot that is filled). Press OK, then accept the default [**Folder A**] and press OK again.

Confirm that [**Mic Sense**] is set to [**Middle**] and press OK.

Select [**Finish**] and press OK.

Repeat for [**Preset 2**] and [**Preset 3**], setting each to start at the end of the previous preset's 8 hour recording period and end 8 hours after the start time, so that one starts right as the previous recording ends. It can be helpful to calculate the start and end times for all three timers on your datasheet for quick reference.

Before closing the box confirm that recording begins properly and that the red light turns on and write the file name for the first recording on your datasheet.

HINT: Confirm that the countdown timer lists at least 73 hours of record time remaining (this should be visible on the display screen). If it lists less (such as 34 hours), you may have to stop the recording, double check that the file destination is set to the **micro SD card**, and reset all of the timers.

For help setting the Olympus Unit to record on a different schedule, consult the Olympus Digital Recorder User's Manual provided by the manufacturer.

Maintenance

The units must be visited for maintenance and renewal of batteries and SD cards periodically. The schedule for this maintenance is created by determining the length of time your units can go before either the SD cards are full or the batteries are low. See the graphs above and appendix for data tables on how long units can be left using different recording schedules and at different amounts of compression. A sample datasheet/checklist for maintenance can be found in the appendix.

****Remember to write all recording start times and SD Card numbers on the datasheet****

Deployment of a Wildlife Acoustics, Inc. Song Meter ARU

The Song Meter SM 1 Unit



Before you go into the field:

Calibration of Units

Methods are being developed for procedures to calibrate units before going into the field. This is to ensure microphone recording quality and uniformity.

Ex: Play back low and high frequency test sounds, using dB meter to ensure a specified volume at 1 m and 10 m. Record these sounds at those distances, and determine how closely mics meet a recorded dB value. Adjust gain settings to meet standard value. This would be important for ensuring that a network of mics is always surveying the same basic area, and that swapping out a mic in the event of equipment failure and the like will not impact results.

Preparing Units

To prepare units for attachment to trees we installed four 5" piece of steel tape in a loop to the back of each unit (one at each corner) using 6x32 x 3/4" long bolts, a washer, and two nuts. The units already have a hole to accommodate the bolts at each corner. An external power supply cable can either be purchased through Wildlife Acoustics, Inc or separately (for much cheaper) that will allow the unit to be powered from a 12V battery.

To use an external power supply the power selection jumper must be moved to select power from the external power supply. When using an external power supply other than the one sold by Wildlife Acoustics, it is extremely important to connect the white wire to the positive (+) terminal and the black wire to the negative terminal (-). Unlike the official SM2PWR external power supply cable, other cables may not provide reverse polarity protection. Failure to connect the external battery properly will likely destroy the voltage regulator, the SM2 motherboard, or both.

For help choosing a power source and a sampling rate refer to the following graphs.

WAC0 is the lossless compression offered by Wildlife acoustics in the SM1 and SM2.

The SM2 has additional lossy compression file types available that are described in the user's manual.

Setting Date and Time

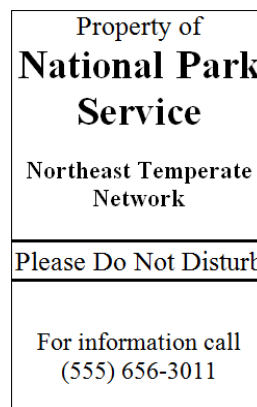
Manually set the time and date according to the SM2 instruction manual as close as possible to the official U.S. time at <http://www.time.gov/timezone.cgi?Eastern/d/-5/java>. You may need to temporarily install 4 D-cell batteries to set the time, or you can connect the SM2 to an external power supply of 6.5v-25v DC (30v DC can be used if a 1k Ω load resistor is added to the circuit).

Setting up 24/7 Recording on a Song Meter

To create a recording schedule, download the Song Meter Configuration Utility from the Wildlife Acoustics website <http://www.wildlifeacoustics.com/downloads.php> and follow the instructions in the user's manual. Note that options are available in the SM2 for solar tracking, or you may wish to use the TWGCRN protocol of recording 5 minutes at the top of every hour. When choosing a sample rate remember that you will only capture sounds $\frac{1}{2}$ the sampling rate. For example if you are recording high-pitched warblers such as the Blackburnian Warbler you will need to record at a minimum sampling rate of 22.05 kHz to capture the high frequency trills above 8 kHz. For this reason we recommend elevating the sample rate above the 16 kHz default if monitoring birds. For monitoring only frogs the default sampling rate is acceptable. To monitor bats you need the SM2BAT ultrasonic package from Wildlife Acoustics, which will enable recording rates of up to 192 kHz. Such a high sample rate will require more memory than typically used for monitoring birds, although it will consume power at the same rate as the SM1 depicted in the earlier graphs. The graphs on the following page can help when choosing how to power and how much storage to provide for bat and mixed bat-bird recording configurations. The exclusive bat recording assumes no triggering and 12 hour bat recording, and the mixed recording schedule assumes no triggering and 12 hour days/nights.

Save the schedule you create to the highest directory of an SD card and load it into the SM 1 recorder during setup as described at the bottom of this page. Be sure to either save the schedule to all cards or load the card with the schedule into slot A of the Song Meter.

As with the Olympus ARU, you may also wish to camouflage the units using brown and green spray paint before deployment. Additionally you may want to number units to match the ID set above and write or affix a sticker with identification of the organization deploying the units and with a request not to tamper with units. See example below:



Installation

Supplies and Equipment

Song Meter recording units
 SM2PWR cable or equivalent if using external power
 4-6 Plastic 14" cable ties (cabletiesplus.com item # CP-14-120-B)
 Group 24 12V deep cycle battery or 4 D-cell batteries
 Group 24 12V battery case (if using external batteries;
 amazon.com item #B001O0D6QA)
 5 1/2" and 7" Diameter hose clamps to secure lid of battery box
 4' 3/32 vinyl-coated steel cable and a 1/8" cable clamp
 8' 3/32 cable with swaged loops at ends for securing battery box to a tree
 2 Packets of silica desiccant
 Knife/diagonal pliers to trim cable ties
 Phillips #2 head screwdriver to open and close unit
 5/16" socket or nut driver

For items listed above with no source ask at your local hardware store or Lowes/Home Depot.

Procedure:

To install the recorder in the field, select a location with a tree or post that is between around 10 cm (4") and (30 cm) 12" in diameter. If using external power, an ideal tree has an area at the base suitable to place a 12v deep cycle battery in a box. The battery should not tip over and should not be immersed in water if heavy rain causes flooding. Pull the unit tight against a tree or post by two chains of plastic cable ties. The cable ties pass through the metal loops at the corners of the cases and wrap completely around the tree or post. We typically install an upper chain of cable ties and a lower chain of cable ties. Optionally, install a length of vinyl covered steel rope through the lower loops around the tree, and fasten it with a cable clamp for security.

If using an external battery, place the battery box at the base of the tree and connect the two hose clamps together at the ends to form a single longer hose clamp. Slip the long portion of the hose clamp under the battery box and place the battery in the box. Securely connect the power cable to the battery and the SM 1, put the lid on the battery box (making sure not to crimp the power cable), and secure the hose clamp over the top of the box to hold it shut.

Install the SD card with the programmed schedule in slot A and power up the SM 1 by pressing and holding the wake/exit button for two seconds. Press the select button and scroll down to the LOAD SONGMETR.SET FILE, then press select again. Confirm that your presets have been loaded, then change the [prefix] for each unit to a 4 letter location/park code plus the site number (for example ACAD4), press select until the prefix has been set, and put the unit to sleep by pressing the wake/exit button once. The unit should begin recording immediately if you are doing 24 hour recording.



Maintenance Datasheet and Checklist:

The units must be visited for maintenance and renewal of batteries and SD cards periodically. The schedule for this maintenance is created by determining the length of time your units can go before either the SD cards are full or the batteries are low. See the graphs above and appendix for data tables on how long units can be left using different recording schedules and at different amounts of compression. A sample datasheet/checklist for maintenance can be found in the appendix.

****Remember to write all recording start times and SD Card numbers in datasheet****

Downloading Audio Data for Olympus and SM 1 ARU

SD Cards

Both the Song Meter and Olympus recording units store the audio data they record on standard sized SD (Secure Digital) cards (SDHC) that can be purchased online or at most electronics stores. The cards we used were a single 32GB card for the Olympus units and a 32GB and a 16GB card for the Song Meter Units. Newer versions of the Song Meter (the SM2) can hold up to 4 SD cards which will allow for longer deployment (up to the point that the battery life becomes a limiting factor). The price for a 16GB card is around \$25 currently, while the price for a 32GB card is around \$50 currently. Prices are expected to drop following the trend of data storage becoming cheaper and cheaper.

Download

Once collected from the field, the audio files on an SD cards can be downloaded onto a computer using a USB card reader. The card is plugged into the reader and the reader is then plugged into the USB port of a computer and the device should then appear on your computer. Files can then be moved to the location of your choice. The date a given audio file was recorded should be part of the properties of the file. If you have not already set up your units to record the location or some other identifier as part of the file name (explained in the procedures above) then it is a good idea to change the file names to reflect any unique identification you wish to give them at this point for easier analysis later.

Depending on the speed of the computer being used, download may take a substantial amount of time (for us it was about 20 minutes per card). This should be kept in mind if downloading is done in the field, which might be the case if you do not have enough SD cards to switch all full ones for empty ones in one visit. Once the audio data has been downloaded to the location of your choice, you may erase files on the card. Occasionally we had a problem with a card malfunctioning and not recording data properly. In this case it sometimes helped to reformat the card upon download. The Olympus unit also has a card reformatting function if you need to reformat in the field (for details see the Olympus instruction manual). The files containing the recording schedule for Song Meter units can be left on the card if you wish to use the same schedule, or it can be erased and replaced with a new schedule. Be careful about reusing schedules that contain specific start and stop dates (rather than those set to record a certain amount per day) as they will not be reusable.

File Types

The files from the Olympus units are in MP3 format while the files from the Song Meter are in WAC format (developed specifically by wildlife acoustics). The MP3 is a lossy compressed file format, meaning that some audio data is thrown out for the sake of smaller file sizes when compression is performed. WAC is a lossless compressed file format and does not lose any information in the process of compression but results in a larger file size than the MP3 format. Different audio software may require different formats in order to play, view, and manipulate audio data, so it may be necessary to convert these files into different formats.

Converting Files

Olympus MP3 files can be converted to other formats using free downloadable audio software. We chose to use a program called Audacity which can be downloaded at <http://audacity.sourceforge.net/> and another option is RealPlayer which can be downloaded at <http://www.real.com/>

Song Meter WAC files can be converted to WAV files using the free WAC2WAV converter available for download on the Wildlife Acoustics website at <http://www.wildlifeacoustics.com/downloads.php>. The files can then be converted to forms other than WAV if necessary using the same audio tools listed above for the Olympus unit.

Sample Maintenance Datasheet

Equipment:

Writing utensil
Empty SD cards
Spare Olympus ARU windscreens
Spare Song Meter windscreens
Phillips #2 head screwdriver to open and close units
Charged 12V deep cycle battery or 4 D-cell batteries
5/16" socket or nut driver to open battery cases
Key to Olympus ARU locks (if used)
Packets of silica desiccant

Date: _____ **Location/Park:** _____ **Site #** _____

	Empty/Taken Out		Full/Put In			
Unit #	32GB	16GB	32GB	16GB	Record Start Time	Notes

Checklist

- ___ Take out old 12V or D-cell batteries and replace with a fresh 12V or D-cell batteries
- ___ Take out the full SD cards and replace with empty SD cards
- ___ Record SD card numbers in datasheet
- ___ Reset the recorder for a new 24 hour (or other desired) recording schedule
- ___ Record start time for recording schedule
- ___ Check the packet of desiccant and replace if necessary
- ___ Check the unit and cables over for any damage or needed adjustments
- ___ Remember to shut all units and battery cases

Song Meter Unit Specifications

Physical Specifications

- Dimensions: 8.0" X 8.0" X 2.5"
- Weight: 2.0 pounds without batteries)
- Enclosure: NEMA Type 1,4,4X and 6 (weatherproof, vented). A self-regenerating humidity control device such as Zorb-It is required to prevent condensation in some conditions.
- Operating Temp.: -4°F to +185°F -20°C to +85°C (Inside the enclosure - avoid exposure to direct sunlight in hot environments. Also note that operating range of the batteries used may be narrower.

Audio Specifications

- Channels: 2
- Interface: 3-pin waterproof connector (ground, signal, 3.3V supply)
- Bias power: 2.5V 2.2K ohm, jumper enabled per channel
- High-pass filter: 2-pole butterworth, jumper selectable per channel at 2, 180 or 1,000Hz
- Pre-amplifier: 2-stage, jumper selectable per channel, at +0, +12, +24, +36, +48, or +60dB gain. For sample rates $\leq$ 48kHz, third-stage digitally-configurable +0-+12dB in 1.5dB steps
- Noise: -115dBV equivalent input noise
- ADC: 1V rms full-scale 16-bit, 90dB SNR
- Sample rates: 4, 8, 16, 22.05, 24, 32, 44.01 and 48kHz standard; 192kHz and 384kHz available with SM2BAT192x2 and SM2BAT384 daughter cards.
- Digital format: 16-bit PCB (.wav) or proprietary lossless and lossy compression formats (.wac).
- Headphones: 3.5mm stereo jack
- Filtering and triggering: Configurable digital high-pass and low-pass filters at sample rate divided by 3, 4, 6, 8, 12, 16, 24, 32, 48 and 96. Adaptable trigger with configurable threshold above background 1-88dB, absolute trigger with configurable threshold -1 - -88dB full scale, inactivity time for trigger off 0.1 - 9.9 seconds.

Sensors

- Channels: 2
- ADC: 10-bit at 3.3V reference (3.2millivolt resolution)
- Parameters available for precise calibration
- Internal temperature sensor accurate to within $\pm 2^{\circ}\text{C}$ at 0°C .
- External sensor port with 3-pin waterproof connector (ground, signal, 3.3V supply)

Storage

- 4 SD/SDHC/SDIO flash card slots (Class 4 or greater)
- 128GB total capacity with 4x32GB cards available today, more as higher capacity cards become available
- Compression increases effective capacity by 60-70% typically

Power

- 4-10VDC main power (internal 4 D-size batteries or external weatherproof connector)
- 6-20VDC through external power adapter for 6 or 12V solar power systems

- < 1mA when idle between scheduled recordings
- *The following estimates can vary 10mA depending on flash cards used:*
- 55-65mA when recording uncompressed up to 48kHz (except 32kHz), compressed up to 16kHz mono, and band triggered up to 8kHz mono.
- 70-75mA when recording compressed up to 48kHz (except 32kHz), and band triggered up to 24kHz mono.
- 80-90mA when recording 32kHz and up to 48kHz compressed, and band triggered up to 44.1kHz mono.
- 90-100mA when recording band triggered up to 48kHz mono.
- 110mA when recording band triggered up to 48kHz stereo.
- Separate power for time-of-day clock uses 2 AA-size batteries, < 0.1milliamps (2-3 year service life)

SMX-II Microphones

- Enclosure: NEMA 4X weatherproof
- Sensitivity: -36±4dB (0dB=1V/pa@1KHz)
- Frequency response: flat 20Hz - 20,000Hz
- Signal-to-Noise Ratio: > 62dB
- Directionality: Omnidirectional

Memory Capabilities

Recording Times (in Hours)

Mono (1 channel)

	48,000	44,100	32,000	24,000	22,050	16,000	8,000	4,000
2GB	5.8	6.3	8.7	11.6	12.6	17.4	34.7	69.4
4GB	11.6	12.6	17.4	23.1	25.2	34.7	69.4	138.9
8GB	23.1	25.2	34.7	46.3	50.4	69.4	138.9	277.8
16GB	46.3	50.4	69.4	92.6	100.8	138.9	277.8	555.6
32GB	92.6	100.8	138.9	185.2	201.6	277.8	555.6	1111.1
64GB	185.2	201.6	277.8	370.4	403.1	555.6	1111.1	2222.2
128GB	370.4	403.1	555.6	740.7	806.2	1111.1	2222.2	4444.4

Stereo (2 channels)

	48,000	44,100	32,000	24,000	22,050	16,000	8,000	4,000
2GB	2.9	3.1	4.3	5.8	6.3	8.7	17.4	34.7
4GB	5.8	6.3	8.7	11.6	12.6	17.4	34.7	69.4
8GB	11.6	12.6	17.4	23.1	25.2	34.7	69.4	138.9
16GB	23.1	25.2	34.7	46.3	50.4	69.4	138.9	277.8
32GB	46.3	50.4	69.4	92.6	100.8	138.9	277.8	555.6
64GB	92.6	100.8	138.9	185.2	201.6	277.8	555.6	1111.1
128GB	185.2	201.6	277.8	370.4	403.1	555.6	1111.1	2222.2

Appendix C: Index and Code Definitions from NAAMP Protocol

Amphibian Calling Index	
1	Individuals can be counted; there is space between calls
2	Calls of individuals can be distinguished but there is some overlapping of calls
3	Full chorus, calls are constant, continuous and overlapping

Beaufort Wind Codes	
0	Calm (<1mph) Smoke rises vertically
1	Light Air (1-3 mph) smoke drifts, weather vane inactive
2	Light Breeze (4-7 mph) leaves rustle, can feel wind on face
3	Gentle Breeze (8-12 mph) leaves and twigs move around, small flags extend
4*	Moderate Breeze (13-18 mph) moves thin branches, raises loose papers
	* Do not conduct survey at Level 4, unless in Great Plains
5**	Fresh Breeze (19 mph or greater) small trees begin to sway
	** Do not conduct survey at Level 5 in ALL REGIONS

Noise Index*		
Massachusetts Noise Index	Yes/No system	Definition
0	No	No appreciable effect (e.g. owl calling)
1	No	Slightly affecting sampling (e.g. distant traffic, dog barking, one car passing)
2	No	Moderately affecting sampling (e.g. nearby traffic, 2-5 cars passing)
3	Yes	Seriously affecting sampling (e.g. continuous traffic nearby, 6-10 cars passing)
4	Yes	Profoundly affecting sampling (e.g. continuous traffic passing, construction noise)
* A regional program may choose whether ambient noise is documented in yes/no format or by using the Massachusetts noise index.		

Appendix D: The probability of each outcome for each class of the variables in the three-way interaction.

Recorder	ID Method	Species	Outcome Probability			
			False +	False -	True +	True -
Olympus	Human	H. versicolor	0.00	0.01	0.26	0.73
Olympus	Human	P. crucifer	0.00	0.03	0.62	0.35
Olympus	Human	A. americanus	0.00	0.00	0.09	0.91
Olympus	Human	L. clamitans	0.02	0.04	0.31	0.63
Olympus	SS1	H. versicolor	0.36	0.03	0.25	0.36
Olympus	SS1	P. crucifer	0.24	0.03	0.63	0.10
Olympus	SS1	A. americanus	0.10	0.00	0.09	0.81
Olympus	SS1	L. clamitans	0.35	0.09	0.27	0.29
Olympus	SS2	H. versicolor	0.17	0.04	0.24	0.55
Olympus	SS2	P. crucifer	0.13	0.06	0.60	0.21
Olympus	SS2	A. americanus	0.03	0.01	0.08	0.88
Olympus	SS2	L. clamitans	0.14	0.19	0.18	0.50
Olympus	SS3	H. versicolor	0.00	0.18	0.10	0.71
Olympus	SS3	P. crucifer	0.00	0.24	0.42	0.34
Olympus	SS3	A. americanus	0.01	0.02	0.08	0.89
Olympus	SS3	L. clamitans	0.01	0.33	0.04	0.61
Song Meter	Human	H. versicolor	0.00	0.00	0.27	0.72
Song Meter	Human	P. crucifer	0.02	0.00	0.65	0.33
Song Meter	Human	A. americanus	0.00	0.00	0.09	0.91
Song Meter	Human	L. clamitans	0.00	0.02	0.33	0.65
Song Meter	SS1	H. versicolor	0.38	0.03	0.25	0.34
Song Meter	SS1	P. crucifer	0.26	0.04	0.62	0.07
Song Meter	SS1	A. americanus	0.09	0.01	0.09	0.81
Song Meter	SS1	L. clamitans	0.26	0.10	0.26	0.38
Song Meter	SS2	H. versicolor	0.18	0.03	0.25	0.54
Song Meter	SS2	P. crucifer	0.15	0.07	0.59	0.19
Song Meter	SS2	A. americanus	0.02	0.02	0.08	0.88
Song Meter	SS2	L. clamitans	0.08	0.22	0.15	0.55
Song Meter	SS3	H. versicolor	0.00	0.18	0.11	0.71
Song Meter	SS3	P. crucifer	0.01	0.24	0.42	0.33
Song Meter	SS3	A. americanus	0.00	0.03	0.07	0.90
Song Meter	SS3	L. clamitans	0.01	0.34	0.03	0.62