

**Tradeoffs of Automation in Monitoring:  
A Comparison of Anuran Acoustic  
Monitoring Methods**

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**DRAFT**

Successful monitoring of wildlife, and in particular threatened groups of species like those in the order Anura (the frogs and toads), is an increasingly important activity for detecting and predicting fluctuations in populations. Yoccoz et al. (2001) defined monitoring as the process of determining the state of a system and measuring changes in that system over time. The purpose of monitoring wildlife populations is to keep track of changes in the populations of species over time, most commonly in order to better understand population dynamics or to assess the effects of management practices (Yoccoz, Nichols, & Boulinier, 2001).

Monitoring activities have been increasing quickly over the last few years, but with them have come growing concerns about the quality and effectiveness of these programs (McDonald-Madden et al., 2010; Sauer & Knutson, 2008; Yoccoz et al., 2001). Creating an effective monitoring program is a difficult task which necessitates an understanding of both the complexities of the system being monitored as well as the often conflicting objectives of the program itself. Critics agree that monitoring initiatives must have well defined objectives and a consideration of the cost and benefits when designing the program, but that this is not always done and the result is a decreased ability to put the data collected to good use (McDonald-Madden et al., 2010; Sauer & Knutson, 2008). The most basic objectives of a program are to minimize the cost (both material and time) while maximizing the accuracy of data collected so that it is capable of answering the questions the program seeks to answer (McDonald-Madden et al., 2010). A recent approach has been to use the tools of structured decision making in order to choose between alternative possibilities in a monitoring program (Lyons, Runge, Laskowski, & Kendall, 2008). Structured decision making basically functions by identifying and comparing a number of alternatives based on a set of objectives and to make a decision based on which alternative best meets those objectives (Lyons et al., 2008). These tools for evaluating

alternatives may be used at any level in the decision making process, from the basics of what species and where to monitor, to the details of what methodology should be employed. Despite the benefits of weighing alternative methods and quantifying their costs and benefits, this careful comparison is often not done, and the choice made may not be the most appropriate and cost-effective alternative.

Anuran monitoring provides a good example of an area where a structured decision making approach could be very useful as a tool for designing monitoring programs. Anurans (and amphibians in general) 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) and growing concerns over the effects of climate change on Anuran habitat and breeding behavior (Corn, 2005.; McMenamin, Hadly, & Wright, 2008; Todd B., Scott D., Pechmann J. H., & Gibbons J., 2010). The choice of what methodology to use when conducting these monitoring programs would be a fitting use of structured decision making, especially in the light of new tools and techniques which have been growing in popularity over the last few years. Many programs monitor Anurans by their unique breeding calls which males emit in order to attract a mate (Heyer, 1994). 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. Recently traditional methods of acoustical monitoring have begun to be coupled with, and often replaced by, the use of new technologies which have many benefits as well as costs that are just beginning to be tested and understood. These alternative methods for anuran acoustic monitoring offer an exciting opportunity to choose amongst possibilities for the

best fit to a given monitoring program, but also add complexity to the decision of which method to choose.

### *Alternatives for Acoustical Monitoring of Anurans*

Traditional call surveys in which a human observer is sent out into the field to listen for different species of frogs, has been a practice used for decades (Heyer, 1994). This method is low on material costs, but very high in time cost, and the rate of error can be difficult to ascertain, since different observers will have varying amounts of experience and even differing hearing capabilities which will result in differences in accuracy (Aaron Lotz & Allen, 2007; Genet & Sargent, 2003; Crouch & Paton, 2002). Another problem is that species may be present but not calling during the time when a person is able to get to the field to conduct a survey. These abiotic or biotic factors include temperature, weather, and sometimes even the presence of the person themselves, which may make individuals less likely to call on certain nights (Bridges and Dorcas 2000; Saenz et al. 2006; Steelman 2010). The time cost of sending a person to each site in order to conduct a survey also limits the length a survey can be. However the typical length of a survey (generally 5 to 10 minutes depending on the program protocol) has been shown to miss a substantial number of species detections, with more species being detected even after 40 minutes of sampling (Pierce & Gutzwiller, 2007).

One possible way to counteract these drawbacks is with audio recordings made during, or in place of, human surveys. The utility of these audio recorders (often called autonomous recording units or ARUs) for monitoring wildlife (including Anurans) acoustically is widely documented, both as a complement to traditional field methods and as a method of data collection in its own right (Anderson, Dave, & Margoliash, 1996; Peterson & Dorcas, 2001; Acevedo & Villanueva-Rivera, 2006; Agranat, 2007; Charif & Pitzrick, 2008; and Waddle,

Thigpen, & Glorioso, 2009). These ARUs solve the problem of high time cost for collection of data in the field, and also make it easier to sample for long periods of time, making them more likely to catch species that might not be calling when an observer is able to go into the field and conduct a survey in person. These recorders are weatherproofed and highly programmable so that they may be set to record on a schedule for long periods of time with very little maintenance (Peterson & Dorcas, 2001). Recording during, or in place of human surveys allows for the possibility of re-examination and re-analyzing of the audio data in order to achieve a higher degree of accuracy. In addition, spectrograms (visual representations of the sound) can be compared with other known samples, either by eye or with computer software designed to detect similarities, allowing for computer mediated detection of species (Altes 1980). The computer software can be taught what sounds a researcher is interested, and then automatically run through hours of audio recordings and find similar sounds (Agranat 2007). This means that the process can be highly automated, allowing for much faster processing of large amounts of data, a necessity in large-scale monitoring programs.

Yet another choice researchers have is to either create their own ARU or purchase or rent one of many models which are available commercially. One such unit is Wildlife Acoustic, Inc.'s Song Meter, which can be programmed to record high quality audio data on a schedule for several weeks or even months, and is available for around \$900 (Wildlife Acoustics, Inc. 2010). Cheaper units can be home-made using off-the-shelf digital voice recorders and widely available, simple electronic components for only a few hundred dollars (Peterson and Dorcas 2001), but generally record lower quality data. Both collect digital data which can be listened to by a person who records the species they hear, or it may be run through computer software for automatic identification, however, there has been little research into the comparative success of

different types of species identification using a home-made model versus a commercially available unit.

The promise of increased automation for speedy data processing is alluring, especially at a time when monitoring efforts often seek to cover large areas or long period of time, and when budget cuts may mean hiring technicians to listen to data or collect it in the field may be limited. However, these newer method are also susceptible to error and have their own set of costs. Like a human observer, the recorders may not “hear” (record) a call, or the computer program might miss a call due to flaws in the detection process. Conversely, the computer might incorrectly identify one species as another. These rates of error are likely to vary depending on the quality of the recording, the quality of computer software or the experience of the human listener, and also the characteristics of the calls themselves, and lastly the presence and level of background noise ( Rempel, Hobson, Holborn, & van Wilgenburg, 2005; Agranat, 2007; Charif & Pitzrick, 2008;).

These errors exist for all methods and play a large role in reducing the accuracy of a study. They include false negatives (a species is present but remains undetected by the surveyor) as well as false positives (a species is not present but is incorrectly detected). Assessing the factors associated with false negatives and positives has begun to receive more attention within wildlife research. Such errors have been found to have a much greater affect on the interpretation of monitoring data than previously assumed, and much emphasis is now being places on the ability to identify and correct for these errors (Tyre et al., 2003). With all of these possibilities for monitoring Anurans by their calls, the question is which method is best suited to which scenarios. A certain program may need to focus on keeping costs low, another might focus on minimizing certain types of error, and yet another might need a high amount of

automation for speedy processing. The complexities of understanding and minimizing errors in the system we wish to assess (in this case Anuran populations) while also minimizing the costs of keeping these errors low for a set of alternative methods, makes this problem a perfect candidate for a structured decision making approach.

The purpose of my study has been to build a structured decision making model in order to compare two alternative methods of ARU and three methods of species identification. The survey methods will include recording surveys with a high quality commercial ARU and a home-made ARU and then determining what species are on those recordings using increasing levels of automation from solely a human identifying species, to both a human and a computer, to a computer software program making identifications all on its own. In this way error rates can be assessed for each method and along with their costs, this information can be placed in a structured decision making framework in order to compare these methods in various scenarios. In order to monitor a highly threatened group of species like Anurans, it is of utmost importance that the best method be chosen to enhance accuracy and limit cost in order to monitor in a way that is both effective and efficient.

## Objectives

The goal of this study is to use structured decision making to compare costs and benefits for 6 alternative monitoring schemes with varying levels of automation.

Specific objectives are to:

1. Collect data with two alternative automated recording units (ARUs)
2. Identify species on the recordings with three alternative methods
3. Use AIC to assess how error rates of each method are a function of different covariates
4. Assess the costs of each method
5. Perform a SMART analysis to weigh the tradeoffs and identify optimal method schemes in different scenarios

## Methods

### **Objective 1. Collect data with two alternative acoustic recording devices.**

#### *Recording Unit Alternatives – Commercial ARU*

For our commercial unit, we chose the Song Scope SM1 developed and available for purchase from Wildlife Acoustics, Inc. The unit (seen in fig.1) has a weatherproof outer case with two weatherproofed microphones which face in opposite directions at the top of the unit. Inside there are two slots to hold SD (Secure Digital) cards, a battery pack for internal battery power, and a display screen which is used to set the timing and data type of recordings. We recorded in WAV format for increased quality of the audio data. We chose to use the external powering capabilities of the Song Meter for increased recording time by powering it with a 12v battery attached by a cord to the base of the unit. Additional specifications of the Song Meter unit can be found at the Wildlife Acoustics, Inc website, <http://www.wildlifeacoustics.com/>.



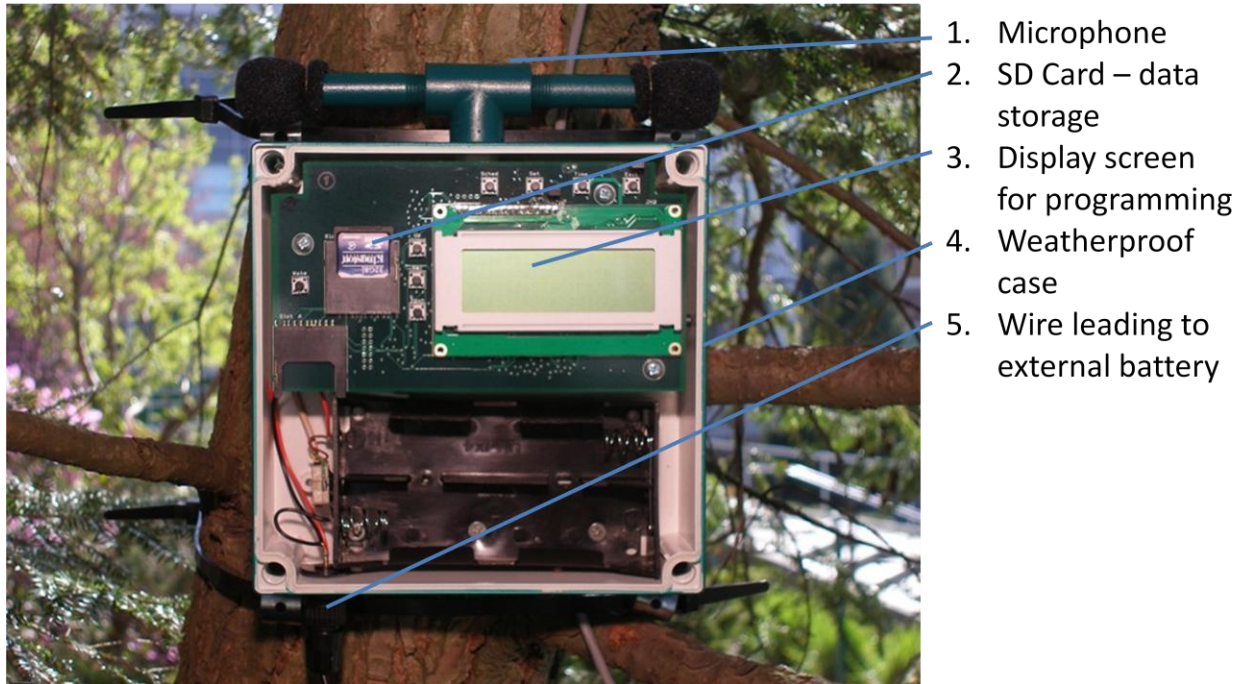


Figure 1. Song Meter SM1 in the field with front cover removed

### *Recording Method Alternatives – Homemade ARU*

A home-made autonomous recording unit (fig. 2) was designed and created by myself and Jon Katz (a PhD student of the Vermont Fish and Wildlife Coop Unit) using a DM-420 Olympus digital voice recorder as the recording component. 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 build an external microphone (fig. 3) 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 capabilities. More details of how this unit was made can be found in appendix A.



1. Pelican case – weatherproofing and protection
2. Battery pack with 4 D Cell batteries – power supply
3. DM-420 Digital Voice Recorder – audio recording device
4. SD Card – data storage
5. Wire leading to external microphone

Figure 2. Olympus ARU in the field with front cover open.



Figure 3. External Microphone for the Olympus ARU.

### *Study Sites*

Ten survey sites for this study were located at three state and national parks in Vermont and New York. 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 hearing frogs at one site which were also audible at another site.

Marsh-Billings-Rockefeller National Historical Park (4 sites) is a 555 acre park located in Woodstock, VT. The property ranges from approximately 700 to 1450 feet in elevation and is primarily dominated by northern hardwood forest, but also contains 33 acres of open hay fields. The park has several trails and carriage roads, and is open to horse and foot traffic year-round. There is also a 15-acre pond known as the Pogue and several vernal pools, streams, and wetland areas are known to contain active amphibian breeding sites (Faccio, 2001).

Gifford Woods State Park (2 sites) is a 13 acre park located in Killington, VT directly adjacent to the Green Mountain National Forest. The park is at an approximate elevation of 1,575 feet, and is unique in containing a large area of relatively undisturbed old hardwood forest. The park is bisected by highway 100, and the western half contains a campground and a system of hiking trails. The park contains several small wetlands and is across Highway 100 from Kent Pond.

Saratoga National Historical Park (4 sites) is located in Stillwater, NY. The park consists of approximately 2,800 acres, including 790 acres of managed grassland. The main mission of the park is to maintain historically important landscape features as they were during the battles which were fought there in the year 1777, but its mission also includes a commitment to conserving critical habitat (Trocki & Paton, 2007). The paved road system which runs through the park is open to foot, bike, and car traffic during most of the year. In addition to the

managed grasslands, the park contains large forested areas, several wetlands, ponds, and a man-made canal at the park entrance. The park contains several wetlands with breeding amphibian populations (Northeast Temperate Monitoring Network, 2009). The park lies across Highway 4 from the Hudson River.

### *Focal Species*

The species of Anura which were recorded and identified in this study are some of the most common in Vermont and New York. Eight species were detected on the recordings: The Northern leopard frog (*Lithobates pipiens*), spring peeper (*Psuedacris crucifer*), green frog (*Lithobates clamitans*), American bullfrog (*Lithobates catesbeiana*), American toad (*Anaxys americanus*), and grey treefrog (*Hyla versicolor*). Of these, three were detected enough times to be eligible as focal species for detection: The spring peeper (*Psuedacris crucifer*), green frog (*Lithobates clamitans*), and grey treefrog (*Hyla versicolor*). The other three species were only detected on a handful of occasions. Computer recognizers were not created for these rarely heard species, but their presence was recorded using the other methods of species identification for consideration as part of the soundscape and as potential candidates for sources of false positives errors.

### *Field Methods*

At each site, a Song Meter ARU and an Olympus ARU were affixed to a tree at approximately 5 feet above the ground with the microphones facing the wetland or body of water at that site.

Data was stored on 32GB SD cards. The Song Meter unit will record in Wildlife Acoustics, Inc.'s unique WAC audio file format which is compressed but lossless and the

Olympus unit recorded in MP3 (a lossy format which loses some audio information in the process of compression). Data from both units was converted to WAV format for processing in the lab, but the MP3 files will not regain the information lost in compression.

All units were set to record continuously for 2 weeks, at which point the memory cards were full. Every two weeks the batteries and SD cards of each unit were exchanged for empty SD cards and freshly charged batteries. Recordings for this project will take place from May 1<sup>st</sup> to July 1<sup>st</sup> during the peak calling times for most Anurans in Vermont and New York.

**Objective 2. Identify species with three alternative methods**

Three methods of species identification were used to determine what species were calling on the recorded audio data; Human Species Identification, Computer Mediated Species Identification, and a combination of both Human and Computer species identification. Coupled with the two recording methods these result in the 6 different alternative methods which were compared:

	<b>Human ID</b>	<b>Computer ID</b>	<b>Human &amp; Computer ID</b>
<b>Commercial ARU</b>	Method 1	Method 2	Method 3
<b>Home-made ARU</b>	Method 4	Method 5	Method 6

Table 1. The 6 methods which were compared in this study

The audio recordings were broken up into 100 surveys (10 at each site) which were recorded during the suggested time period for performing amphibian call surveys (NAAMP Frog Call Survey Protocol) between a half hour after sunset and midnight. These surveys were

recorded on nights when we were in the field to change batteries and SD cards so that we were able to record information about the temperature, weather, and noise conditions at the time of each survey. Each method of species identification was performed on each survey so that differences in detection could be found. The most extensive review of the data by both a computer and human (methods 3 and 6) was considered the “truth” and the results from all other methods were compared to these in order to determine error.

#### *Traditional Call Surveys (Human Species Identification)*

I conducted a call survey using the recordings from both the Song Meter and the Olympus ARU as if I were in the field. The survey method was adapted from protocol developed by the United States Geological Survey and used for the North American Amphibian Monitoring Program (USGS 2010). For each site, two consecutive 5 minute surveys were conducted. Every two weeks, at the time each survey was recorded in the field, the time and temperature were recorded, along with two number codes indicating the wind level and noise level, respectively. Back in the lab, I 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, I recorded the species of frogs I 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). In this way I could have a record of what was captured by the tapes and thus where errors were made, whereas if I have done my call surveys in the field, it would have been impossible to tell whether I had false heard a species that did not call, or if it was simply out of the recording range of the ARU.

## *Computer Mediated Species Identification*

### *Reformatting the Data*

The computer software we used to mediate identification of calls required that files be in WAV format, however, audio data from the ARUs was recorded in two different file formats for an additional comparison of a high quality format which takes up more storage space and a low quality format which is a smaller. Audio data for the Song Meter units were recorded in WAC format, which is a lossless compression format specific to Wildlife Acoustic, Inc. (2010). Before analysis, these files were converted to WAV files using the free WAC to WAV software available from Wildlife Acoustics, Inc. The Olympus ARUs will record audio data in MP3 format, which is a compressed file format where loss of data does occur (called lossy compression) resulting in smaller file sizes, and increased data storage capacity for the recording unit. These MP3 files were converted to WAV format using the free RealPlayer converter software available for download online (RealNetwork 2010).

### *Creating, Optimizing, and Running a Recognizer in Song Scope*

Once all of the data has been converted into WAV format, computer mediation of species identification will proceed in the same way for data from both units. These WAV audio data files were opened in Song Scope, a bioacoustics analysis tool developed by the Wildlife Acoustics, Inc. We used the Song Scope recognizer, which uses a library I created of examples of a call in order to create a template which is then compared with sounds within the audio data. It then automatically identifies those sounds which are most similar to the template. Once a file is open, a recognizer is selected, a quality and score level (each from 0 to 100) were chosen for how closely the target sound must match the template to be detected, and the template detector was run. The result is a list of sounds found within the data that match the template,

and a number indicating how closely they match the template. These species detections, along with a date, time, and location were then exported into a database for analysis.

The sounds for creating the recognizer were collected from 2 sources; sounds borrowed from outside databases such as Cornell's Macaulay Library of Sounds, and sounds from the ARUs themselves which have been verified. The sounds chosen for use in building the recognizer were those which are easily audible and not overlapped by other sounds or excessive background noise. Some species require more than one recognizer for detection, for example one for single individuals calling and one of many individuals calling in a chorus. These sounds are annotated by species, and then used by Song Scope to create a recognizer for use in the automated detection process.

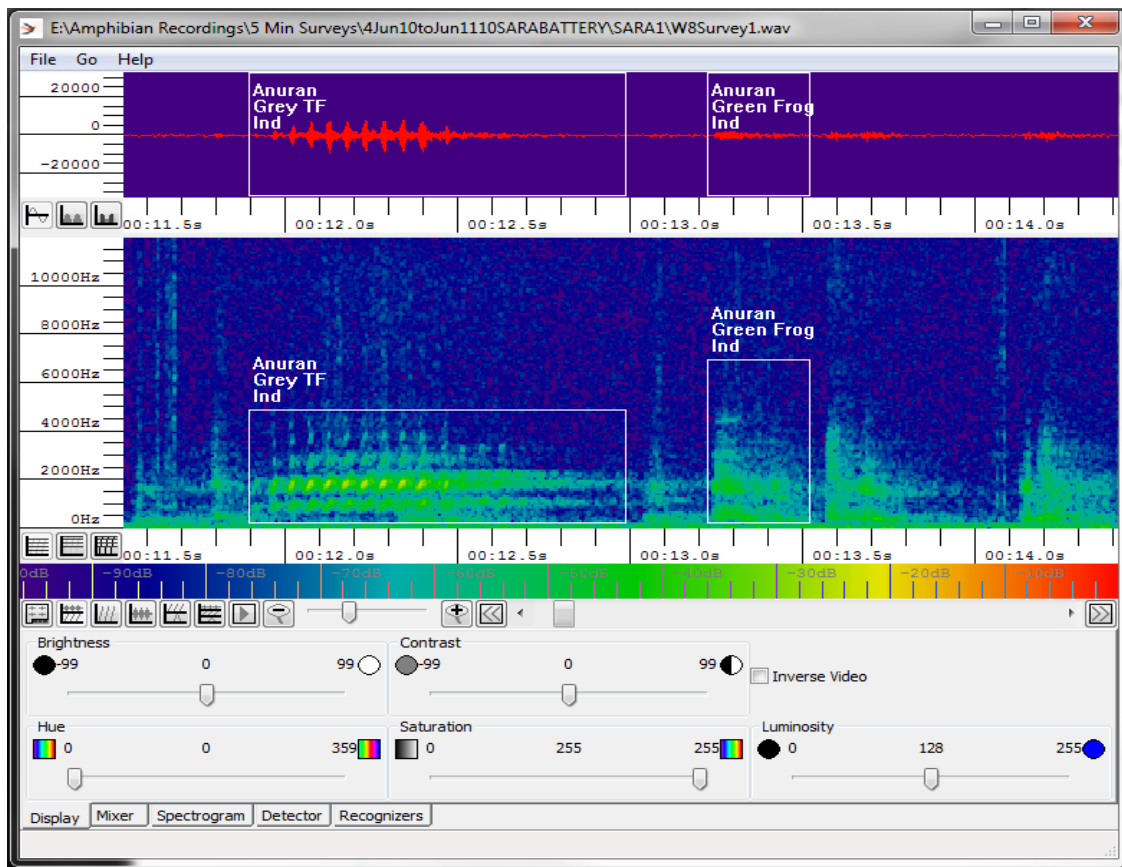


Figure 4. Example of Song Scope interface with several anuran species selected and identified



### *Comprehensive Examination of the Data Using Human and Computer Identification*

Lastly, I examined the data in depth in an effort to correctly identify accurately every species recorded in the audio data. I viewed the each 5 minute surveys from both the Song Meter and Olympus units as a spectrogram using the Song Scope software while listening through it with pauses and replays in order to be sure of identifications. I also used the Song Scope tools to filter, zoom in on, and otherwise better see and hear each sound in order to insure that identification was correct. Along with Anuran calls I also identified the other sounds on the recordings where possible. This examination of the recordings was meant to create a set of data which is very likely to be the most accurate, and therefore the standard to which the other methods are compared. Therefore, differences in the data from the other four methods from this dataset are very likely as a result of error and were recorded as such. In an instance where this comprehensive examination of the data detected a species and another of the four methods did not, this was considered a false negative. On the other hand if the in-depth examination did not identify a species during a certain minute and another method did, then this would be considered a false positive and if possible the sound would be correctly identified and recorded.

### *Additional Data Collected*

In addition to documenting the species heard during each survey, I also recorded information about background noise. The major sources of noises were rain (for which each a survey was given a 1 for rain present or 0 for rain absent), wind (for which each survey was given a 0 through 1 on the Beaufort wind scale), and traffic (for which I counted the number of passing

vehicles in each survey). This information was collected for use later in determining if these noises were a factor in the error rates.

## **Analysis**

### ***Objective 3. Use AIC to assess error rates of each method as a function of covariates***

#### *The AIC Analysis*

AIC is the acronym for Akaike's Information Criterion, a method developed by Hirotugu Akaike in 1974 in order to compare statistical methods on the basis of their relative ability to fit the data. It is a measure of the information lost when using a certain model to represent a real system, and therefore the smaller number the closer the fit. AIC is a relative measure and can only rank alternative models based on which is relatively the best, however, if all models are poor, this will not show up in the analysis. The equation for AIC is

$$AIC = 2k - 2 \ln(L)$$

In which the AIC 2 times the number of covariates (k) minus 2 times the natural log of the maximum likelihood function for the model. For more information on AIC please see Akaike et al.'s 1974 paper, A New Look at the Statistical Model Identification.

#### *Covariates*

We will test a wide range of covariates in order to determine whether they are contributors to the error rates found in the data. The main covariates we will test were the type of ARU, the method of species ID, as well as the species being identified, the presence or amount of background noise in the recording, and any possible interactions between these covariates. This would be modeled by the following equations:

$$\text{Error Rate} = \beta_0 + \beta_1 \text{Recorder} + \beta_2 \text{SpeciesID}$$

$$\text{Error Rate} = \beta_0 + \beta_1 \text{Recorder} + \beta_2 \text{SpeciesID} + \beta_2 \text{Species}$$

$$\text{Error Rate} = \beta_0 + \beta_1 \text{Recorder} + \beta_2 \text{SpeciesID} + \beta_2 \text{Noise}$$

$$\text{Error Rate} = \beta_0 + \beta_1 \text{Recorder} + \beta_2 \text{SpeciesID} + \beta_2 \text{Noise} \times \text{Species}$$

An AIC value will then be derived for each model and a decision made about which is the best.

That model will then be used to get the error rates that were used in the SMART analysis table.

#### ***Objective 4. Assess the costs of each method***

*Material Costs*

*Time Costs*

*Data Storage*

#### ***Objective 5. Perform a SMART analysis to compare method schemes in different scenarios***

*Creation of a SMART Analysis*

SMART Analysis is a structured decision making tool which compares alternatives in a table where each is given a value for each of several objectives. In this study the alternatives are the 6 methods and the objectives are cost, error (false positives and false negatives), and time. These can then each be given different weights to simulate one objective being considered more important than another, and therefore its effect being weighted more heavily. This tables results in a score for each alternative, and by manipulating the weights and numbers in the table, you can simulate different scenarios and determine which alternative performs the best.

Alternatives:	Objective			
	Cost (\$)	False Neg Rate	False Pos Rate	Time (Hours)
Method 1	1000	0.3	0.1	50
Method 2	1500	0.4	0.05	100
Method 3	500	0	0	75
Method 4	700	0.3	0.2	30
Method 5	500	0.1	0.03	75
Method 6	700	0	0	30
Min:	500	0	0	30
Max:	1500	0.4	0.2	100
Goal:	<b>Minimize</b>	<b>Minimize</b>	<b>Minimize</b>	<b>Minimize</b>
<b>Weights</b>				
	100	100	100	100

Table 2. Example SMART analysis tables comparing 6 alternative methods based on the objectives of cost, false positive and false negative error rates, and time all with equal weighting.

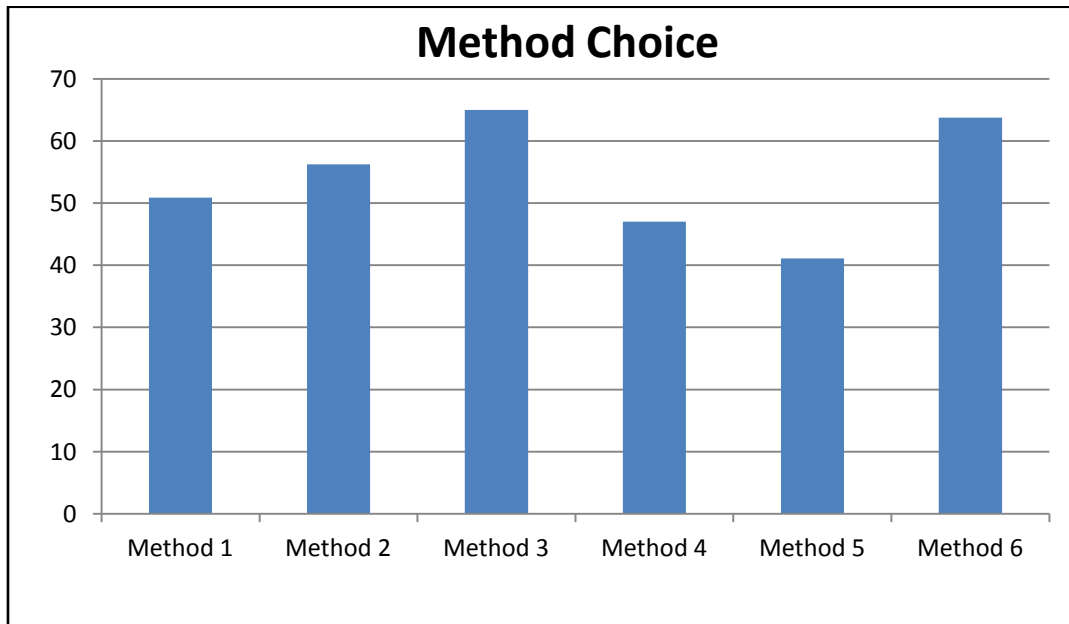


Figure 5. Example graph showing the scores for 6 alternative methods obtained from the SMART Analysis. This graph indicates that method 3 and 6 are tied for best choice in this scenario.

### *Comparing Methods in Different Scenarios*

Using the model chosen by the AIC analysis and the weights in the SMART analysis we will determine which of the 6 alternative methods performs the best in each of several common monitoring scenarios:

#### *Low Budget Scenario*

This scenario will be simulated by weighting the cost objective in the SMART analysis table

#### *Noisy Site Analysis*

If noise has been determined to be a driver of error rates, it will be possible to perform the SMART analysis using error rates gotten from the model chosen by the AIC analysis with low noise and with high noise, to see if a certain method performs better in these conditions (i.e. method 4 works best in noisy conditions)

#### *Species of Interest Scenario*

If the species being detected has been determined to be a driver of error rates, it will be possible to perform the SMART analysis using error rates gotten from the model chosen by the AIC analysis with each species, to see if a certain method performs better for different focal species (i.e. method one works best for Spring Peepers, etc.)

#### *Rare Species Scenario*

In this scenario it is important that there are a minimum of false negatives (where species are present but not detected). This will mean more false positives and therefore more work by a human to sort through the detections, but less chance

that the species of interest will go undetected. This would be simulated by weighting the false negative objective in the SMART analysis table.

#### *High Automation/Low Time Scenario*

This scenario calls for a high amount of automation, potentially due to a need for fast analysis or a large amount of data and low number of personnel to listen through it. This would be simulated by minimizing the number of false positives and therefore making it more possible to assume that detections are correct and do not need close reviewing (which is time consuming). This could be done by either weighting the false positive objective in the SMART Analysis or by weighting the time objective, or both.

#### **Results (under construction)**

- 1. Collect data with two alternative automated recording units (ARUs)*
- 2. Identify species on the recordings with three alternative methods*
- 3. Use AIC to assess how error rates of each method are a function of different covariates*
- 4. Assess the costs of each method*
- 5. Perform a SMART analysis to weigh the tradeoffs and identify optimal method schemes in different scenarios*

#### **Discussion (under construction)**

Overall which method performed the best? Why does each variable in the model have the effect it does on the error rate?

Which performed best in each of the scenarios and some guesses as to why?

- ARU Type – high vs. low quality microphone and MP3 vs WAV
- Species Identification Method – what were common mistakes, how does a computer vs a human make identifications
- Focal Species – call characteristics that make them easier or harder to detect
- Etc, whatever ends up being in the AIC model

In general what do the results mean? Are higher quality ARUs really better? Or does it depend on your objectives? Are homemade ARUs really more cost effective? Does your choice of method depend heavily on the species assemblages or noisiness of your sites?

#### *Limitations*

- Challenges of Computer Identification and Recognizer Building
- Major effect of the skill of the observer and how good your recognizer is
- Results will vary depending on the specific soundscape of the monitoring program
- Other variables that we did not think of or could not collect may affect error rates – other types of noise, interference of similar sounding species not found here, etc
- Future research into the effects of the survey schedule – definitely effects detection based whether a species can be heard over the other species calling (possibly as seen in this research) AND based on whether a species is calling or not (not the focus of this research)

#### *Implications and Big Picture*

Choosing the right method of your monitoring program requires careful consideration of your goals, resources, and the specifics of the soundscape you hope to monitor in. You must consider both the variables associated with the research being done as well as the variables in the natural

world which may interact in complex ways. My hope is that this model may serve to illustrate that point and aid in selection of a method appropriate to the specific needs of an Anuran monitoring program.

*Awesome Final Paragraph/Sentence!*

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## **Appendices**

### **Appendix A – Construction of the Olympus ARU**