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Auditory monitoring of anuran populations

Michael E. Dorcas, Steven J. Price, Susan C. Walls, and William J. Barichivich

16.1 Introduction

Because anurans rely on vocalization for most communication, detection of species-specific calls provides relatively efficient mechanisms for studying and evaluating the status of anuran populations. Consequently, most amphibian monitoring programs focus on anurans and use call detection as their sole or primary monitoring technique. The overall goal of these programs is to determine and monitor the status of populations over time. Some monitoring programs may actually attempt some form of quantification of anuran population size or density, but this is often difficult when using only calling data. In this chapter we describe approaches for monitoring anuran populations based solely on auditory techniques. These approaches include manual calling surveys (MCS), automated recording systems (ARS), or some combination of the two. MCS can be used by researchers to monitor multiple amphibian populations, often over large spatial scales. ARS can be used by researchers interested in intensively monitoring populations of anurans at a single or a few locations. In this chapter, we describe both approaches and the potential costs and benefits of each. We also explain how data resulting from ARS can be used to optimize manual survey protocol and to interpret data resulting from MCS. Our goal is to provide an overview of these techniques and questions that can be addressed using them.

16.2 MCS

Generally, MCS simply involve observers listening to the vocalizations of male frogs and recording all species detected for the duration of the survey or for a given area. In many surveys, observers also score abundance of each species heard vocalizing. Researchers have long used MCS to conduct inventories of anurans in a given area. For example, Wright and Wright (1949) understood the importance of MCS when they stated that "If one knows the frog notes, he can in one night do more work on frog distribution than he might otherwise do in years." However, only within the last 30 years, when concerns of declining amphibian populations prompted the development of formal monitoring programs, have MCS been widely used for large-scale investigations of anuran populations. The widespread use of MCS for monitoring anurans has led numerous investigations into survey protocol, study design, and efficiency as a technique to detect anurans.

16.2.1 History and current status of MCS

Many historic and recent small-scale investigations have used MCS to detect anurans for ecological, behavioral, and conservation-related investigations (i.e. Martof 1953; Blair 1961; Woolbright 1985; Knutson *et al.* 1999). In this chapter, we emphasize MCS approaches that have specific objectives to monitor the proportion of sites where a given anuran species is observed, accounting for the potential effects of imperfect detection and other biases (site and sampling covariates such as habitat type and weather conditions). This metric is known as occupancy (MacKenzie *et al.* 2002, 2006).

Most MCS programs use surveys in which observers listen to anuran vocalizations at several points along a roadside transect or at designated sampling locations. Since the early 1980s, the use of roadside surveys to detect calling anurans has become used widely by many local and regional environmental monitoring programs. At least five Canadian provinces and 28 US states conduct, or have conducted, roadside surveys for calling anurans (Weir and Mossman 2005). If similar protocols are used, MCS data collected at the local or regional level (e.g. state or province) can be incorporated into a centralized database allowing for the evaluation of anuran populations at the national level. Two US programs initiated by the Department of Interior's US Geological Survey, the North American Amphibian Monitoring Program (NAAMP; www.pwrc.usgs.gov/naamp/; Weir and Mossman 2005), and the Amphibian Research and Monitoring Initiative (ARMI; http://armi.usgs.gov/), are good examples of this. Many US Geological Survey scientists use both MCS and ARS (see section 16.3) to meet their monitoring objectives, primarily on federal lands. Additional examples of North American MCS include the Marsh Monitoring Program in the Great Lakes region (Weeber and Vallianatos 2000), Ontario Backyard Frog Survey (de Solla *et al.* 2005), and FrogWatch USA (Inkley 2006). MCS are also used to monitor trends in anuran populations in Australia (Australia Frog Census; Walker 2002), as well as some European (e.g. Anthony 2002; Pellet and Schmidt 2005; Schmidt 2005; Scott *et al.* 2008), and Central American countries (e.g. Kaiser 2008).

16.2.2 Study objectives: what can MCS tell us?

The objective of any contemporary MCS is typically to conduct an inventory of an area of interest to determine the status of anurans in that region and/or to monitor populations and communities, over time, to address how species are responding to habitat change, climatic variation, or some other ecological or management issue. An objective of many monitoring programs, including those using MCS that are rapidly gaining recognition, is that of determining site occupancy (Marsh and Trenham 2008).

16.2.3 Survey design

Establishment of sampling sites is a critical component of all monitoring programs for which it is essential that sites are sampled according to a probabilistic scheme, so that statistical inference may be extrapolated to a defined area of interest. According to the NAAMP protocol (Weir and Mossman 2005), surveys are conducted along routes that generally are established along roads, dikes, waterways, or other points of access. Routes consist of 10 stops that are either placed at least 0.8 km apart or are stratified by habitat. Although NAAMP is often used as a template for designing MCS, roads are not typically established in a randomized fashion, thus illustrating one of the weaknesses of the NAAMP approach. One compromise for conducting road surveys and meeting this criterion is to, for example, randomly select stops along a given route that are at least 0.8 km apart. In this modification the area of inference would be limited to the route, rather than to a larger area of interest (e.g. a large protected area). Determining the number of routes and their associated sites/stops is another critical element if the resulting data are destined for occupancy analysis. The number of sites to be sampled varies depending upon the distribution and natural history of the anuran species being monitored, the question of interest, and other factors. But, generally speaking, a good rule of thumb in determining the number of sites to sample is usually as many as possible, typically at least 50, assuming that sites are sampled for a minimum of four seasons (see Figure 7.3 of MacKenzie *et al.* 2006).

MCS are usually conducted at night, starting one-half hour after sunset, and are completed by 01:00 h. For many anuran species, especially those in temperate regions, peak calling does occur within this sampling time. Bowers *et al.* (1998) found that the majority of species in their surveys ended peak calling at midnight. To minimize the potential effect of anthropogenic noise (see section 16.2.4), researchers typically allow 1 min between arriving at each site and beginning the chorus survey. All anuran species heard in a specified time frame (usually 5 min, but see section 16.2.4) are recorded; each calling anuran species is given a score, known as an amphibian calling index (ACI), ranging from 1 to 3, where 1 means distinct calls of individuals that can be counted and have no overlapping calls, 2 means calls of individuals that can be distinguished but have some overlapping calls, and 3 means a full chorus, with calls of individuals indistinguishable. Generally, MCS should not be conducted during heavy rain, high wind, or other inclement weather that could affect the detection of calling anurans. At each site, air temperature, relative humidity, barometric pressure, wind speed, and other variables are often measured immediately after recording call data to be used as sample covariates in occupancy analysis. These covariates can be used to help explain variation in site occupancy or detection probabilites.

In regions where anurans vocalize in a somewhat predictable manner, many MCS, such as NAAMP, recommend sampling each stop along a roadside route during a specified sampling period, such as during early spring, late spring, and summer. The NAAMP protocol recommends a single survey, based on convenience to volunteer observers, despite studies that have shown that significant variation in calling behavior does occur within the specified sampling periods (e.g. Todd *et al.* 2003; Gooch *et al.* 2006; Kirlin *et al.* 2006). For example, Gooch *et al.* (2006) conducted three MCS during the NAAMP-specified "summer" sampling period in the western Piedmont region of North Carolina, USA, and found that detection probabilities increased for some species (e.g. *Acris crepitans*, *Rana catesbeiana*) and decreased for other species (e.g. *Rana clamitans*) from survey 1 to survey 3 (Figure 16.1). Variation in calling behavior with prescribed sampling periods may cause the observer to not detect a species if single sampling occasions are employed. At least two surveys are required to calculate detection probabilities (preferably a minimum of three; J. Nichols, personal communication) during a sampling period (see MacKenzie *et al.* 2002 and Table 6.1 of MacKenzie *et al.* 2006 for more details).

16.2.4 Other survey-design issues to consider: the efficiency of MCS

The widespread use of MCS has led to numerous investigations that focus on the efficiency of MCS to detect anurans. In fact, few if any amphibian survey methodologies have been scrutinized to the extent of MCS. A central issue in all wildlife-monitoring programs, including MCS, is that of imperfect detection (MacKenzie *et al.* 2002, 2006). For example, even during the peak breeding season for a given anuran species, calling does not occur each night; variations

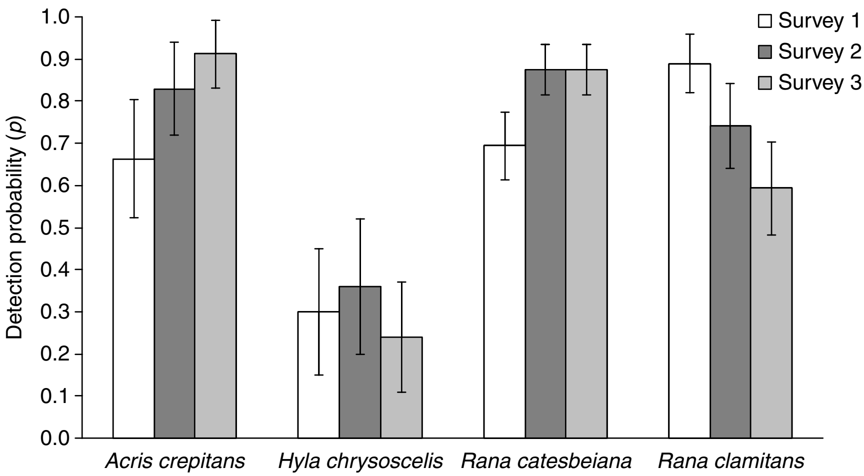

Fig. 16.1 Detection probability, p (± 1 standard error), for four summer-breeding anurans in the western Piedmont region of North Carolina, USA. MCS were conducted from 10 June through 13 July 2004. Detection probabilities were calculated using a model with survey-specific p and constant occupancy estimate, ψ (i.e. $\psi \cdot p(t)$), allowing for the calculation of p for each species during each of the three surveys within the sampling period. Note the influence of sampling occasion on p for *Acris crepitans* and *Rana clamitans*. Adapted from Gooch *et al.* (2006).

in species-specific calling behaviors and abiotic and biotic conditions can lead to the inference of absence despite the presence of a species. Aspects of survey protocol and observer bias can also influence detection probabilities. Fortunately, recent advances in statistical techniques have allowed for calculation of species-specific detection probabilities (e.g. program PRESENCE; MacKenzie *et al.* 2002, 2006; Chapter 24), which can greatly aid in inferring population status and potentially long-term population trends.

Inter- and intraspecific variation in anuran calling behavior may affect detection probability and should be considered when conducting a MCS or evaluating MCS data. Anurans exhibit a vast array of acoustic properties (Duellman and Trueb 1986) which influence probability of detection by observers. Some species have calls that can carry long distances (e.g. 1 km), whereas calls of other species cannot be detected until the observer is 100 m or less from the breeding site. Many species, such as *R. catesbeiana*, may call sporadically every few minutes. Other species (e.g. *Pseudacris crucifer*) call more continuously. In species-rich communities, louder, higher-pitch calls of one species may interfere with the detection of other, quieter species (Droege and Eagle 2005) or inhibit calling in another sympatric species (Littlejohn and Martin 1969). In general, MCS are best suited for regions where all species vocalize during a somewhat predictable breeding season. Species that breed in response to localized heavy rains (e.g. *Spea* and *Scaphiopus*), call quietly or not at all (e.g. *Ascaphus truei*), call infrequently (e.g. *Rana capito*), or have relatively short breeding (i.e. vocalizing) seasons (e.g. *Rana sylvatica*) should not be monitored exclusively by MCS. Droege and Eagle (2005) suggest that MCS are suitable for detecting and inferring population trends for approximately 55 of the 103 anuran species in North America.

Abiotic factors also influence calling behavior in many anuran species (Blair, 1961) and thus influence detection probability via MCS. Because anurans are ectotherms, air temperature has been shown to influence calling, especially for species that vocalize during winter and early spring (e.g. Todd *et al.*, 2003; Weir *et al.* 2005; Kirlin *et al.* 2006). Weir *et al.* (2005) found that air temperature explained calling variation in eight of 10 species studied; however, five species displayed preference for particular temperatures, indicating an optimal temperature for detection. Additionally, Pellet and Schmidt (2005) found that air temperature was a predictor of calling in *Hyla arborea* in Switzerland, with greater detections during warm temperatures. For winter-breeding species in temperate zones, calling behavior may be more sporadic and limited to daylight or early evening hours when temperatures are moderate (Todd *et al.* 2003; Kirlin *et al.* 2006; Saenz *et al.* 2006).

Abiotic factors other than air temperature have also been shown to influence anuran calling. For example, Oseen and Wassersug (2002) suggested that water temperature was the overall most important predictor of calling behavior of some Canadian anurans. Precipitation can also influence calling because many species are known to call more intensely after periods of heavy rain (Blair 1961; Oseen and Wassersug 2002). However, heavy rainfall during MCS is not recommended as it may obfuscate anuran vocalizations and decrease probability of detection. Other factors, such as wind speed (Weir *et al.* 2005; Oseen and Wassersug 2002; Johnson and Batie 2001), humidity of air (Oseen and Wassersug 2002), barometric pressure (Oseen and Wassersug 2002), and moonlight (Weir *et al.* 2005), may also influence anuran detection probability. However, anuran species respond differently to abiotic factors (Saenz *et al.* 2006). Knowledge of the relationship between anuran breeding strategies and abiotic factors prior to conducting MCS may allow for increased efficiency and/or detection.

Anthropogenic noise also likely impacts anuran detection probability. Most calling anurans will respond to anthropogenic noise disturbance. For this reason, some MCS programs recommend that after arriving at a stop the observer must wait for a few minutes prior to conducting the survey. However, few studies have been conducted on the effects of noise on anuran calling behavior. Weir *et al.* (2005) found that only three of 10 species decreased calling behavior due to increased traffic. Regardless, anthropogenic noise can affect the observer's ability to detect frogs and should be recorded during MCS. Additionally, anthropogenic noise can also reduce a species proclivity to call, thus lowering its detectability (Sun and Narins 2005; C. Steelman, personal communication)

Several studies have investigated the effects of survey length on anuran detection. The majority of MCS range from 3 to 10 min per stop. Pierce and Gutzwiller (2004) found that 15 min was required to detect 90% of all species known to be present, whereas Shirose *et al.* (1997) found that 3 min surveys were adequate to detect most species. Gooch *et al.* (2006) found that 94% of summer-breeding anurans in the North Carolina Piedmont region were detected within the first 5 min of the MCS and detection probabilities were slightly higher as observers spent longer listening (3 min compared to 10 min). However, these and other investigations highlight that some species may go undetected even if surveys are extended up to an hour. The length of survey should be determined based on the specific objectives of the MCS; however, for detecting long-term population trends for most species, 3–5 min appears to be adequate.

Variation among observers can also substantially influence the quality of MCS data. Some large-scale MCS (e.g. NAAMP) rely heavily on volunteers, who may vary in experience and/or hearing ability. As a result, observers may not detect all species present, include species not present, or incorrectly identify vocalizations, resulting in flawed assessments of anuran populations (Lotz and Allen 2007). Weir *et al.* (2005) found that volunteer experience may influence species detection. However, studies by Genet and Sargent (2003), Shirose *et al.* (1997), and Lotz and Allen (2007) suggest that even relatively inexperienced volunteers were reliable in their abilities to determine species, yet estimating abundance categories often differed among observers. Pierce and Gutzwiller (2007) showed 79% agreement among nine observers conducting MCS in central Texas, USA, and stressed the importance of accounting for interobserver variation in data analysis. NAAMP currently requires all volunteers to pass an online anuran call test (available at www.pwrc.usgs.gov/frogquiz/) prior to conducting MCS. In general, training of volunteers will likely increase the probability of ensuring quality data.

16.2.5 Limitations of MCS data

MCS are excellent tools for monitoring changes in anuran occupancy or for inventorying which species occur in an area. At a given site, however, these surveys only yield qualitative data on abundance as obtained through the use of the ACI (section 16.2.3). These types of abundance data are of limited utility in assessing population densities. However, Nelson and Graves (2004) compared population estimates (via mark–recapture) of male *R. clamitans* with ACI collected at the same sites and found abundance to be correlated positively with ACI. In contrast, Corn *et al.* (2000) found that another measure of call frequency failed to reflect "a relatively large population" of *Bufo woodhousii* and only weakly distinguished among different-sized populations of *Pseudacris maculata*. The need to be able to use indices of relative abundance, such as the calling index, in occupancy models has been conceptualized and is currently an active area of research (Royle and Nichols 2003; Dorazio 2007).

Because call surveys are based upon the vocalizations of adult male anurans, they do not provide complete information on population structure; that is, non-calling females and subadults are not assessed by this method (Stevens and Paszkowski 2004). Similarly, this method is not useful for other non-calling amphibians, such as salamanders and caecilians. The males of many species of anurans will vocalize in contexts not necessarily related to breeding; moreover, the MCS does not consider the presence of egg masses, tadpoles, or metamorphosing juveniles in the population. Thus, the MCS provides no information about whether there was successful reproduction at a given site. Depending on the questions of interest in a given study, the MCS is therefore most useful when used in conjunction with other survey methods, such as visual encounter surveys and the use of traps or dipnets to assess the larval component of the population.

16.3 ARS

In addition to MCS, automated systems (ARS) can be used to detect anuran vocalizations and can be useful in monitoring many anuran populations (Peterson and Dorcas 1994). Typically, ARS (or so-called frogloggers) are used to collect data intensively at a single or a few locations, whereas MCS provide more superficial data but for a larger number of sites. ARS can be used to survey for anuran species in places difficult to access for MCS and can be left in the field for extended periods of time, thus increasing the probability of detecting a given species. ARS may be the only practical way to reliably detect species that have very short or unpredictable breeding seasons, such as *R. capito*. ARS minimize disturbance to calling anurans and provide a permanent sampling record that can be evaluated by multiple experts if required (Mohr and Dorcas 1999; Todd *et al.* 2003). When combined with information on environmental variation, data from ARS can be incorporated into models that can be used to optimize monitoring programs based on MCS (Bridges and Dorcas 2000; Oseen and Wassersug 2002).

16.3.1 Sources for ARS

At the time Peterson and Dorcas (1994) published on building and using ARS, there were few options for their procurement. Although not specifically intended for anuran monitoring, the Cornell Laboratory of Ornithology builds robust ARS units that have been used in a wide variety of tasks ranging from the detection of ivory-billed woodpeckers (*Campephilus principalis*) to monitoring whales around the world's oceans. Bedford Technical (www.frogloggers.com) and Wildlife Acoustics (www.wildlifeacoustics.com) have both produced ARS systems with a variety of options that make them attractive for monitoring frogs. Although their software has not been tested on anuran vocalizations, both Cornell Lab of Ornithology and Wildlife Acoustics produce products, Raven and Song Scope respectively, which may prove useful in automated call detection.

16.3.2 Construction, deployment, and retrieval of data

Although sources for ARS now exist, some biologists may still choose to build their own. This may be a logistical hurdle for some investigators; however, construction of an ARS can have the added benefit of familiarizing the user with the inner workings of their equipment. Construction of an ARS generally requires combining several simpler components: a recorder, timer/controller, microphone, power supply, and housing (Peterson and Dorcas 1994; Barichivich 2003). If the investigator is not familiar with electronics, we recommend working with someone skilled in building electrical devices.

The core component of an ARS is the recorder. Devices that have been successfully used include analog cassette and various digital (e.g. MPEG-1 Audio Layer 3, or MP3) recorders. Selection of a recorder is dependent on the required recording quality, capacity, and budget. Recordings produced on inexpensive analog cassette recorders are sufficient for manual listening, but higher sampling rates and frequency responses may be required in some circumstances. Additionally, storage capacity can usually be greatly increased when using digital recordings.

In most cases, researchers choose to make recordings at specific times of day (e.g. dusk) and on set intervals rather than continuously. Some recording devices (e.g. PDAs and digital voice recorders) have built-in timers or clocks. The addition of a timer/controller allows programming of the desired recording schedule. A wide variety of devices, from mechanical (K. Wharton, personal communication) to computer microprocessors (Acevedo and Villanueva-Rivera 2006), have been used for this purpose. Timers generally work in one of two ways: controlling the function of the recorder or interrupting the power supply to the recorder. In addition to time-based triggers, environmental triggers can be used to activate an ARS. For example, to detect explosive breeders like *Spea* or *Scaphiopus*, a tipping-bucket rain gauge with a reed valve could be used so a rainfall event would trip an ARS into service.

The choice of microphones is a crucial decision, as recordings will only be as good as the microphone, regardless of the recording device. At least nine types of microphone are available but condenser or dynamic varieties are those most commonly used. Unlike dynamic microphones, condenser microphones require a power supply. Condenser microphone power sources are often small (e.g. a single AA battery) and may not be sufficient if the ARS is deployed for extended periods of time without maintenance. This issue can be addressed by using the timer/controller to control the microphone as well as the recorder. Another consideration in selecting a microphone is the directional or acceptance cone. Cones can range from a 360° circle around the microphone (omnidirectional) to just a few degrees in front of the microphone (unidirectional or shotgun). To capture the vocalizations of species that call while partially or completely submerged (e.g. *Rana sevosa* or *Rana subaquavocalis*), a hydrophone would be more appropriate to use than a microphone (Platz 1993).

The final considerations of building an ARS are power supply and protection. Rechargeable batteries generally provide the best option for most researchers. Cost, power, size, and weight should be considered when selecting batteries. In environments with sufficient sunlight, rechargeable batteries can be supplemented by a solar panel and can generally operate without interruption. With the exception of the microphone, all components of an ARS should be firmly mounted inside a protective case. The case should provide adequate environmental protection and be large enough to hold all the components, yet small enough to be reasonably portable for ease of field deployment. For most field deployments, waterproof boxes (e.g. Otter or Pelican brands) work well, but less costly options exist. These include surplus ammunition cans, polyethylene coolers, plastic tool boxes, and plastic watertight marine boxes. Consideration should be given to the environment in which the ARS will be deployed. In areas frequented by people, the ARS can be locked, hidden, or even buried. Animals, such as raccoons and bears, may damage equipment and thus more rugged cases might be needed in some situations (Corn *et al.* 2000). Microphones should also be protected by a windscreen to reduce wind noise, along with a cover to shield the windscreen and microphone from the environment.

Before deploying an ARS, careful consideration should be given to placing and programming the ARS to capture the data germane to the question(s) of interest. Although the program should be restrictive enough to minimize the collection of superfluous data, sampling only during perceived peak times could lead to erroneous interpretation of data (Figure 16.2). Typically an ARS is placed near anuran breeding habitats with the microphone mounted facing the water. After the recordings have been retrieved, data need to be transcribed, either manually (i.e. by human ear) or by computer recognition. Manual assessment of recordings requires a trained observer to listen to and review the recordings while transcribing the data. Calling activity can be scored much like that in MCS and is typically semi-quantified as an ACI. Depending on observer experience and the complexity of the calling choruses, 1.5 h per hour of recording are required to review analog cassette tapes (Corn *et al.* 2000). Slightly less time

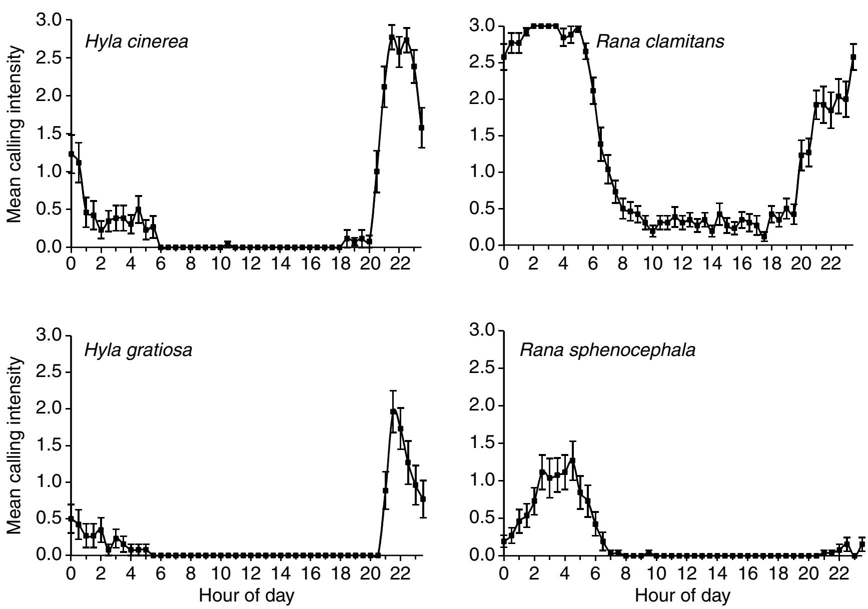

Fig. 16.2 Daily calling pattern of *Hyla cinerea*, *Hyla gratiosa*, *Rana clamitans*, and *Rana sphenocephala* recorded using an ARS at Carolina Bay near Aiken, SC, USA. Mean calling activity was calculated by averaging the recorded calling activity levels for each 30 min time recording period over all days of the study (from 16 June to 12 July 1997). Error bars denote ± 1 standard deviation. Note that calling in both species of treefrog peaked during the time period when manual calling surveys are recommended (dusk to midnight), but peak calling in *Rana* peaked well after midnight and *R. sphenocephala* called almost exclusively after midnight, and would thus likely be missed on most calling surveys. Adapted from Bridges and Dorcas (2000).

is usually required to review digital recordings. While in its infancy, computer recognition of high-quality recordings shows great promise for decreasing the time, and cost, of manually listening to ARS recordings and potentially increasing the accuracy of call recognition. Though not an automated process, one study showed that in a mixed-species chorus, including the acoustically dominant coqui (*Eleutherodactylus coqui*), several species were omitted or significantly underrepresented using only a manual data review (Villanueva-Rivera 2007). By adding a simple visual analysis of the spectrograms of digital call recordings using Adobe Audition, the calls of the less acoustically dominant species were no longer eclipsed (Villanueva-Rivera 2007). Research on birds demonstrates the potentially significant time savings when using computer recognition software. In 12 h, Agranat (2007) scanned more than 250 h of field recordings for bird vocalizations using Song Scope software. This process allowed a human observer to review 1552 potential calls of the cerulean warbler (*Dendrocia cerulea*) in under 1 h.

16.3.3 Monitoring environmental data

Automatically monitoring environmental data, while simultaneously monitoring anuran calling activity using ARS, can allow interpretation of how environmental variation affects calling activity (Dorcas and Foltz 1991; Peterson and Dorcas 1992, 1994; Saenz *et al.* 2006) and detection probability. Typically, investigators use dataloggers to monitor variables such as air and water temperatures, relative humidity, solar radiation, precipitation, wind speed, and barometric pressure. Numerous types of dataloggers of varying quality and capabilities are available (e.g. Onset Computer Corp., Pocasset, MA, USA; Campbell Scientific, Logan, UT, USA). Like ARS, some investigators find dataloggers to be particularly challenging to learn to use. However, recent advances in software interfaces for nearly all dataloggers make learning to use them simple enough for even novice researchers.

16.3.4 Answering questions using ARS

ARS can be used by researchers to address basic questions such as whether a species is present at a given location or to conduct more detailed investigations of factors affecting calling activity and population fluctuations (Corn and Muths 2002; Todd *et al.* 2003). Generally, investigators using ARS for monitoring purposes are simply interested in detecting whether a species is present. As such, many ARS systems can be set to only come on and record at certain times of the day when a particular species is most likely to vocalize (e.g. dusk until midnight), thus minimizing the number of recordings that must be evaluated. However, one must be careful not to assume that anurans call primarily during times traditionally recognized as peak calling periods (Bridges and Dorcas 2000).

In some cases, researchers use ARS to attempt to detect a species that is either rare or has very unpredictable calling patterns. Anurans such as *Spea* and *Scaphiopus* that generally only call under certain conditions (i.e. during or after heavy rains) may be particularly hard to detect using MCS and ARS may offer the best opportunity to detect their populations. For some extremely rare species (e.g. *R. sevosa*) detecting every known population is important for proper management and thus, increasing detectability of populations using ARS can play a vital role in conservation efforts.

Because ARS can collect data at regular and precise intervals, mathematical models can be developed that allow prediction of when and under what conditions species are likely to call, thus providing data that can be used to optimize MCS. Typically, data collected simultaneously with anuran calling data, such as temperature, precipitation, wind speed, and time of day, are used as independent variables in a logistic regression to predict the optimal conditions to conduct MCS (i.e. the times when detectability is maximized; Oseen and Wassersug 2002). Anurans may respond differently to environmental variables across their ranges, and thus development of models should be done for particular regions as needed. Such models were developed for three species of winter-breeding anurans (*Pseudacris crucifer*, *Pseudacris feriarum*, and *Rana sphenocephala*) in the western Piedmont region of North Carolina (Steelman and Dorcas, in press). Models showed that for *P. crucifer* day of year, time, precipitation, and water temperature positively influenced calling and air temperature negatively influenced calling; for *P. feriarum* time, precipitation, air temperature, and water temperature positively influenced calling, and day of year negatively influenced calling; for *R. sphenocephala* day of year, time, precipitation, and air temperature positively influenced calling, and higher water temperature negatively influenced calling. The models described for the winter-breeding species above were tested using previously collected data from MCS along with spot measurements of environmental data (Kirlin *et al.* 2006). Models accurately predicted whether a species was calling approximately 70% of the time.

In addition to using models to predict the best times and conditions to manually sample anurans, ARS can be used to interpret data collected previously, assuming sufficient environmental data are collected at the time of the surveys. Fortunately, nearly all existing MCS programs require collection of at least some environmental data. To do this, an investigator would insert the spot measurements of environmental variables collected by volunteers at the time the surveys were conducted into the model equation for each species of interest to generate a likelihood of calling (e.g. ranging from 0 to 1). Calling likelihoods can then be used to interpret previously collected calling survey results. If a species was not heard at a particular location but the model indicates a high likelihood of calling if it was present (e.g. 0.9), then the investigator can have a higher confidence in concluding that the species was not present, rather than it simply not vocalizing and being undetectable.

16.3.5 Limitation of ARS

Despite the advantages of using ARS, there are some disadvantages when compared to surveys based on MCS (Corn *et al.* 2000; Penman *et al.* 2005). For many investigators, ARS can be expensive compared to volunteer-based MCS. Additionally, ARS can typically only be deployed at one or a few sites, thus decreasing the number of anuran populations that can be monitored. This can have major implications for statistical analyses of data when each site is a replicate. The possibility of wildlife damage, vandalism, or theft of equipment is another issue that may limit investigators' ability to use ARS in some localities (e.g. Corn *et al.* 2000). Although ARS can be hidden relatively easily, one of us (M.E.D.) has had equipment stolen even in remote locations. Some investigators find using automated systems particularly challenging, especially if they consider themselves technologically challenged. However, we have found that nearly anyone can be taught to use automated systems effectively and for those that are apprehensive about doing so we suggest initial consultations with a biologist experienced with the equipment being used.

16.4 Conclusions

Auditory monitoring of anuran populations, either by MCS or by ARS, is a useful tool for assessing the status and trends of populations, as well as the responses of populations and communities to environmental and anthropogenic change. The use of auditory monitoring has increased tremendously since the realization that amphibian populations are undergoing global population declines, and has become a standard approach to monitoring in many state, national, and international programs. Auditory monitoring has limitations in that (1) its utility in estimating abundance is restricted, (2) this method provides little information about the complete structure of a population (i.e. the status of non-calling adult females and subadults) or about whether a given population has experienced successful reproduction, and (3) this method cannot be used on non-calling amphibians, such as salamanders and caecilians. The two means by which auditory monitoring may be conducted (manual or automated) differ in their relative costs and benefits, and the appropriate approach for a given study ultimately depends on the study objectives and resources available. Nevertheless, MCS can provide vital information on changes in occupancy states of various sites, which can be overlaid with environmental data to assess potential causes of change in occupancy for a given species or community. Data from ARS can be used to optimize the effectiveness of MCS or interpret data based on MCS. As such, auditory monitoring has great utility in assessing the extent of declines of anuran amphibians, a topic of heightened concern in ecology and conservation biology.

16.5 Acknowledgments

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16.6 References

Acevedo, M. A. and Villanueva-Rivera, L. J. (2006). Using automated digital recording systems as effective tools for the monitoring of birds and amphibians. *Wildlife Society Bulletin*, **34**, 211–14.

Agranat, I. D. (2007). *Automatic Detection of Cerulean Warblers Using Autonomous Recording Units and Song Scope Bioacoustics Software*. www.wildlifeacoustics.com/

Anthony, B. P. (2002). Results of the first batrachian survey in Europe using road call counts. *Alytes*, **20**, 55–66.

Barichivich, W. J. (2003). Appendix IV: Guidelines for building and operating remote field recorders. In C. K. Dodd, Jr, *Monitoring Amphibians in Great Smoky Mountains National Park*, pp. 87–96. U.S. Geological Survey Circular no. 1258. U.S. Geological Survey, Tallahassee, FL.

Blair, W. F. (1961). Calling and spawning seasons in a mixed population of anurans. *Ecology*, **42**, 99–110.

Bowers, D. G., Anderson, D. E., and Euliss, Jr, N. H. (1998). Anurans as indicator of wetland condition in the Prairie Pothole Region of North Dakota: an environmental monitoring and assessment program pilot project. In M. Lannoo (ed.), *Status and Conservation of Midwestern Amphibians*, pp. 369–78. University of Iowa Press, Iowa City, IO.

Bridges, A. S. and Dorcas, M. E. (2000). Temporal variation in anuran calling behavior: implications for surveys and monitoring programs. *Copeia*, **2000**, 587–92.

Corn, P. S. and Muths, E. (2002). Variable breeding phenology affects the exposure of amphibian embryos to ultraviolet radiation. *Ecology*, **83**, 2958–63.

Corn, P. S., Muths, E., and Iko, W. M. (2000). A comparison in Colorado of three methods to monitor breeding amphibians. *Northwestern Naturalist*, **81**, 22–30.

de Solla, S. R., Shirose, L. J., Fernie, K. J., Barrett, G. C., Brousseau, C. S., and Bishop, C. A. (2005). Effect of sampling effort and species detectability on volunteer based anuran monitoring programs. *Biological Conservation*, **121**, 585–94.

Dorazio, R. M. (2007). On the choice of statistical models for estimating occurrence and extinction from animal surveys. *Ecology*, **88**, 2773–82.

Dorcas, M. E. and Foltz, K. D. (1991). Environmental effects on anuran advertisement calling. *American Zoologist*, **31**, 3111A.

Droege, S. and Eagle, P. (2005). Evaluating calling surveys. In M. Lannoo (ed.), *Amphibian Declines: The Conservation Status of United States Species*, pp. 314–19. University of California Press, Berkeley, CA.

Duellman, W. E. and Trueb, L. (1986). *Biology of Amphibians*. McGraw-Hill Publishing Company, New York.

Genet, K. S. and Sargent, L. G. (2003). Evaluation of methods and data quality from a volunteer-based amphibian call survey. *Wildlife Society Bulletin*, **31**, 703–14.

Gooch, M. M., Heupel, A. H., Price, S. J., and Dorcas, M. E. (2006). The effects of survey protocol on detection probabilities and site occupancy estimates of summer breeding anurans. *Applied Herpetology*, **3**, 129–42.

Inkley, D. B. (2006). Final report assessment of utility of Frogwatch USA data 1998–2005. www.nwf.org/frogwatchUSA/FinalRptFW-ScienceAssess.pdf. National Wildlife Federation for U.S. Geological Survey, Washington DC.

Johnson, D. H. and Batie, R. D. (2001). Surveys of calling amphibians in North Dakota. *The Prairie Naturalist*, **33**, 227–47.

Kaiser, K. (2008). Evaluation of a long-term amphibian monitoring protocol in Central America. *Journal of Herpetology*, **42**, 104–10.

Kirlin, M., Gooch, M. M., Price, S. J., and Dorcas, M. E. (2006). Predictors of winter anuran calling activity in the North Carolina Piedmont. *Journal of the North Carolina Academy of Science*, **122**, 10–18.

Knutson, M. G., Sauer, J. R., Olsen, D. A., Mossman, M. J., Hemesath, L. M., and Lannoo, M. J. (1999). Effects of landscape composition and wetland fragmentation on frog and toad abundance and species richness in Iowa and Wisconsin, U.S.A. *Conservation Biology*, **13**, 1437–46.

Littlejohn, M. J. and Martin, M. M. (1969). Acoustic interaction between two species of leptodactylid frog. *Animal Behaviour*, **17**, 785–91.

Lotz, A. and Allen, C. R. (2007). Observer bias in anuran call surveys. *Journal of Wildlife Management*, **71**, 675–9.

MacKenzie, D. L., Nichols, J. D., Lachman, G. B., Droege, S., Royle, J. A., and Langtimm, C. A. (2002). Estimating site occupancy rates when detection probabilities are less than one. *Ecology*, **83**, 2248–55.

MacKenzie, D. I., Nichols, J. D., Royle, J. A., Pollock, K. H., Bailey, L. L., and Hines, J. E. (2006). *Occupancy Estimation and Modeling: Inferring Patterns and Dynamics of Species Occurrence*. Academic Press, San Diego, CA.

Marsh, D. M. and Trenham, P. C. (2008). Current trends in plant and animal population monitoring. *Conservation Biology*, **22**, 647–55.

Martof, B. S. (1953). Territoriality in the green frog, *Rana clamitans*. *Ecology*, **34**, 165–74.

Mohr, J. R. and Dorcas, M. E. (1999). A comparison of anuran calling patterns at two Carolina bays in South Carolina. *Journal of the Elisha Mitchell Scientific Society*, **115**, 63–70.

Nelson, G. L. and Graves, B. M. (2004). Anuran population monitoring: comparison of the North American Amphibian Monitoring Program's calling index with Mark-Recapture estimates for *Rana clamitans*. *Journal of Herpetology*, **38**, 355–9.

Oseen, K. L. and Wassersug, R. J. (2002). Environmental factors influencing calling in sympatric anurans. *Oecologia*, **133**, 616–25.

Pellet, J. and Schmidt, B. R. (2005). Monitoring distributions using call surveys: estimating site occupancy, detection probabilities and inferring absence. *Biological Conservation*, **123**, 27–35.

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

Peterson, C. R. and Dorcas, M. E. (1992). The use of automated data acquisition techniques in monitoring amphibian and reptile populations. In D. McCullough and R. Barrett (eds), *Wildlife 2001: Populations*, pp. 369–78. Elsevier Applied Science, London.

Peterson, C. R. and Dorcas, M. E. (1994). Automated data acquisition. In W. Heyer, R. McDairmid, M. Donnelly, and L. Hayek (eds), *Measuring and Monitoring Biological Diversity. Standard Methods for Amphibians*, pp. 47–57. Smithsonian Institution Press, Washington DC.

Pierce, B. A. and Gutzwiller, K. J. (2004). Auditory sampling of frogs: detection efficiency in relation to survey duration. *Journal of Herpetology*, **38**, 495–500.

Pierce, B. A. and Gutzwiller, K. J. (2007). Interobserver variation in frog call surveys. *Journal of Herpetology*, **41**, 424–9.

Platz, J. E. (1993). *Rana subaquavocalis*, a remarkable new species of Leopard Frog (*Rana pipiens* complex) from southeastern Arizona that calls under water. *Journal of Herpetology*, **27**, 154–62.

Royle, J. A. and Nichols, J. D. (2003). Estimating abundance from repeated presence-absence data or point counts. *Ecology*, **84**, 777–90.

Saenz, D., Fitzgerald, L. A., Baum, K. A., and Conner, R. N. (2006). Abiotic correlates of anuran calling phenology: the importance of rain, temperature and season. *Herpetological Monographs*, **20**, 64–82.

Schmidt, B. R. (2005). Monitoring the distribution of pond-breeding amphibians when species are detected imperfectly. *Aquatic Conservation: Marine and Freshwater Ecosystems*, **15**, 681–92.

Scott, W. A., Pithart, D., and Adamson, J. K. (2008). Long-term United Kingdom trends in the breeding phenology of the common frog, *Rana temporaria*. *Journal of Herpetology*, **42**, 89–96.

Shirose, L. J., Bishop, C. A., Green, D. M., MacDonald, C. J., Brooks, R. J., and Helferty, N. J. (1997). Validation tests of an amphibian call count survey technique in Ontario, Canada. *Herpetologica*, **53**, 312–20.

Steelman, C. K. and Dorcas, M. E. (in press). Anuran calling survey optimization: developing and testing predictive models of anuran calling activity. *Journal of Herpetology*.

Stevens, C. E. and Paszakowski, C. A. (2004). Using chorus-size ranks from call surveys to estimate reproductive activity of the wood frog (*Rana sylvatica*). *Journal of Herpetology*, **38**, 404–10.

Sun, J. W. C. and Narins, P. M. (2005). Anthropogenic sounds differentially affect amphibian call rate. *Biological Conservation*, **121**, 419–27.

Todd, M. J., Cocklin, R. R., and Dorcas, M. E. (2003). Temporal and spatial variation in anuran calling activity in the western Piedmont of North Carolina. *Journal of the North Carolina Academy of Science*, **119**, 103–10.

Villanueva-Rivera, L. J. (2007). Digital recorders increase detection of *Eleutherodactylus* frogs. *Herpetological Review*, **38**, 59–63.

Walker, S. J. (2002). *Frog Census 2001: Community monitoring of water quality and habitat condition in South Australia using frogs as indicators*. Environment Protection Authority, Adelaide.

Weeber, R. C. and Vallitanios, M. (2000). *The Marsh Monitoring Program 1995–1999: Monitoring Great Lakes wetlands and their amphibian and bird inhabitants*. www.bsc-eoc.org/mmpreport.html. Bird Studies Canada with the U.S. Environmental Protection Agency, Ontario.

Weir, L. A. and Mossman, M. J. (2005). North American amphibian monitoring program (NAAMP). In M. Lannoo (ed.), *Amphibian Declines: The Conservation Status of United States Species*, pp. 307–13. University of California Press, Berkeley, CA.

Weir, L. A., Royle, J. A., Nanjappa, P., and Jung, R. E. (2005). Modeling anuran detection and site occupancy on North American Amphibian Monitoring Program (NAAMP) routes in Maryland. *Journal of Herpetology*, **39**, 627–39.

Woolbright, L. L. (1985). Patterns of nocturnal movement and calling by the tropical frog, *Eleutherodactylus coqui*. *Herpetologica*, **41**, 1–9.

Wright, A. H. and Wright, A. A. (1949). *Handbook of Frogs and Toads of the United States and Canada*. 3rd edn. Comstock Publishing Associates, Ithaca, NY.