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Temporal Variation in Anuran Calling Behavior: Implications for Surveys and Monitoring Programs

ANDREW S. BRIDGES AND MICHAEL E. DORCAS

Recent awareness of amphibian declines has raised the need for effective monitoring programs. Call surveys are a standard approach to monitoring populations of most anuran species. Temporal variation in calling activity, however, may result in failure to detect some species. Automated recording systems (ARS) allow consistent sampling for extended periods with little or no disturbance to calling anurans. We used an ARS to measure temporal variation in anuran calling activity during the summer of 1997 at a Carolina bay on the U.S. Department of Energy's Savannah River Site, South Carolina. We documented considerable interspecific variation in calling activity, a phenomenon that, using traditional call survey techniques, would result in failure to detect some species. In particular, we found that Southern Leopard Frogs (*Rana sphenocephala*), thought to breed only in early spring and fall in the region, called consistently from midnight until dawn during July. Because protocols for most call surveys dictate that the listener survey only during early evening hours, most call surveys would not detect the presence of this species. Our results indicate that temporal variation in anuran calling activity warrants further investigation and should be considered when developing anuran monitoring programs.

RECENT concerns over amphibian declines have resulted in the development and standardization of surveying and monitoring methods (Heyer et al., 1994). Techniques used in such programs are based on the supposition that the animals are active during the time of sampling. Because many amphibians are active for limited periods of time during any given day or season, knowledge of amphibian activity patterns should form an essential component of such programs (Peterson and Dorcas, 1992). Volunteer-based call surveys (McDiarmid and Donnelly, 1994) are the primary method for censusing anurans in numerous regional and state monitoring programs. To assist program coordinators, the North American Amphibian Monitoring Program (NAAMP) has developed specific protocols for conducting anuran calling surveys. Volunteers, after listening to identification tapes of anuran vocalizations, proceed to selected wetland areas were they listen for three minutes. Observations begin one-half hour after sunset, and the entire route should be run, including travel time to and from the wetlands, within two hours (U.S. Geological Survey, North American Amphibian Monitoring Program, http://www.im.nbs.gov/amphibs.html, accessed 25 June 1999).

Volunteer-based call surveys, while allowing economical coverage of large areas, may fail to detect all species present and result in an inaccurate assessment of anuran populations. Potential problems include misidentification of anuran calls by inadequately trained volunteers; lack of a permanent sampling record to verify species identification; disturbance to calling anurans; and interspecific, temporal, and environmentally induced variation in calling behavior.

The use of automated recording systems (ARS) can remedy many problems associated with manual call surveys (Dorcas and Foltz, 1991; Peterson and Dorcas, 1992, 1994). These systems provide the ability to sample for extended periods of time, thus increasing the probability of detecting a given species; decreased disturbance to calling anurans, thus decreasing the probability of missing easily disturbed species; a permanent sampling record allowing repeated evaluation by multiple investigators; and the ability to accurately evaluate interspecific and temporal variation in calling behavior. Perhaps most important, data from ARS can be used to develop models to optimize effectiveness of manual call surveys.

We used ARS to quantify and evaluate temporal variation in calling activity of summer breeding anurans at an isolated wetland in South Carolina. We documented considerable interspecific variation in calling activity, a phenomenon that, using traditional call survey techniques, would result in failure to detect some species. In particular, we found that Southern Leopard Frogs (*Rana sphenocephala*), thought to breed only in early spring and fall in the region, called consistently from midnight until dawn during July.

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Materials and Methods

Using an ARS, we monitored anuran vocalizations at Flamingo Bay, a 5-ha Carolina bay on the U.S. Department of Energy's Savannah River Site (SRS) in the Upper Coastal Plain of South Carolina. Carolina bays are natural depressions that retain water to varying degrees and are fed by rainwater and ground water discharge (Gibbons and Semlitsch, 1991). Flamingo Bay is one of approximately 200 Carolina bays on the SRS. Although it has dried several times in the past 30 years, Flamingo Bay is considered to function as a permanent wetland (Gibbons and Semlitsch, 1991).

The upland habitat surrounding Flamingo Bay is primarily mature slash (*Pinus elliottii*) and loblolly (*P. taeda*) pine. The perimeter of the bay consists of sweet gum (*Liquidambar styraciflua*), oak (*Quercus* sp.), red maple (*Acer rubrum*), and wax myrtle (*Myrica cerifera*) with an interior dominated by buttonbush (*Cephalanthus occidentalis*), bulrush (*Scirpus* sp.), spikerush (*Eleocharis* sp.), lizard's tail (*Saururus cernuus*), and yellow water lilies (*Nelumbo lutea*; Gibbons and Semlitsch, 1991).

The ARS consisted of a cardioid microphone (Model AT815A Audio Technica, Singapore) and a stereo analog tape recorder (Model TCD-5PROII, Sony Electronics, Park Ridge, NJ) controlled by a recycling timer (Model RS-1A12, SSAC, Baldwinsville, NY). A voice clock (Model RS-63-915, Radio Shack, Ft. Worth, TX) was used to audibly time stamp each sampling interval. Detailed information on construction of ARS systems is available in Peterson and Dorcas (1994). We recorded on high bias, type II cassette tapes (C-100CDT2A, Sony Electronics, Park Ridge, NJ). The ARS was housed in a modified plastic toolbox and the microphone was covered using a plastic shield, which protected the top of the microphone from falling precipitation but allowed sound to reach the microphone from all directions. The microphone was attached to a tree at the water's edge and positioned facing the bay approximately 2 m above the ground. The sound of rain striking the microphone shield allowed us to determine time and approximate intensity of rainstorms.

We collected data using the ARS for 26 days (24 h/day), beginning at midnight 16 June 1997 and ending at midnight on 12 July 1997. The ARS recorded for 12 sec every 30 min. Tapes were changed once every two days. Upon retrieval, each tape was played on a stereo cassette deck (Technics model RS-TR232; Matsushita Industrial Co., Ltd., Singapore) and analyzed in the laboratory. Anuran vocalizations were identified to species, and calling activity was quantified according to a modified version of the numerical classification scheme recommended by the NAAMP (U.S. Geological Survey, North American Amphibian Monitoring Program, http://www.im.nbs.gov/amphibs.html, accessed 25 June 1999): 0 = no vocalization recorded; 1 = only one male heard vocalizing; 2 = multiple males vocalizing, but not a full chorus; and 3 = many males calling in a full chorus. For all species other than *Rana catesbeiana*, a "2" meant that it was possible to distinguish among individual calling males, and a "3" meant that individuals could not be distinguished from the overall chorus. For *R. catesbeiana*, a species that occurred at a lower density at our study site, a "2" meant there were only two individuals calling, and a "3" meant there were three or more individuals calling.

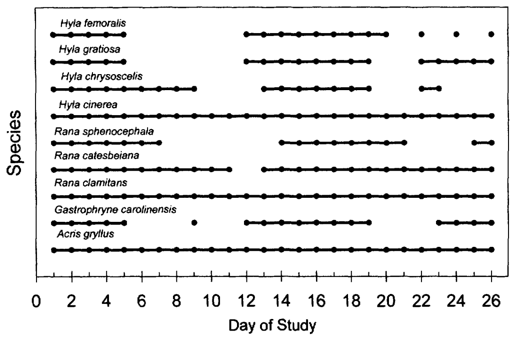

Fig. 1. Calling anuran species recorded over the 26-day study. Note consistency of *Hyla cinerea*, *Rana clamitans*, *Aris gryllus*, and *R. catesbeiana.*

Results

Nine species of anurans were recorded calling at Flamingo Bay during the study. These included the Southern Cricket Frog (*Acris gryllus*), Eastern Narrow-Mouthed Toad (*Gastrophryne carolinensis*), Green Treefrog (*Hyla cinerea*), Pine Woods Treefrog (*H. femoralis*), Barking Treefrog (*H. gratiosa*), Gray Tree Frog (*H. chrysoscelis*), Bullfrog (*R. catesbeiana*), Bronze Frog (*R. clamitans*), and southern leopard frog (*R. sphenocephala*). Our sampling regime (12 sec every 30 min) resulted in 1248 sampling intervals for each species and 11,232 total datapoints.

Interspecific variation and seasonal variation in calling activity occurred during the sampling period (Fig. 1). A mode of seven species of anurans was recorded per day. Some species were recorded on every day of the study, whereas others were not. For example, *H. cinerea* was recorded on all 26 days, but a congener, *H. gratiosa*, was recorded on only 18 days. Other species

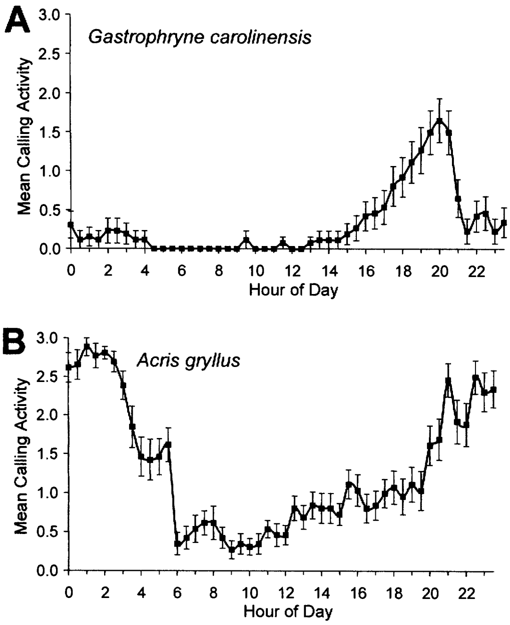

Fig. 2. Daily calling patterns in *Acris gryllus* and *Gastrophryne carolinensis.* Mean calling activity was calculated by averaging the recorded calling activity levels for each 30-min time period over all days of the study. Error bars denote ± SD. *Acris gryllus* called all day, whereas *G. carolinensis* called primarily in the late afternoon and early evening.

that were recorded every day during the study included *R. clamitans* and *A. gryllus.*

Interspecific variation was also found in the daily temporal calling patterns of the species recorded. *Gastrophryne carolinensis* usually began calling at about 1500 h and gradually increased throughout the afternoon until dusk (Fig. 2A). Afternoon thunderstorms occurred periodically during the study, and *G. carolinensis* called most intensely shortly after these storms. *Acris gryllus* called during the daytime and at relatively high levels throughout every evening (Fig. 2B). Daytime calling by *A. gryllus* was typically lowest in the morning with a gradual increase throughout the day and into the evening.

The four species of *Hyla* consistently called from sunset until about midnight (Fig. 3). *Hyla cinerea* (Fig. 3A) exhibited a calling peak between 2130 and 2230 h. *Hyla gratiosa* (Fig. 3B) exhibited a sharp peak in calling activity shortly after sundown (2130 h). *Hyla femoralis* (Fig. 3C) and *H. chrysoscelis* (Fig. 3D) showed peaks in calling shortly before midnight as well but did not occur in choruses as large as those of the other two *Hyla.*

The three species of *Rana* showed peaks in calling activity between midnight and dawn

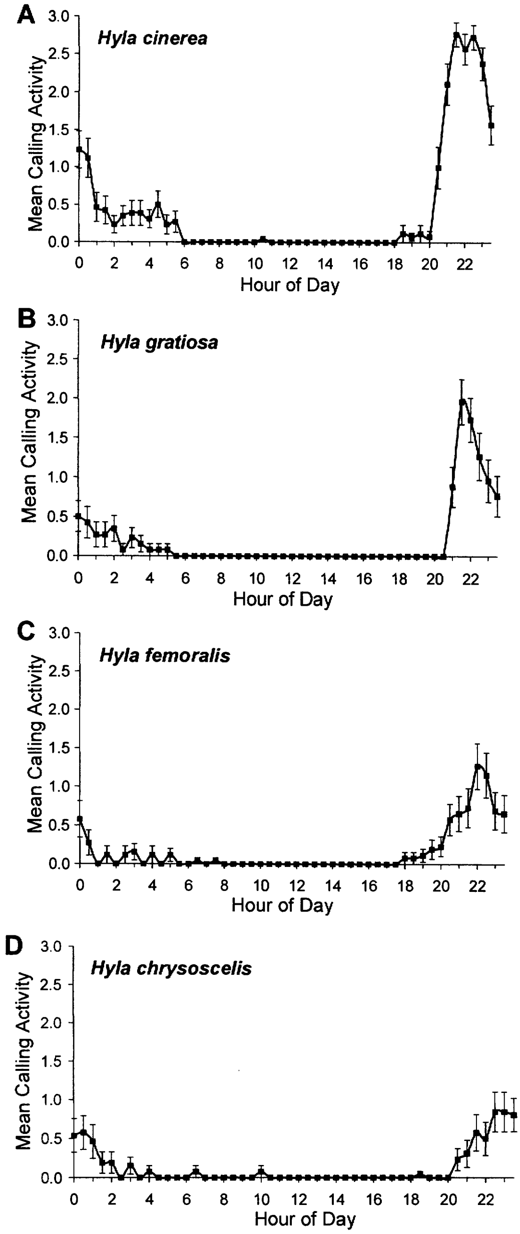

Fig. 3. Daily calling patterns in the genus *Hyla.* Mean calling activity was calculated by averaging the recorded calling activity levels for each 30-min time period over all days of the study. Error bars denote ± SD. Most calling occurred between sunset and midnight.

(Fig. 4). *Rana sphenocephala* typically did not start calling until after midnight and reached a peak of calling activity between 0230 and 0500 h (Fig. 4A). Although *R. catesbeiana* called throughout the day, peak calling activity occurred between 0200 and 0600 h (Fig. 4B). Likewise, *R. clamitans* called throughout the day,

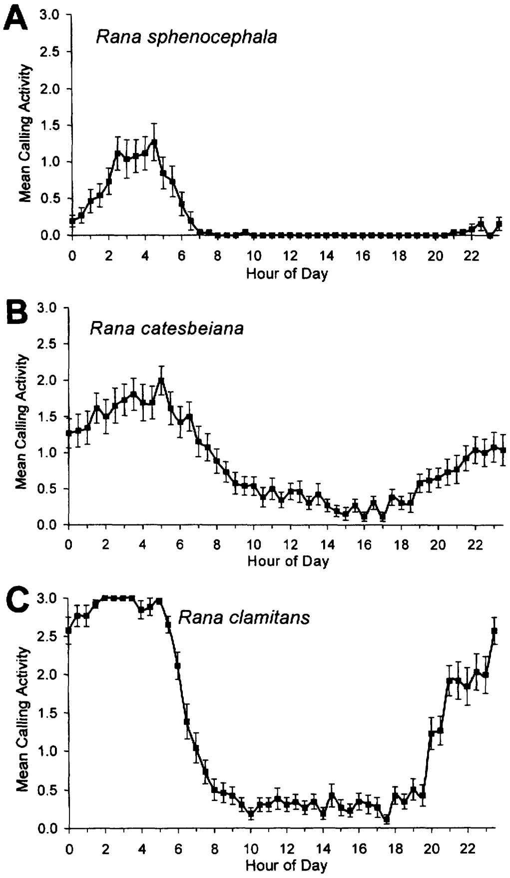

Fig. 4. Daily calling patterns in the genus *Rana*. Mean calling activity was calculated by averaging the recorded calling activity levels for each 30-min time period over all days of the study. Error bars denote ± SD. Note that the most intense calling occurred between midnight and dawn.

but peak calling occurred after midnight, between 0100 and 0530 h (Fig. 4C).

Discussion

The high diversity of anurans (nine species) recorded during this study is not surprising. Shallow, isolated wetlands such as Flamingo Bay are vital areas for amphibian reproduction in the southeastern United States (Semlitsch et al., 1996). Such wetlands periodically dry and thus provide environments free from predatory fishes, making them ideal for larval amphibian development.

During this study, there was no clear phylogenetic pattern governing whether a particular species called on a given night. For example, *R. catesbeiana* and *R. clamitans* called almost every day of the study, but their congener, *R. sphenocephala*, called only 17 of the 26 days (Fig. 1). Among the hylids, *A. gryllus* and *H. cinerea* called every day of the study, but *H. gratiosa, H. chrysoscelis,* and *H. femoralis* did not (Fig. 1). Although explanation for observed seasonal variation in calling activity is unclear, the implications of such patterns are profound for monitoring programs, especially if concentrating on sporadically calling species.

Interspecific daily variation.—Few studies have examined daily variation in calling activity. Bevier (1997) found considerable variation in tropical anurans in Panama, and Runckle et al. (1994) found that calling in *Hyla versicolor* peaked in early evening. Given (1987) reported that *Rana virgatipes* calling activity peaked around midnight, and Shimoyama (1989) reported that *Rana porosa* called more after midnight than before midnight.

Observed daily temporal partitioning of calling at a Carolina bay may have occurred for several reasons. First, air and water temperatures vary throughout the day. Some species, such as *R. sphenocephala*, modify their breeding behavior when exposed to different water temperatures (Caldwell, 1986). Lower early morning temperatures could help account for increased predawn calling activity in the summer for this primarily spring and fall breeder (Gibbons and Semlitsch, 1991). Second, calling anurans may attempt to avoid interspecific competition and possible associated acoustic interference by staggering breeding seasons, daily calling patterns, or by segregation of call frequency and pulse rate (Littlejohn and Martin, 1969). In the southeastern United States, *H. cinerea* and *H. gratiosa* often produce deafening choruses that may "drown out" weaker voiced anurans such as *G. carolinensis* and, thus, may be partially responsible for apparent temporal partitioning. Our data show a peak in calling for *G. carolinensis* late in the afternoon (Fig. 2A), but *G. carolinensis* could have called more after sunset without being recorded. Third, daily variation in calling behavior may conform to a phylogenetic pattern. All hylids (*Acris* and *Hyla*) recorded at Flamingo Bay reached peaks in calling activity between sunset and midnight (Figs. 2–3). The peak calling by ranids occurred between midnight and sunrise (Fig. 4).

Implications for monitoring programs.—Our study has profound implications for amphibian monitoring programs based on call surveys. Seasonal variation is an obvious factor and has long been taken into consideration when evaluating anuran populations (Wells, 1977). Long-term variation, in terms of years or even decades, has recently been recognized as an important consideration when evaluating variation in amphibian populations (Pechmann et al., 1991). Species-specific patterns of calling behavior at a fine temporal scale should also be considered in the development of monitoring protocol.

Most anuran monitoring studies have sampled solely in the early evening and almost never in the predawn hours (Vandewalle et al., 1996; U.S. Geological Survey, North American Amphibian Monitoring Program, http://www.im.nbs.gov/amphibs.html, accessed 25 June 1999). Some species, such as hylids in our case, can be accurately sampled using such early evening sampling. However, peak calling activity for ranids occurred between midnight and dawn, long after the sampling times dictated by most monitoring programs.

If observers sampled from sunset until dawn on only one night during our study period, they would miss on average two of the nine species per night. However, if observers followed NAAMP recommendations and sampled between 2100 and 2300 h only, we would expect them to miss three or more of the nine species we recorded.

Our most unexpected example of this potential error involves the southern leopard frog. *Rana sphenocephala* has been considered either a spring breeder or a year-round breeder with distinct peaks in early spring and again in early fall (Mount, 1975; Dundee and Rossman, 1989; Martof et al., 1980). Even at the SRS, among the most intensively studied herpetological sites in the world, *R. sphenocephala* is thought to call only in the spring and fall, generally during early evening and even during daylight (Gibbons and Semlitsch, 1991). However, *R. sphenocephala* can be an active vocalizer in midsummer. *Rana sphenocephala* was seldom heard calling before midnight during our study and had a peak of calling activity between 0200 and 0500 h (Fig. 4A). *Rana sphenocephala* was found to be actively vocalizing on 17 of 26 nights surveyed (Fig. 1). A call-count survey conducted during the typical hours of 2100–2300 would have recorded this species on only four nights or 15% of our study period.

Automated recording systems have great potential to improve the effectiveness and thoroughness of anuran monitoring programs by two primary means. When used to intensively sample one or a few sites, ARS may serve as a population monitoring technique. Tapes would provide a permanent record and would minimize observer error in species identification. However, using ARS as the primary sampling method may only be practical on protected tracts of land, such as military bases and wildlife refuges, where vandalism of expensive equipment can be minimized, and where personnel to maintain and analyze data from the ARS are available. Automated recording systems may also be used to develop regional models capable of predicting calling activity, thus allowing optimization of monitoring protocols. For example, we now know if a survey were conducted of a Carolina bay in South Carolina during the month of June between 2100 and 2300 h, *R. sphenocephala* is unlikely to be heard, yet this may not be indicative of species absence. Using our results as a model, *R. sphenocephala*, if present, would only be heard 15% of the time under these circumstances. In contrast, if *H. cinerea* was not heard, we could conclude its absence due to its predictable and consistent early evening calling patterns.

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SAVANNAH RIVER ECOLOGY LABORATORY, DRAWER E, AIKEN, SOUTH CAROLINA 29803. PRESENT ADDRESS: (ASB) DEPARTMENT OF FISHERIES AND WILDLIFE SCIENCES, VIRGINIA POLYTECHNIC INSTITUTE AND STATE UNIVERSITY, BLACKSBURG, VIRGINIA 24060-0321; AND (MED) DEPARTMENT OF BIOLOGY, DAVIDSON COLLEGE, DAVIDSON, NORTH CAROLINA 28036. E-mail: (ASB) abridges@vt.edu; and (MED) midorcas@davidson.edu. Send reprint requests to Reprints, Savannah River Ecology Laboratory, Drawer E, Aiken, South Carolina 29803. Submitted: 4 Dec. 1998. Accepted: 19 Aug. 1999. Section editor: W. L. Montgomery.