The HERPETOLOGICAL BULLETIN

Number 78 – Winter 2001

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PROJECT ANURAN: A MULTI-SPECIES MONITORING PROJECT AT THE TROPICAL LOWLAND FOREST SITE OF LAS CUEVAS, CHIQUIBUL FOREST RESERVE, BELIZE

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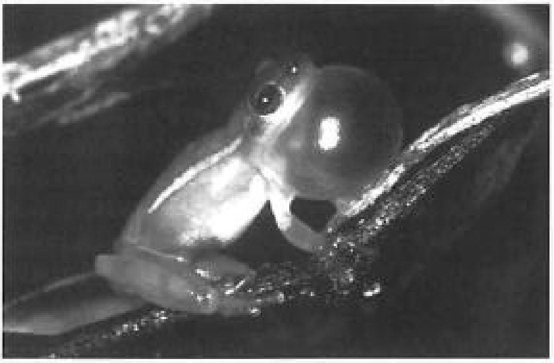
IN the decade following the establishment of the Declining Amphibian Populations Task Force (DAPTF) of the IUCN in 1990, an increasing number of reports from monitoring projects, comparative studies, and experimental research worldwide, have identified the observed phenomenon of declining amphibian populations as being both real and global in nature (Lips, 1998; Wake, 1998; Alford & Richards, 1999; Houlahan et al., 2000; Young et al., 2001). Particular concern for the plight of amphibians in comparison to other taxonomic groups has come from reports of declines across entire amphibian communities, and from areas that are largely intact from direct human impacts (e.g. Drost & Fellers, 1996; Laurance et al., 1996; Lips, 1998). Despite this concern there are three main questions concerning amphibian declines in which a large amount of uncertainty remains:

(1) How to distinguish real long-term declines from natural or stochastic population fluctuations?
(2) Whether human agents can be isolated as the potential cause of declines?
(3) Whether a small number of global agents are responsible for the majority of declines?

Although the picture is far from clear, convincing new research suggests that the majority of declines are unlikely to be the result of a small number of independent global agents, but rather the result of a complex interaction of local processes in the context of human-induced environmental change (Kiesecker et al., 2001; Pounds, 2001). Unravelling such complexity will allow for more confident and efficient isolation of population declines, the establishment of effective conservation management plans, and even a capacity to predict impending declines. Central to these aims is a need to improve our understanding of the levels of variability naturally inherent in amphibian populations, and how the forces that influence these dynamics vary across different spatial and temporal scales, and across different environmental conditions.

Project Anuran is an undergraduate monitoring project established in 1999 as a joint venture between the University of Edinburgh and students in Belize, which through the intensive monitoring of an entire frog (Amphibia: Anura) assemblage is attempting to improve our understanding of some of the issues raised above. Data collected include information on the population dynamics, reproductive behaviour, and environmental requirements of all local species during each breeding season (2000 and 2001 to date). The purpose of this article is to provide the reader with a preliminary insight into both the project in general and the natural history of the amphibian community at Las Cuevas, Belize.

Our study serves to complement existing work by concentrating on both an area and species assemblage that remain largely unstudied. The study site at Las Cuevas, the Natural History Museum's research station, lies within the Chiquibul Forest Reserve, which represents one of the most pristine and extensive stretches of forest in Central America (Furley, 1998). The vegetation type can best be described as a mosaic of



Hyla picta. Photograph © Project Anuran.

deciduous semi-evergreen and deciduous seasonal tropical forest punctuated by stands of pine (*Pinus carribea*). Despite the biological importance of the region, the basic ecology of many of the amphibian species in Belize remains largely unknown. Furthermore, there remains a desperate need for monitoring studies throughout the tropics (Wake, 1991, 1998; Pearman et al., 1995; Houlahan et al., 2000), and in particular in the neotropics where amphibian diversity reaches its peak (Lee, 1996). A recent workshop involving herpetologists from across Latin America noted that despite over 50 declines reported in 13 countries from across 30 amphibian genera, only 5% of studies have been published, whilst the vast majority of both sites and species remain poorly understood (Young et al., 2001). The DAPTF are presently co-ordinating a monitoring program entitled the Maya Forest Anuran Monitoring Program (MAYAMON), as part of a large internationally funded biological monitoring project of the entire Selva Maya region (Carr & de Stoll, 1999). The information collected by Project Anuran is fed into a regional picture collated by MAYAMON using data from studies throughout Belize, the southern states of Mexico, and the Péten of Guatemala. Our study site at Las Cuevas is able to provide a good comparison against many more disturbed areas in other parts of the region.

Monitoring protocol

Monitoring of vocalising and non-vocalising frog species was carried out using two separate survey

Hyla microcephala. Photograph © Project Anuran.

techniques. For vocalising species, a series of seven (increasing to nine in Phase II) breeding sites representing a variety of habitat types were chosen. Surveys of species richness, relative abundance and environmental variables were conducted between 19:00 and 02:00 h, with measurements of each being taken at half-hourly intervals. The index of relative abundance follows the protocol used in the regional MAYAMON scheme, and assigns the number of calling males heard during the first 15 minutes of each recording to a Vocalisation Category (Meyer, 1999). An additional index of Vocalisation Intensity was also noted to allow for analysis of patterns of the overall vocalisation activity for each species.

Digital recordings of all species were made using a Sony mini-disc recorder, copies of which can be obtained from the authors. Measurements of the abiotic environment, which were also taken every half-hour, included air and water temperature, rainfall duration for the previous half-hour, and relative humidity. Measurements taken once for each site visit were: length of two principle pond axis, water pH, phase of moon and summary weather conditions. Repeat surveys of each study site were conducted at even intervals throughout the study period, with a minimum of three repeat visits per site in Phase I (2000), increasing to a minimum of five in Phase II (2001) (increased effort was made possible due to increased manpower, which can be adjusted to allow for comparison between years). The main features of the floristic community were also recorded for each site.

With respect to the second part of the survey work, non-vocalising or leaf litter species are far more difficult to assess, owing to their rather cryptic and solitary nature. In view of the variability in effectiveness between different methods in relation to different sites, species, and environmental conditions (Pearman et al., 1995), we employed three techniques: intensive surveys of randomly sampled 8 x 8 m plots, less intensive visual surveys of 6 x 600 m transects, and five pitfall trap arrays. Techniques follow standard protocol outlined in Heyer et al. (1994) — traps using two arrays; 8-bucket/4 fence cross and 6-bucket straight-line fences. Weather recordings of rainfall volume and duration, relative humidity, ambient temperature, maximum/minimum temperature, and cloud cover were taken at 09:00 h throughout the duration of each study period from the main site at the research station.

Family	Species
Leptodactylidae	*Eleutherodactylus chac*
	Eleutherodactylus laticeps
	Eleutherodactylus rhodopis
	Eleutherodactylus sabrinus
Bufonidae	*Bufo campbelli*
	Bufo marinus
	Bufo valliceps
Ranidae	*Rana berlandieri*
	Rana juliani
	Rana vaillanti
Hylidae	*Agalychnis callidryas*
	Agalychnis moreletii
	Hyla ebraccata
	Hyla loquax
	Hyla microcephala
	Hyla picta
	Smilisca baudinii
	Smilisca cyanosticta
Microhylidae	*Gastrophryne elegans*
Centrolenidae	*Hyalinobatrachium fleischmanni*
Rhinophrynidae	*Rhinophrynus dorsalis*

Table 1. A complete species list of anurans identified at Las Cuevas during both study periods.

Amphibian fauna of Las Cuevas

In light of the large size of our data set a comprehensive account of our results to date is inappropriate for this journal (both the main report Phase I and preliminary report Phase II are available on request from the authors). Our intention is therefore to provide the reader with an overview of the diversity, relative abundance, and vocalisation activity of the amphibian community at Las Cuevas.

Table 1 presents the total anuran species richness recorded at Las Cuevas from across both field studies. A total of 21 species identifies the site as being one of the most diverse with respect to amphibians in Belize (Miller & Miller, 1995). In order to provide a clear picture of the anuran fauna at Las Cuevas, it is appropriate to consider the species with respect to their method of surveillance — i.e. vocalising or non-vocalising.

Table 2 presents the summary of relative abundance statistics for all 21 species in Table 1. Due to the fact that two distinct survey techniques were used it is impossible to standardise across all species. Despite this, Table 2 gives an appreciation of the relative abundance amongst both the vocalising and non-vocalising species. A number of species were recorded under both methods, whilst one (*Smilisca cyanosticta*) was not recorded under either. Clear inadequacies in both methods are identified by the high number of anecdotal recordings of species that were rarely observed in official surveys — notably explosive breeding species (e.g. *Gastrophryne elegans*).

Vocalising species: The nine breeding sites under study can be divided into two principle habitat types: (1) those characterised by an almost complete canopy cover, a palm dominated flora, and little herbaceous vegetation, and (2) relatively open sites with less than 30% canopy cover, often with dense herbaceous vegetation.

The closed-canopy sites were almost exclusively dominated by the two *Agalychnis* species — *A. callidryas*, the Red-eyed Treefrog,

Species	Summed maximum Vocalisation Category	Transect encounter rate (individuals/km)	Anecdotal sightings
Agalychnis callidryas	20	-	20-50
Agalychnis moreletii	15	-	10-20
Bufo campbelli	-	0.2	28
Bufo marinus	-	0.1	3
Bufo valliceps	4	0.25	20-50
Eleutherodactylus chac	-	-	1
Eleutherodactylus laticeps	-	0.2	8
Eleutherodactylus rhodopis	-	0.1	2
Eleutherodactylus sabrinus	-	0.7	4
Gastrophryne elegans	6	0.1	350-400
Hyalinobactrachium fleischmanni	-	0.1	0
Hyla ebraccata	4	-	10-20
Hyla loquax	13	-	20-50
Hyla microcephala	12	-	10-20
Hyla picta	11	-	20-50
Rana berlandieri	3	-	10-20
Rana juliani	-	1.05	13
Rana vaillanti	-	2.5	2
Rhinophrynus dorsalis		-	10-20
Smilisca baudinii	12	-	50-100
Smilisca cyanosticta	1	-	26

Table 2. Summary of relative abundance indices for all 21 anuran species. Index values relate to the appropriate survey technique for each species, as such comparisons between all species are impossible. Data are only taken from 2001, which due to a higher sampling effort allows for a more accurate resolution of the true relative abundance. For vocalising species this is given as a summed Vocalisation Category across all study sites (taking the maximum category value for which each species was observed at each site in turn — maximum from across all recorded hours at each site). Vocalisation categories; 1 = 1-5 individuals, 2 = 6-20, 3 = 21-50, 4 >50. For leaf-litter species the appropriate index is their encounter rate from across the total transect distance surveyed (20 km) (using data from all five transect lines). Anecdotal sightings during 2001 are also given for each species, representing an estimate of the number seen outside any official survey period. Note that this column includes a number of species not recorded using either survey technique. The absence of any value indicates that the species was not assessed under that technique.

and *A. moreletii*, Morelet's Treefrog. The Red-eyed Treefrog is a very common inhabitant of the Yucatán Peninsula, making its high local abundance unsurprising. However, Morelet's Treefrog, which we found in almost equal numbers (Table 2), has been rarely reported in Belize (Lee, 2000). Aside from being found at sites with similar physical properties, the ecological similarity of these two species is further emphasised in their vocalisation behaviour, with both displaying patterns typical of prolonged breeders (sensu Wells, 1977); males were heard calling for a large proportion of the night, and across the whole range of environmental conditions experienced in each study period.

On one occasion a male *A. callidryas* was observed in amplexus with a female *A. moreletii*, which succeeded in producing a small cluster of eggs. The eggs were monitored closely whilst being protected from predation (using a mosquito net and an empty dustbin); however, they proved to be unviable. Despite the lack of viability, the event highlights the remarkable similarities in the ecology, breeding requirements, and physical acoustic properties of the two species. As an aside it is interesting to note that over 150 hours of recorded observation of these species allowed for a number of rare observations of aggressive fighting between males, with each female being hounded by anything up to six males!

Whilst both *Agalychnis* species were frequently active during relatively dry conditions in the absence of any other species, periods of intense rain stimulated the arrival of a number of explosive breeders (sensu Wells, 1977) to the closed canopy sites. This emphasises the importance of frequent site visits in order to capture the variation in community level amphibian dynamics over the suite of potential environmental conditions. Such species included the ubiquitous Mexican Treefrog (*Smilisca baudinii*), the more elusive Elegant Narrowmouth Frog (*Gastrophryne elegans*), and the remarkable Mexican Burrowing Toad (*Rhinophrynus dorsalis*).

In contrast to the closed-canopy breeding sites, the open-canopy sites exhibit a much higher level of species richness. It seems intuitive that as the complexity of the surrounding vegetation matrix increases the observed diversity also increases, perhaps due to an increase in the availability and diversity of calling and oviposition sites. Commonly observed species at these sites included *Hyla loquax* and *H. microcephala*, with *H. ebraccata*, *H. picta*, *Bufo valliceps* and *Rana berlandieri* being recorded less frequently (Table 2). *Agalychnis callidryas* was also recorded across all of these sites and on a large proportion of the study nights, although *A. moreletii* was not observed outside of closed-canopy ponds at all during 2000, and only rarely during 2001. Although an ecological explanation for the observed spatial and temporal distribution of species across study nights is far from clear, some indication is given from analysis of the data describing vocalisation activity patterns. These data (taken from all study nights) clearly indicate that despite significant levels of variation, different species were recorded exhibiting peaks in their calling activity (an index incorporating both relative abundance and individual calling rates) at different times throughout any one night (Figure 1).

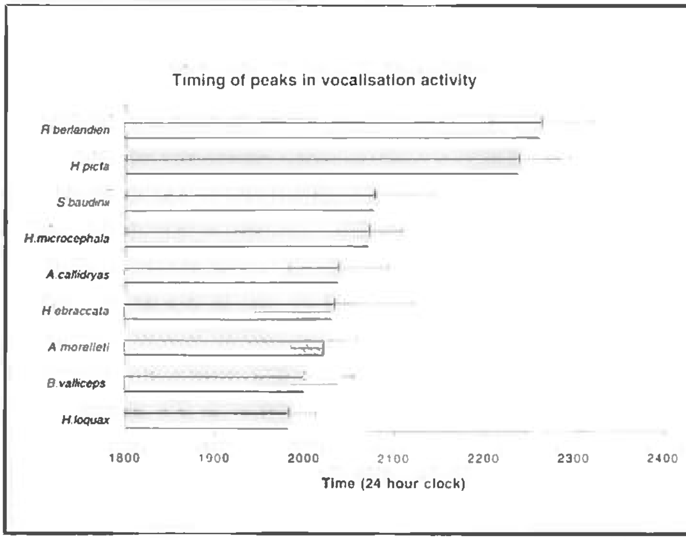


Figure 1. Timing of peaks in vocalisation activity of anuran species local to Las Cuevas (24 hour clock) each bar length gives the mean time of peak +/- 1*SE. Vocalisation activity is measured as Vocalisation Category (audible abundance) multiplied by Vocalisation Intensity. Data taken from 2000 only.

This temporal partitioning could be interpreted as a result of strong inter-specific competition for acoustic space — a conclusion that has been made by a number of other studies (Bowker & Bowker, 1979; Aichinger, 1987; Rand & Myers, 1990; Donnelly & Guyer, 1994). Support for this theory comes from the belief that breeding call characteristics are thought to be some of the most important reproductive isolating mechanisms that allow amphibian coexistence (Fouquette, 1960). For the case of *A. moreletii* it would therefore follow that its absence from open-canopy sites was due not to the lack of any specific habitat requirement at those sites, but rather to the excluding effect of other (more acoustically dominant) species. It is important to note here that an understanding of the relative importance of factors that structure the spatial and temporal dynamics of amphibian communities is an important asset for conservation. Such an understanding allows some prediction as to the potential effect of environmental and habitat

Above: Morelet's Treefrog, *Agalychnis moreletii*. Photograph © Project Anuran.

Left: amplectant male *A. callidryas* with female (larger) *A. moreletii*. © Project Anuran.

Broad-headed Robber Frog, *Eleutherodactylus laticeps*. Photograph © Project Anuran.

Elegant Narrowmouth Frog, *Gastrophryne elegans*. Photograph © Project Anuran.

Maya Mountains Frog, *Rana juliani*. Photograph © Project Anuran.

Vaillante's Frog, *Rana vaillanti*. Photograph © Project Anuran.

change, as well as the consequences of alterations in population size and reproductive activity of any one species on the dynamics of the rest of the community. Aside from this, an understanding of both temporal and spatial community patterns is critical in optimally allocating time and resources in budget-constrained monitoring projects — a fundamental exercise throughout much of the tropics (Guyer, 1990; Pearman et al., 1991).

As noted above for the closed-canopy sites, the group of species described as explosive breeders were also found at high levels of relative abundance following intense rainfall events at the open canopy sites. It seems clear that the distribution and reproductive activity of these species is determined far more by rainfall patterns than by any local environmental characteristics. It is interesting to note that all the explosive breeders observed at Las Cuevas have either a very loud (e.g. *Rhinophrynus dorsalis*, *Bufo valliceps*, *Smilisca baudinii*) or distinctive (*Gastrophryne elegans*) vocalisation. These characteristics are perhaps a result of a selection pressure for a call that has dominant acoustic properties, thus ensuring reproductive success when the rare, but appropriate conditions are presented. The high level of variability in the presence and level of reproductive activity of these species, in addition to the unpredictability in weather patterns, imposes serious caveats in our ability to monitor populations effectively and reliably. This fact serves to re-emphasise the importance of frequent site-survey repeats, and recording over a significant proportion of the night in order to capture true measures of relative abundance.

One disturbing result from the weather recordings was an increase in the length of dry periods throughout the wet season of 2001 — a trend that appears to be relatively long term following anecdotal reports (N. Bol pers. comm. — Las Cuevas Operations Manager). Although the volume of rainfall seems to show little change, there seemed to be a change in the pattern of rainfall events — with rain falling in intense, relatively short time periods, interspersed by long

Rio Grande Leopard Frog, *Rana berlandieri*. Photograph © Project Anuran.

dry spells. This is shown by the fact that many of our study sites that were permanently active during 2000 remained empty for up to 80% of the 2001 study period. Clearly such long periods of desiccation between breeding attempts will have drastic consequences for the reproductive success of many species — most of which require more than 10 weeks for the tadpoles to develop (Lee, 2000). Although no evidence exists from Las Cuevas, alterations in weather patterns throughout Central America following increasingly intense El Ninô events (Holmgren et al., 2001) have been causally linked to amphibian declines in Costa Rica (Pounds et al., 1999; Pounds, 2001).

Non-vocalising species: Non-vocalising leaf litter anurans have been assessed using three methods, resulting so far in over 100 hours of intense plot searching, 20 km of transect surveys, and over 1000 pitfall trap nights. This has provided us with a valuable comparison of the effectiveness of these three commonly employed survey methods. The analysis of this is intended for independent presentation, although in summary, transect searches returned by far the highest numbers of species and individuals (see Table 2), with inter-specific differences being observed between day and night transects, whilst plots and pitfall traps proved to be almost useless (i.e. less than 0.05% trap success, and almost all species were observed to have the ability to escape).

A number of interesting recordings of the non-vocalising group were made. Two sightings of *Eleutherodactylus rhodopis*, the Polymorphic Robber Frog were of particular interest, having been described by Meyer & Foster (1996) as having only one record from Belize, 50 years ago. The Maya Mountains endemic *Rana juliani*, for which few records exist outside Caribbean Pine (*Pinus carribea*) formations, was found to be locally abundant close to small streams (Table 2). The newly described *Eleutherodactylus sabrinus* (Campbell & Savage 2000) was also found in relatively high numbers alongside both minor water-courses and the main Monkey Tail river. The Broad-headed Rainfrog (*Eleutherodactylus laticeps*) noted to be much rarer than the closely related Chac's Rainfrog (*Eleutherodactylus chac*) in field guides (e.g. Lee, 2000), was actually found in significantly higher numbers than the latter species (Table 2). It is important to note with respect to the above records, that for many ground-dwelling amphibians next to nothing is known about their basic ecology. It is therefore likely that records of rare species, or relatively high local abundances, better reflect a deficiency in survey work than any ecological significance of the Las Cuevas site.

CONCLUSIONS

Following the aim of Project Anuran to increase our understanding of the ecology and population dynamics of anuran populations at Las Cuevas, we have collected data over two field seasons on species richness, relative abundance (including levels of spatial and temporal variation), and where possible, vocalisation activity patterns, and environmental associations. This account has provided a brief overview of a number of salient points. It is hoped that following future studies such a comprehensive consideration of an entire assemblage across multiple sites, and different temporal scales, will provide valuable information on the natural levels of variability in amphibian populations — an understanding that is essential for conservation planning.

Few conservation projects in developing countries have the levels of expertise, money or time necessary for thorough ecological assessments (Pearman et al., 1995). Project Anuran has benefited from having had access to all of these, and it is our belief that through the collaboration of student communities from countries rich in such resources with those from developing parts of the world, where so many of today's conservation projects are focussed, a great deal of progress can be achieved.

ACKNOWLEDGEMENTS

We are enormously grateful to a great number of people and institutions for their support in this project. We would like to thank in particular: Jack Meyer, Peter Stafford and John Wilkinson for assistance in herpetological matters, Peter Furley for unstinting encouragement and support, and Chris Minty, Nicodemus Bol, Celia Bol and Enrique Saquil of the NHM (Las Cuevas) for making our time in the field so enjoyable and successful. For financial assistance we are grateful to: British Ecological Society, Edinburgh Trust No.2, Gilchrist Educational Trust, Royal Geographical Society, Royal Scottish Geographical Society, and the University of Edinburgh. Thanks are also due to the Ministry of Natural Resources of Belize for granting the necessary research permits.

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