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## **GAS President's Comments and Report from the Academy Council**

Let me begin by welcoming everyone back. I hope you all had a productive and restful summer. We begin this academic year with a special issue highlighting some of the research undertaken by our undergraduate students; each paper in this issue includes undergraduates as major authors and researchers. Take some time to look over what they have accomplished and think about the impact this experience will have on their lives. Let us see if we can all emulate these examples. If you haven't worked with undergraduates in a research setting before, consider finding some way to involve students in scientific research this year. If you have worked with undergraduates, consider taking on one more. And, don't wait for them to come to you, invite them into your lab. Many good students, especially the younger ones, are still intimidated by professional scientists and need that invitation to get started. And then, while you are thinking about it, remember that the call for papers for the 80<sup>th</sup> Annual Meeting of the Academy is officially out. This would be perfect opportunity for those students to present their work in a public setting.

On the down side, I am sure you have all heard by now that Georgia ranks 50<sup>th</sup> in SAT scores. While we can argue the significance of ranking 50<sup>th</sup> instead of, say, 43<sup>rd</sup>, or the meaning of the SAT in general, I think we can agree that the news is not good. This is verified by the fact that this summer 625 Title I schools were identified as needing improvement. Clearly, something needs to be changed, something more fundamental than offering semester-long SAT preparation courses in the high schools. Some of the needed change is cultural. As was pointed out in a recent editorial, in some parts of Georgia a high school diploma was not considered to be a necessary part of a child's education and marriage at fifteen was at least widely accepted if not the norm. Our work with undergraduates and with the Junior Academy is part of an effort to influence the culture of Georgia. So too are the special programs and projects designed to bring an awareness of science and scientific thought to the schools and to the community at large that I think most of us participate in as individuals and representatives of our respective institutions. Changing a culture is difficult and all that I can say about this aspect is that we must continue our efforts, while always looking for new ways to expand them.

There is another aspect of the problem. Are our educational institutions teaching the right material at the right time and at the right level? As you are probably aware, Georgia has developed a state-wide curriculum guide, the Quality Core Curriculum or QCC, for grades K through 12. Several state agencies, including the Department of Education and the Board of Regents, are currently revising the QCC and developing course content standards for grades K, 3, 5, 8, 12, and 14. This would be an opportune time for each of us to take a look at the QCC for our respective areas and see if the curriculum is appropriate and to suggest changes and revisions. For those who do not keep a copy of the QCC on their desks, the complete curriculum can be found at <http://www.glc.k12.ga.us>. At some point a web site will be set up for public comment. Until then, you can send your comments to me and I will forward them to the appropriate people.

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**CALL FOR PAPERS:  
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**IDENTIFICATION OF MATURE LARVAE OF THE GENUS HYDROCOLUS LARSON AND ROUGHLEY (COLEOPTERA: DYTISCIDAE) IN GEORGIA.**

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**ABSTRACT**

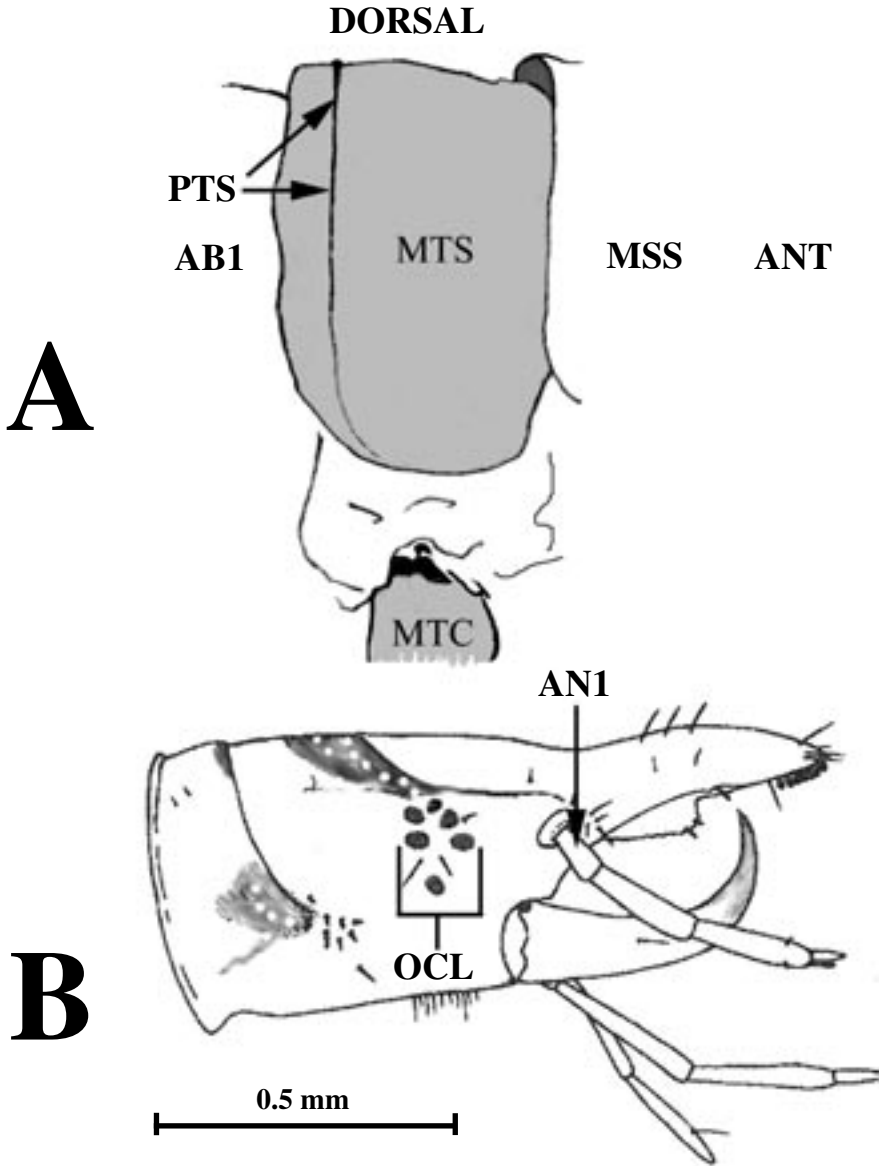
Characters for identification of mature larvae of the genus *Hydrocolus* in Georgia are presented. These are: (i) the presence of metanotal posterotransverse sutures on *Hydroporus* and *Hygrotus* that are absent on larvae of *Hydrocolus* and (ii) rudimentary stemmata on *Hydrocolus* that are located in ocellaria with diameters subequal to those of first antennal segments.

**Key words:** *Hydroporus*, *Hygrotus*, key, larvae.

Larson et al. (1) gave generic status to several dytiscid lineages formerly included in the genus *Hydroporus* Clairville, including three genera represented in Georgia. As a result, Georgia's faunal list (2) now includes species in the genera *Hydrocolus* Roughley and Larson, *Heterosternuta* Strand, and *Neoporus* Guignot. The validity of *Neoporus*, and *Heterosternuta* was anticipated and these genera were included in a key to the mature dytiscid larvae of Georgia (3). However, larvae of *Hydrocolus* are likely to be identified as *Hydroporus* if this key is used. Turnbow and Smith (2) listed *Hydrocolus* *filiolus* (Fall), *H. oblitus* (Aubé), and *H. paugus* (Fall) as the species of record for Georgia (as *Hydroporus*) with collection data indicating that these dytiscids have been collected infrequently in only a few counties. However, as currently defined, *H. paugus* has a Boreal distribution (1), so its occurrence in the southeast is unlikely. The range of *Hydrocolus* *deflatus* (Fall) is along the Atlantic Coastal Plain from New York to Florida and westward along the Gulf Coast to Texas (1), making it a likely but unrecorded component of Georgia's fauna.

Larvae of *Hydrocolus* should key to couplet 8 in Barman's (3) key to dytiscid larvae of Georgia. Alarie (4) described larvae of *Hydrocolus* *paugus*, providing the only known detailed descriptions of North American immatures of the genus. Stemmata are not present on first and second instars and are rudimentary and located in small ocellaria on the third instar of *H. paugus*. Mature larvae of *Hydroporus* (4) and *Hygrotus* (5) have well-developed stemmata located in ocellaria that are as large as or larger than the antennal basal segments (Fig. 1B). The mature larva of *H. paugus* lacks a metanotal posterotransverse suture that is present and prominent on larvae of *Hydroporus* (4). This suture is also present on the metanotum (Fig. 1A) of *Hygrotus* *nubilus* LeConte (pers. observation) and *H.*

*impressopunctatus* (Schaller) (5), the only *Hygrotus* species of record in Georgia (2). By using these characters to modify couplet 8 of the key to mature dytiscid larvae (3), *Hydrocolus* may be distinguished from other hydroporine genera in Georgia.



**Figure 1.** Lateral views of hydroporine metathoracic segment (A) and head (B). Abbreviations used are: ANT, anterior; AN1, first antennal segment; AB1, first abdominal segment; MSS, mesothoracic segment; MTC, metacoxa; MTS, metathoracic segment; and PTS, postero-transverse suture.

## MODIFICATIONS FOR SEPARATION OF HYDROCOLUS, HYDROPORUS, AND HYGROTUS

“8a. Metanotum with prominent posterodorsal suture (Fig. 1A); width of ocularium greater than 1.2 times the diameter of the first antennal segment (Fig. 1B). ..... 8a

“8b. Metanotum without posterodorsal suture; width of ocularium less than or subequal to diameter of first antennal segment. .... Hydrocolus Larson and Roughley 2000

8a. A small sensillum on the anterior surface of face of distal segment (2TR) of each protrochanter (lit. cit. Fig. 1E). .... Hydroporus Clairville, 1806

8b. Above sensillum absent. .... Hygrotus Stephens. 1828

### ACKNOWLEDGEMENTS

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**ANTERIOR CRANIAL MORPHOLOGY OF THE MATURE LARVA  
OF THERMONECTUS BASILLARIS (HARRIS)  
(COLEOPTERA: DYTISCIDAE: DYTISCINAE).**

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**ABSTRACT**

Internal and external cranial structures related to extra-oral digestion by the mature larva of *Thermonectus basilaris* are examined and described. The mandible is serrated along the ventral edge with the channel closed between distal and proximal openings. The mature larva has a closed cibarium and cranial meatuses.

**Key words:** *Thermonectus*, larva, cranium, internal anatomy.

**INTRODUCTION**

A majority of predaceous arthropods engage in extra-oral digestion (1), including larvae of most species of Dytiscidae. This mode of feeding requires external and internal modifications of the morphology of the cranium and the mouthparts that vary among larvae of various dytiscid taxa. Most dytiscids that feed extra-orally have deep medial mandibular channels for delivery of digestive enzymes into and the ingestion of liquefied materials from prey. The extent of closure of the channels and the complexity of the mechanisms responsible for their closure differ among the various dytiscid taxa (2). Anterior cranial adaptations to provide pathways connecting the mandibular channels and the larval mouth also vary in complexity, reaching their most advanced development among the Dytiscinae (3). In those species of Dytiscinae that have been described, cibarial meatuses (channels) are present on each side of the head that lead posteriorly from the venter of the adnasale (lateral lobes) to unite medially as a closed cibarium just anterior to the mouth (4, 5, 6, 7).

The only descriptions of anterior cranial morphology of *Thermonectus* Dejean that we have found are in a general study of aquatic Coleoptera by Wilson (8),

where mature larvae of *T. basilaris* (Harris) and *T. ornaticollis* (Aubé) are described. This study includes descriptions of only external morphology that lack detail, and the descriptions and identifications may not be reliable (9). The purpose of our study was to describe the anterior cranial morphology of *T. basilaris* that is directly related to extra-oral digestion with an emphasis on the morphology of mandibles, the cibarium, and cibarial meatuses.

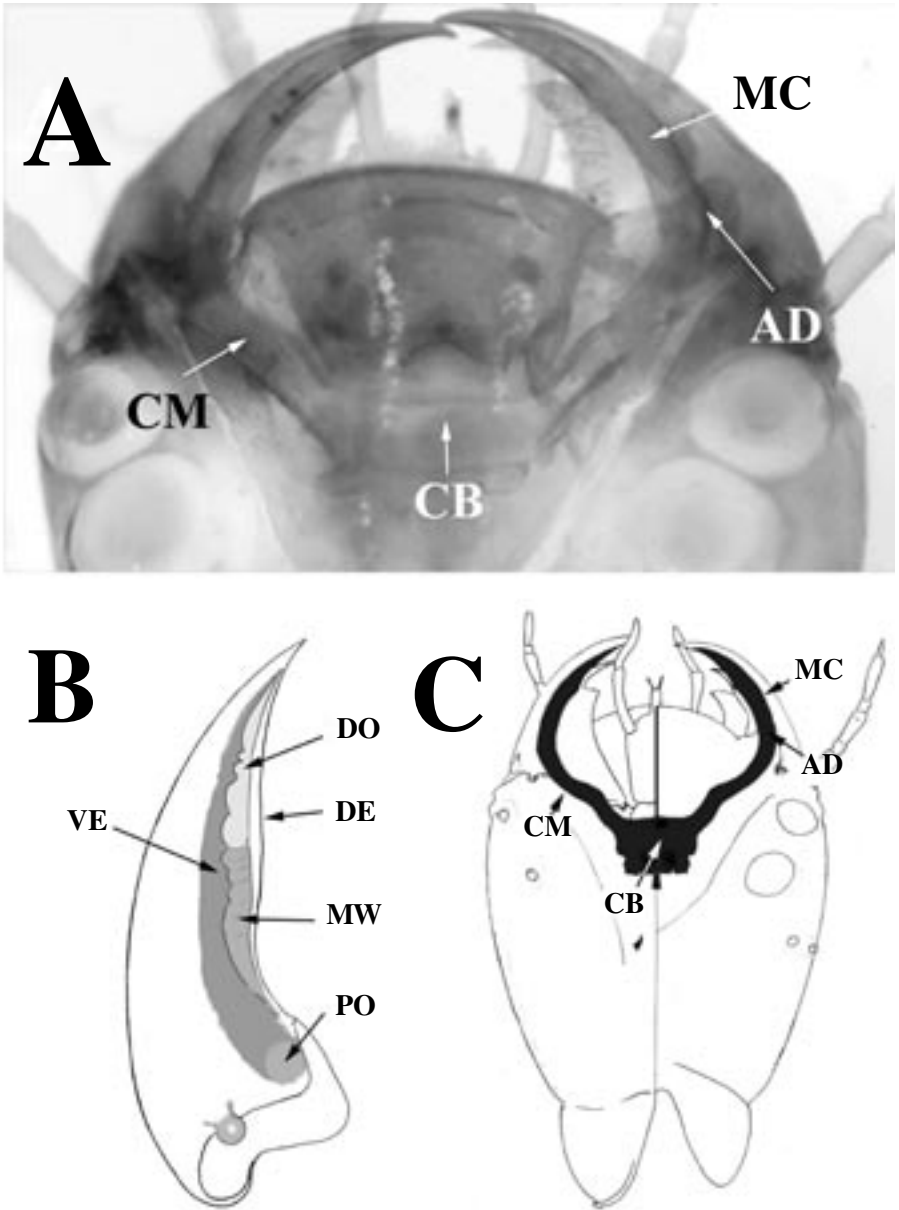
## **MATERIALS AND METHODS**

Mature larvae and exuviae of mature (prepupal) larvae examined were from the aquatic Coleoptera fluid (70 per cent glycerated ethyl alcohol) collection of Georgia College & State University. The larvae had been identified previously as *Thermonectus basilaris* by culturing larvae into the adult stage. Mandibles described were removed from mature larvae and exuviae and examined with a Wilde (M-5) equipped with a camera lucida and a Meiji (ML2000) microscope. Crania and frontoclypeal complexes (Fig. 1A) of third instar exuviae were used to evaluate internal and anterior cranial structures related to extra-oral digestion

Descriptive terms used are those of Snodgrass (10) and Beutel (11).

## **RESULTS AND DISCUSSION**

The mandible of *Thermonectus basilaris* is moderately curved with its ventral edge serrated distally. It has a deep channel (Fig. 1A) that is closed between a relatively large teardrop shaped distal opening and a smaller proximal and dorsal aperture (Fig. 1B). The integrity of the ventral and dorsal edges of the mandible of *Thermonectus* is retained and closure of the mandibular channel results from what appears to be a sclerotized medial wall between the dorsal and ventral edges. Mandibular channels of the genus *Acilius* are partially closed medially by contact (3) and perhaps some fusion of the dorsal and ventral edges. In the genus *Dytiscus* (3), the medial closure of the mandibular channel is more extensive than on *T. basilaris* and *Acilius* and is accomplished by a complex mechanism that locks the ventral and dorsal edges together. Although the mechanism of closure is different from that of *Acilius*, *Dytiscus*, and other described larvae of *Dytiscinae* (2), the result is that the mature larva of *T. basilaris* has a partially closed mandibular channel, facilitating an efficient flow of fluids into and out prey through the mandibular channel.



**Figure 1.** Cranium of exuvium (A), mandible (B), and dorsal and ventral views of head (C) of the mature larva of *Thermonectus basilaris* (Harris). Abbreviations used are: D, dorsal; V, ventral; AD, adnasale; CB, cibarium; CM, cibarial meatuses; DE, dorsal edge; DO, distal opening; MC, mandibular channel; MD, mandible; MW, medial wall; PO, proximal opening; and VE, ventral edge.

The cranium and frontoclypeal complex of mature (prepupal) larval exuviae are transparent, permitting observations of the labrum, cibarium, cibarial meatuses (Fig. 1A), and, on some specimens, the cuticular intima of the stomodaeum. The labrum (11) is a relatively large somewhat rectangular plate that extends obliquely and posteroventrally from the frontoclypeal margin between the adnasale that is surrounded by less heavily sclerotized epipharyngeal tissues. Internally and medially, there is well-defined, transverse, and sclerotized cibarium with the mouth in its posterior wall. Sclerotized and closed cibarial meatuses provide pathways for flow of fluids between the cibarium and anterior openings on the venter of the adnasale near the proximal pores of each mandibular channel. Thus, the larva of *Thermonectus basilaris* has a more or less closed cibarial system between the distal opening of the mandibles and the mouth that is similar to systems described for other species of Dytiscinae (4, 5, 6, 7, 10).

Losses of enzymes and partially digested prey tissues may occur in and around the distal end of the mandible when *Thermonectus basilaris* larvae capture prey and during feeding. These losses of fluids are probably an inevitable consequence of extra-oral digestion, regardless of the mandibular morphology of the various dytiscid taxa. However, the medial wall that partially closes the mandibular channel will likely reduce loss of fluids by *Thermonectus* larvae. A loss of fluids may also occur at the junction of mandibular channels and cibarial meatuses. Leakage there may be reduced or prevented when mandibles are opened during feeding (10) and by the prominent adnasale that projects well over the base of the mandible where the cibarial and mandibular systems meet. The cibarium, cibarial meatuses, and mandibular channels of the mature larva of *T. basilaris* represent a system for injection of enzymes into and the ingestion of partially digested materials from prey that is at least as efficient as systems described for larvae of other species of Dytiscinae.

### ACKNOWLEDGEMENTS

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## CONNECTING RATIONAL EXPONENTS AND FUNCTIONS

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### Abstract

An article by Evans and Tirosh, in the July 1995 issue of the Journal of Educational Studies in Mathematics, which addresses a difficulty with rational exponents is epitomized by the equation  $-2 = (-8)^{1/3} = (-8)^{2/6} = [(-8)^2]^{1/6} = 2$ . We suggest that perhaps a different perspective, namely a functional approach, is in order. We offer the reader a means of resolving the dilemma by defining the rational exponent as a function composition.

In the July 1995 issue of the Journal of Educational Studies in Mathematics, Evans and Tirosh claim that the quantity  $(-8)^{1/3}$  is undefined. Based on their study, Evans and Tirosh argues that the vast majority of teachers participating in their study of “undefined mathematical operations,” incorrectly argues that  $(-8)^{1/3} = -2$ . They go on to suggest that  $(-8)^{1/3}$  is undefined because

$$-2 = (-8)^{1/3} = (-8)^{2/6} = [(-8)^2]^{1/6} = 2 \quad (1)$$

If we take the argument given in equation (1) to its ultimate conclusion, it can be deduced that the negative real numbers do not exist. Let “a” be any positive real number. Then “-a” represents a negative number. According to the rationale suggested in equation (1),

$$-a = (-a)^1 = (-a)^{2/2} = [(-a)^2]^{1/2} = a.$$

Moreover, one can develop a parallel discussion to show that imaginary numbers do not exist. Evans and Tirosh have fallen into a common notational trap regarding rational exponents of real numbers. It is precisely because of such pitfalls that care must be taken when defining and manipulating such forms and why rational exponents should be revisited later in the curriculum. In 1997, Goel and Robillard rebutted the Evans and Tirosh arguments; using a classic definition of  $a^r$ , where  $r$  is a rational number, it was shown that the quantity  $(-8)^{1/3}$  is a well-defined real number with the value  $-2$ .

**Key Words:** rational exponents, mathematics education.

## METHODS AND MATERIALS

In order to further examine the perceptions held by pre-service teachers with respect to rational number exponents, we surveyed our students enrolled in Calculus II and II, History of Mathematics, Probability and Statistics, and Linear Algebra. These courses are required for our secondary education majors and are populated by mostly juniors and seniors. The students were asked to find the error in equation (1) and asked how to correct the error. Of the 55 students who participated in the survey, only two were able to correctly identify the error and adequately rectify the misconceptions. Eight students recognized the error, but could not clearly communicate a remedy. Seven students were able to identify the error, but could not explain the misconception. The remaining students (about 69%) did not identify the actual error. The responses to this survey offer some evidence that rational number exponent behavior should be revisited later in the curriculum.

The traditional method of revisiting the rational number exponent issue is to re-examine the implications of a classic definition, such as the one found in Sullivan (1999: p.72), which defines the rational number exponent as follows:

If  $a$  is a real number and  $m$  and  $n$  are integers containing no common factors with  $n \geq 2$ , then  $a^{\frac{m}{n}} = \sqrt[n]{a^m} = (\sqrt[n]{a})^m$ , provided  $\sqrt[n]{a}$  exists.

The resumes of this method of review and clarification of the definition of the rational number exponent have been at best mixed, as evidenced by our earlier discussion.

Noticing the lack of success of our students, we suggest another approach. We propose a definition of  $x^{\frac{m}{n}}$  that establishes a link with the learner's prior knowledge of functions and rational exponents. In doing so, the student will see the notion of function as a unifying strand of mathematics and see mathematics as a whole rather than as pieces of unrelated topics. The perspective proposed in this paper will also furnish instructors of pre-service and in-service secondary mathematics teachers an opportunity to provide a clearer understanding of the behavior of rational number exponents.

**A Functional Approach:** Consider  $f, g: \mathbb{R} \rightarrow \mathbb{R}$  defined by  $f(x) = x^m$  and  $g(x) = x^{1/n}$ , where  $m$  is an integer and  $n$  is a positive integer. We note that  $f$  is a well-defined function on  $\mathbb{R}$  for all values of  $m$ ; however, for even values of  $n$ ,  $g$  is not defined for negative real numbers and therefore, it is not a function on  $\mathbb{R}$ . Thus,  $f \circ g = x^{m/n}$  is not a function on  $\mathbb{R}$ . Therefore, to complete the functional definition of  $x^{m/n}$ , we need to investigate further the definition of  $g$ .

We note that  $g$  is the inverse relation of the function  $h: \mathbb{R} \rightarrow \mathbb{R}$  defined by  $h(x) = x^n$ , where  $n$  is a positive integer. Moreover, for  $g$  to be a function on  $\mathbb{R}$ ,  $h$  must be a one-to-one function. We know that on the set of positive real numbers  $h$  is a one-to-one function for all values of  $n$ . However, on  $\mathbb{R}$ ,  $h$  is a one-to-one function if and only if  $n$  is an odd integer (E.g.  $h(x) = x^2$  is not a one-to-one function on  $\mathbb{R}$ , but it is on  $\mathbb{R}^+$ ). Thus,  $h$  is invertible on  $\mathbb{R}$ , if and only if  $n$  is odd and therefore, in this case,  $g(x) = h^{-1}(x)$  is a function on  $\mathbb{R}$ . Hence, if  $n$  is odd, then  $x^{\frac{m}{n}}$  may be defined as a composition of the functions  $f$  and  $g$ . This definition makes sense on all of  $\mathbb{R}$  regardless of whether  $m$  and  $n$  have a common factor. This completes the definition of rational exponents of real numbers as a composition of functions.

## RESULTS

Defining rational number exponents using functions focuses on the definition of the  $n^{\text{th}}$  root as an inverse of a function. If  $m$  is an integer and  $n$  is a positive integer, then  $x^{\frac{m}{n}}$  is a convenient shortcut for expressing the image under the sequence of mappings  $x \rightarrow x^m$  followed by the inverse of  $x \rightarrow x^n$ , i.e.  $x \rightarrow x^{1/n}$ .

We now return to our example  $-2 = (-8)^{1/3} = (-8)^{2/6} = [(-8)^2]^{1/6} = 2$ . We first note that the function  $p(x) = x^{1/3}$  has domain  $\mathbb{R}$ , whereas the function  $q(x) = x^{1/6}$  has domain  $\mathbb{R}^+$ . Let  $h(x) = x^2$ . Then  $p(x) = x^{1/3} = x^{2/6} = (x^2)^{1/6} = q \circ h(x)$  only if  $x$  belongs to the set of positive real numbers. Hence, positive real numbers may be meaningfully raised to any rational exponent, but negative numbers may only be raised to a rational power if the denominator of the rational exponent is odd. Thus,  $(-8)^{1/3}$  is a number and its value is  $-2$ .

By revisiting the topic of rational exponents in a junior/senior level course and connecting this idea with that of functions, students see functions as a unifying strand in mathematics. The function-centered approach provides the opportunity to look as a single concept through a different set of lenses.

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## DEMONSTRATING THE CENTRAL LIMIT THEOREM USING A TI-83 CALCULATOR

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### ABSTRACT

In this article we show how the graphing calculator can be used to introduce the Central Limit Theorem of Probability and Statistics to the students. We start by giving the history and motivation behind the Central Limit Theorem. We give several examples related to the CLT and finally a TI-83 program demonstrates the CLT. The TI-83 program selects 30 integers between one and six computes the mean and stores it in a list. It repeats itself  $N$  times. At the end it gives the histogram plot for the  $N$  means to demonstrate the CLT.

### INTRODUCTION

In its simplest form, the Central Limit Theorem (CLT) states that for random samples taken from a population that is not normal, the sampling distribution of the sample mean  $\bar{x}$  is approximately normal when the sample size  $n$  is large enough ( $n \geq 30$ ). A slightly more sophisticated way of stating the theorem is: The mean of  $n$  independent, identically distributed random variables approaches the normal distribution as  $n$  increases. This is one of the most famous theorems of probability and statistics. Before the discovery of this theorem, mathematicians treated Statistics and Probability as two unrelated disciplines. Our two statements of this theorem illustrate that the Central Limit Theorem serves as a result to unify these two disciplines.

Before introducing the CLT, a brief discussion of some of the rudiments of probability theory is in order. For example, suppose that a "fair" coin is flipped 100 times. What does it mean for the coin to be fair? Does it mean that we should get 50 heads and 50 tails? In our experience, we have seen many students quickly, without reflection, jump to this type of conclusion, when actually the probability of obtaining exactly 50 heads and 50 tails is quite small. Probability and chance, by their very nature, are elusive to us. All that we can say above is that if the coin is fair, then there is a high probability that there will be about 50 heads and 50 tails. Tossing a coin is an experiment, that is, a procedure that leads to results or outcomes that can be observed and recorded.

The law of large numbers tells us that we must repeat an experiment many times in order for probabilistic results to appear. For example, if we roll a fair die 6000 times, we expect to see each number appear approximately  $1/6 \approx 16.7\%$  of the time. However, if we only roll the die 12 times, then it is very likely that some of the outcomes will deviate significantly from the theoretical 16.7% frequency of occurrence.

Next, suppose we toss a die 60 times. Then we should expect about an equal distribution of each of the possible outcomes. This is rather tedious; however, it is easy to simulate this experiment using a graphic calculator. Using the PROBABILITY submenu from the MATH menu we can quickly “roll a die” 60 times and store the results in a list.

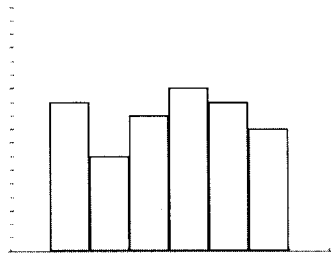
```
randInt(1,6,60)*L1
{4 6 2 2 4 4 2 3 1 1 5 1 5 1 3
 3 1 3 6 3 5 6 5 3 5 4 2 6 5 6
 5 3 3 4 5 2 4 5 1 5 1 1 5 6 1
 4 1 3 1 6 4 4 4 4 2 3 4 6 6 2}
mean(L1)
3.5333333333
```

Here, we have calculated the mean using the MATH submenu from the LIST menu.

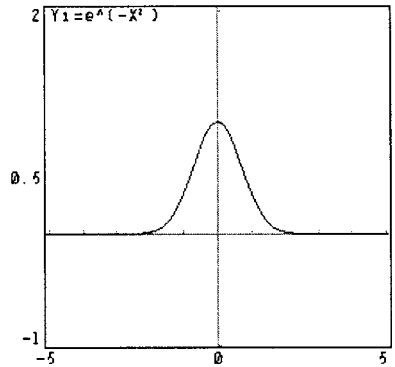
Perhaps the simplest way of analyzing this experiment is by using a frequency distribution or a histogram. The power of a histogram relies on the adage “A picture is worth a thousand words.” It gives us an instant visualization and a feel for the data list. For this particular list of data, we have set  $X_{min} = -1$ ,  $X_{max} = 8$ ,  $Y_{min} = -1$ ,  $Y_{max} = 20$ , and  $Y_{scl} = 1$ .

We have turned on STAT PLOT 1, using Histogram Type: **(the symbol for Histogram)** and Xlist **L1**. Of particular importance will be the Xscale. For this set of data, the natural choice is  $X_{scale} = 1$ , but later we will want to experiment with various settings.

It is very important to realize that a computer or calculator does not produce truly random output, but uses deterministic algorithms to produce strings of numbers that appear random and, in fact, may pass many tests for randomness (1). The issue of how “random” a particular random number generating algorithm is of great importance, since computer generated strings of random data are used routinely for applications (e.g. simulations of an economy) as well as theoretical investigation (2). The term **pseudorandom**, to describe these types of numbers, has caught on recently and it is indeed an appropriate description.



The normal distribution is the continuous probability distribution given by  $f(x) = \frac{1}{\sigma\sqrt{2\pi}} e^{-\frac{(x-\mu)^2}{2\sigma^2}}$  where  $\sigma=1$ . It is the function  $y=e^{-x^2}$  transformed by a horizontal shift, and horizontal and vertical scaling so that the total area under the curve is one. It is the familiar bell-shaped curve. However, not every bell-shaped curve is a normal distribution. Just as a parabola has a precise definition as a locus of points, the curve  $y=x^4$  may look like a parabola, but it is not a parabola. Later, we will discuss how to determine whether a bell-shaped distribution of data is truly normal.



### Some Historical Background

The Central Limit Theorem may be traced back to Pierre-Simon de Laplace (1749-1827) and Abraham De Moivre (1667-1754), though their motivations were quite different.

De Moivre developed the CLT as a method for estimating discrete probabilities, in particular those involving the binomial distribution. For example, if a coin is flipped 100 times, the probability that between 40 and 60 heads are obtained can easily be calculated, but the amount of arithmetic is daunting, especially if done by hand. De Moivre discovered that the distribution was approximately normal and could use this fact to quickly arrive at an approximation for these types of probabilities.

On the other hand, Laplace was motivated by observational science. In astronomy, for instance, we may be interested in determining some unknown quantity, such as the maximum distance between the sun and a planet, but when the quantity is observed or measured several times, most likely the measurements will be different, and also limited by the accuracy of the measuring device. To determine an estimate for the unknown “constant,” the natural approach is to take sample of independent measurements  $x_1, x_2, \dots, x_n$  and compute the mean value  $\bar{x} = (x_1 + x_2 + \dots + x_n)/n$ . Even then, if another person repeated the process, i.e. chooses a sample, another sample of  $n$  measurements and calculated the mean, it was highly unlikely their measurements would produce this same mean as another’s.

Thus, a dilemma the natural scientists were faced with a fundamental dilemma of how to determine a physical quantity.

Laplace discovered that the means are distributed approximately according to the normal curve and the Central Limit Theorem is sometimes known as the “normal law of random errors.” Essentially, we can only guarantee that the quantity being studied has a high probability of being in some range according to the normal distribution.

## The Central Limit Theorem Discovered

Let's suppose we roll a die 30 times. Before going further, some questions to pose the students might be

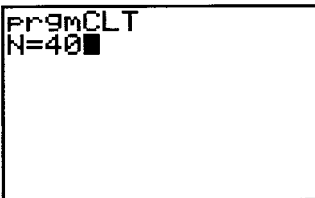
- Question 1: Before rolling the die 30 times and tabulating the results, describe how your histogram will likely turn out.
- Question 2: Before rolling the die 30 times and tabulating the results, what do you think the mean will likely turn out to be?
- Question 3: What are unlikely results for the histogram and mean? Can they happen?

The following program executes a loop  $N$  times. Every time it selects 30 random integers between 1 and 6, computes their mean and plots them on a histogram (please make sure the histogram plot is turned ON and list is  $L_1$ ). In each iteration, the program stores the mean in  $L_5$ . It plots the mean in  $L_5$  every time so the students can see the histogram of the means shaping into a bell shape progressively. In  $L_5$ , there will be  $N$  means. At the end, the program gives a histogram for the means in  $L_5$ . If you would like to try the program, please enter the program by entering the first column, then the second and finally the third. Make sure you turn on the histogram plot for  $L_1$  before running the program.

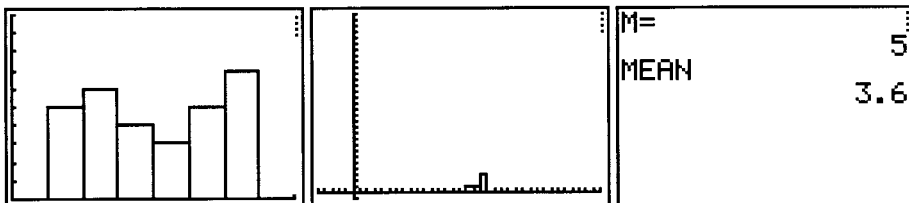
PROGRAM: CLT

:clrlst $L_1, L_5$	:randInt(1,6,30) $\rightarrow L_1$	:Pause
:1 $\rightarrow X_{min}$	:ClrHome	: $L_5 \rightarrow L_1$
:1 $\rightarrow X_{scl}$	:1 $\rightarrow X_{scl}$	:0.2 $\rightarrow X_{scl}$
:8 $\rightarrow X_{man}$	:DispGraph	:DispGraph
:1 $\rightarrow Y_{min}$	:mean( $L_1$ ) $\rightarrow L_5$ (M)	
:1 $\rightarrow Y_{scl}$	:0.2 $\rightarrow X_{scl}$	
:20 $\rightarrow Y_{max}$	: $L_5 \rightarrow L_1$	
:Input "N=",N	:DispGraph	
:N $\rightarrow dim(L_5)$	:Disp "M=",M	
:ClrList $L_5$	:Disp "MEAN", $L_5$ (M)	
:For(M,1,N)	:End	

Let us now illustrate the Central Limit Theorem in action. We execute CLT on the TI-83 and enter  $N = 40$ . The program will roll a die 30 times, flash the histogram for these 30 die rolls, flash the histogram of the means stored in  $L_5$ , and then flash the  $M$  iteration number and the mean of the 30 integers in  $L_1$ . Since  $N = 40$ , this will be repeated 39 more times. The count also appears each time the mean is flashed. For example, on the next page is the histogram and mean for the fifth time the die is rolled 30 times.

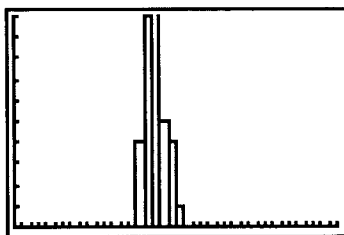


Almost immediately, another histogram will be flashed, and then the mean,



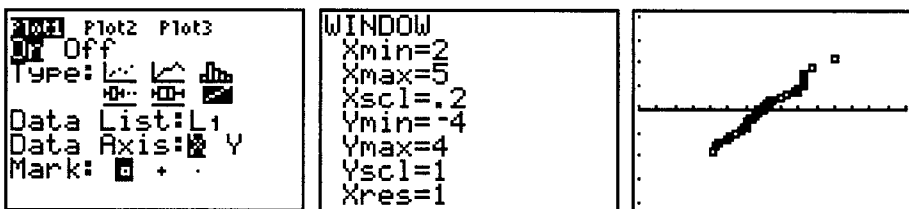
for the sixth time, etc. After the 40th time, the program will pause. When we continued (by hitting the ENTER key), the histogram of the means will be shown:

As expected, the familiar bell-shape of the normal distribution has emerged.



In order to test whether the distribution of the sample means is really normal, we finally plot the data list using the Normal Probability plot (NormProbPlot) feature of the TI-83. We choose Plot1 from STAT PLOT and set to type: **(the symbol for the Normal Probability Plot it is the third symbol on the second row)**. We've readjusted the window with the x range symmetric about the theoretical mean  $\mu = 3.5$  and the y range symmetric about zero.

Since the GRAPH is approximately a straight line, the distribution of data is



approximately normal. For a more sophisticated approach to testing whether a set of data is normally distributed, we recommend the recent article by Maria E. Calzada and Stephen M. Scariono (3).

## CONCLUSION

A graphing calculator is one approach to help the students discover the Central Limit Theorem. This approach can be used in the classroom as an activity with discussion to help the students discover and have a much better understanding of this crucial theorem in probability and statistics.

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## NOTES ON THE LATE SUMMER DIET OF MALE AND FEMALE EASTERN PIPISTRELLES (*PIPISTRELLUS SUBFLAVUS*) AT FORT MOUNTAIN STATE PARK, GEORGIA

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### ABSTRACT

On 21 August 1998, we collected fecal samples from 37 eastern pipistrelles (6 females and 31 males) from an abandoned talc mine at Fort Mountain State Park in Murray Co., Georgia and examined them to determine diet. We also compared the diet between females and males. We detected insect fragments from six insect orders in the fecal samples: Homoptera, Coleoptera, Diptera, Lepidoptera, Hemiptera and Hymenoptera. Female eastern pipistrelles foraged primarily on Homoptera (47.0 ± 14.07%) and Coleoptera (17.5 ± 12.63%), whereas males foraged primarily on Diptera (32.3 ± 17.71%) and Homoptera (18.2 ± 4.81%). Sex-based differences were dramatic at the family level and insect size categories. Cicadellidae comprised 46.7% (± 14.24%) of female eastern pipistrelles' diet but only 18.2% (± 4.81%) of the males' diet. Unidentified small Dipterans comprised 21.3% (± 6.74%) of male eastern pipistrelles' diet, whereas none of these was detected in female fecal samples. Our study provides information that suggests late summer diets of eastern pipistrelles in northwest Georgia are contrary to previous diet studies of other pipistrelle species. Moreover, the diets of female and male eastern pipistrelles may differ during certain seasons or in particular regions of the species' range.

**Key Words:** diet, eastern pipistrelle, Fort Mountain State Park, *Pipistrellus subflavus*

### INTRODUCTION

Few studies have investigated the diet of most bat species (1). However, diet data are available for pipistrelles in general (e.g. *Pipistrellus pipistrellus*; 2), and the eastern pipistrelle in particular (1, 3-8).

One of the first eastern pipistrelle diet studies was by Hamilton in 1930 in Kentucky (3). He noted that the diet consisted of Diptera and Coleoptera (Table I). A few years later, Sherman (4) found fragments of Diptera (specifically the family Anthomyiidae) and Hymenoptera (specifically Formicinae, ants) in an eastern pipistrelle stomach he examined from Florida. Approximately 10 years later, Barbour and Davis (5) reported observing eastern pipistrelles foraging on Lepidoptera that were emerging from a corn crib in eastern Kentucky.

**Table I.** The occurrence of insect orders (Co.=Coleoptera, Di.=Diptera, Ep.=Ephemeroptera, He.=Hemiptera, Ho.=Homoptera, Hy.=Hymenoptera, Le.=Lepidoptera, Tr.=Trichoptera) in eastern pipistrelle diets reported in previous studies. The order that predominated the diet, if reported, is denoted with a D.

Study	Co.	Di.	Ep.	He.	Ho.	Hy.	Le.	Tr.
Hamilton (3; n=6)	X	X						
Sherman (4; n=1)		X				X		
Barbour and Davis (5)*							X	
Whitaker (1; n=23)	X	X			D		X	
Zinn (6; n=1)	X		D					
Carter et al. (7; n=4)	X	X		X		X	D	
Carter et al. (8; n=2)								
female (n=1)				X			X	D
male (n=1)	D			X	X		X	
this study (n=37)								
females (n=6)	X	X			D	X	X	
males (n=31)	X	D		X	X	X	X	

\*Sample size is not applicable. Eastern pipistrelles were observed foraging on moths.

In 1972, Whitaker (1) conducted the only study of eastern pipistrelles' diet that involved examining samples collected from a relatively large number of individuals. From the contents of 23 eastern pipistrelle stomachs, Whitaker found that the diet was mostly Homoptera (specifically cicadellids) and Coleoptera (specifically carabids), followed by small amounts of Diptera and Lepidoptera.

Isolated research on the diet of a total of <10 eastern pipistrelles has been published during the 25 years since the Whitaker (1) study. In 1977, Zinn (6) examined an eastern pipistrelle fecal sample from Florida and determined that the diet was composed of Ephemeroptera (90%) and Coleoptera (10%). In four fecal samples collected on Sapelo Island, Georgia in the summer, Carter et al. (7) found predominately Lepidoptera (74%), but also Hemiptera (12%), Coleoptera (6%), Hymenoptera (4%), and Diptera (4%). Carter et al. (8) also examined the food of a male and female eastern pipistrelle captured at the Savannah River Site in the upper Coastal Plain of South Carolina. The female's diet contained Trichoptera (80%), Hemiptera (10%), and Lepidoptera (10%), whereas the male consumed Coleoptera (40%), Hemiptera (30%), Lepidoptera (15%), and Homoptera (15%; Table I).

A review of eastern pipistrelle food habits suggests the diet can vary greatly (Table I). Although some of this diet variability probably is the result of temporal or spatial differences in foraging, it may indicate that eastern pipistrelles may be able to take advantage of a wide variety of foods when available. Swift et al. has

reported that *Pipistrellus* forage opportunistically, preying on each insect order in roughly the same proportion as available in the environment (2). However, Carter et al. (7) suggested that eastern pipistrelles did not forage opportunistically and found that 66% of the “forageable-sized” insects in the environment consisted of Coleoptera, but only 6% of the eastern pipistrelle diet consisted of insects from this order. Conversely, only 5% of the insects in the environment were Lepidopterans, whereas 74% of the fecal samples examined contained Lepidoptera.

The objectives of this study were (1) to determine the insect orders that occurred in eastern pipistrelle diets in the extreme Southern Appalachians of northwestern Georgia, and (2) to document and compare our results with previous studies of eastern pipistrelle food habits.

## MATERIALS AND METHODS

We conducted our survey at Fort Mountain State Park in Murray Co., Georgia. Fort Mountain State Park is located in the Blue Ridge physiographic subsection of the Southern Appalachians in northwestern Georgia. On 21 August 1998, we placed two harp traps (1 X 1.5 m; 9, 10) over the entrance to an abandoned talc mine at 595 m elevation on the northwest-facing slope of Cohutta Mountain. We also set three mist nets in front of canopy gaps at the mine entrance. We opened harp traps and mist nets at dusk (ca. 2100 hrs.) and closed them at 0200 hrs.

After removing bats from the harp traps and mist nets, we determined sex, species, reproductive condition, and mass. Studies have shown that fecal analysis is a useful method for determining the food habits of bats (11). After each bat was examined and measured, it was placed in a 946-cm<sup>3</sup> plastic cup for 20 mins. Bats were released after 20 mins., regardless of whether a fecal sample had been collected. Of 125 eastern pipistrelles captured, 37 (30%) provided fecal samples.

For food-habits analysis, fecal samples were placed in a petri dish, softened with ethanol, and teased apart with probes and forceps (12). We examined all samples collected from a single individual together using a dissecting microscope. Because of the subjective nature of fecal analysis, one author (JOW) analyzed all fecal samples. We visually estimated percent volume of each insect order in each fecal sample. Because Lepidopterans often were represented only by scales in the fecal samples, we estimated their percent volume in the fecal samples (13).

We compared the proportion of the insect orders in the diets of male and female eastern pipistrelles using a G-squared log-likelihood ratio test (14) before pooling the data from each sex.

## RESULTS

We captured 145 bats including 125 eastern pipistrelles (*Pipistrellus subflavus*, 24 females and 101 males), 8 northern long-eared myotis (*Myotis septentrionalis*, 3 females and 5 males), 7 big brown bats (*Eptesicus fuscus*, 1 female and 6 males), 4 little brown bats (*M. lucifugus*, 1 female and 3 males), and 1 male eastern small-footed myotis (*M. leibii*). Most male bats were reproductively active (15), suggesting that the high level of activity around the mine entrance may have been associated with a late summer/early fall swarm.

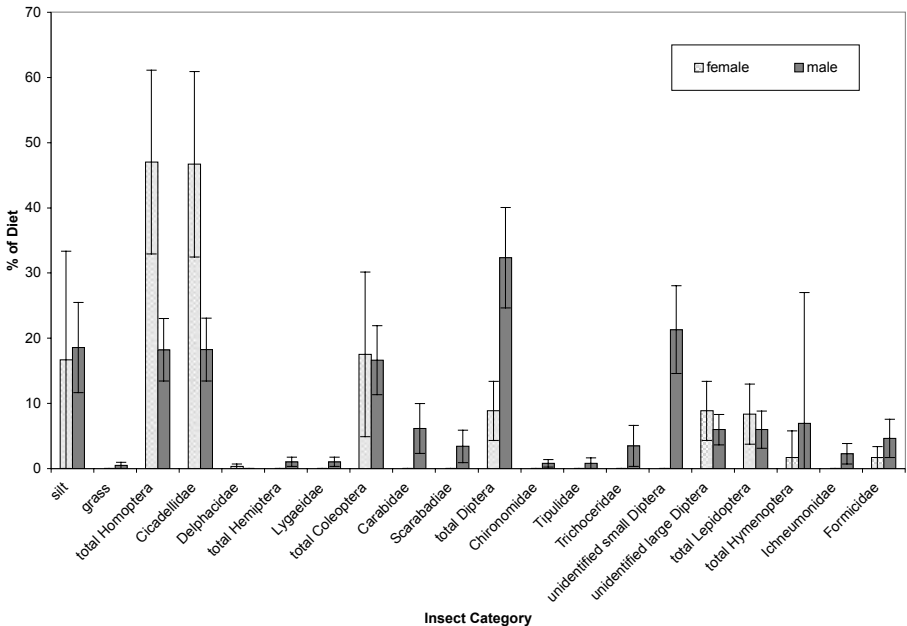
We collected fecal samples from 37 (6 females and 31 males) eastern pipistrelles. Fecal analysis showed that eastern pipistrelles preyed on members of six insect orders: Homoptera, Coleoptera, Diptera, Lepidoptera, Hemiptera and Hymenoptera. The prey of the eastern pipistrelles we captured consisted of two families of Homopterans: Cicadellidae (leafhoppers), Delphacidae (planthoppers); two families of Coleopterans: Carabidae (ground beetles) and Scarabaeidae (scarab beetles); three families of Dipterans: Chironomidae (midges), Tipulidae (crane flies), and Trichoceridae (winter crane flies); two families of Hymenopterans: Ichneumonidae (ichneumons) and Formicidae (ants); and one family of Hemipterans: Lygaeidae (seed bugs; Table II).

**Table II.** A comparison of the percent occurrence of fecal sample contents of male and female eastern pipistrelles (*Pipistrellus subflavus*) captured at a mine entrance in northwest Georgia during late August, 1998.

Diet Component (% Occurrence Female/Male)	Female		Male	
	Mean	SE	Mean	SE
silt	16.7	16.67	18.5	6.93
grass	0.0	0.00	0.5	0.48
total Homoptera (100%/54%)	47.0	14.07	18.2	4.81
Cicadellidae	46.7	14.24	18.2	4.81
Delphacidae	0.3	0.33	0.0	0.00
total Hemiptera (0%/3%)	0.0	0.00	1.0	0.71
Lygaeidae	0.0	0.00	1.0	0.71
total Coleoptera (80%/42%)	17.5	12.63	16.6	5.28
Carabidae	0.0	0.00	6.1	3.84
Scarabadae	0.0	0.00	3.4	2.49
total Diptera (60%/65%)	8.8	4.55	32.3	7.71
Chironomidae	0.0	0.00	0.8	0.57
Tipulidae	0.0	0.00	0.8	0.81
Trichoceridae	0.0	0.00	3.5	3.13
unidentified small Diptera	0.0	0.00	21.3	6.74
unidentified large Diptera	8.8	4.55	6.0	2.34
total Lepidoptera (60%/42%)	8.3	4.59	6.0	2.85
total Hymenoptera (20%/23%)	1.7	4.08	6.9	20.06
Ichneumonidae	0.0	0.00	2.3	1.57
Formicidae	1.7	1.67	4.6	2.93

We were unable to pool the diet data for female and male eastern pipistrelles because G-squared test indicated that the diets differed significantly between sexes ( $df = 5$ ,  $\chi^2 = 32.59$ ,  $P < 0.0001$ ). Differences between female and male diets were most extreme with regard to two insect orders: Homoptera and Diptera (Table II). Almost 50% of female eastern pipistrelles' diet consisted of Homopterans, whereas Homopterans comprised only 18.2% of the males' diet (Table II, Fig. 1). This difference was even more pronounced with respect to a single family of Homopterans, Cicadellidae (Fig. 1). Whereas female eastern pipistrelles fed heavily on Homopterans, males consumed large quantities of Dipterans. A total of 32.2% of male diets consisted of Dipterans, but only 8.8% of female diets did. Although female and male eastern pipistrelles consumed approximately the same relative quantities of members of the Dipteran families Chironomidae, Tipulidae, and Trichoceridae, as well as unidentified large Dipterans, there was a pronounced difference in the proportion of unidentified small Dipterans consumed by female and male eastern pipistrelles (Table II, Fig. 1).

**Figure 1.** A comparison of the diet (mean and standard error bar of each insect order or family) between female and male eastern pipistrelles (*Pipistrellus subflavus*) during late summer at Fort Mountain Park, Murray Co., Georgia.



Diets of female eastern pipistrelles consisted predominantly of Homopterans and Coleopterans (ca. 65%). Dipterans and Lepidopterans comprised lesser components of the females' diet (ca. 17%). Male diets consisted primarily of Dipterans, Homopterans, and Coleopterans (ca. 68%). Males consumed approximately the same relative volume of Lepidopterans as females (6.0 and 8.3%, respectively; Table II). Unlike the diet of female eastern pipistrelles, male diets frequently contained significant quantities of Hymenopteran fragments. Hymenopteran

were rarely consumed by female eastern pipistrelles. A significant amount of silt was found in the fecal pellets of both male and female eastern pipistrelles (18.5 and 16.7%, respectively; Table II). This component of the pipistrelles' diet may possibly come from licking the mine walls for water or minerals.

## DISCUSSION

Our study provides additional information about the diet of eastern pipistrelles and indicates that their diet is diverse in northwestern Georgia. Our results also indicate that the diets of eastern pipistrelles may differ by sex during a single foraging period and that these differences may be related to the insects' size or taxonomic classification.

Our study involved the analysis of approximately the same number of fecal samples as all previous eastern pipistrelle diet studies combined. However, we were unsuccessful in supporting the results of one of the previous studies indicating that Coleoptera, Ephemeroptera, Homoptera, Lepidoptera, or Trichoptera dominates the diet of eastern pipistrelles (Table I). Each of the previous diet studies indicated a different dominant insect order (Table I). Previous studies document eastern pipistrelles foraging on eight insect orders: Coleoptera, Diptera, Ephemeroptera, Hemiptera, Homoptera, Hymenoptera, Lepidoptera, and Trichoptera. Unlike previous research, we found that the diet of female and male eastern pipistrelles predominately consisted of Homopterans and Dipterans, respectively (Table I).

The results of our study, along with a review of all previous eastern pipistrelle diet studies, confirm that the diet of eastern pipistrelles is diverse. Determining food habits through fecal analysis is not an exact science; there is a relatively high number of errors associated with the technique (11). In previous studies of the diet of eastern pipistrelles, the difference between the percentage of the diet comprised of the "dominant" insect order and the percentage of the diet comprised of the next most heavily consumed taxa was <4% (1). Differences of this magnitude could be caused by differential rates of digestion between hard and soft-bodied insects (16) or the error inherent in determining diet through fecal analysis (11).

Because of the relatively high degree of variance associated with fecal analysis, perhaps a better method of determining the insect types that are important diet constituents would be to examine general diet trends among several independent studies. The effect of size involved in each study should be considered when analyzing these trends.

Colepterans, Lepidopterans, Dipterans, and Hemipterans consistently have been identified in the diets of eastern pipistrelles. Although Hymenopterans have been identified in the diets of eastern pipistrelles in previous studies, members of this order have never dominated the diet. Ephemeropterans and Trichopterans are not usual prey items for eastern pipistrelles; however, they dominate the diet when they are found. This indicates that, when present, these orders may be preferred prey items. Alternatively, the abundance of Ephemeropterans and Trichopterans in the diet of eastern pipistrelles may be a factor of the emergent nature of insects in these orders and the propensity of bats to concentrate their foraging activity on areas of high insect density (17).

Unlike previous studies, we found that the diet differed between female and male eastern pipistrelles (2). Sex-based diet differences could have been a result of size differences between the sexes (18-21), or differences in their reproductive state (22).

Factors affecting food partitioning between sympatric bat species, or between sexes of a species, to reduce competition are not well understood. Some potential factors include wing shape, ear shape and size, flight style, echolocation call characteristics, jaw morphology, dental characteristics, and body size (23). Smaller bats might be able to forage on smaller insects more efficiently than larger bats. For instance, males might have fed heavily on Dipterans because their smaller size allowed them to forage more efficiently on smaller insects.

Alternatively, the sex-biased diet may have resulted from differences in the foraging habitats used. Bats may selectively forage on specific insect orders within a habitat; however, differences in foraging habitat selection among species or between sexes probably have much larger influences on the composition of a group's diet (24). We captured male and female bats in the same location. However, if the bats captured were involved in a late summer swarm, the males may have spent most of their foraging time near the mine entrance in an attempt to mate with females entering and exiting the mine. Accordingly, males could forage only on insects that were present in the area surrounding the mine entrance. Females entering and exiting the mine may have been traveling to other areas away from the mine entrance to forage. Both sexes may have been consuming members of insect orders in proportion with their availability in their respective foraging areas (24).

Our results support the general results of previous studies indicating that larger bat species forage selectively, while smaller species, including pipistrelles, forage opportunistically (2, 13, 25, 26). The differences we observed in the diets of female and male eastern pipistrelles captured at the same mine entrance probably reflect differences in the foraging habitats used by female and male bats during a late summer swarm.

Because the diet of eastern pipistrelles is so diverse, conserving food resources for this species should not be difficult. Although land-use changes that decrease the abundance of "forageable sized" Coleopterans, Dipterans, Homopterans, or Lepidopterans may affect the diet of eastern pipistrelles, the species probably would be able to simply increase the foraging pressure on other orders. However, changes that simultaneously decreased the abundance of insects in all four orders may have a significant negative impact on eastern pipistrelle foraging efficiency.

**Appendix I.** The late summer diets of five bat species at Fort Mountain State Park, Murray Co., Georgia (PISU = eastern pipistrelle, EPFU = big brown bat, MYSE = northern long-eared myotis, MYLE = small-footed myotis, MYLU= little brown bat). Number indicates percent occurrence in fecal pellets.

Diet Item	PISU (n=37)		EPFU (n=2)		MYSE (n=3)		MYLE	
	$\bar{x}$	SE	$\bar{x}$	SE	$\bar{x}$	SE	$\bar{x}$	$\bar{x}$
MYLU								
silt	18.2	6.31	0.0	0.00	0.0	0.00	0.0	0.0
grass	0.4	0.41	0.0	0.00	0.0	0.00	0.0	0.0
Homoptera								
Cicadellidae	22.8	4.87	0.0	0.00	0.0	0.00	0.0	0.0
Delphacidae	0.1	0.05	0.0	0.00	0.0	0.00	0.0	0.0
Hemiptera								
unident. Hemiptera	0.3	0.27	0.0	0.00	0.0	0.00	0.0	0.0
Lygaeidae	0.5	0.54	0.0	0.00	0.0	0.00	0.0	0.0
Pentatomidae	0.0	0.00	22.5	17.50	0.0	0.00	0.0	0.0
Coleoptera								
unident. Coleoptera	8.8	3.41	0.0	0.00	1.7	1.67	2.0	0.0
Carabidae	5.1	3.23	70.0	25.00	0.0	0.00	0.0	0.0
Scarabidae	2.8	2.09	7.0	7.00	0.0	0.00	0.0	0.0
Diptera								
Chironomidae	0.7	0.48	0.0	0.00	0.0	0.00	0.0	65.0
Chironomidae pupae	0.0	0.00	0.0	0.00	0.0	0.00	0.0	30.0
Tipulidae	0.7	0.68	0.0	0.00	21.7	21.67	0.0	0.0
Trichoceridae	2.9	2.63	0.0	0.00	0.0	0.00	95.0	0.0
unident. small Diptera	17.8	5.78	0.0	0.00	0.0	0.00	0.0	5.0
unident. large Diptera	6.4	2.07	0.5	0.50	10.0	10.00	3.0	0.0
Lepidoptera	6.4	2.48	0.0	0.00	8.3	8.33	0.0	0.0
Hymenoptera								
Ichneumonidae	1.9	1.32	0.0	0.00	0.0	0.00	0.0	0.0
Formicidae	4.1	2.47	0.0	0.00	0.0	0.00	0.0	0.0
Orthoptera								
Gryllidae	0.0	0.00	0.0	0.00	58.3	30.05	0.0	0.0

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