ONLINE INQUIRY & INVESTIGATION

An Identification Key to Rodent Prey in Owl Pellets

from the Northwestern & Southeastern United States: Employing Incisor Size To Distinguish Among Genera

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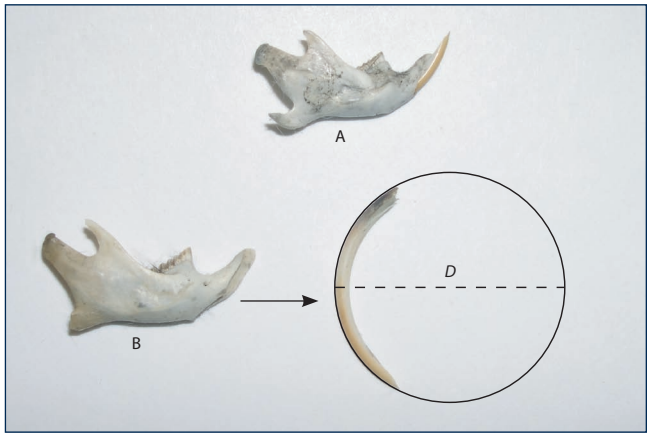
Owl pellet dissection is a common laboratory exercise in science classes. The contents of owl pellets are used to study and address broad ecological issues related to owl biology, such as diet, prey distribution and abundance, food webs, and conservation. The large owls of North America, such as the Barn Owl (*Tyto alba*) and Great Horned Owl (*Bubo virginianus*), are known to consume mostly vertebrates (Johnsgard, 2002) and invertebrates to a lesser extent. Owls are limited in what they can digest and thus bone, hair, feathers, and chitinous exoskeletons from arthropods are regurgitated in the form of oval-shaped pellets (Proctor & Lynch, 1993). The bony tissue in a pellet can be used to identify the vertebrates consumed, which include amphibians, reptiles, birds, and mammals.

Mammals are usually the most abundant prey of large owls. Moles and shrews can be taken in large numbers, but small- and medium-sized rodents, such as gophers, voles, mice, and rats, are very common in owl pellets. Traditional identification of rodent prey involves using guides that emphasize particular skull characteristics (Hall, 1981; Ingles, 1965; Maser & Storm, 1970; Glass, 1973; Roest, 1986).

Akersten (1981) and Weintraub and Shockley (1980) described methods for rodent identification by concentrating on isolated incisors. These teeth are long and curved and can be assumed to have an arc of a circle. Generally, incisor size is species-specific and shows a positive relationship between the arc of the tooth and size of the rodent. A perfectly constant arc, however, is not possible since the incisor curvature occurs along two planes resulting in an incomplete helix (Landry, 1957). As shown in Figure 1, an incisor arc can be extrapolated to form a full circle whose diameter can also be mea-

Figure 1. A) Lateral view of right mandible from *Microtus* with incisor in socket. B) Lateral view of right mandible from *Microtus* with incisor extracted from socket. Incisor arc diameter (D) can be measured by fitting the outer edge of an extracted tooth (in lateral view) to the inner edge of a circle from a circle template.



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sured (referred to as "incisor arc diameter"). Weintraub and Shockley (1980) quantified incisor arc diameter for rodents of the Southern California region using a circle template. Similar to Akersten (1981), the outer edge of a complete incisor (in lateral view) is fit to a particular circle. Both methods effectively identified the rodents examined. Moreover, application of the method in Weintraub and Shockley (1980) reduced handling time by approximately 11 minutes per specimen and increased identification accuracy from 75% to near 90% relative to the more traditional identification guides described previously.

In this article we describe an identification key to the rodent prey found in owl pellets that emphasizes differences in incisor arc diameter among rodent genera. It contains several notable features that will enhance laboratory exercises employing owl pellet dissections:

- specificity to the northwestern and southeastern United States, two regions of the country from which owl pellets are collected for and sold by biological supply companies
- highlights a little known, yet interesting feature—incisor morphology—that can be used to identify rodent prey
- provides detailed illustrations of important cranial and mandibular features to augment rodent identification using incisor sizes
- supplies required to use the key are inexpensive
- promotes diligent data collection by encouraging student accuracy when making measurements of tooth size
- bolsters students' graphing skills
- introduces students to a relatively unknown measuring tool—a circle template—that can be used to quantify biological traits
- includes a data sheet to organize the results of prey identification
- can fit into an existing laboratory that focuses on owl pellet dissection.

Development & Evaluation of the Key

We built the identification key using digital pictures of upper and lower incisors from various species that occur in the Northwest and Southeast. The preferred method for developing an identification key based on incisor arc diameter would be the method used by Weintraub and Shockley (1980). They began by identifying rodents from owl pellets using tooth and skull features. After identification, incisors were extracted and measured using a template containing multiple circles of known diameter. This allowed for an association between incisor size and rodent genus. However, the samples we needed to replicate this method were only available in the form of museum specimens. Incisor extraction from museum-prepared specimens is very difficult and usually damages the teeth and bones housing the teeth. Consequently, we estimated the size of incisors from known species captured in digital images so it would not prove destructive to invaluable museum specimens.

Preliminary Experiments

We conducted two pilot studies to test the effectiveness and accuracy of electronically estimating arc diameter of upper and lower incisors. In the first study we compared the values of electronically measured circles from a circle template to actual circle sizes listed on the template. Adobe® Photoshop® was used to complete electronic measurements from digital images of circles. The difference between the estimated (electronic) and actual values was not significant (t = 0.011, P = 0.504).

The second experiment evaluated more directly the accuracy of electronically quantifying rodent incisors. Using Photoshop® and digital images, we compared the electronic measurements of intact incisors—found within the tooth sockets—to measurements of the same incisors that were extracted and fitted to a circle of known diameter in a circle template. (Owls generally digest the connective tissue holding teeth within their sockets. Unlike most museum specimens, incisors found within owl pellets can usually be extracted relatively easily without damaging bones and teeth.) The difference between the values for intact and extracted incisors was not significant (t = 0.22, P = 0.83). These results suggested that electronically estimating the size of upper and lower incisors is accurate. Moreover, these estimates could be used to make an identification key to the rodent prey found in owl pellets since incisor size has the potential to vary with the size of different genera.

Construction of the Key

We identified 15 rodent species from which to digitally quantify incisor arc diameter. Northwestern species included the Northern pocket gopher (*Thomomys talpoides*), Great Basin pocket mouse (*Perognathus parvus*), Heermann's kangaroo rat (*Dipodomys heermanni*), Western harvest mouse (*Reithrodontomys megalotis*), deer mouse (*Peromyscus maniculatus*), dusky-footed woodrat (*Neotoma fuscipes*), montane vole (*Microtus montanus*), Townsend's vole (*Microtus townsendii*), Norway rat (*Rattus norvegicus*), and house mouse (*Mus musculus*). Southeastern species included the fulvous harvest mouse (*Reithrodontomys fulvescens*), white-footed mouse (*Peromyscus leucopus*), rice rat (*Oryzomys palustris*), hispid cotton rat (*Sigmodon hispidus*), pine vole (*Microtus pinetorum*), Norway rat (*Rattus norvegicus*), and house mouse (*Mus musculus*). This list was constructed using the following criteria:

1. Species was cited in at least one previously-published study reporting the results of owl pellet dissections from the Northwest and Southeast.
2. Species was reported to constitute a large percentage of total rodent prey in owl pellets.
3. Species of the same genus, i.e., *Microtus*, were used only when the literature suggested that there were appreciable size differences among species.
4. Included as many species as possible in the key (Burt & Grossenheider, 1980; op. cit. Campbell et al., 1987; op. cit. Key, 1995; op. cit. Lyman et al., 2001; op. cit. Johnsgard, 2002).

These criteria allowed us to assemble a useful and comprehensive list of species whose presence has a high probability of being represented in owl pellets from the Northwest

and Southeast. We expect taxa not included in our key will occasionally be present in pellets, such as *Zapus* from the Northwest and *Geomys* from the Southeast. Indeed, the literature reported 37 rodent species (within 25 genera) in owl pellets from these two regions (Ibid.). However, adding just a few uncommon species whose predicted incisor size overlapped with the more common taxa had the potential to dilute the effectiveness of the key.

All rodent specimens used to develop the identification key came from the National Museum of Natural History, Washington, DC (contact first author for a list of specimens examined). We used a minimum of 18 adult individuals, split equally between males and females, that were collected from Oregon and Washington in the Northwest and Louisiana and east Texas in the Southeast. Owl pellet material sold by biological supply companies was collected from these locations (Carolina Biological Supply Company, personal communication; Nasco, personal communication; Ward's Natural Science, personal communication). A total of 595 incisors was measured *in situ* from digital images (360 Northwest; 235 Southeast). The method for estimating incisor arc diameter was similar to the method used in the second preliminary experiment described previously, except that incisors were not extracted. One of us took the digital images (first author) and the other measured tooth sizes from only the right teeth (second author).

The key utilizes genera instead of species since in both regions there may be species of the same genus of similar size that, although not analyzed, may still be found in an owl pellet. In addition, we combined the data for *Microtus montanus* and *M. townsendii* to maintain consistency in the key's format and focus on genera. Most upper and lower incisors came from the same specimen. Although we had access to enough specimens for each species, those for the Norway rat were not used. The museum specimens for this species were adult size, and it is known that adult Norway rats are too large and not taken by owls (Cowan, 1942). Thus, including them in our key would have overestimated tooth sizes. Instead, we chose to include the incisor sizes for juvenile Norway rats that were measured by Weintraub and Shockley (1980). We believe these measurements are valid for our study since there is little geographic variation in the body size of this species across the United States (R. Fisher, personal communication).

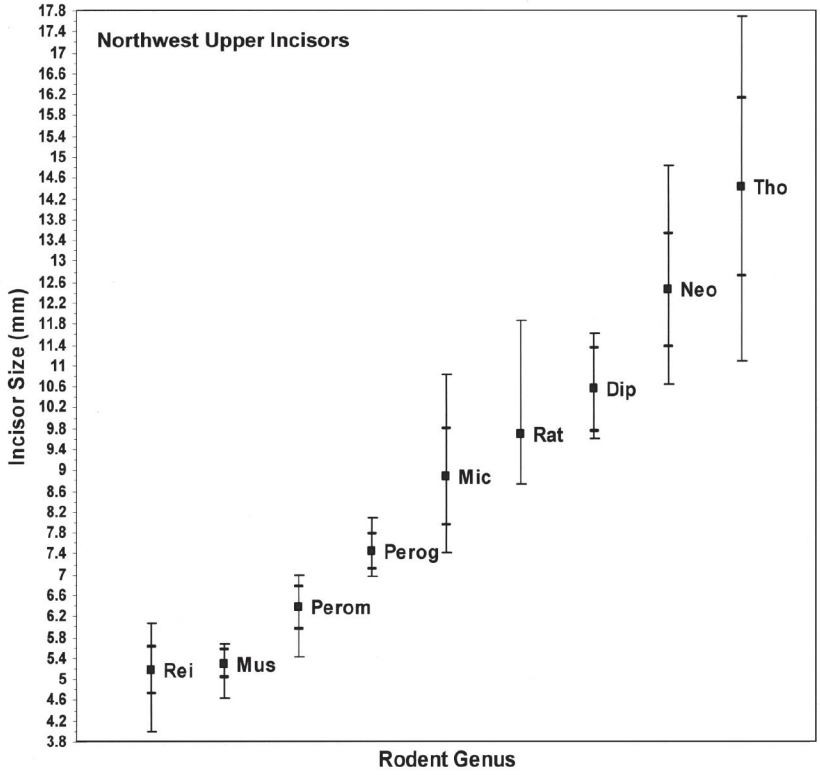
We present the identification key in graphical format. Normality for incisor arc diameter was assessed for each genus using the Shapiro and Wilk test (Zar, 1984). *Rattus* was not used in this analysis since sample size was low (N = 5; Weintraub & Shockley, 1980). Descriptive statistics, including the mean (±1 SD) and range, were used to illustrate the data. We argue that these yield the most information in the context of the key and allow users to identify most readily the genera of teeth. Statistics aimed at evaluating differences in incisor size distributions among genera and between locations were not completed.

Incisor sizes for each rodent genus were distributed normally, with the exception of the lower teeth for *Reithrodontomys* from the Northwest. We plotted for each genus the mean (±1 SD) and range of each incisor size (Figures 2-5), including *Reithrodontomys* from the Northwest to maintain consistency.

Evaluation of the Key

Students in a college-level zoology class dissected 49 and 45 pellets (purchased from a biological supply company) from the Northwest and Southeast, respectively. Upper and lower incisors extracted from these pellets were measured using a Timely Small Increment Circles Template, No. T-89. Only one tooth from the cranium was used in this measurement. Students measured each lower incisor found in the pellet since

Figure 2. Upper incisor sizes (diameters; mm) for Northwestern rodent genera. Solid squares represent means, inside brackets ±1 SD (except in *Rattus*), and ranges shown by outer brackets.



Legend (includes other unique cranial features; see Figure 6 for illustrations of most of these features; all have 3 cheek teeth unless otherwise noted)

Rei = *Reithrodontomys*: anterior surface of incisors grooved

Mus = *Mus*: incisors notched in lateral view; incisive foramina extend beyond 1st cheek teeth

Perom = *Peromyscus*: incisive foramina end before or even with 1st cheek teeth

Perog= *Perognathus*: 4 cheek teeth; anterior surface of incisors grooved

Mic = *Microtus*: molars continuous and flat-crowned; each molar a series of interlocking triangles

Rat = *Rattus*: 1st molar has five roots

Dip = *Dipodomys*: 4 cheek teeth; anterior surface of incisors grooved; large auditory bullae

Neo = *Neotoma*: 1st molar has two roots

Tho = *Thomomys*: 4 cheek teeth; anterior surface of incisors with shallow groove toward medial edge of tooth

it is common to find mandibles that are unpaired and disassociated from their cranium.

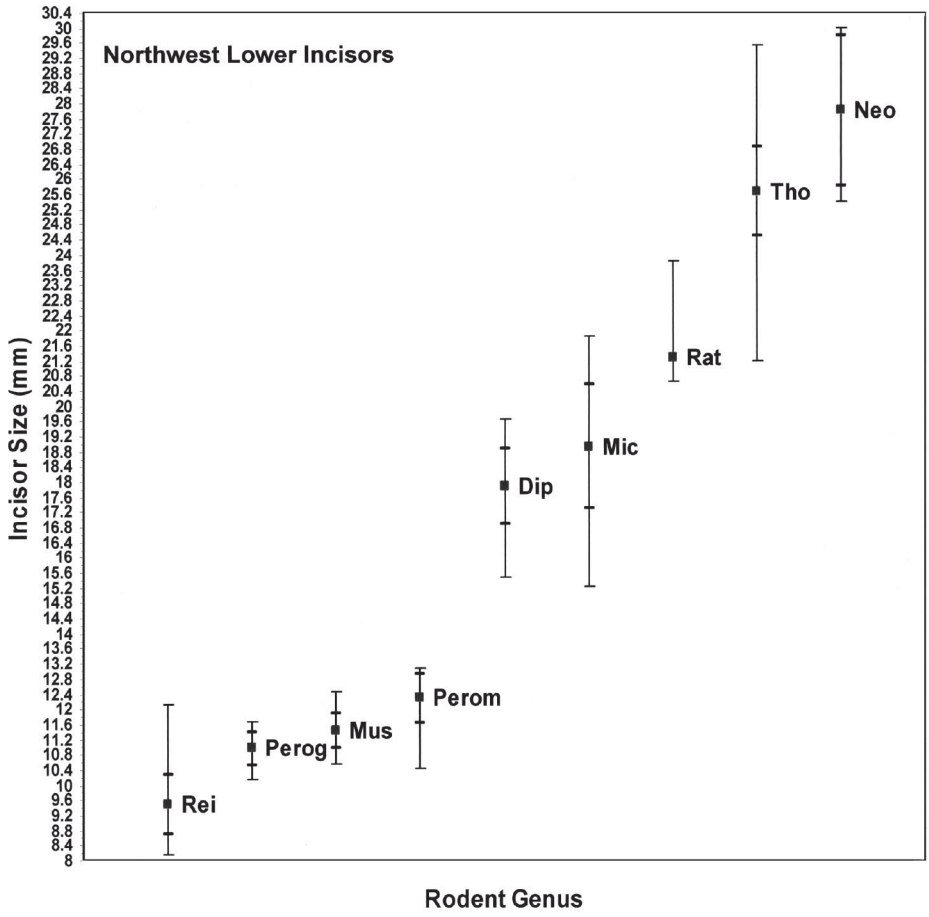
Using our key, students employed incisor arc diameter to identify rodent genera. We verified the accuracy of tooth size measurements by having students measure each incisor in our presence. We also checked their identification against genera-specific skull characters exclusive of incisor arc diameter. Any misidentifications were corrected.

To understand the accuracy of rodent identification by students we evaluated percent fit, which is the ratio of the number of teeth that correctly corresponded to the actual genus to the total number of teeth examined for that genus. For all non-matches, we also calculated the difference between the size range of a tooth identified for a particular genus and the tooth's measurement. For teeth measured above the high value of the range of a genus, we subtracted the tooth measurement from the high value. If a tooth measured below the range of a genus, we subtracted the low value of the range from the tooth measurement.

Using our key, students correctly identified 88.7% of the incisors examined from owl pellets (Table 1). The fit was better for the Northwest (90.4%) than the Southeast (85.4%). Of the 63 teeth that did not fit the key, 92% measured below the reported ranges for incisor arc diameter. Moreover, all northwestern *Microtus* and all southeastern *Reithrodontomys* measured below the range identified in Figures 2-5. Despite this, the average difference was < 1mm. Genera included in the key but not observed during the pellet dissection were *Rattus* and *Neotoma* for the Northwest and *Peromyscus* for the Southeast. Additionally, we failed to find rodent taxa that were not included in the key.

Results from the zoology class owl pellet dissection show that our key accurately identifies the genera of rodent prey. Moreover, the genera included in the key are diverse enough to allow students to identify the majority of the specimens dissected from pellets. Most of the 63 teeth for which there was no fit measured lower than the size reported in our key. We anticipated that not all of the student-measured teeth would result in a positive identification because of variation in the sizes of individuals taken by owls. Owls are known to take juveniles and/or subadults (Fitch, 1947; Dawe et al., 1978; Maser et al., 1980; Lyman et al., 2001), which helps explain why most of the teeth measured below the reported size range in our key. Alternatively, we may have inadvertently selected large specimens from the museum collection from which to evaluate.

Figure 3. Lower incisor sizes (diameters; mm) for Northwestern rodent genera. Solid squares represent means, inside brackets ±1 SD (except in *Rattus*), and ranges shown by outer brackets.



Legend (includes other unique mandibular features; see Figure 7 for illustrations of most of these features; all have 3 cheek teeth unless otherwise noted)

Rei = *Reithrodontomys*: <12 mm from base of incisors to condyloid; 1st, 2nd, and part of 3rd molars visible from lateral view; condyloid roughly even with coronoid; molars relatively flat crowned

Perog= *Perognathus*: 4 cheek teeth; large angular extending up to condyloid

Mus = *Mus*: <12 mm from base of incisors to condyloid; 1st and part of 2nd molars visible from lateral view; condyloid lower than coronoid; molars with cone shaped crowns

Perom = *Peromyscus*: >12 mm from base of incisors to condyloid; 1st, 2nd, and part of 3rd molars visible from lateral view; condyloid slightly higher than coronoid

Dip = *Dipodomys*: 4 cheek teeth; large angular extending up to condyloid

Mic = *Microtus*: molars continuous and flat-crowned; each molar a series of interlocking triangles (see Figure 6)

Rat = *Rattus*: 1st molar has five roots; length of lower jaw (including incisor) >22 mm

Tho = *Thomomys*: 4 cheek teeth

Neo = *Neotoma*: 1st molar has two roots

Application of the Key in the Classroom

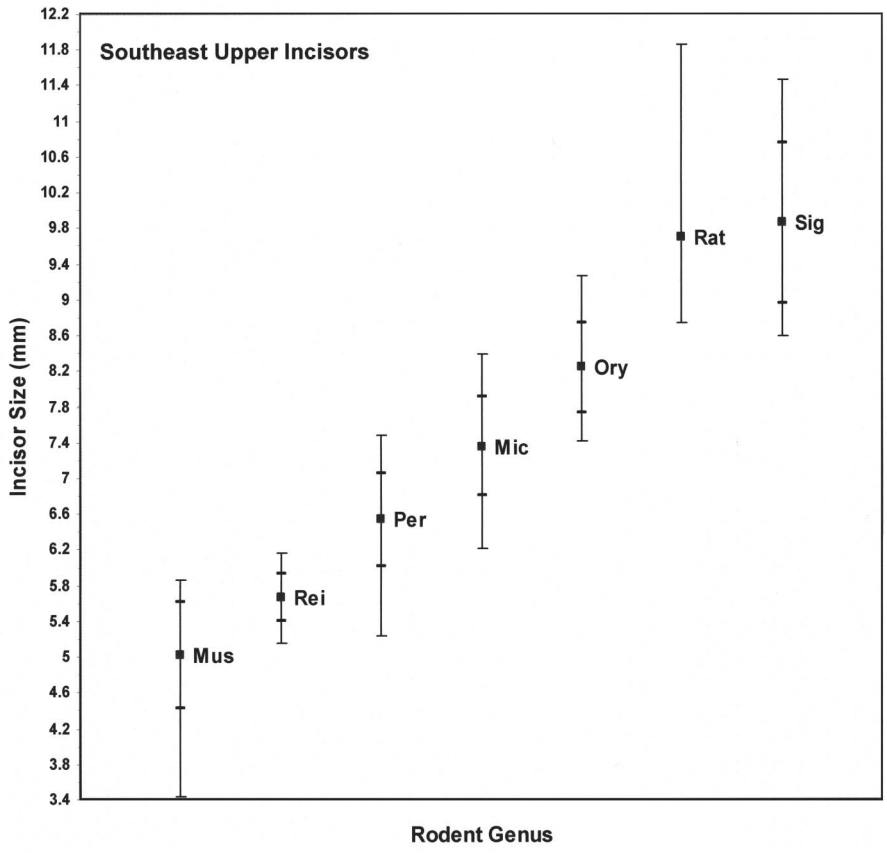
Users of the key will have to purchase a plastic circle template from an art or graphics supply store. We recommend purchasing templates with circle sizes identified in millimeters. If circles of a template are only measured in inches, the user will have to make the proper conversion (25.4 mm = 1 inch) in order to use our key. Templates should have as many circles as possible within the range of approximately 3.175 mm (0.125 inches) to 31.75 mm (1.25 inches).

After dissecting an owl pellet, have students organize the contents by segregating rodent crania and mandibles away from other material. Begin by pulling with either forceps or fingers an incisor out of its socket using small arc-shaped movements to accommodate the tooth's shape.

Once extracted, the outer curvature of a rodent incisor can be fitted to the inner curvature of an appropriate circle on a circle template (see Figure 1). This is not difficult to do, but we recommend inserting the tooth into several circles that closely match the arc of a particular tooth. Choose the circle that is the best fit for the tooth. The value of that circle, as shown on the template, is used to draw a horizontal line across the graph from the Y-axis (Figures 2-5). Draw the line long enough so that it intersects vertically with the range of a particular genus. Lines that intersect the standard deviation of a genus have a higher probability of an accurate identification. It is possible that a match between an incisor and its respective genus based on our key will not occur for reasons described earlier in this paper. In these cases, and in general, we encourage users of our key to employ other genera-specific skull and tooth features, as illustrated in Figures 6 and 7, to assist in identifying rodent prey in pellets.

After identification, include the measurement value and rodent genus on the horizontal line drawn on the graph. Place this tooth and associated cranium or mandible in a safe location in the event it needs to be re-examined. To avoid mixing up incisors, we recommend extracting, measuring, and identifying teeth one at a time. We have found that a given owl pellet can contain 15 small mandibles and several crania. It is therefore important that all skull material be carefully examined and neatly organized on classroom bench tops.

Figure 4. Upper incisor sizes (diameters; mm) for Southeastern rodent genera. Solid squares represent means, inside brackets ±1 SD (except in *Rattus*), and ranges shown by outer brackets.



Legend (includes other unique cranial features; see Figure 6 for illustrations of most of these features)

Mus = *Mus*: incisors notched in lateral view; incisive foramina extend beyond 1st cheek teeth
Rei = *Reithrodontomys*: anterior surface of incisors grooved
Per = *Peromyscus*: incisive foramina ending before or even with 1st cheek teeth
Mic = *Microtus*: molars continuous and flat-crowned; each molar a series of interlocking triangles
Ory = *Oryzomys*: posterior edge of palate (bony plate between cheek teeth) ending beyond last cheek teeth
Rat = *Rattus*: 1st molar has five roots
Sig = *Sigmodon*: molars with flattened "S" shaped crown; posterior edge of palate (bony plate between cheek teeth) ending even with or slightly beyond last cheek teeth

Suggestions for Data Management

Have students create their own data sheet that lists incisor sizes and prey type for all teeth measured. This information can be used to arrange the results of prey identification according to the number of individual prey taken (Table 2). Assigning these numbers can be somewhat tricky since one may find in a pellet various numbers of crania and mandibles for a genus. Consider that each individual rodent had one cranium and two mandibles before it was eaten by an owl. Given this, three mandibles from *Mus* in a pellet would be equal to two individuals. Two crania and one mandible suggest that two individuals were consumed. Note that Table 2 also contains space for moles, shrews, bats, birds, small reptiles, insects, and crayfish found in owl pellets. Lastly, care must be taken to ensure that owl pellets correspond to the geographic location from which they were collected. We have occasionally

found that pellets purchased from biological supply companies are misidentified in that pellets labeled as coming from the Southeast had prey that only occurs in the Northwest, and vice versa.

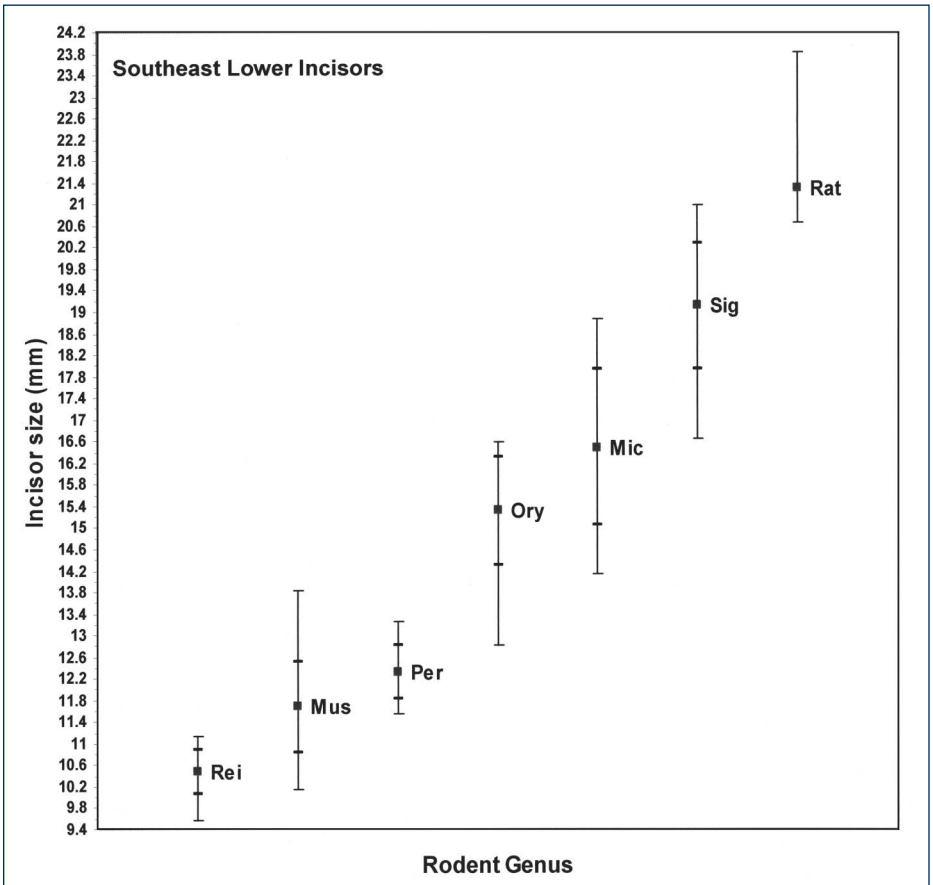
Using individual and class totals from Table 2 students can:

1. compare the diversity of prey type within and between the Northwest and Southeast
2. calculate and analyze biomass for each species and for each region
3. make food webs
4. address questions related to owl and small mammal ecology and conservation biology
5. study variation present in biological characters (incisor arc diameter), a necessary condition for natural selection.

Supplies Needed

- owl pellets from the Northwest and Southeast
- dissecting utensils: forceps and dissection needles
- circle templates
- rulers
- glass bowls filled with warm water to soften highly compacted owl pellets
- Ziploc® sandwich bags and permanent markers to temporarily store owl pellet material in the process of dissection.

Figure 5. Lower incisor sizes (diameters; mm) for Southeastern rodent genera. Solid squares represent means, inside brackets ±1 SD (except in *Rattus*), and ranges shown by outer brackets.



Legend (includes other unique mandibular features; see Figure 7 for illustrations of most of these features)

Rei = *Reithrodontomys*: <12 mm from base of incisors to condyloid; 1st, 2nd, and part of 3rd molars visible from lateral view; condyloid roughly even with coronoid; molars relatively flat crowned

Mus = *Mus*: <12 mm from base of incisors to condyloid; 1st and part of 2nd molars visible from lateral view; condyloid slightly lower than coronoid; molars with cone shaped crowns

Per = *Peromyscus*: >12 mm from base of incisors to condyloid; 1st, 2nd, and part of 3rd molars visible from lateral view; condyloid slightly higher than coronoid

Ory = *Oryzomys*: side view of mandibular arch appears circular to oblong; molars with cone shaped crowns

Mic = *Microtus*: molars continuous and flat-crowned; each molar a series of interlocking triangles (see Fig. 6)

Sig = *Sigmodon*: molars with flattened "S" shaped crown (see Fig. 6); molars relatively flat crowned; side view of mandibular arch generally circular, but tends to have a straight edge toward bottom and rear

Rat = *Rattus*: 1st molar has five roots; length of lower jaw (including incisor) >22 mm

Acknowledgments

We thank Joel Weintraub, Sandy Whidden, and Kelly McKay for comments on early drafts of the paper. Robert Fisher, Collections Manager, North American Mammals, provided valuable assistance during our visit to the National Museum of Natural History. Lance Mayer helped early in the study with the literature search. Deanna Rybak kindly illustrated skull features shown in Figures 6 and 7. Taylor Hager managed data input while at the National Museum. We are grateful to the students in the Fall and Winter 2004 General Zoology classes at Augustana College for their assistance in evaluating the key. The Augustana Research Foundation provided funding through the Hill-Erickson Award (to the second author) and Faculty Summer Stipend (to the first author). A Faculty Research Award from the Administration of Augustana College provided further funding to the first author.

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Table 1. Correspondence between student incisor measurements from owl pellet dissection and incisor arc diameter identified in the key. Data are for upper and lower incisors taken from Northwestern and Southeastern pellets.

LOCATION/TOOTH	# PELLETS DISSECTED	GENERA	# FIT	LACK OF FIT	TOTAL TEETH	% FIT
Northwest Upper Incisors	49	*Thomomys*	13	1	14	92.9
		Dipodomys	1	0	1	100
		Perognathus	1	0	1	100
		Microtus	71	10	81	87.7
		Peromyscus	13	0	13	100
		Mus	2	0	2	100
		Reithrodontomys	4	0	4	100
Northwest Lower Incisors		*Thomomys*	20	0	20	100
		Dipodomys	3	0	3	100
		Microtus	169	22	191	88.5
		Peromyscus	23	2	25	92.0
		Mus	3	0	3	100
		Reithrodontomys	7	0	7	100
Totals			330	35	365	90.4*
Southeast Upper Incisors	45	*Sigmodon*	29	5	34	85.3
		Oryzomys	7	0	7	100
		Rattus	1	0	1	100
		Microtus	4	1	5	80
		Mus	11	0	11	100
		Reithrodontomys	0	6	6	0
Southeast Lower Incisors		*Sigmodon*	56	6	62	90.3
		Oryzomys	16	1	17	94.1
		Rattus	1	0	1	100
		Microtus	11	0	11	100
		Mus	28	0	28	100
		Reithrodontomys	0	9	9	0
Totals			164	28	192	85.4*
Combined totals			494	63	557	88.7*

*represent means

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Figure 6. Cranial characteristics for selected rodent genera.

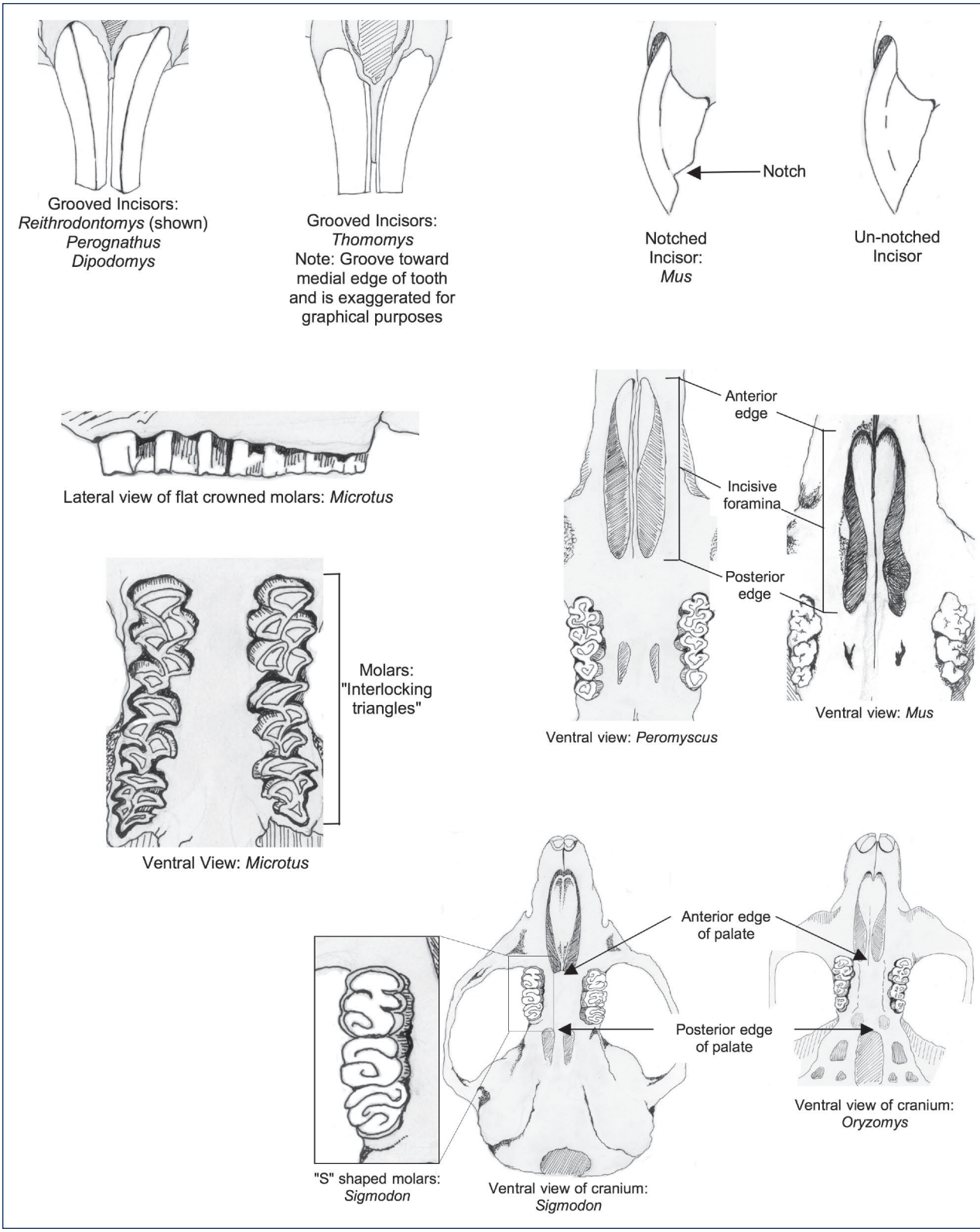

Figure 7. Mandibular characteristics for selected rodent genera.

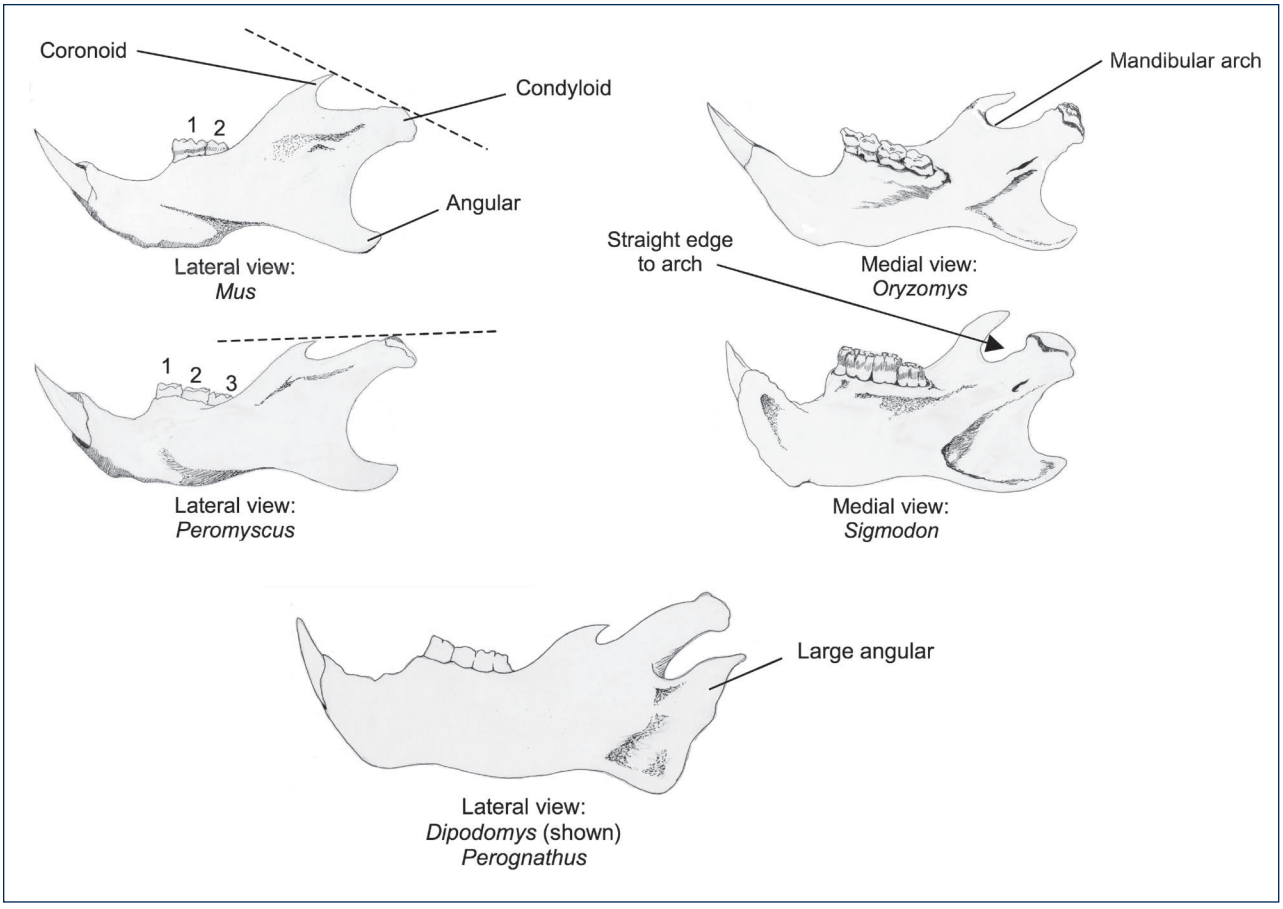

Table 2. Data sheet for the results of dissections using owl pellets from the Northwest and Southeast (modified from Tietjen, 2004). The number of solid circles (•) represents the predicted frequency of occurrence in a pellet for each prey type: •••• Very common; ••• Common; •• Occasional; • Rare; — Does not occur. Note that rodents are listed as well as moles, shrews, and other prey.

		NORTHWEST PELLETS					SOUTHEAST PELLETS				
Order	**Prey**	Occurrence	Individual Total	Prey wt. (g)	Class Total	Total Biomass	Occurrence	Individual Total	Prey wt. (g)	Class Total	Total Biomass
Rodentia Rodents	Pocket Gopher *Thomomys*	•••		100			—		—		
	Rat										
	Sigmodon	—		—			••••		100		
	Oryzomys	—		—			••		80		
	Rattus	•		200			•		200		
	Dipodomys	••		75			—		—		
	Neotoma	•		250			—		—		
	Vole *Microtus*	••••		60			••••		30		
	Mice										
	Peromyscus	•••		30			••		25		
	Mus	••		18			••		18		
	Reithrodontomys	•••		12			••		20		
	Perognathus	••		25			•		25		
Insectivora Insectivores	Mole										
	Scapanus	•		120			—		—		
	Scalopus	—		—			•		100		
	Shrew										
	Blarina	—		—			••		20		
	Cryptotis	—		—			••		6		
	Sorex	••		8			•		5		
Other Prey	Bats	•		7			•		7		
	Birds	••		15			••		15		
	Insects	•		1			•		1		
	Crayfish	•		5			•		5		
	Small Reptiles	•		20			•		20		
	Others										
Totals											