How Many Squirrels Are in the Shrubs? A Lesson Plan for Comparing Methods for Population Estimation

Johanna Varner[1]*, Hayley C. Lanier[2], Jennifer M. Duggan[3], Laurie Dizney[4], Elizabeth A. Flaherty[5], Patrice K. Connors[1], Liesl P. Erb[6], Christopher J. Yahnke[7], and John D. Hanson[8]

[1]Department of Biological Sciences, Colorado Mesa University

[2] Sam Noble Museum and Department of Biology, University of Oklahoma

[3]Department of Applied Environmental Science, California State University, Monterey Bay

[4]Department of Biology, University of Portland

[5]Department of Forestry and Natural Resources, Purdue University

[6]Department of Conservation Biology and Environmental Studies, Warren Wilson College

[7]Department of Wildlife Ecology, University of Wisconsin – Stevens Point

[8]Institute for Biodiversity Research and Education

Abstract

Estimating the population sizes of animals is a key skill for any student interested in ecology, conservation, or management. However, counting animals in natural habitats is difficult, and the many techniques that exist each rely on assumptions that can bias results. Most wildlife courses teach one or two of these methods, but rarely are students given an opportunity to compare approaches and explore how underlying assumptions affect the accuracy of estimates. Here, we describe a hands-on activity in which students estimate the size of a single population of animals using multiple methods: strip censuses, scat counts, and camera traps. They then compare the estimates and evaluate how the assumptions of each model (e.g., random use of habitats and animal behavior) bias the results. Finally, students submit their data to a national database that aggregates observations across multiple institutions as part of Squirrel-Net (http://squirrel-net.org). They can then analyze the national dataset, permitting exploration of these questions across a broader variety of habitats and species than would be possible at any single institution. Extensions of this activity guide students to enumerate the advantages and disadvantages of each method in different contexts and to select the most appropriate method for a given scenario. This activity and the database focus on estimating population sizes of squirrels, which are diurnal, charismatic, easily identified, and present in a wide range of habitats (including many campuses), but the same methods could be broadly used for other terrestrial species, including birds, amphibians, reptiles, or invertebrates.

Citation: Varner J, Lanier HC, Duggan JM, Dizney L, Flaherty EA, Connors PK, Erb LP, Yahnke CJ, Hanson JD. 2020. How many squirrels are in the shrubs? A lesson plan for comparing methods for population estimation. *CourseSource*. https://doi.org/10.24918/cs.2020.6

Editor: Justin Shaffer, Colorado School of Mines

Received: 9/22/2019; **Accepted:** 11/12/2019; **Published:** 9/14/2020

Conflict of Interest and Funding Statement: JV has been supported by the Colorado Mesa University Faculty Professional Development Fund. JV, PKC, and JMD were supported by the 2019 CourseSource Writing Studio. Support for EAF was provided by the USDA National Institute of Food and Agriculture, Hatch Project 1019737. This material is based upon work supported by the National Science Foundation under a collaborative grant (Nos. 2013483, 2013281, 2013308, and 2013320). None of the authors has a financial, personal, or professional conflict of interest related to this work.

Supporting Materials: S1. How many squirrels – List of helpful resources in identifying field sites; S2. How many squirrels – Instructor preparation resources; S3. How many squirrels – Student protocol and datasheet for strip censuses; S4. How many squirrels – Student protocol and datasheet for scat counts; S5. How many squirrels – Student protocol and datasheet for camera trapping; S6. How many squirrels – Master datasheet and upload instructions for national dataset; S7. How many squirrels – Assessment and reflection questions; S8. How many squirrels – Lab report writeup instructions; and S9. How many squirrels – Mark-recapture methods extension.

***Correspondence to:** 1100 North Avenue, Grand Junction, CO 81501. Email: jvarner@colroadomesa.edu.

Learning Goal(s)

- Describe how ecologists and wildlife managers estimate population sizes for animal species.
- Provide a rationale for selecting the most appropriate method for censusing populations, given the species' natural history and the structure of the habitat.
- Compare the assumptions of different population estimation models, and how violations of these assumptions affect the validity of the results.
- Demonstrate science process skills, such as making observations, analyzing data, interpreting results, and communicating results.

Learning Objective(s)

- Census an animal population in the same study area using three different methods.
- Quantitatively compare estimates of population size and/or density generated by each method.
- Articulate the assumptions of each method and explain how violations of these assumptions may bias the results in a given scenario.
- Select the most appropriate method for estimating population size and/or density for a given species and habitat. Justify this choice by explaining why it will produce more reliable data in this scenario than other methods.
- Possible extension: Predict how a given method will perform in a different habitat or for a different species and test this hypothesis by querying a national dataset.

INTRODUCTION

Effective wildlife management depends on obtaining accurate estimates of species population size (1). Specifically, knowing how many animals live in a given area is important for wildlife managers to reliably assess changes (e.g., as a result of human modifications to their habitat), set harvest objectives, and assess the effectiveness of management and/or conservation actions designed to boost rare species' numbers (2). Although counting animals may seem trivial at the outset, it is rarely possible to count every member of an animal population. Such "complete counts" are typically only feasible for large species that occur in open areas at predictable times of year (e.g., seals or birds on breeding beaches or large mammals on open prairie) but are nearly impossible for smaller, more dispersed, or more cryptic species.

In practice, complete counts are typically prohibitively expensive or laborious, and they sometimes disturb the population or the habitat. Instead, most animal population censuses involve incomplete counts and/or indices that use indirect sign (e.g., scat) as a proxy for individuals. These techniques census a part of a population and then extrapolate to the entire population. However, there are many factors that can influence the ability to census part of a population or extrapolate beyond the area studied. These factors include detection probability, observer biases, habitat heterogeneity, and animal behavior (e.g., habitat use, responses to human observers; 1,3). Furthermore, different methods for estimating population sizes depend on fundamental assumptions about the species' distribution in space and behavior, and violations of these assumptions can produce vastly different results for the same population in the same area.

Because of these subtleties, familiarity with basic methods to monitor and estimate population sizes of animals is critical for students wishing to pursue careers in wildlife and/or land management. Specifically, selecting the most appropriate method for monitoring a given species in a given habitat requires a working knowledge of the assumptions and limitations of each method. A variety of published lessons cover aspects of population biology, such as effective population size and genetic diversity (4) or population growth models (e.g., 5, 6). Other resources (e.g., 1, 3, 7) provide useful background on various methods of population estimation but do not provide much guidance for students to try these methods themselves. While there are also resources that provide instructions or lesson plans for students to try a single method (e.g., camera trapping via the eMammal Academy; 8), these resources do not provide students the structured experience of comparing estimates obtained by multiple methods, which may further help them understand the feasibility and limitations of the approaches. Indeed, we have not encountered any lessons that specifically teach students to conduct population censuses using multiple methods, compare results among methods, or consider underlying assumptions that may explain disparate results.

Here, we present a lesson in estimating population sizes of sciurid rodents (i.e., squirrels), which are diurnal, charismatic, easily identified, and available on or near many college campuses (9). In this activity, students practice collecting data about a single population of animals using multiple methods (strip censuses, scat counts, and camera traps), and using these raw data to quantify population size and/or density. They can then compare the results that they obtain with each method and consider how the assumptions of each model (e.g., random use of habitats and animal behavior) may bias the results (1,3). Assessments and extensions of this activity then guide students to enumerate the advantages and disadvantages of each method in different contexts and to select the most appropriate method for a given scenario.

Rationale and Origin of Lesson

Squirrel-Net is a group of nine teacher-scholars that share a common goal to promote authentic course-based research experiences, or CUREs, for undergraduate students. We are mammalogists that hold research and teaching positions at higher educational institutions across the United States, which range from research universities to primarily undergraduate institutions and colleges serving under-served and/or underrepresented populations. Our goals are to create inquiry-based lesson plans that take students out of the classroom and engage them in research on locally relevant and widely distributed mammals, while also collecting data with standardized protocols to test a wide array of ecological questions across spatial and temporal scales.

This lesson is part of the Squirrel-Net module series (http://squirrel-net.org). All of the Squirrel-Net modules are designed for adaptation to diverse educational contexts, from a single two-hour laboratory period (basic skills acquisition) to a semester-long student-driven research project (open inquiry CURE). In each module, students can submit data to a national dataset that aggregates observations from multiple institutions. Students can therefore access and analyze the freely available national database, which allows them to explore the focal questions of the module across a broader variety of habitats and species than would be possible at a single institution. Finally, the four Squirrel-Net modules published in this set (this lesson and 10-12) are designed so that they can be scaffolded into multiple levels in a curriculum, allowing students to return to similar taxa and themes and uniting inquiry across different courses. In the current lesson plan, we describe the most basic implementation of this module (i.e., basic skills acquisition in a single, two-hour laboratory period).

Intended Audience

This lesson was originally developed for upper-division, undergraduates, likely in elective courses in biology, ecology, wildlife management, natural resources, or zoology programs. In the past, it has been taught about halfway through the semester in a mammalogy laboratory course (n = 24 students) for junior- and senior-level biology majors at Colorado Mesa University, an undergraduate-focused, four-year, public institution. Students in this course are extremely diverse in terms of their preparation (i.e., courses taken prior to mammalogy) and their quantitative and research skills. Many of these students come from rural, western Colorado and are interested in pursuing agency careers in wildlife and/or land management (e.g., through Colorado Parks and Wildlife, US Forest Service, Bureau of Land Management). Finally, the lesson could also be adapted for a lower-level course (e.g., Introduction to Ecology, Introduction to Wildlife/Resource Management). We include some suggestions to this effect in the teaching discussion.

Required Learning Time

This lesson was designed for a single two-hour laboratory period; however, it can be easily expanded to cover multiple class periods or taught in combination with any of the other Squirrel-Net CURE modules (10-12). See Teaching Discussion for more details on expanding the lesson to include structured and open inquiry activities.

Prerequisite Student Knowledge

We recommend that students are familiar with the basic premise of estimating population sizes of animals, including the difference between estimating density (i.e., animals per unit area) versus population size (i.e., the total number of animals in a given area). Specifically, students should review why population estimates are important to management and conservation and why they are challenging. An open-source textbook option on this topic is "Monitoring Animal Populations and Their Habitats: A Practitioner's Guide" (http://library.open.oregonstate.edu/monitoring/; Chapter 8 covers population estimators; 3).

Prerequisite Teacher Knowledge

We recommend that instructors familiarize themselves with how wildlife biologists estimate animal population sizes and the three main techniques covered in the lesson (strip censuses, scat counts, and camera trap analyses). Instructors will also need a basic knowledge of the ecology and natural history of the focal species. We provide instructor resources on selecting a focal species of sciurid (Supporting File S1: How many squirrels – List of helpful resources in identifying field sites) and a list of resources for instructors to review individual methods and the assumptions and limitations of each one (Supporting File S1: How many squirrels – Instructor preparation resources).

SCIENTIFIC TEACHING THEMES

Active Learning

Although the data collection protocols are prescribed (indeed, a key goal of the activity is teaching students how to perform each method), students can actively develop questions with the national dataset, including how each technique performs in different habitats or for different kinds of species (e.g., ground versus tree-dwelling squirrels, social versus. solitary species, etc.). We also use small-group work and think-pair-share during the lesson.

Assessment

Students will prepare a scientific lab report in which they describe why population estimation is important to wildlife management and conservation, each method they used in the lab, and the results of each method. As part of this report, students will also plot their data and examine plots of different estimations among groups. Finally, they will discuss the assumptions and limitations of each method, describe which method they thought was the most accurate, and defend this choice given the habitat and natural history of the focal species.

Inclusive Teaching

Squirrel-Net modules in general are designed to provide all students in a class (not just those who are already well-prepared through previous research experiences; 13) with the opportunity to engage in authentic research experiences. Participating in a CURE like this Squirrel-Net module has been shown to have significant impacts on students' sense of self-efficacy as a scientist and may promote retention in science, particularly for students from under-represented groups (14). One unique element of our CURE is the use of the national network, which will further help students feel as though they are making important contributions and belong to a broader scientific community beyond their institution (15). Finally, in this specific lesson, materials are presented in different modalities (e.g., written in handouts, spoken in mini-lecture), and small-group activities or techniques such as multiple-hands, multiple-voices provide a less-intimidating opportunity for all students to contribute their voices to the discussion (16).

LESSON PLAN

Pre-Class Preparation

This lab requires instructors to identify a field site that has the focal species of interest (Supporting File S1: How many squirrels – List of helpful resources in identifying field sites) and to set up the lab at that field site 4-6 days in advance (Supporting File S2: How many squirrels – Instructor preparation resources). Specifically, instructors will need to place camera traps and establish scat plots by delimiting a plot and clearing it of scat ahead of time. Finally, calculations in lab will be simplified if instructors also measure the study area in Google Earth or another GIS platform.

Instructors should consider the activity patterns of the focal species and run the lab during a time when the focal species is likely to be active and detectable. For example, for a crepuscular, desert-adapted ground squirrel species, consider running the field trip on a Saturday morning instead of during regularly-scheduled mid-afternoon lab hours. In this case, you will need an option for students who could not attend to make up the material and the experience. The species' lack of activity during the lab period could be used as an opportunity for discussing the importance of surveying when the species is active and the varying ability of each survey method to detect the species, given activity patterns (e.g., nocturnal species may be better targeted with camera traps or scat surveys).

We also recommend that students are familiar with the basic premise of estimating population sizes (e.g., why it is important to management and conservation and why it is challenging). This can be accomplished through prior readings, assignments, or lectures. We suggest having students read through the lab handout and familiarize themselves with the three population estimation protocols prior to starting the lab (Supporting File S3: How many squirrels – Student protocol and datasheet for strip censuses, Supporting File S4: How many squirrels – Student protocol and datasheet for scat counts, Supporting File S5. How many squirrels – Student protocol and datasheet for camera trapping). These three files can be combined into a single handout.

Progressing Through the Lesson

<u>1. Lesson introduction and assessing prior knowledge (10 minutes).</u>

Upon arrival at the field site, the instructor and students spend a few minutes reviewing the foundational learning goals for the lesson (see above). Why is population estimation important for wildlife managers, and what makes this task difficult to accomplish? We used inclusive teaching strategies such as multiple hands, multiple voices or Whip Around (16) to ensure that all students have an opportunity to share what they learned in their pre-class preparation and to identify any common misconceptions. Specifically, we review the idea that estimating population sizes of animals is important to reliably assess changes (e.g., as a result of human modifications of their habitat) and to assess the effectiveness of management and/or conservation actions designed to boost species' numbers (17). However, counting animals is difficult because we must account for the detection probability, observer biases, and the behavioral responses of animals to human observers (1, 3).

Instructors then provide some background to the students on the natural history of the focal species. This lesson can easily be adapted for many species of small mammals (Supporting File S1: How many squirrels – List of helpful resources in identifying field sites). We provide this information as front-matter in the lab handout, including a photo of the animal and features that will allow students to reliably identify it and distinguish it from other species present in the same habitat area. The instructor then briefly reviews the protocols, datasheets, and materials for the three population estimators: transect surveys (Supporting File S3: How many squirrels – Student protocol and datasheet for strip censuses), scat counts (Supporting File S4: How many squirrels – Student protocol and datasheet for scat counts), and camera traps (Supporting File S5: How many squirrels – Student protocol and datasheet for camera trapping). Squirrel-Net has also developed an overview video that walks viewers through the protocols and calculations of each method, available via our website: http://www.squirrel-net.org. This video could be assigned for students to watch before collecting data.

2. Data collection (30-45 minutes).

Students work together to collect data for each of the three protocols below. With a small class size (<10 students) and a relatively small survey area (< 2 ha), students can work together as a single group. However, for larger classes and/or shorter class periods, the instructor may wish to break the class into smaller groups (4-6 students) that each focus on a single survey protocol or multiple smaller groups that survey different parts of the study area. At the end of class, these break-out groups would then report their data back to the rest of the class such that all students obtain complete datasheets.

2(a). Strip census.

To conduct a strip census, students in small groups (3-4 students) walk a straight-line transect through the habitat and record the distances at which animals are detected (typically by flushing or calling) to either side (Fig. 1A). Students record the following data: length of transect, perpendicular distance from the transect at which each animal was sighted (recorded with a laser range-finder) or straight-line distance and detection angle (measured with a protractor, as described in Supporting File S3: Student protocol and datasheet for strip censuses), and the number of students in the group acting as "observers" (actively searching for flushing animals). If a laser range-finder is not available, students may also use tape measures to measure these distances. Be sure that all students are collecting data in metric units. Keep in mind that larger groups will detect more individuals than smaller groups (i.e., because more eyes are looking for darting animals); larger groups should therefore either be broken into smaller groups or the group should designate one "observer" and allow other group members to tackle other tasks (e.g., measuring or estimating distances and angles or recording data).

2(b). Scat counts.

To conduct scat counts, students revisit the plots that were previously cleared of scat by the instructor and count new pellets that have been deposited at each station since the plot was cleared (Supporting File S4: How many squirrels – Student protocol and datasheet for scat counts; Fig. 1B). To encourage proper safety and hygiene when working with animals, students wear disposable nitrile gloves when handling scat, even if the focal species is not known to carry any diseases that are communicable to humans.

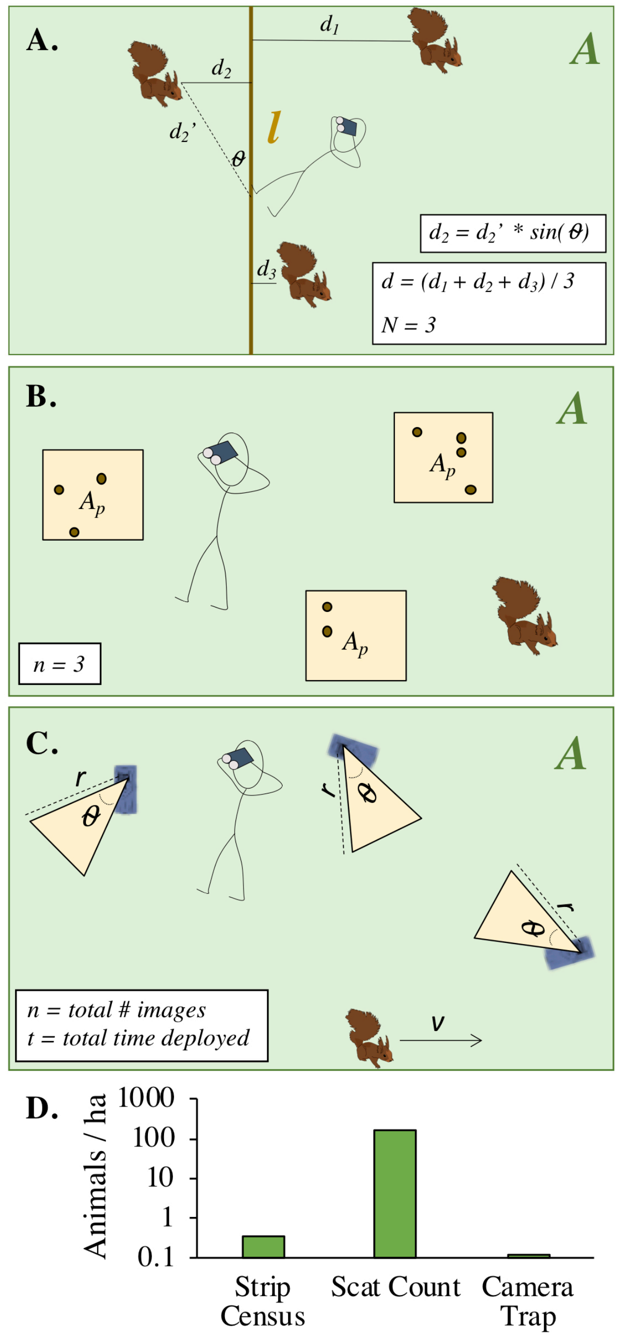

Figure 1. Schematic representation of the three methods of population estimation, (A) strip censuses, (B) scat counts, and (C) camera trapping. Details of each calculation are covered in Supporting Files S2-S5. (D) Example data from our class showing large discrepancies between the three methods. These differences led to a fruitful discussion in lab about the assumptions of each method and which was likely to be most accurate, given the conditions. Squirrel vector image from https://pixabay.com/vectors/squirrel-animal-cute-rodent-fluffy-41255/; stick-figure image drawn by JV.

2(c). Camera traps.

Students collect the camera traps that were previously placed by the instructor (Supporting File S5: Student protocol and datasheet for camera trapping; Fig. 1C). When possible, students transfer camera trap images directly to a mobile phone or tablet with a portable memory card reader so that images of the focal species on each camera can be identified immediately in the field. The number of independent sequences of photos of the focal species on each camera is then tallied for each camera (18).

3. Calculations (10-15 minutes).

Students complete datasheets and calculate the estimated population size (i.e., number of animals in the study area) for each of the three estimators. Cell phone calculators should be sufficient. These data should then be added to the master datasheet (Supporting File S6: How many squirrels – Master datasheet and upload instructions for national dataset) and data from the entire survey should be submitted to the national dataset. Instructors should follow instructions on the website (http://www.squirrel-net.org) to request access for students to submit data to the national dataset and to download the dataset for class use. Please be sure that only one student per group submits the data for each survey to the national dataset. Even if students do not use all three methods, we still request that they upload data to the national dataset; doing so will help other students who may not be able to conduct their own surveys (e.g., due to field access limitations).

4. Discussion of assumptions (10-15 minutes).

Students receive a list of the assumptions for the strip census methods in the handout (Supporting File S3: How many squirrels – Student protocol and datasheet for strip censuses); however, after data collection, we ask them to generate a list of assumptions for the other two methods. Specifically, the instructor first walks through the list of assumptions for the strip census in a mini-lecture. Then, the instructor divides the class in half and asks students to think about the assumptions for one of the other two methods. After a minute of independent thought, students pair with a partner in the same group to discuss their lists, and then report out to the whole class to generate a complete list of assumptions for each method.

5. Synthesis (5-10 minutes).

For the last few minutes of class, the instructor recaps the three methods, ensures that students have access to the complete list of assumptions for each method, and discusses the reflection and/or analysis assignment. At the simplest level, we recommend asking students to reflect on the similarities and/or differences between the methods, which assumptions they think are realistic (or not realistic), and to make predictions about how each estimator would perform in a different habitat or with a different species (see Supporting File S7: How many squirrels – Assessment and reflection questions). In more advanced courses, we recommend asking students to write a formal lab report in the format of a scientific paper. In our classes, we have asked students to reference the primary literature and consider these reflection questions in the discussion of their paper (Supporting File S8: How many squirrels – Lab report writeup instructions).

TEACHING DISCUSSION

This lesson was implemented in the spring of 2018 with an upper-division mammalogy course (24 students) in a single 2-hour lab period and went smoothly. Students enjoyed the opportunity to be outside looking for animals and downloading the data from the camera traps. In particular, comments in an informal feedback survey reflected that many students felt this activity taught them skills that would be useful in helping them to obtain jobs in their fields of interest. The 4DEE Teaching framework developed by the Ecological Society of America (19) further underscores the importance of teaching these methods to students, since the methods draw on both the Core Ecology Concepts of populations and all of the Ecology Practices (19).

Instructors should be aware that ecological field work, particularly with vertebrate animals, is inherently unpredictable, but we recommend that these unpredictable events be treated as an opportunity for discussion. For example, on one day of this lab, no animals were detected on any of the camera traps, but one scat plot had an exceedingly large number of pellets. The resulting population estimates for our study area were therefore 0 for camera traps and nearly 300 for the scat plots (Fig. 1D). Although students were initially confused by the fact that neither of these numbers was very accurate, we turned the experience into a meaningful opportunity for them to consider what assumptions underlie each method and which of these assumptions were likely violated in the activity. Specifically, in their interpretive assignments, many students turned to the specific placements of the scat plots and camera traps and made predictions (unprompted by the instructor) about the habitat features that could have caused this disparity and how they might improve the placement in the second round of testing, which they did.

Extensions and Modifications

We conducted the lesson as a 2-hour laboratory field trip and held group discussions about the assumptions of each method in the field; however, depending on the time available for the lesson and the conditions, instructors could also ask students to reflect on assumptions and facilitate discussions in the next class period. Such a set-up would lend itself well to a jigsaw technique. For more advanced students and/or courses, instructors might consider transferring the preparation to the students themselves. Furthermore, additional class periods could be devoted to conducting the same protocols on a different species and/or habitat or to querying the national dataset to test hypotheses about how different population estimators differ among habitats or species.

With respect to extensions for this lesson, all Squirrel-Net modules are specifically designed to be implemented by instructors in a variety of classroom contexts (e.g., different class sizes, institutions, etc; Table 2; 20). In all cases, the most basic level of the assignment (described in the lesson plan for CourseSource) is structured inquiry, where students are focused on learning data collection skills. Although students are not fully engaging in a CURE experience at this level, they are still gathering data, evaluating results, and submitting these data to the national dataset. At the highest level of inquiry (free inquiry; 20), students are only provided the protocols. They then use the literature to generate hypotheses about the conditions under which each population estimator might be the most appropriate method and to test these hypotheses using the national dataset (in addition to the data that they themselves generate).

Another extension activity specific to this lesson is a discussion of and/or practice with mark-recapture techniques for estimating population sizes. This extension may be particularly easy for instructors that are already capturing and marking animals (e.g., for other Squirrel-Net modules or other projects). See

Supporting File S9: How many squirrels – Mark-recapture methods extension, for an example handout on the Lincoln-Peterson Estimator (1), the simplest of these techniques. In our lessons, we have provided this information to students and discussed its application in lecture but did not collect any data for this technique. However, this method is included as an add-on data field for the national dataset to allow instructors to collect and submit data for this estimator if they have the appropriate skills, equipment, and permits (e.g., state agency's scientific permits and Institutional Animal Care and Use Committee) to conduct mark-recapture studies.

Although this activity was originally developed for an upper-division university course, we believe it could also be adapted into a lesson for a lower-division or introductory course (e.g., Introduction to Ecology). If they were provided with adequate background knowledge (i.e., assigned readings and/or lectures prior to implementing the activity), less-advanced students in STEM majors or even non-STEM majors could easily carry out this lesson. The activity could therefore serve as an exciting exposure to ecology and could possibly even help draw students into majors or careers that deal with ecology, conservation, or management.

Finally, instructors may also wish to adapt this approach to inventory populations of other species beyond squirrels. Although the national dataset is specific to sciurids (9), the techniques can be seamlessly adapted to other species of diurnal small mammals (e.g., lagomorphs). Nocturnal small mammals (e.g., other rodents) can still be surveyed with scat plots and camera traps, although strip censuses will not be a useful technique for these species. Larger mammals (e.g., ungulates or carnivores) can also be surveyed with these techniques; however, because these animals tend to have larger home ranges and lower densities in a study area, they may be less detectable for a single lab period and/or require special considerations (e.g., for scat plots). Lastly, the protocols may also be useful for some species of birds (e.g., ptarmigans or turkeys). Such comparisons may also make fruitful extensions for senior-level students and/or those participating in a semester-long project.

SUPPORTING MATERIALS

- Supporting File S1. How many squirrels – List of helpful resources in identifying field sites
- Supporting File S2. How many squirrels – Instructor preparation resources
- Supporting File S3. How many squirrels – Student protocol and datasheet for strip censuses
- Supporting File S4. How many squirrels – Student protocol and datasheet for scat counts
- Supporting File S5. How many squirrels – Student protocol and datasheet for camera trapping
- Supporting File S6. How many squirrels – Master datasheet and upload instructions for national dataset
- Supporting File S7. How many squirrels – Assessment and reflection questions
- Supporting File S8. How many squirrels – Lab report writeup instructions
- Supporting File S9. How many squirrels – Mark-recapture methods extension

ACKNOWLEDGMENTS

JV has been supported by the Colorado Mesa University Faculty Professional Development Fund. JV, PKC, and JMD were supported by the 2019 CourseSource Writing Studio to develop this article. Support for EAF was provided by the USDA National Institute of Food and Agriculture, Hatch Project 1019737. This material is based upon work supported by the National Science Foundation under a collaborative grant (Nos. 2013483, 2013281, 2013308, and 2013320). We would also like to acknowledge all of the students who provided helpful feedback on these modules as we developed and piloted them in our courses.

REFERENCES

1. Pierce B, Lopez R, Silvy N. 2012. Estimating Animal Abundance, p. 311–318. In Silvy, N (ed.), The Wildlife Techniques Manual, 7th ed. Johns Hopkins University Press, Baltimore, MD.
2. Rasmussen K. 2017. How Biologists Estimate Populations of Animals. Alsk Fish Wildl News.
3. McComb B, Zuckerberg B, Vesely D, Jordan C. Chapter 8: Field Techniques for Population Sampling and Estimation. Monitoring Animal Populations and Their Habitats: A Practitioner's Guide. Open Oregon State, Corvallis, OR.
4. Woodin SA, Grove M, Heath DD. 2000. Effective Population Size: Biological Duality, Field & Molecular Approaches. Am Biol Teach 62:51.
5. Street G, Laubach T. 2013. And So It Grows: Using a Computer-Based Simulation of a Population Growth Model to Integrate Biology & Mathematics. Am Biol Teach 75:274.
6. Trenckmann E, Smith MK, Pelletreau KN, Summers MM. 2017. An active-learning lesson that targets student understanding of population growth in ecology. CourseSource. https://doi.org/10.24918/cs.2017.11
7. Powell R. 2007. Estimating Wildlife Populations. https://projects.ncsu.edu/cals/course/fw353/Estimate.htm. Accessed 9/1/19.
8. eMammal Academy - Science. https://emammal.si.edu/content/emammal-academy-science. Accessed 9/1/19.
9. Peplinski J, Brown JS. 2020. Distribution and diversity of squirrels on university and college campuses of the United States and Canada. J Mamm. doi: 10.1093/jmammal/gyaa033
10. Connors PK, Varner J, Erb LP, Dizney L, Lanier HC, Hanson JD, Yahnke CJ, Duggan JM, Flaherty EA. 2020. Squirreling around for science: Observing sciurid rodents to investigate animal behavior. CourseSource. https://doi.org/10.24918/cs.2020.7
11. Yahnke CJ, Dizney L, Varner J, Duggan JM, Erb LP, Lanier HC, Flaherty EA, Connors PK, Hanson JD. 2020. Sorry to eat and run: A lesson plan for testing trade-off in squirrel behavior using Giving Up Densities (GUDs). CourseSource. https://doi.org/10.24918/cs.2020.30
12. Duggan JM, Varner J, Lanier HC, Flaherty EA, Dizney L, Yahnke CJ, Connors PK, Erb LP, Hanson JD. 2020. Squirrels in space: Using radio telemetry to explore the space use and movement of sciurid rodents. CourseSource. https://doi.org/10.24918/cs.2020.25
13. Kim YK, Sax LJ. 2009. Student–faculty interaction in research universities: Differences by student gender, race, social class, and first-generation status. Res High Educ 50:437–459.
14. Rainey K, Dancy M, Mickelson R, Stearns E, Moller S. 2018. Race and gender differences in how sense of belonging influences decisions to major in STEM. Int J STEM Educ 5:10.
15. Dewsbury B, Brame CJ. 2019. Inclusive Teaching. CBE—Life Sci Educ 18:fe2.
16. Tanner KD. 2013. Structure Matters: Twenty-One Teaching Strategies to Promote Student Engagement and Cultivate Classroom Equity. CBE—Life Sci Educ 12:322–331.
17. IUCN Species Survival Commission (SSC). 2012. IUCN Red List categories and criteria, version 3.1, second edition. Gland, Switzerland.
18. Forrester T, O'Brien T, Fegraus E, Jansen PA, Palmer J, Kays R, Ahumada J, Stern B, McShea W. 2016. An Open Standard for Camera Trap Data. Biodivers Data J 4:e10197.
19. Ecological Society of America 4DEE Working Group. 2018. Detailed 4DEE Framework – Outline. https://www.esa.org/4DEE/outline/. Accessed 11/5/19.
20. Dizney L, Connors PK, Varner J, Duggan JM, Lanier HC, Erb LP, Flaherty EA, Yahnke CJ, Hanson JD. 2020. An introduction to the Squirrel-Net teaching modules. *CourseSource*. https://doi.org/10.24918/cs.2020.26

Table 1. How many squirrels are in the shrubs? Teaching Timeline

Activity	Description	Time	Notes
Preparation for Class (at least 4-7 days prior to implementing the lesson)			
Identify field site and focal species	See resources in Supporting File S1.	Depends on location of campus and resources available.	• See resources in Supporting File S1. • Field sites should be accessible to students during scheduled class time, and the focal species should be active and detectable during this time.
Set up scat plots	Identify scat from the focal species, delimit a plot (typically < 1m2), and clear the plot of scat.	15 minutes to a few hours, depending on ease of finding and identifying scat.	• Use a field guide to identify scat from the focal species. • See resources and detailed instructions in Supporting File S2.
Set up camera traps	Identify an area of habitat that is likely used by the focal species and place camera traps.	15 minutes	• Ensure that camera trap(s) has field of view appropriate for focal species, will capture quality images (i.e., free of vegetation), and is unlikely to be stolen. • See resources and detailed instructions in Supporting File S2.
Student preparation	Ask students to review handouts and familiarize themselves with protocols prior to class.	< 15 minutes	Students could also watch the overview video available via the website: http://www.squirrel-net.org.
Class Session – Progressing Through the Activity			
Introduction and assessing prior knowledge	Review learning goals for the lesson and identify any common misconceptions.	~10 minutes	Consider using inclusive teaching strategies, such as multiple-hands multiple-voices or whip around, to ensure all students have an opportunity to share what they learned in their pre-class preparation.
Data collection	Students work together to collect data on animal population using three methods.	30-45 minutes	In a small class (<10 students), students can work together, but consider breaking students into smaller groups (3-4 students) in larger classes.
Calculations	Students complete datasheets to calculate population size estimators for each technique.	10-15 minutes	Cell phone calculators should be sufficient for these calculations. Be sure students fill out master datasheet (Supporting File S6) in the field.
Discussion of assumptions	Students brainstorm a list of assumptions for each method and consider which assumptions are likely violated.	10-15 minutes	Instructor walks through assumptions for the first method (Strip Censuses) but uses think-pair-share to generate a list of assumptions for the other two methods (Scat Plots and Camera Traps).
Synthesis	Ensure students have generated a complete list of assumptions for each method. Discuss reflection and/or analysis assignments.	5-10 minutes	Tailor analysis and/or reflection to the level of the students.
Post-Class Assessment			
What students complete	Students compose a formal lab report or respond to a series of discussion questions.	20 minutes - several hours, depending on depth of assignment.	See Supporting Files S7 and S8 for a list of suggested assessments. In upper division classes, students should access the national dataset and test hypotheses beyond their focal species. See Table 2 and the Squirrel-Net Companion Essay (20) for examples of extensions.

Table 2. Examples of extensions and modifications for this lesson. Levels of inquiry are explained in more detail in companion essay (20).

Level of Inquiry	Structured Inquiry	Controlled Inquiry	Guided Inquiry	Free Inquiry
Example Activities for this Module	Instructor sets up lesson ahead of time. Students collect data for 3 population estimators (strip census, scat plots, camera traps) in one habitat for one species. One interpretive assignment asks students to reflect on assumptions of each method and which one might be most appropriate for the focal species in the focal habitat.	Instructor sets up lesson ahead of time. Students collect data for 3 population estimators in one habitat, but also analyze national dataset to look for consistent trends in how estimators perform in other habitat types or for species with different natural histories (e.g., ground versus tree squirrels, or communal versus solitary species). One interpretive assignment asks students to quantitatively compare estimators across explanatory categories in the national dataset.	Students set up activity themselves outside of class (i.e., placing camera traps and clearing scat plots) and collect data in multiple habitats and/or with multiple species. Possible questions could be associated with species' natural history, habitat structure (e.g., dominant vegetation type), or survey conditions (e.g., season or weather). Students analyze national dataset to test their own hypotheses and predictions.	Students set up activity themselves outside of class and collect data throughout the semester. Students generate their own questions and analyze their data and/or the national dataset to test their hypotheses and predictions about the validity of the different methods under various circumstances. Students could also conduct intensive re-sampling of one method to generate "best practice recommendations" for wildlife managers interested in this species (e.g., where to place scat plots or camera traps to obtain the most-accurate estimates). Students communicate results of inquiry in formal report, paper, or poster.