

How Many Critters Can an Island Hold? Using Digitized Natural History Collections to Test Real Hypotheses about Island Biogeography

Carly N. Jordan¹, Janice L. Krumm², Tiffany M. Doan³, Jason S. Kilgore⁴, and Debra Linton⁵

¹The George Washington University, Women's Leadership Program, 2100 Foxhall Rd NW, Academic Bldg 202A, Washington DC 20002 USA

²Widener University, Biology Department, One University Place, Chester PA 19013 USA

³New College of Florida, Division of Natural Sciences, 5800 Bay Shore Rd, Sarasota FL 34243 USA

⁴Washington & Jefferson College, Biology Department, 60 S Lincoln St, Washington PA 15301 USA

⁵Central Michigan University, Department of Biology, 1455 Calumet Ct, Mount Pleasant MI 48859 USA

(cnjordan@gwu.edu; jlkrumm@widener.edu; tiffperu@yahoo.com; jkilgore@washjeff.edu; linto1dl@cmich.edu)

Quantitative and data literacy skills are vital to the advancement of biological theory, as large data sets and quantitative modeling are increasingly used to answer critical questions in ecology. Increased availability of educational modules that teach quantitative and data literacy skills in ecological contexts may encourage faculty to incorporate more of these skills into their courses. To help meet this need, we customized and extended a teaching module on Island Biodiversity, as part of an iDigBio Workshop on Resources for Collections-Based Undergraduate Research. In this module, students create and test hypotheses about island biodiversity using information from the Arctos database, an online repository for natural history collections data. Students evaluate and analyze the downloaded data, test their hypotheses, and draw conclusions from their results. This module is highly adaptable, requires only a computer and internet access, and can be extended to suit a variety of curricula.

Keywords: island biogeography, species richness, natural history collections, data literacy, digital data, museum collections

Introduction

For this activity, students will explore digitized natural history resources in order to analyze the relationship between island size and mammal species richness. Students search for and download information on mammals collected on the islands of the Alexander Archipelago of Alaska from the Arctos database, an online repository for natural history collections data. Students evaluate and analyze the downloaded data, testing hypotheses about island biodiversity and drawing conclusions from their results. Designed to be flexible in its use, this activity could be implemented in an introductory biology course or an ecology course, in a single lecture period or a long lab, and can be tailored to

the challenge level needed for different student populations.

Learning Objectives

- Formulate a testable hypothesis
- Evaluate assumptions of existing datasets
- Manipulate, graph, and analyze data
- Determine if data support a hypothesis in context of biological theory
- Analyze, explain, and predict patterns of species diversity on islands
- Use digitized natural history collections data to test a biological hypothesis
- Appreciate the importance of natural history collections

Logistics

Instructor prep time: 15 minutes - 1 hour, depending on instructor experience and module components chosen

Student prep time: 15 minutes or more, depending on how instructor chooses to assign background reading and data collection tasks

Class time: 30 minutes - 2 hours, depending on student background and options selected

Formats: Student instructions are available as PDF and Word documents at

<https://www.biodiversityliteracy.com/island-bio>

Materials needed: One computer for each group of students (or individual), and either internet access or spreadsheet files. Projector and screen may be needed if instructor chooses to show videos in class.

Student Outline

Do Larger Islands Have Greater Species Richness? Testing a Biodiversity Hypothesis Using Data from Natural History Collections



Figure 1. “Overcast skies over Kuiu Island” by Roy Luck / CC BY 2.0

Learning Objectives

- Formulate a testable hypothesis
- Evaluate assumptions of existing datasets
- Use digitized natural history collections data to test a biological hypothesis
- Analyze, explain, and predict patterns of species diversity on islands
- Manipulate, graph, and analyze data in a spreadsheet
- Determine if data support a hypothesis in context of biological theory
- Appreciate the importance of natural history collections

Pre-module Preparation

1. Watch video about [using natural history collections by undergraduates](https://www.youtube.com/watch?v=rL7kAv323Bk) (<https://www.youtube.com/watch?v=rL7kAv323Bk>)
2. Watch video about [digitizing natural history collections data](https://www.youtube.com/watch?v=WyRc6QtZQgo) (<https://www.youtube.com/watch?v=WyRc6QtZQgo>)
3. Watch video about [Arctos](https://youtu.be/XQwXw0e9w-E) (<https://youtu.be/XQwXw0e9w-E>)
4. Watch video about [Excel tools](https://www.youtube.com/watch?v=QLDGZQARL6Q) to become familiar with Excel (<https://www.youtube.com/watch?v=QLDGZQARL6Q>)
5. Read the relevant sections of your textbook about Island Biogeography
6. Review the Glossary of Terms for any vocabulary that is unfamiliar

Introduction

Island biogeography is the study of the distribution and dynamics of species on islands. Due to their natural fragmentation and variation in available area, island systems are natural laboratories for evolutionary processes. Island biogeography can also provide a foundation for the design of conservation plans, given that many habitats all over the world have become fragmented due to human-initiated habitat disturbance and loss. Over the past 150 years, studies of island systems have played a key role in the formation of ecological and evolutionary theory, including advances in our understanding of colonization, extinction, and speciation. Today, new technologies (e.g., DNA markers, Google Earth, Geographic Information Systems applications) allow intensive studies of island systems on a global scale, and these studies continually provide new insights about how nature works on islands. Studies of island systems are especially important for conservation efforts because islands harbor a large number of range-restricted endemic species of which many are endangered. Furthermore, among terrestrial vertebrates, more than 50% of all documented extinctions in the past 400 years have been island species.

Islands can be classified as either oceanic or continental by assessing their geological origin (Figure 2). Oceanic islands are formed over oceanic plates and were never connected to continental landmasses. These islands typically are devoid of life at the outset but gradually accumulate species from distant mainland source populations through primary succession. In contrast, continental (land bridge) islands are found on the continental shelf and in the past were directly connected to the mainland, most recently during the Pleistocene ice ages when sea levels dropped by as much as 130 m. Because of their proximity to the mainland, land bridge islands are more heavily dominated by repeated colonization than are distant island archipelagos. Repeated colonization can result in a relatively high diversity of organisms. Some organisms may also have speciated on the islands themselves, with new species arising that are endemic to only that area on Earth.

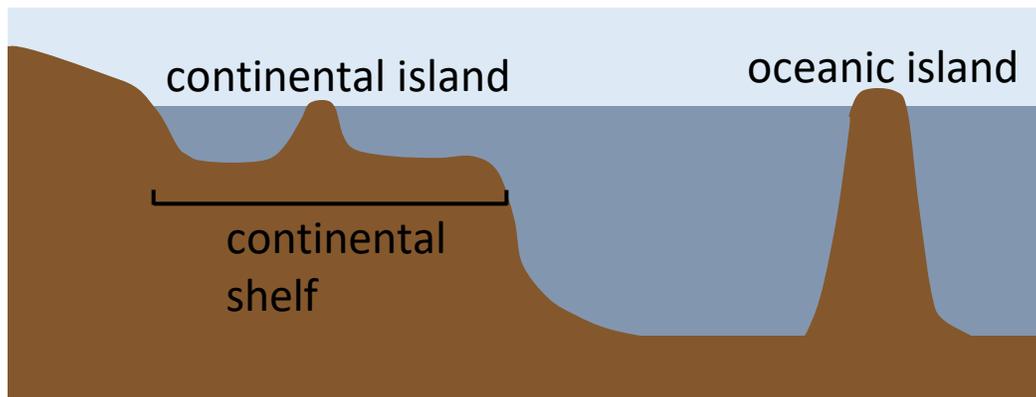


Figure 2. Continental and oceanic islands

The islands studied in this module are part of the **Alexander Archipelago (AA)** of Southeast Alaska (Figure 3). This archipelago contains about 1100 named islands, all of which are continental islands. The AA is part of both the largest temperate rainforest in the world and the largest National Forest in the United States, the Tongass.



Figure 3. Map of the Alexander Archipelago. Modified from “Map of Alaska, Yukon Territory and British Columbia showing connections of the White Pass and Yukon route.” Library of Congress.

This module will focus on a subset of the 1100 named islands. These islands were the focus of collection efforts for the publication of “Mammals and Amphibians of Southeast Alaska” (MacDonald and Cook 2006) and were chosen for this module based on specimen availability in digitized natural history collections. The AA is a continental island chain, with varying degrees of isolation and connectivity, as a result of historical climate change and a complex glacial history. For example, since some islands were covered in ice at different times, only when the ice receded could colonization occur to these islands as if they were isolated oceanic islands. Table 1 on the next page includes a list of the 32 islands with associated areas that will be used in your study.



Figure 4. Representative mammals of the Alexander Archipelago from the Museum of Biological Diversity, Ohio State University; photograph by Janice Krumm.

Table 1. Alexander Archipelago islands available for study. Island name and land area (in m²) are provided. Islands are sorted by increasing land area.

Island	Area (m²)
West Brother	3,261,843
Hassler	4,348,176
Inian	12,275,281
Vank	14,153,023
Woewodski	15,227,909
Shelter	21,782,299
Lemesurier	27,502,850
Krestof	27,932,716
Warren	45,264,308
Bell	51,055,878
Woronkofski	59,548,409
Tuxekan	69,872,791
Lulu	73,852,111
Coronation	74,703,312
San Fernando	85,419,535
Noyes	97,369,520
Baker	115,552,154
Suemez	149,242,517
Sukkwan	166,256,014
Heceta	172,401,840
Gravina	244,366,553
Kruzof	438,573,289
Kosciusko	442,826,651
Zarembo	475,011,969
Dall	655,013,180
Etolin	874,560,363
Kuiu	1,922,681,313
Kupreanof	2,796,753,052
Baranof	4,056,530,258
Admiralty	4,341,948,688
Chichagof	5,312,164,867
Prince of Wales	6,611,533,020

In order to conduct research on publicly-available data, such as natural history collections data, we will:

1. Develop a testable hypothesis
2. Investigate the data resources
3. Collect (download) the data
4. Clean the data to remove errors and to discard unneeded data
5. Visualize the data to discover patterns
6. Explain the results and write conclusions

Develop a Testable Hypothesis

In this activity, you will be investigating the relationship between the size of an island and the number of species found on that island (i.e., species richness).

1. Discuss this idea with your team and develop a testable hypothesis. Write your hypothesis below.
2. Describe how you would test this hypothesis if you did not have access to any pre-existing data.

Investigate Data Resources

Fortunately, scientists have collected and stored data that can help you test your hypothesis. These data are located in natural history collections. Most of you know about some of the great museums, such as the Smithsonian or the American Museum of Natural History (remember the *Night at the Museum* movies?), where animal specimens are exhibited. These institutions derive their importance not only from the public exhibits, but they are also critically important repositories of the evidence underpinning everything we know about nature! Natural history collections data are based on archived specimens, maintained by qualified museum staff in perpetuity to serve as references for the taxonomy, evolution, and ecology of the species. These so-called voucher specimens are linked with valuable metadata (e.g., collection date, location, habitat, images, community assemblage, seasonality, climate) and remain accessible for repeatable or expanded observations when information needs to be verified, when new questions arise, or when new and better investigative techniques are developed. Natural history collections provide a source of biodiversity data that is unparalleled in temporal, geographic, and taxonomic complexity.

As you can imagine, such a huge repository of data is only useful if it can be widely accessed. As a consequence, museums have been diligently working to put their collection data into systems that allow researchers (and students!) to use this information with just a few clicks. The portal called Arctos is one such system.

Arctos integrates access to diverse types of collections (e.g., plants, insects, mammals, birds, amphibians, reptiles, fossils, parasites), including basic specimen data, field observations, availability of tissue samples for DNA studies, presence of parasites, and data on stomach contents. It can also be used to access other documents and media, such as photos, audio recordings, and video. The system can be used by professionals (e.g., collection managers, curators, scientists) and the public, but also by educators and their students to access natural history information.

3. For this activity, navigate to Arctos: <http://arctos.database.museum/>
 - a. Look at the webpage. Exactly how many records are accessible through the Arctos portal today?
 - b. What are the different criteria that you can specify in the search tool?

Collect Species Richness Data

4. We will examine the data from all 32 islands. Your instructor will help you divide up the islands among teams of students. Each student should be able to do a search.

5. Go to the Arctos database (<http://arctos.database.museum/SpecimenSearch.cfm>), and create a user ID. Then click “My Stuff”, then “Profile”, and complete your personal profile. You must fill in all required yellow boxes. For preferred file format, select CSV.
6. Go back to the Arctos home page and perform a search for each of the islands you were assigned.
 - a. Under **Identifiers** select the drop down menu called **Collection**. Select **check all**.
 - b. Under **Locality** on the top right of the section click on **Show More Options**.
 - c. Also under **Locality** go to **Island Group** and select **Alexander Archipelago**.
 - d. For **Island** type in one of your island names.
 - e. Click the **Search** button at the bottom.
7. Select the dropdown **Tools: Map, Customize, or Download**, select **Customize Form**, and choose **Add or Remove Data Fields** (columns) and select the data columns you wish to add or remove (you may have to search around to find what you are looking for). Make sure at least the following are included in the display:

island
phylclass
species

Note: It is much easier to clean up your data in Excel, so don’t worry about removing any unwanted rows before downloading.

8. From the same **Tools** dropdown box, select **Download**. Choose **educational** as the purpose of the download, and read and agree to the terms of use statement. Then select **Continue to Download**.
9. Rename your downloaded data file with the name of the island.
10. Repeat Steps 6–8 for each island that you were assigned.
11. What assumptions are we making about the data you have collected from Arctos?
12. What are the most common species on your islands?

Clean Your Data

13. To create a list of species found on each island, open each spreadsheet individually in Excel or Google Sheets. Select all of your data. Sort by “phylclass”, and delete any rows that are not mammals.
14. Under the Data tab, select “Remove Duplicates” and the column containing the Scientific Name. Click “remove duplicates”. (If you are using Google Sheets, you will need to activate the Add-On for Remove Duplicates.)
15. Sort by Scientific_Name, and review the results. Treat all subspecies as the same species; i.e. remove any additional subspecies or misspellings.
16. Count the total number of species for each of your assigned islands, and enter these data into Table 2.

Table 2. Island areas and species richness.

Island Name	Area (m²)	Number of Species

17. On the class Google Sheet prepared by your instructor, type or paste in your data from your table (Island Name, Area, and # Species). Be careful not to delete any data that were entered by other students.

Visualize Your Data

18. Create a scatterplot of number of species (Y-axis) vs. island area (X-axis) for all of the islands. Add labels to the axes, delete the title, and add a descriptive figure caption below the graph. Turn in the graph as directed by your instructor.

Explain Your Results

19. What relationship, if any, is shown by the graph?

20. Do these data support or reject your hypothesis? Explain your evidence.

21. What additional hypotheses might you be able to test using the types of data available in digitized natural history collections?

Glossary of Terms

Colonization: the action by an organism of establishing itself in an area.

DNA markers: genes or DNA sequences with a known location on a chromosome that can be used to identify individuals or species.

Endemic: a species whose range is restricted to a particular country or area.

Extinction: the dying out or termination of a species.

Fragmentation: the process of breaking or being broken into smaller parts.

Geographic Information Systems (GIS): a computerized system designed to capture, store, manipulate, analyze, manage, and present spatial or geographic data.

Google Earth: a browser that accesses satellite and aerial imagery and other geographic data over the internet to represent the Earth as a three-dimensional globe.

Pleistocene: the geological epoch that lasted from about 2.5 million years ago to 11,700 years ago, spanning the world's most recent period of repeated glaciations, also known as ice ages.

Primary succession: one of two types of ecological succession of organisms, occurring in an environment in which new land is devoid of vegetation and other organisms and usually lacking soil, such as a lava flow or area left from retreated glacier. Species arrive and begin to establish a new habitat.

Speciation: the formation of new and distinct species in the course of evolution.

Specimen: an individual animal, plant, piece of a mineral, etc., used as an example of its species or type for scientific study or display. Specimens may consist of the organism itself or a photo, audio recording, or other type of evidence.

Temperate: latitudes of Earth that lie between the tropics and the polar regions.

Terrestrial: living on or in the ground and not aquatic.

Cited References

MacDonald SO, Cook JA. 2007. Mammals and amphibians of Southeast Alaska. Special Publication Number 8. Albuquerque: Museum of Southwestern Biology. 191 p.

Materials

Each student (or group of students, depending on the preferences of the instructor) needs a computer with reliable internet access and a spreadsheet program (Microsoft Excel or Google Sheets). We recommend using the most recent version of Excel if possible.

To ensure smooth execution of this activity, students need reliable internet access. If students will be using their own laptops, instructors should confirm the strength of the wireless signal in their classroom. If the wireless network is not reliable, instructors may choose to download records from the database ahead of time and provide those files to students, or to hold the class in a computer lab. It is also important that all computers have an acceptable spreadsheet program. Microsoft Excel is the preferred program for ease of data sorting and cleaning. Encourage all students to update their personal computers before class, or confirm that computer lab machines have the most recent version of the software.

Instructors may choose to print the student handouts for the class or to post them as PDFs or editable documents for students to access and complete online.

Notes for the Instructor

Preparation

Major Concepts for Instructors

- In the study of island biogeography, “islands” can include isolated areas of habitat such as small lakes and forest fragments, as well as actual islands surrounded by water.
- As the size of an island increases, the number of species present on the island will increase.
- As the distance of an island from the source community of immigrants or “mainland” increases, the number of species on the island will decrease.
- The equilibrium number of species located on an island can be predicted by examining the interaction between immigration of new species to the island and extinction of species on the island (MacArthur and Wilson 1963).
 - There is a limited pool of species available to immigrate to an island, therefore immigration rate of new species to the island will decrease as the number of species already present on the island increases.
 - Species vary in their dispersal mechanisms and capabilities. Therefore, as the distance from the “mainland” or larger area of habitat increases, the rate of immigration to the island decreases.

- Resources are limited in an island habitat, and competition between species will increase as the number of species increases. Therefore, as the number of species on an island increases, the extinction rate of species will increase.
- The equilibrium point is where the rate of immigration of new species equals the rate of extinction of current island species, thus allowing a prediction of the equilibrium number of species for the island.
- MacArthur and Wilson’s original model has been criticized for ignoring topics such as speciation and the effects of geological processes on island formation and subsidence (Lomolino 2000). However, the ideas are still useful as a starting point for introducing undergraduates to the dynamics of island biodiversity. The model also allows for the creation of testable hypotheses and a discussion of its limitations.

Background for Students

This activity is appropriate for a variety of courses, and students need only a basic understanding of biodiversity and species concepts. Prior to this activity, students should acquire information about island biogeography, an idea included in ecology chapters of most introductory biology texts. The student handout for this activity gives additional information about island formation and the Alexander Archipelago, and should be read before beginning the module. The following videos on natural history collections and relevant tools for this activity may also be helpful for students to view in preparation for this activity.

- Using natural history collections
<https://www.youtube.com/watch?v=rL7kAv323Bk>
- Navigating the Arctos database
<https://youtu.be/XQwXw0e9w-E>
- Useful Excel tools
<https://www.youtube.com/watch?v=QLDGZQA RL6Q>

Common Student Misconceptions

The major conceptual hurdle for students is generally a lack of awareness about the existence of digitized natural history collections. Most students have never heard of this idea and may not understand what natural history collections actually contain, beyond the public exhibits at museums. First-year students may also have misconceptions about how scientists collaborate and may carry stereotypes of the lone scientist toiling away in their laboratory. This activity shows that scientists work in diverse environments, like museums, and that hypotheses can be tested on a computer outside of a lab setting. It can help to demonstrate how scientists work together to collect

data and use shared data to answer their own experimental questions. Some students may believe that using another person's data is unethical and that scientists must repeat every step of an experiment themselves. This activity could lead to a meaningful discussion about the difference between appropriate use of a shared data source and inappropriate use of ideas without attribution.

Once students begin the activity in class, they may stumble through the procedure if they fail to carefully read the instructions. The most common error occurs at the data download step, where students may not select the proper data fields to be displayed in their spreadsheet. This is Step 7 on the Student Handout, under Collect Species Richness Data. A reminder to carefully read this step may help students avoid this problem.

In-Class Activity

Description

A student handout guides students through this activity, with the following steps:

1. Develop a testable hypothesis
2. Investigate the data resources
3. Collect (download) the data
4. Clean the data to remove errors and to discard unneeded data
5. Visualize the data to discover patterns
6. Explain the results and write conclusions

First, students discuss ideas about how island size may relate to species richness, and they write a testable hypothesis. Then they think about how they would test their hypotheses without the use of existing datasets, which can lead to a discussion about sampling, field techniques in ecology, and the many challenges of this type of work.

Next, an introduction to natural history collections data is needed. This can be a good time to show and discuss the first two videos linked above. The student handout also provides textual explanation about natural history collections and how they have been digitized for increased accessibility. Students then access the online Arctos database interface and explore the search options available. Instructors may choose to walk students through the website using a projector and screen, or allow students to explore at their own pace.

When students are comfortable with the database, the next step is to download data to address their hypotheses. The student handout contains step-by-step instructions for downloading the relevant data about mammal specimens collected on each island. At the end of that process, each student or group will download a spreadsheet with a list of all specimens collected on a given island. Each student or group could work through the search and download process for every island, or this work could be shared among the class. Using Google Sheets is an effective way to pool collected data into a

shared file so that everyone can access and manipulate the entire data set. For instructors unfamiliar with sharing Google Drive files, this short video tutorial can be helpful: <https://www.youtube.com/watch?v=25CtYkqamIA>.

Next, students will need to examine and clean the data they have downloaded. Some of the downloaded specimen records will not be relevant to the hypotheses, while other entries may be duplicated, incomplete, or contain errors. The student handout provides instructions on how to sort, clean, and reorganize the data for next steps. Once the data are prepared, students use Google Sheets or Excel to visualize the relationship between island size and number of species on each island. The handout instructs students to create a scatterplot with island size on the X axis. For students who need help creating a graph, the third video listed in background resources above provides an overview of Excel.

Finally, students examine their graphs and draw conclusions, accepting or rejecting their stated hypotheses. This can be a good time for instructors to lead a conversation about the limitations of the data; for example, these data only indicate detected presence of a species and no indication of whether that species was absent. With a clearer understanding of the information available in digitized natural history collections, students end the activity by considering what other types of questions one might ask using this resource.

Adapting for Different Class Environments

For short class times, instructors may choose to assign the background reading and videos as pre-class work and only briefly discuss them in class. The tasks of data collection could also be shared among students, limiting the amount of time that each person would spend acquiring information. Instructors could distribute the tasks of information acquisition, so that each student or group only downloads information about a single island. Instructors should note that data collection takes much longer for the large islands than the small islands, so consideration of this when assigning islands is important. If navigation of the databases themselves is not desired, an instructor could create a very short data analysis activity by providing the data and asking students to draw conclusions.

For large classes, forming groups and distributing tasks could make the logistics of the activity more manageable. An instructor could have students work together in small groups that each complete the entire activity, or split the class into sections with groups asking different questions from the same database.

For use in a lab setting, a few modifications could make the activity more hands-on. Instructors could provide large maps of the featured islands for students to better visualize the distribution of animals and terrain of the islands, or for students to annotate with data about species. If available, students could examine preserved specimens of some of the animals found on the islands

(e.g., rodents and small mammals are likely held in some university collections). For the ultimate implementation of this module, take students to a natural history museum to see animals and talk to a curator about how they digitize their collections.

Extensions to the Core Module

When more challenge is desired, students could be assigned additional questions to explore or asked to design their own questions. Students could also expand the range of their hypotheses to include all of the available islands, compare data from other archipelagos, examine islands' distance from the mainland, or explore species beyond mammals. If more focus on quantitative skills is desired, students could collect data on the relative abundance of each mammal species, calculate diversity indices, or determine the correlation of island size versus species richness. Instructors could bring in a discussion of taxonomy by pointing out the differences in how a species has been named over time (e.g., the assigned genus name for minks varies in the database). This could lead to a conversation about data cleaning, introducing relevant tools, or searching for other inaccurate data (e.g., find the cheetah tagged on Prince of Wales Island!).

Assessment

In an effort to examine the learning gains attributable to completion of this module, pre- and post-tests were created to measure student understanding (included as Appendices A and B, respectively). These items assess student hypothesis testing skills, data literacy skills, application of natural history data, and understanding of species diversity theory. Questions were designed with the goals of improving the teaching module and publication of the results to increase module dissemination among biology and environmental science educators.

If an instructor wishes to demonstrate learning gains from the module, the pre-test should be given prior to any introduction of the module content, including background lectures, handout, and internet links, in the classroom setting, noting that some students may be unfamiliar with some of the terms in the questions. This pre-test should take up to 15 minutes. Similarly, the post-test should be implemented following the completion of the module and should take up to 20 minutes, whether in the same or future class sessions. The correct responses for the pre-test are 1-D, 2-B, 3-B/C/E, 4-A, 5-C, and 6-A/C/D/F, and correct responses for the post-test are 1-D, 2-B, 3-A/C, 4-C, 5-C, and 6- D/F. Instructors may also choose to use some of the questions as summative assessment items on subsequent quizzes or exams.

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About the Authors

Carly Jordan is an assistant professor in the Department of Biological Sciences at The George Washington University, and serves as the Program Coordinator for the Science, Health and Medicine cohort of the Women's Leadership Program. She earned her Ph.D. in Cellular Biology and an Interdisciplinary Certificate in University Teaching from the University of Georgia. She

teaches introductory biology for majors, nonmajors biology online, and Honors seminars on nutrition and human reproduction. Her current scholarship is focused on science education, and she strives to create teaching materials and tutorials that will help faculty increase engagement and active learning in their courses. She is also interested in the factors that encourage women to persist in STEM majors.

Janice Krumm is an associate professor in the Department of Biology at Widener University. She earned her Ph.D. in Evolutionary Biology at the University of California Riverside. She is developing and teaching an undergraduate course in natural history collections in collaboration with the curators at the Delaware Museum of Natural History. She also teaches invertebrate zoology, evolution of sex, introductory statistics, and introductory ecology and evolution. She enjoys incorporating student-led research into her courses, and engaging undergraduates in independent research projects in the laboratory and the field. Her students are currently working on independent research projects on endophyte-host plant interactions, tri-trophic interactions in an insect, host plant, predator/parasitoid system, and using natural history collections to explore questions in ecology and evolutionary biology.

Tiffany Doan is a visiting assistant professor of biology in the Division of Natural Sciences at New College of Florida. She earned her Ph.D. in Quantitative Biology at the University of Texas at Arlington. She teaches courses in general biology, evolution, ecology, zoology, biostatistics, and animal behavior. She also leads international courses in Peru, Costa Rica, Panama, and South Africa about field ecology, behavior, and public health. Her research focuses on the global biogeography of reptiles, especially South American lizards, and the disease ecology of lizards and their malaria parasites and how that relationship contributes to the establishment of invasive species.

Jason Kilgore is an associate professor of biology and coordinator for the environmental science major at Washington & Jefferson College. He earned his Ph.D. in Plant Biology and the Ecology, Evolutionary Biology, and Behavior Program, as well as a Certification in Teaching College Science and Mathematics, at Michigan State University. He teaches courses in evolution and biological diversity, plant diversity, field biology, environmental plant physiology, forest ecology, applied statistics, and environmental studies. He also teaches travel courses in the natural history of the Sonoran Desert and immigration policy at the Arizona-Mexico border. His recent student-based research focuses on the ecology of invasive species like emerald ash borer and garlic mustard, heavy-metal sequestration by grasses in coal mine wastes, sand dune ecology, and long-term forest monitoring. Jason's outreach efforts include training the Envirothon team at a local high school, leading tours and workshops on wetlands for watershed groups, and teaching science-related merit badges to Boy Scouts.

Debra Linton is an associate professor in the Department of Biology at Central Michigan University. She earned her Ph.D. in Ecology and Evolution at Rutgers, the State University of New Jersey, studying life history strategies and optimal foraging of marine benthic invertebrates. After earning her Ph.D., she began teaching Introductory Biology at Rutgers and became interested in biology education research. Debra completed a postdoctoral research experience at Michigan State University, specializing in undergraduate biology education and professional development for college biology instructors. At CMU, Debra conducts research in undergraduate biology education, where her interests include biodiversity literacy in undergraduate education, active learning pedagogy, and K-12 science teacher training. She is co-PI on the NSF-funded Biodiversity Literacy in Undergraduate Education (BLUE) RCN-UBE.

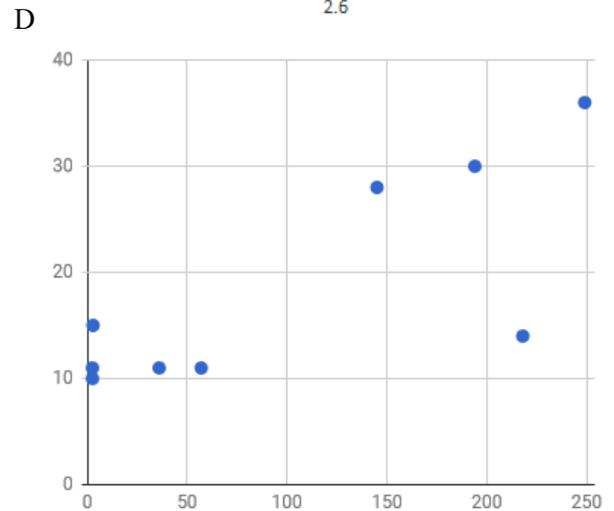
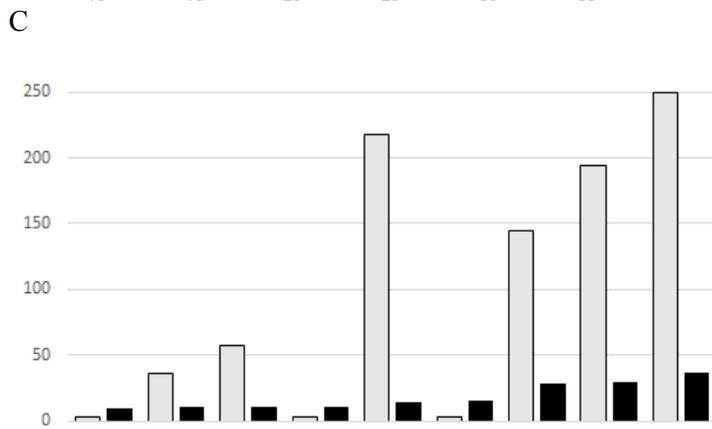
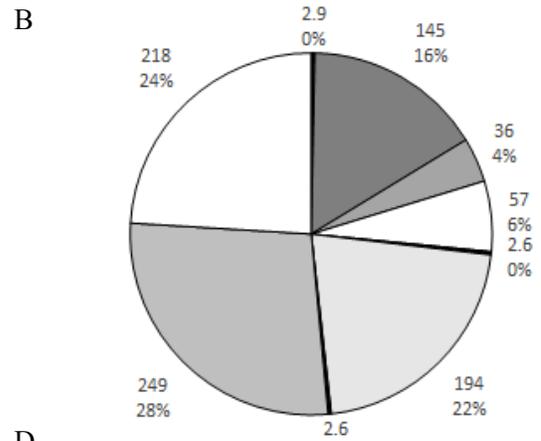
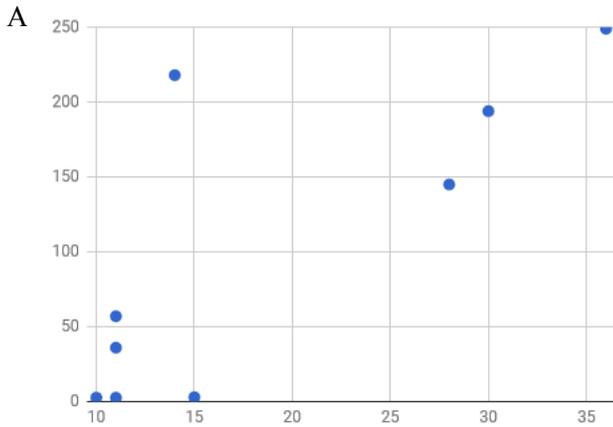
Appendix A: Pre-test

In a book published in 1917, Alfred Brazier Howell summarized the number of land and freshwater bird species found in the Channel Islands off southern California. This archipelago, or group of islands, contains nine islands varying from 13 km (8 miles) to 98 km (61 miles) to the mainland, ranging from 2.6 km² (1 square-mile) to 249 km² (96 square-miles) in size. His results are summarized in Table 1.

Table 1. Number of land and freshwater bird species surveyed by Howell (1917) in the Channel Islands off southern California (referenced by Diamond 1969; [link](#)).

Island	Area (km ²)	Distance to mainland (km)	Number of bird species
Santa Barbara	2.6	61	10
Los Coronados	2.6	13	11
San Nicholas	57	98	11
San Miguel	36	42	11
Santa Rosa	218	44	14
Anacapa	2.9	21	15
San Clemente	145	79	28
Santa Catalina	194	32	30
Santa Cruz	249	31	36

1. Circle the graph that best depicts how island area affects the number of bird species in these islands.



2. From these data (Table 1), what kind of pattern do you see?

- A. Island size increases as distance from mainland increases.
- B. Somewhat positive relationship between island size and number of bird species
- C. Somewhat negative relationship between island size and number of bird species
- D. No idea

3. Circle all of the letters, if any, listing reasonable assumptions that you must make about the source and validity of these data:

- A. Greater effort was made to fully survey the larger and thus more important islands
- B. Birds are not being chased from island to island by the researchers
- C. Surveys occurred across all seasons for each of the islands
- D. The same predators are located on every island
- E. Surveys occurred at the same time of day, or throughout the day, for all islands
- F. No idea

4. Given these data, choose the most appropriate hypothesis to explain the number of land and freshwater birds on these Channel Islands:

- A. Larger islands provide more types of habitats and areas thus more niches for bird species
- B. Islands closer to the equator have more bird species
- C. Larger islands have more people
- D. Larger islands that are closer to the mainland have more opportunities for immigration of new species and survival of existing species
- E. Larger islands have fewer egg-eating snakes
- F. I don't know how to detect and/or evaluate an hypothesis

5. If the island area were converted from square kilometers to square miles, any observed relationship between island area and number of bird species would:

- A. Increase
- B. Decrease
- C. Stay the same
- D. No idea

6. Fifty-one years later, Jared Diamond resurveyed these same Channel Islands for land and freshwater birds. From an ecological standpoint, select ALL of the relevant reasons why he may have wanted to resample these islands:

- A. The equilibrium number of species on each island may have changed
- B. Shifts in relative abundance of each species may have occurred
- C. The ability to survey the birds on the islands became easier with new technologies
- D. Environmental conditions have changed in the region
- E. The birds may have grown up since the first surveys in 1917
- F. Novel (new) species may have been introduced onto the islands
- G. Rates of species turnover (i.e., new species) should be lower on more distant islands
- H. Old data, like from 1917, have no value and must be renewed with new data

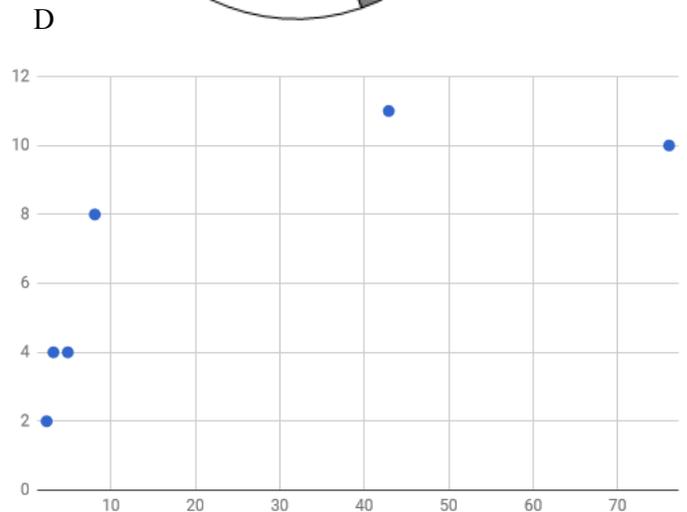
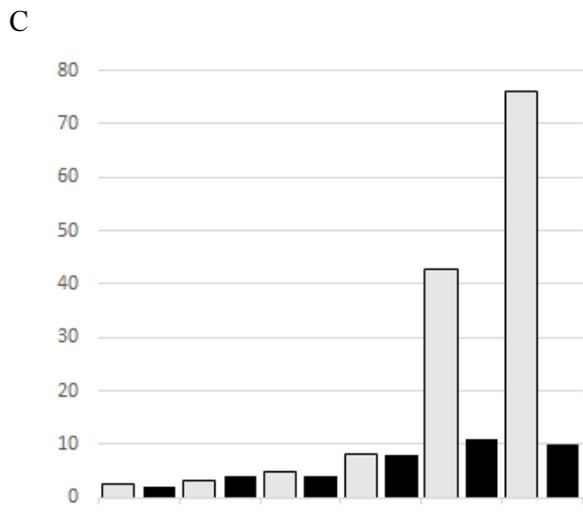
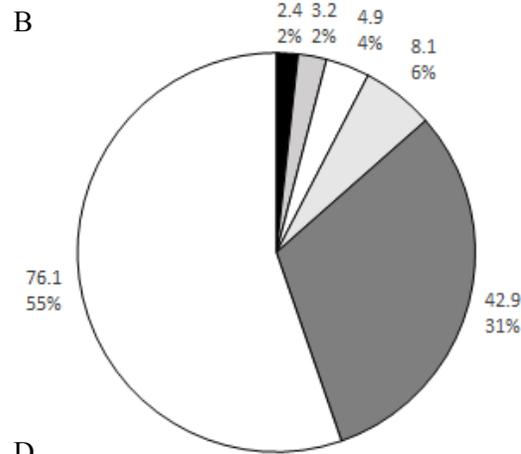
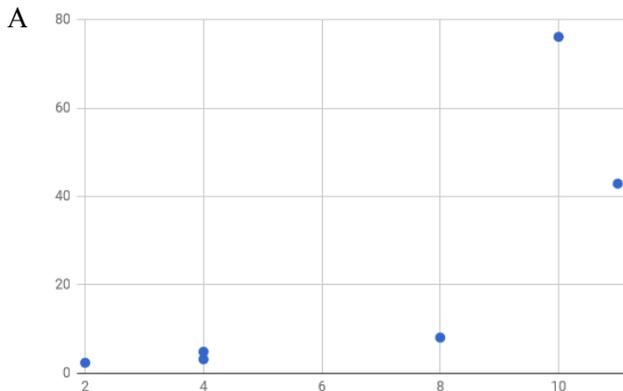
Appendix B: Post-test

In a paper published in 1982 in the journal *Ecology*, William Tonn and John Magnuson reported the number of fish species found in minnow traps during two 9-week periods in winter (January-March) and summer (June-August) in six lakes in northern Wisconsin. Their results are shown in Table 1; note that lake area is expressed in hectares, a unit of measurement equal to 10,000 m².

Table 1. Number of fish species sampled by minnow traps (Tonn and Magnuson 1982; [link](#)).

Lake	Lake area (hectares)	Number of species
33-6	2.4	2
Whynot	3.2	4
Blueberry	4.9	4
Mystery	8.1	8
Grassy	42.9	11
Apeekwa	76.1	10

1. Circle the graph that best depicts how lake area affects the number of fish species in these lakes.



2. From these data (Table 1), what kind of pattern do you see?

- A. No pattern whatsoever
- B. Somewhat positive relationship between size of lake and number of fish species
- C. Somewhat negative relationship between size of lake and number of fish species
- D. No idea

3. Circle all of the letters, if any, listing reasonable assumptions that you must make about the source and validity of these fish data:

- A. Equal sampling effort across seasons
- B. Fish are not migrating from winter to summer
- C. The entire lake was sampled
- D. Some fish species are wary of traps
- E. Fish are not migrating vertically within the lake from season to season

4. Choose the most appropriate hypothesis to explain the relationship between size of lake and number of fish species:

- A. Larger lakes hold a larger number of fish
- B. Lake temperature affects the number of fish species
- C. Larger lakes generally offer more types of habitats and area thus more niches for fish species
- D. Bullfrogs are eating the fish eggs in smaller lakes
- E. People prefer to go fishing in larger lakes
- F. I don't know how to detect and/or evaluate an hypothesis

5. If the lake area were converted from hectares to square miles, any observed relationship between lake area and number of fish species would:

- A. Increase
- B. Decrease
- C. Stay the same
- D. No idea

6. Tonn and Magnuson (1982; [link](#)) actually generated these fish data in 1978 from a collection of 18 lakes. From an ecological standpoint, select all of the relevant reasons why might you want to resample these lakes:

- A. The fish may have grown in size since 1978
- B. Shifts in relative abundance of each species may have occurred
- C. You have some new nets for catching large fish
- D. Environmental conditions have changed in the lakes since 1978
- E. The kinds of fishing lures have changed since 1978
- F. Novel (new) species may have been introduced into the lakes
- G. Boat sizes have increased over the years
- H. Old data, like from 1978, have no value and must be renewed with new data

For the following open-response questions, please take a few minutes to provide written feedback below each question.

7. What was the most interesting thing that you learned by completing this module?

8. What research questions came to you as you went through this module?

9. What do you perceive as the value of natural history collections?

10. How else would you use natural history collections online databases?

11. How would you improve this module? Please be specific.

Mission, Review Process & Disclaimer

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