# How many critters can an island hold? Using digitized natural history collections to test real hypotheses about island biogeography 

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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 in a spreadsheet
- 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.

## 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=rL7kAv323 Bk
- 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 (Appendix A) 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, as well as the challenges of using presence-only data. 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 posttests were created to measure student understanding (included as Appendices B and C, 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 posttest 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-B, 2-B, 3-B/C/E, 4-A, 5-C, and 6-A/C/E, and correct responses for the post-test are 1-B-, 2-D, 3-A/C, 4C, $5-\mathrm{C}$, and $6-\mathrm{B} / \mathrm{D} / \mathrm{F}$. Instructors may also choose to use some of the questions as summative assessment items on subsequent quizzes or exams.

## 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.

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

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.

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# Appendix A: Student Handout <br> Do Larger Islands Have Greater Species Richness? Testing a Biodiversity Hypothesis Using Data from Natural History Collections 


"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)
2. Watch video about digitizing natural history collections data (https://www.youtube.com/watch? v=WyRc6QtZQgo)
3. Watch video about Arctos (https://youtu.be/XQwXw0e9w-E)
4. Watch video about Excel tools 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 1). 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 1. Continental and oceanic islands
The islands studied in this module are part of the Alexander Archipelago (AA) of Southeast Alaska (Figure 2). 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 2. Islands of the Alexander Archipelago. Image from Google Earth; Map Data: LDEO-Columbia, NSF, NOAA, SIO, NOAA, U.S. Navy, NGA, GEBCO; Image: IBCAO; Image Landsat/Copernicus

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. This glacial history may result in the islands acting as oceanic islands because only as the ice receded from the area and the islands were uncovered did they provide opportunities for colonization. Table 1 on the next page includes a list of the 32 islands with associated areas that will be used in your study.


Figure 3. 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 $\mathrm{m}^{2}$ ) are provided. Islands are sorted by increasing land area.

| Island | Area $\left(\mathbf{m}^{2}\right)$ |
| :---: | :---: |
| 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 depositories 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 some of 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
state
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 select 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 island, and enter these data into Table 2.

Table 2. Island areas and species richness.

| Island Name | Area (m$\left.{ }^{2}\right)$ | 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. Once all of the data has been entered, make a copy of the Google sheet and edit the title to add your name.

In your file, 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 draft a descriptive figure legend 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 which 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 devoid of vegetation and other organisms 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.

## Appendix B: 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 and range from $2.6 \mathrm{~km}^{2}$ ( 1 square-mile) to $249 \mathrm{~km}^{2}$ ( 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 $\left(\mathbf{k m}^{2}\right)$ | 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 | 249 | 31 |
| Santa Cruz | 240 |  |  |

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 C: 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 (JuneAugust) 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 $10,000 \mathrm{~m}^{2}$.

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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