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| **Biodiversity, Big Data, and the Fossil Record** | Logo  Description automatically generated |

**Objectives:** Students completing this module will be able to:

1. Access and evaluate data from the fossil record to identify and study major events in the history of life;
2. Explain how science is a non-linear process of investigation.

**Introduction**

Biodiversity, the range and diversity of life, is critical to the healthy functioning of both individual ecosystems and the biosphere. Understanding how global biodiversity has changed throughout the Earth’s history is an important contribution of paleobiology to the biological sciences. By studying the fossil record, paleobiologists can determine how the diversity of different taxonomic groups has changed over hundreds of millions of years, and how global change may drive major shifts in global biodiversity.

In this lab, we will be making and testing hypotheses about how the biodiversity of groups of organisms may vary through time. To keep track of our scientific process, we will be using the How Science Works interactive from the University of California Museum of Paleontology. Click on this link [here](https://undsci.berkeley.edu/interactive/) and work through the tutorial to learn how to use the interactive. Keep this web page open– we will use this to track our own scientific process in the lab today!

**Reflection**: Paleobiologists study the fossil record to build our knowledge of the history of life, asking questions such as “Have modern organisms been as diverse as they are today throughout the Earth’s history?” To start your How Science Works flowchart, click on the “Asking Questions” bubble in the “Exploration and Discovery” circle. (Be sure to give your project a name.)

**Question 1a:** In a short paragraph, describe how you think science works to build new knowledge about the natural world.

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**Question 1b:** In what ways is the Nature and Process of Science flowchart different to the view you described in **Question 1a**? In what ways is it similar?

**Forming a Hypothesis**

Changes in the biodiversity of a taxonomic group (e.g., species, genus, family, etc.) are a function of extinction and origination:

**Extinction:** When a taxonomic group has no surviving members; the loss of biodiversity.

**Origination:** The evolution of a new taxonomic group; the addition of biodiversity.

Extinction and origination within a taxonomic group is in part controlled by both their ecology (i.e. how they interact with their surrounding) and physiology (i.e. how they function internally). Thus, we might expect that different groups of organisms would have different patterns of diversity throughout the Earth’s history!

Let’s start by studying the biodiversity history of two taxonomic groups: Brachiopoda and Bivalvia. Each of these groups have thrived in the oceans for the last 500 million years. Take a look at the table below to learn more about each group of organisms:

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| **Brachiopoda**  (Class: Rhynchonelliformea) | **Bivalvia** |
| [A picture containing invertebrate, mollusk, seasnail, dark  Description automatically generated](https://skfb.ly/6RKuV) |  |
| 1. Soft body covered by two hard shells 2. Filter-feeders (i.e., capture food particles from water) 3. Limited movement, fixed in place or free-lying 4. Small muscle mass | 1. Soft body covered by two hard shells 2. Filter feeders, deposit feeders, carnivores 3. Highly active, capable of swimming and burrowing 4. Large muscle mass including a muscular “foot” and siphon |

**Question 2:** We stated that the biodiversity of a group of organisms depends on their ecology and physiology. Do you think brachiopods and bivalves will display similar patterns of diversity across the Earth’s history based on our knowledge of their ecology and physiology? Phrase this in terms of a new hypothesis: “I believe that X *because* Y.”

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**Reflection:** Your answer to **Question 2** will function as your hypothesis for your analysis. Add this step to your How Science Works chart by clicking on "Hypothesis” and "Expected results/observations" to your flowchart. To test this hypothesis, let’s go gather some data from the fossil record!

**Gathering Data and Evaluating Hypotheses**

To study the fossil record, we will be using the Paleobiology Database. The Paleobiology Database is a compilation of published fossil occurrences from the scientific literature. Using the Paleobiology Database will allow us to tabulate the total genus-level richness of brachiopods and bivalves throughout the Earth’s history, which we can use as a simple measurement of their global biodiversity. By tracking the diversity of a taxonomic group across Earth’s history, we can reconstruct diversity curves that allow us to study patterns of extinction (drops in diversity) and origination (rises in diversity) within each group.

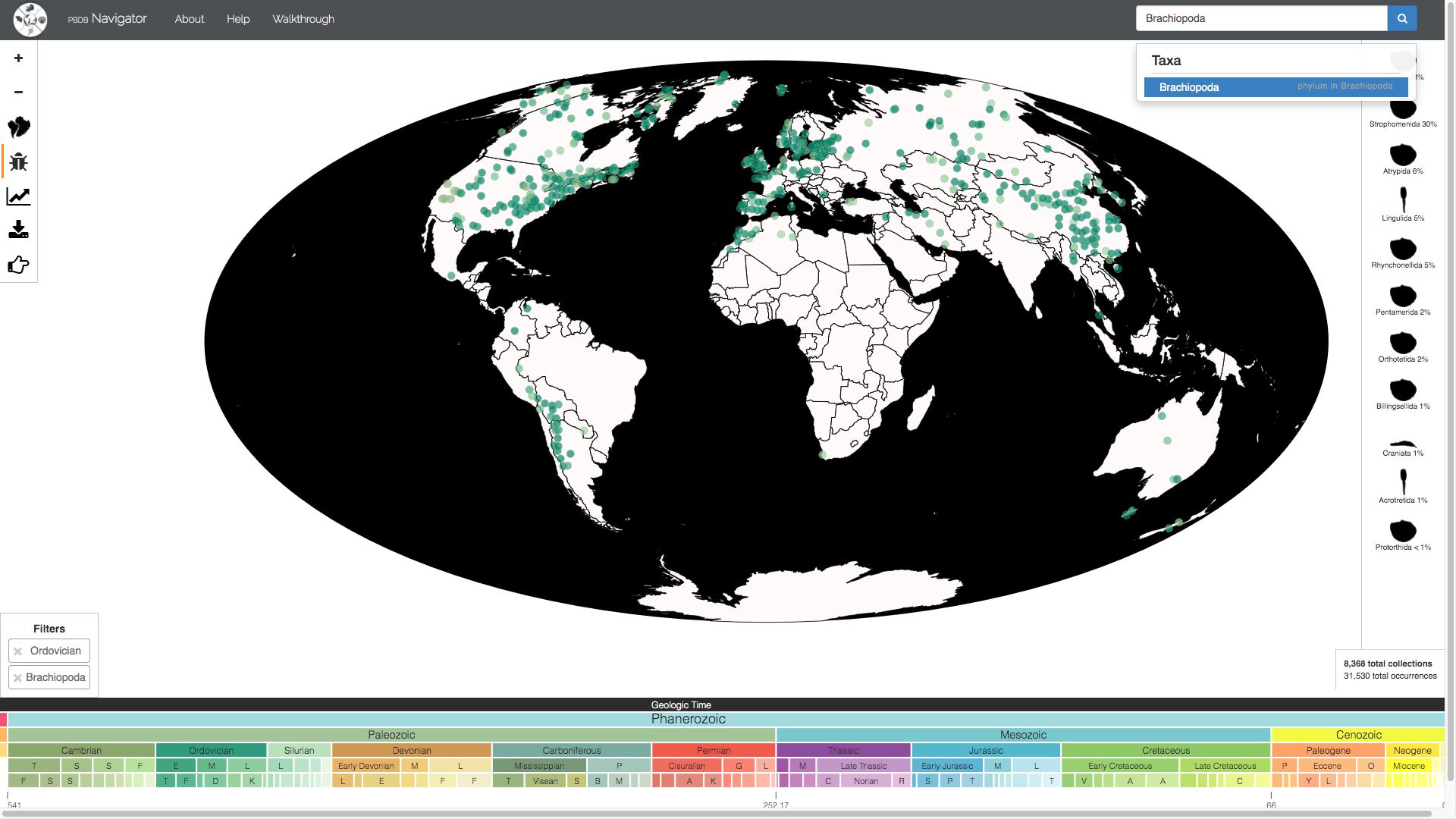
Follow these instructions to learn more about the Paleobiology Database (PBDB):

1. Click on this link to go to the PBDB: <https://paleobiodb.org/navigator/>
2. Click on “Go to Application” to see the main page of the PBDB.
3. To learn about the layout of the PBDB, take a look at the following page.

*Note: Your map may not look exactly like the image on the next page, but that is okay!*

1. Enter the taxon of interest in this box and click on it in the drop-down menu.

2. The map shows the locations of the fossils searched for in the PBDB as colored dots.



Youngest

(Present day)

Oldest

3. The color of each dot corresponds to the geological time scale at the bottom of the screen. Clicking on a segment searches for fossils from that time interval.

4. Search parameters are shown in the bottom-left of the screen.

5. Click this icon to construct a diversity curve of the fossils shown on the map.

Let's create our own PBDB search to create a diversity curve for bivalves:

1. In the search box, type Bivalvia and select it from the drop-down menu
2. Click on the icon showing a tiny line graph on the far left of the screen to create a global record of genus-level diversity for Bivalvia for the last 540 million years
3. Click on “Use advanced diversity curve generator”
4. Make sure “Rangethrough diversity” is the only check-box selected. This tabulates diversity assuming that a taxon is present in every interval between its origination and extinction.
5. Take a moment to observe the diversity curve you produced before answering the following questions. Do NOT close your PBDB tabs!

*Note: Time along the x-axis goes from oldest (540 million years ago, left) to youngest (Present day, right) and its units are "millions of years ago”, same as the main PBDB page.*

**Question 3a:** Briefly describe the general pattern in bivalve diversity (i.e., is it gradually increasing, decreasing, and/or is there a sudden change in diversity)? Ignore the sharp drop in diversity close to the present-day (0)– this is caused by how the PBDB compiles data.

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**Question 3b:** When is the biggest drop (largest extinction) in bivalve diversity? Provide the time bin(s) in which this occurs, along with the approximate age of the drop in diversity. Ignore the artificial drop in diversity towards the present. (Listing the initial of the time period here is fine.)

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Keep your first PBDB window open and create a new window with the PBDB using this link here (<https://paleobiodb.org/navigator/>). Now search for "Rhynchonelliformea" (a group of brachiopods at the same taxonomic level as bivalves) in the database, repeating the same steps as you used to create the diversity curve for bivalves.

**Question 4a:** In a sentence or two, describe the general pattern in brachiopod diversity (i.e., is it increasing, decreasing, and/or is there a sudden change in diversity)? Once again, ignore the sharp drop in diversity close to the present.

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**Question 4b:** When is the biggest drop (largest extinction) in brachiopod diversity? Provide the time bin(s) in which this occurs, along with the approximate age of the drop in diversity. Ignore the artificial drop in diversity towards the present. (Listing the initial of the time period here is fine.)

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**Reflection:** Look at the How Science Works flowchart and consider what steps you completed in this station. We started by “Exploring the literature” (the PBDB) and then produced our “Actual results/observations.” Click on these steps, in order, to add them to your flowchart.

**Question 5a:** You identified the largest drops in diversity for both brachiopods and bivalves. Look back at your graphs: For each drop, does the other group also show a similar drop in diversity?

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**Question 5b:** In **Question 2**, you proposed a hypothesis regarding diversity patterns in brachiopods and bivalves. **Bold** or circle the answer below that you think best completes this description of our findings thus far: "The coordinated drops in diversity observed in both brachiopods and bivalves..."

1. …Support this hypothesis.
2. …Oppose this hypothesis.
3. …Inspire a new/revised hypothesis.
4. …Inspire revised assumptions.

**Question 5c:** Explain why your answer to **Question 5b** best describes your findings thus far.

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**Question 6a:** Our initial set of assumptions stated that the ecology (how an organism interacts with its environment) and physiology (how an organism functions and the range of environmental conditions it can tolerate) of a taxonomic group can affect its diversity. What critical control on diversity (included in the definitions of ecology and physiology here) have we yet to consider?

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**Question 6b:** Let's generate a hypothesis using your answer to **Question 6a**. Complete this hypothesis: "Because this control (your answer to **Question 6a**) directly impacts how organisms interact with their surroundings, large and abrupt changes to this control would..."

1. ...Cause major extinctions (drops in diversity) across many groups of organisms.
2. ...Cause major extinctions across only a few organisms.
3. ...Cause no impact on diversity (no extinctions).
4. None of the above.

**Question 6c:** Explain your reasoning for your answer to **Question 6b**.

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**Reflection:** Add to your How Science Works flowchart based on your answer to **Question 5b**. If you did not select “Inspire revised assumptions,” you should add this to your flowchart as well. Then, you should also add that you created a new hypothesis by clicking on the “Hypothesis” bubble. This hypothesis also generated “Expected results/observations”– you can click on that bubble as well.

**Gathering Data and Evaluating Hypotheses II**

We found that brachiopods and bivalves have very different patterns in diversity throughout the history of life. However, during particular intervals in time, we noticed that both brachiopod and bivalve diversity sharply drops during certain intervals of time. This seems odd given the differences between brachiopods and bivalves.

Let’s explore further: Do we see similar patterns if we begin to look at diversity patterns of marine organisms that are very different from brachiopods and bivalves?

Choose two of the three groups above to investigate in the PBDB:

1. **Foraminifera** are a group of single-celled protists that create a hard outer shell to protect themselves. They extend their cell through tiny pores in this shell to capture food particles. While some foraminifera passively drift through the ocean, some also live at or underneath the seafloor.
2. **Anthozoa** are a group of organisms that include stony corals. There have been several different groups of coral throughout their existence. Modern corals have symbiotic green algae that provide them with the food they need to survive.
3. **Osteichthyes** (bony fish) are very common in the oceans today. They are active swimmers that can be found everywhere from beaches to the deepest depths of the ocean and have a range of feeding habits from filter feeders to carnivores!

Then, follow the same procedure as before:

1. Open a new [PBDB](https://paleobiodb.org/navigator/) page
2. In the search box, enter either Foraminifera, Anthozoa, or Osteichthyes and select it from the drop-down menu
3. Click on the icon showing a tiny line graph to create a diversity curve
4. Click on “Use advanced diversity curve generator”
5. Make sure “Rangethrough diversity” is the only check-box selected.

**Question 7a:** In which group of animals did you look at diversity patterns first? In terms of its ecology and physiology, would you consider this organism to be similar or different to brachiopods and bivalves? Explain your answer.

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**Question 7b:** For the group you described in **Question 7a**, do you observe the same drops in diversity that you observed in both brachiopods and bivalves?

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**Question 8a:** In which group of animals did you look at diversity patterns second? In terms of its ecology and physiology, would you consider this organism to be similar or different to brachiopods and bivalves? Explain your answer.

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**Question 8b:** For the group you described in **Question 8a**, do you observe the same drops in diversity that you observed in both brachiopods and bivalves?

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**Question 9:** In **Question 6**, you made a hypothesis about how changes to an alternative control on diversity may or may not generate major extinction events in the fossil record. Do your observations in this station support your hypothesis? Explain why or why not.

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**Reflection:** Add your answer from **Question 9** to your How Science Works flowchart!

**Conclusion**

In this lab, you discovered two of the largest extinction events known in the fossil record! These events are referred to as mass extinctions, cataclysmic global events that drive large numbers of taxonomic groups to extinction in a geologically-short period of time, greatly reducing global biodiversity. Every known mass extinction is associated with abrupt environmental change on a global scale that disrupts the normal functions of organisms and entire ecosystems, causing widespread extinction. Thus, ecology, physiology, and conditions on Earth together play major roles in controlling the diversity of taxonomic groups.

There have been five major mass extinctions throughout the last 540 million years. The “Big Five” mass extinctions were established in a very similar way to what we did today: Paleobiologists compiling diversity data across different groups of organisms across the Earth’s history to study patterns of biodiversity found coordinated drops in diversity across different marine groups of organisms. They were able to show that these events were statistically different from other intervals and represented dramatic perturbations to life on Earth.

**Question 10:** What might be the benefit of identifying and studying mass extinction events in the fossil record?

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Studying mass extinctions provides paleobiologists with case studies of biodiversity crises and how life recovered from these events, allowing us to better understand the history of life on Earth. Without the fossil record, we would have no information on events like mass extinctions that fundamentally altered our planet. This perspective is critical for better understanding both the short- and long-term effects of the biodiversity crisis happening on Earth today!

**Reflection:** Our work today has shown that mass extinction events have occurred over geological time and have had a major impact on the history of life. You can now add "Coming up with new questions/ideas" and “Build Knowledge” to your How Science Works flowchart!

**Question 11a:** Using your How Science Works flowchart, briefly describe the path we took today to discover the presence of mass extinctions in the fossil record. Be sure to explain each step in your flowchart in your response.

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**Question 11b:** You may have been introduced to scientific thought as the scientific method:

Does this perspective accurately represent your work today (**Question 11a**), or does it fail to capture the complexity of your study? Explain why or why not.

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