# TrEnCh-Ed High School Teacher Guide

## Introduction

This teacher guide will provide you with a better understanding as to how the tools of the [TrEnCh-Ed](https://trench-ed.github.io/#) program are organized and how they can be potentially used in your classroom. These tools can be used to teach the Next Generation Science Standards (NGSS) or even the Advanced Placement (AP) Environmental Science course.

TrEnCh-Ed is the educational extension of the [TrEnCh Project](https://trenchproject.github.io/). This project, based in the [Buckley Lab](http://faculty.washington.edu/lbuckley/) at the University of Washington, Seattle, was designed to build computational and visualization tools to **Tr**anslate **En**vironmental **Ch**ange into organismal responses. The project was funded by a National Science Foundation Division of Biological Infrastructure grant (DBI#1349865). The hope is that educators use these tools to educate their students about how living things on our planet are impacted by the current global scale climate change.

Each module consists of a visualization including introductory material and an accompanying worksheet. TrEnCh-Ed consists of the following visualizations:

* **Metabolic Impacts of Climate Change**: Use historic climate data and the temperature dependence of metabolism to compare climate impacts between temperate and tropical regions.
* **Energy Budgets**: Use weather and terrain data to explore how an energy budget is constructed and use it to estimate an organism’s body temperature.
* **Robomussels**: Use data from biomimetic temperature sensors to explore how organisms experience climate.
* **Butterfly Museum Specimens**: Use data from museum specimens to explore how temperature influences morphology and phenology.
* **Wildflower Phenology**: Use historical and resurvey data to explore how temperature influences phenology.
* **RMBL Phenology**: Use climate and phenological data from Rock Mountain Biological Laboratory to explore migration and overwintering species in a high-elevation ecosystem.
* **Grasshopper Resurvey**: Use historical and resurvey data to explore how temperature influences developmental rates and phenology.
* **Marine Range Shifts**: Use survey data to explore the range shifting of marine populations in response to climate change.

The visualizations are arranged above with visualizations at the level of single organisms followed by those addressing population responses to climate change. The visualizations vary in complexity with the first two being the most accessible. The visualizations can be adapted for a range of pedagogies, but most worksheets incorporate inquiry-based learning.

## Standards Alignment

*Next Generation Science Standards (NGSS)*

The Next Generation Science Standards (NGSS) can be directly related to the concepts used in the TrEnCh-Ed program. The standards most closely aligned with TrEnCh-Ed are below along with a description of how the activities align with each standard.

The Next Generation Science Standards are a set of national standards dedicated to the education of secondary (high school) students in a broad field of sciences ([National Research Council, 2012](https://www.nationalacademies.org/our-work/conceptual-framework-for-new-science-education-standards)). The science standards are based around “three dimensional” learning. Disciplinary core ideas (**DCI**s) are the basic science content students should be able to explain by the end of their time in school, the traditional focus of high school science courses. An example of this is the traditional chemistry course learning about gases through a mathematical equation called the combined gas law. The new standards have students focusing on the conceptual nature of gases’ motion rather than the memorization of the gas law equation. NGSS adds two other dimensions to learning beyond the traditional content. Students learn science skills through Science and Engineering Practices (**SEP**s). In addition to SEPs, NGSS also includes Cross-Cutting Concepts (**CCC**s). Cross-cutting concepts are science concepts which are used and shared among all science courses as well as courses outside of science. A cross-cutting concept (CCC) most common in science is the idea of energy. Energy is taught in all science classes in different ways, but it all represents a common theme. The concept of energy can then be used to explain many concepts in science ranging from photosynthesis to the mechanisms behind chemical reactions. These three dimensions create a more well-rounded student who has science skills to succeed in their everyday life or at the university level.

For more information on NGSS, go to <https://www.nextgenscience.org/>. This website provides in depth explanations around the work that went into developing these standards.The NGSS require in depth, multidimensional learning requiring students to deeply understand science content and utilize skills to demonstrate their understanding. These suggested standards can be touched on using content from the TrEnCh-Ed materials; however, in order to truly cover the standard, additional information may need to be supplemented.

*Life Science Standards (LS)*

A TrEnCh-ed focus is on using models to understand how organisms experience their environment (HS-LS2-4). Translating environmental conditions into how organisms experience their environment is central to understanding biological responses to climate change. The activities guide students through engaging with a variety of models ranging from energy budgets to understand heat flow between organisms and their environment to physical replicas of intertidal mussels to investigate patterns of thermal stress.

The flow of heat between organisms and their environment is central to how climate change impacts organisms (HS-LS2-4). Estimating heat flow and balancing an energy budget allows understanding the conservation and cycling of energy. Heat determines an organism’s body temperature which in turn determines the level of activity for ectothermic organisms (those dependent on external heat sources). Activity levels influence energy expenditure and intake, which drives the cycling of matter between organisms and their environment.

TrEnCh-Ed facilitates student exploration of models and engagement with data to probe how organisms and populations and ultimately communities and biodiversity respond to climate change (HS-LS2-2). The activities allow students to evaluate evidence and develop reasoning to understand and predict what aspects of ecosystems are likely to remain stable as climate changes and which will change (HS-LS2-6). TrEnCh-Ed also facilitates students understanding how individual response and group response relate and can impact survival (HS-LS2-8) through activities spanning organismal level responses and proceeding to population level responses, and the impacts of extreme climate change on distribution and extinction (HS-LS4-5).

The performance expectations along with their three dimensional components are listed in the following four pages. This information was taken directly from the Next Generation Science Standards and the work of the National Research Council.

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| **Performance Expectation** | **Visualization(s) with Links** |
| HS-LS1-3 | Energy Budget; Robomussels |
| HS-LS2-2 | Butterfly Museum Specimens; Temperature Metabolism; Wildflower Phenology; Robomussels |
| HS-LS2-4 | Energy Budget; Temperature Metabolism; Robomussels |
| HS-LS2-6 | Grasshopper Resurvey; RMBL Phenology; Robomussels; Marine Range Shifts |
| HS-LS2-8 | Marine Range Shifts |
| HS-LS4-5 | Marine Range Shifts |

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| **HS-LS1-3 From Molecules to Organisms: Structures and Processes** | | |
| Students who demonstrate understanding can: | | |
| **HS-LS1-3.** | Plan and conduct an investigation to provide evidence that feedback mechanisms maintain homeostasis. | |

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| **Science and Engineering Practices (SEP)** | **Disciplinary Core Ideas (DCI)** | **Crosscutting Concepts (CCC)** |
| **Planning and Carrying Out Investigations**  Planning and carrying out in 9-12 builds on K-8 experiences and progresses to include investigations that provide evidence for and test conceptual, mathematical, physical, and empirical models.   * Plan and conduct an investigation individually and collaboratively to produce data to serve as the basis for evidence, and in the design: decide on types, how much, and accuracy of data needed to produce reliable measurements and consider limitations on the precision of the data (e.g., number of trials, cost, risk, time), and refine the design accordingly. | **LS1.A: Structure and Function**   * Feedback mechanisms maintain a living system’s internal conditions within certain limits and mediate behaviors, allowing it to remain alive and functional even as external conditions change within some range. Feedback mechanisms can encourage (through positive feedback) or discourage (negative feedback) what is going on inside the living system. | **Stability and Change**   * Feedback (negative or positive) can stabilize or destabilize a system. |

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| **HS-LS2-2 Ecosystems: Interactions, Energy, and Dynamics** | | |
| Students who demonstrate understanding can: | | |
| **HS-LS2-2.** | Use mathematical representations to support and revise explanations about factors affecting biodiversity and populations in ecosystems of different scales. | |

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| **Science and Engineering Practices (SEP)** | **Disciplinary Core Ideas (DCI)** | **Crosscutting Concepts (CCC)** |
| **Using Mathematics and Computational Thinking**  Mathematical and computational thinking in 9-12 builds on K-8 experiences and progresses to using algebraic thinking and analysis, a range of linear and nonlinear functions including trigonometric functions, exponentials and logarithms, and computational tools for statistical analysis to analyze, represent, and model data. Simple computational simulations are created and used based on mathematical models of basic assumptions.   * Use mathematical representations of phenomena or design solutions to support claims. | **LS2.A: Interdependent Relationships in Ecosystems**   * Ecosystems have carrying capacities, which are limits to the numbers of organisms and populations they can support. These limits result from such factors as the availability of living and nonliving resources and from such challenges such as predation, competition, and disease. Organisms would have the capacity to produce populations of great size were it not for the fact that environments and resources are finite. This fundamental tension affects the abundance (number of individuals) of species in any given ecosystem.   **LS2.C: Ecosystem Dynamics, Functioning, and Resilience**   * A complex set of interactions within an ecosystem can keep its numbers and types of organisms relatively constant over long periods of time under stable conditions. If a modest biological or physical disturbance to an ecosystem occurs, it may return to its more or less original status (i.e., the ecosystem is resilient), as opposed to becoming a very different ecosystem. Extreme fluctuations in conditions or the size of any population, however, can challenge the functioning of ecosystems in terms of resources and habitat availability. | **Scale, Proportion, and Quantity**   * Using the concept of orders of magnitude allows one to understand how a model at one scale relates to a model at another scale. |

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| **HS-LS2-4 Ecosystems: Interactions, Energy, and Dynamics** | | |
| Students who demonstrate understanding can: | | |
| **HS-LS2-4.** | Use mathematical representations to support claims for the cycling of matter and flow of energy among organisms in an ecosystem. | |

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| **Science and Engineering Practices (SEP)** | **Disciplinary Core Ideas (DCI)** | **Crosscutting Concepts (CCC)** |
| **Using Mathematics and Computational Thinking**  Mathematical and computational thinking in 9-12 builds on K-8 experiences and progresses to using algebraic thinking and analysis, a range of linear and nonlinear functions including trigonometric functions, exponentials and logarithms, and computational tools for statistical analysis to analyze, represent, and model data. Simple computational simulations are created and used based on mathematical models of basic assumptions.   * Use mathematical representations of phenomena or design solutions to support claims. | **LS2.B: Cycles of Matter and Energy Transfer in Ecosystems**   * Plants or algae form the lowest level of the food web. At each link upward in a food web, only a small fraction of the matter consumed at the lower level is transferred upward, to produce growth and release energy in cellular respiration at the higher level. Given this inefficiency, there are generally fewer organisms at higher levels of a food web. Some matter reacts to release energy for life functions, some matter is stored in newly made structures, and much is discarded. The chemical elements that make up the molecules of organisms pass through food webs and into and out of the atmosphere and soil, and they are combined and recombined in different ways. At each link in an ecosystem, matter and energy are conserved. | **Energy and Matter**   * Energy cannot be created or destroyed - it only moves between one place and another place, between objects and/or fields, or between systems. |

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| **HS-LS2-6 Ecosystems: Interactions, Energy, and Dynamics** | | |
| Students who demonstrate understanding can: | | |
| **HS-LS2-6.** | Evaluate claims, evidence, and reasoning that the complex interactions in ecosystems maintain relatively consistent numbers and types of organisms in stable conditions, but changing conditions may result in a new ecosystem. | |

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| **Science and Engineering Practices (SEP)** | **Disciplinary Core Ideas (DCI)** | **Crosscutting Concepts (CCC)** |
| **Engaging in Argument from Evidence**  Engaging in argument from evidence in 9–12 builds on K–8 experiences and progresses to using appropriate and sufficient evidence and scientific reasoning to defend and critique claims and explanations about the natural and designed world(s). Arguments may also come from current scientific or historical episodes in science.   * Evaluate the claims, evidence, and reasoning behind currently accepted explanations or solutions to determine the merits of arguments. | **LS2.C: Ecosystem Dynamics, Functioning, and Resilience**   * A complex set of interactions within an ecosystem can keep its numbers and types of organisms relatively constant over long periods of time under stable conditions. If a modest biological or physical disturbance to an ecosystem occurs, it may return to its more or less original status (i.e., the ecosystem is resilient), as opposed to becoming a very different ecosystem. Extreme fluctuations in conditions or the size of any population, however, can challenge the functioning of ecosystems in terms of resources and habitat availability. | **Stability and Change**   * Much of science deals with constructing explanations of how things change and how they remain stable. |

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| **HS-LS2-8 Ecosystems: Interactions, Energy, and Dynamics** | | |
| Students who demonstrate understanding can: | | |
| **HS-LS2-8.** | Evaluate the evidence for the role of group behavior on individual and species’ chances to survive and reproduce. | |

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| **Science and Engineering Practices (SEP)** | **Disciplinary Core Ideas (DCI)** | **Crosscutting Concepts (CCC)** |
| **Engaging in Argument from Evidence**  Engaging in argument from evidence in 9–12 builds on K–8 experiences and progresses to using appropriate and sufficient evidence and scientific reasoning to defend and critique claims and explanations about the natural and designed world(s). Arguments may also come from current scientific or historical episodes in science.   * Evaluate the claims, evidence, and reasoning behind currently accepted explanations or solutions to determine the merits of arguments.   **Scientific Knowledge is Open to Revision in Light**  **of New Evidence**   * Scientific argumentation is a mode of logical discourse used to clarify the strength of relationships between ideas and evidence that may result in revision of an explanation. | **LS2.D: Social Interactions and Group Behavior**   * Group behavior has evolved because membership can increase the chances of survival for individuals and their genetic relatives. | * **Cause and Effect:** Empirical evidence is required to differentiate between cause and correlation and make claims about specific causes and effects. |

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| **HS-LS4 Biological Evolution: Unity and Diversity** | | |
| Students who demonstrate understanding can: | | |
| **HS-LS4-5.** | Evaluate the evidence supporting claims that changes in environmental conditions may result in: (1) increases in the number of individuals of some species, (2) the emergence of new species over time, and (3) the extinction of  other species. | |

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| **Science and Engineering Practices (SEP)** | **Disciplinary Core Ideas (DCI)** | **Crosscutting Concepts (CCC)** |
| **Engaging in Argument from Evidence**  Engaging in argument from evidence in 9-12 builds on K-8 experiences and progresses to using appropriate and sufficient evidence and scientific reasoning to defend and critique claims and explanations about the natural and designed world(s). Arguments may also come from current or historical episodes in science.   * Evaluate the evidence behind currently accepted explanations or solutions to determine the merits of arguments. | **LS4.C: Adaptation**   * Changes in the physical environment, whether naturally occurring or human induced, have thus contributed to the expansion of some species, the emergence of new distinct species as populations diverge under different conditions, and the decline–and sometimes the extinction–of some species. * Species become extinct because they can no longer survive and reproduce in their altered environment. If members cannot adjust to change that is too fast or drastic, the opportunity for the species’ evolution is lost. | * **Cause and Effect:** Empirical evidence is required to differentiate between cause and correlation and make claims about specific causes and effects. |

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## Crosscutting concepts

Climate change biology provides an excellent venue for students to investigate each of the crosscutting concepts.

***Cause and Effect***

TrEnCh-ed facilitates understanding of cause and effect by exploring the mechanisms by which organisms respond to changing and variable environments. Most activities investigate correlations between climate conditions and biological responses, so they can not definitively attribute causation. However, using models and exploring mechanisms helps substantiate cause and effect relationships. Students are encouraged to consider experiments or additional data collections that would establish causal relationships.

***Scale, Proportion, and Quantity***

Translating environmental conditions such as air temperature into the physiological experience of organisms allows students to engage with the concepts of scale, proportion, and quantity. For example, students quantify how body size determines to what extent heat flow warms up an organism. They explore how the accelerating temperature dependence of metabolic rate influences how much energy use changes with changes in temperature. Spatial scales are invoked by examining how an organism can move between habitats to alter its experience of the environment. Temporal scales are essential to consider since organisms are responding to both short term climate extremes and variability and long term climate change.

***Systems and System Models***

Defining the system of an organism and its environment is central to understanding the biological impacts of climate change. One visualization encourages students to identify the forms of heat exchange between organisms and their surroundings (e.g., heat exchange through contact with the ground surface). Students then explore how the forms of heat exchange are balanced in an energy budget to estimate the organism’s body temperature. Students can also explore heat flow between organisms and their environment by examining how physical replicas of intertidal mussels indicate patterns of thermal stress.

***Energy and Matter***

The flow of heat between organisms and their environment is central to how climate change impacts organisms. Estimating heat flow and balancing an energy budget allows understanding the conservation and cycling of energy. Heat determines an organism’s body temperature which in turn determines the level of activity for ectothermic organisms (those dependent on external heat sources). Activity levels influence energy expenditure and intake, which drives the cycling of matter between organisms and their environment.

***Stability and Change***

Concepts of stability and change are central to TrEnCh-ed. Understanding and predicting climate change impacts requires distinguishing between responses to climate change and climate variability. Organisms use physiology and behavior to attempt to maintain constant physiological conditions (homeostasis) when faced with climate extremes. Scientists must select a few processes to focus on that are likely to produce change while simplifying their studies by controlling for those processes that are likely to remain stable. In particular, our butterfly visualization explores the link between environmental conditions and the fitness of butterflies with different traits (levels of wing absorptivity). Students consider evolutionary selection to predict whether traits will remain constant or evolve in response to climate change.

## Science and Engineering Practices

TrEnCh-Ed is designed to engage students with each of the science practices.

***Asking Questions and Defining Problems***

The TrEnCh-Ed visualizations are designed to guide students through asking questions and then refining the questions in response to data on climate change responses. Most of the interactive visualizations allow the user to select what to plot on axes to enable posing and investigating questions.

***Developing and Using Models***

TrEnCh-ed focuses on using models to understand how organisms experience their environment. Translating environmental conditions into how organisms experience their environment is central to understanding biological responses to climate change. The activities guide students through engaging with a variety of models ranging from energy budgets to understand heat flow between organisms and their environment to physical replicas of intertidal mussels to investigate patterns of thermal stress.

***Planning and Carrying Out Investigations***

TrEnCh-Ed includes the stories of the scientists and the research behind the data to facilitate students understanding the process of science. We also include interviews with the scientists that aim to highlight the diverse backgrounds of scientists and the variety of paths they follow into science. We hope that they will expand the number of students who recognize aspects of themselves in scientists.

***Analyzing and Interpreting Data***

The TrEnCh-Ed visualizations are designed for students to participate in analyzing and interpreting data. Students choose what to graph based on hypotheses they develop. The visualizations span a variety of data types from the temperatures of intertidal mussels to the traits of museum specimens to the field surveys of grasshoppers. We also introduce statistical regression analysis to detect trends in the data.

***Using Mathematics and Computational Thinking***

Several activities provide practice with using mathematical representations and computer simulations to investigate climate change responses. For example, one activity allows students to construct and alter an energy budget to understand heat flow between organisms and their environment. We highlight the role of mathematics and computation in understanding how organisms interact with their environments.

***Constructing Explanations and Designing Solutions***

Questions associated with each activity guide students through explaining the implications of the data for understanding of how organisms respond to climate change.

***Engaging in Argument from Evidence***

Students respond to questions about the plots they create. Students are challenged to craft coherent arguments based on the data.

***Obtaining, Evaluating, and Communicating Information***

The interactive components of the visualization allow students to form their own hypotheses and test the hypotheses with data. This flexibility is well suited for students to hone their science communication skills in small group discussions.

*Advanced Placement Environmental Science*

The AP Environmental Science course is outlined through the [Course and Exam Description](https://apcentral.collegeboard.org/pdf/ap-environmental-science-course-and-exam-description.pdf?course=ap-environmental-science) found on [College Board’s](https://www.collegeboard.org/) website. These learning objectives were created to prepare students for their AP Exams which may be accepted by universities to grant college credit and potentially placement within degree programs.

TrEnCh-Ed provides a venue for students to explore many of the focal topics for Advanced Placement Environmental Science courses. Environmental tolerance determines organismal sensitivity to climate change (L.O. 2.4). Tolerance is introduced in the “Physiology” section of the TrEnCh-Ed introductory material and is a foundation for the science presented in the visualizations. A key concept in applying tolerance to understand climate change responses is thermal specialization (L.O. 3.1). Populations in more constant environments-- for example, tropical populations that experience limited seasonality-- often evolve to tolerate only a narrow range of temperatures (L.O. 2.6). This thermal sensitivity can increase their susceptibility to climate change and require responses including shifting behaviors and distributions to persist (L.O. 2.6).

The materials provide a basis for further examining the implications of climate change responses for ecosystem functioning, biodiversity, and human well being. The materials extensively investigate biological responses to climate change and can readily be extended to investigate how changes including to agriculture, pollinators, and disease impact (L.O. 9.4). Thermal stress and constricted distributions provides a concrete venue in which to explore how species become endangered (L.O. 9.9). The TrEnCh-Ed activities can be readily extended to explore how organisms evade thermal stress through behaviors such as thermoregulation and by shifting their distributions through space or time (for example, see the visualizations of shifts in wildflower and grasshopper phenology, L.O. 9.9). Shifting distributions alters interactions among species, reshaping communities and ecosystems. These mechanisms threatening population and species persistence can be used to understand biodiversity impacts and strategies to combat the problem (L.O. 9.10). For example, the TrEnCh-Ed activities provide a platform for exploring how maintaining intact and connected thermal refuges can combat biodiversity loss.

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| **AP Learning Objective** | **Visualization** |
| 2.4 - Describe ecological tolerance |  |
| 2.6 - Describe how organisms adapt to their environment. | Grasshopper Resurvey  Butterfly Museum Specimens  RMBL Phenology  Marine Range Shifts |
| 3.1 - Identify differences between generalist and specialist species. |  |
| 9.4 - Identify the threats to human health and the environment posed by an increase in greenhouse gases |  |
| 9.9 - Explain how species become endangered and strategies to combat the problem. |  |
| 9.10 - Explain how human activities affect biodiversity and strategies to combat the problem. |  |

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| **Learning Objectives (L.O.)** | **Essential Knowledge** |
| 2.4 - Describe ecological tolerance | * **ERT-2.F.1** - Ecological tolerance refers to the range of conditions, such as temperature, salinity, flow rate, and sunlight that an organism can endure before injury or death results. |
| 2.6 - Describe how organisms adapt to their environment. | * **ERT-2.H.1-** Organisms adapt to their environment over time, both in short- and long-term scales, via incremental changes at the genetic level. * **ERT-2.H.2** - Environmental changes, either sudden or gradual, may threaten a species’ survival, requiring individuals to alter behaviors, move, or perish. |
| 3.1 - Identify differences between generalist and specialist species. | * **ERT-3.A.1 -** Specialist species tend to be advantaged in habitats that remain constant, while generalist species tend to be advantaged in habitats that are changing. |
| 9.4 - Identify the threats to human health and the environment posed by an increase in greenhouse gases | * **STB-4.E.1 -** Global climate change, caused by excess greenhouse gases in the atmosphere, can lead to a variety of environmental problems including rising sea levels resulting from melting ice sheets and ocean water expansion, and disease vectors spreading from the tropics towards the poles. These problems can lead to changes in population dynamics and population movements in response. |
| 9.9 - Explain how species become endangered and strategies to combat the problem. | * **EIN-4.B.1** - A variety of factors can lead to a species becoming threatened with extinction, such as being extensively hunted, having limited diet, being outcompeted by invasive species, or having specific and limited habitat requirements. * **EIN-4.B.2** - Not all species will be in danger of extinction when exposed to the same changes in their ecosystem. Species that are able to adapt to changes in their environment or that are able to move to a new environment are less likely to face extinction. * **EIN-4.B.3** - Selective pressures are any factors that change the behaviors and fitness of organisms within an environment. * **EIN-4.B.4** - Species in a given ecosystem compete for resources like territory, food, mates, and habitat, and this competition may lead to endangerment or extinction. |
| 9.10 - Explain how human activities affect biodiversity and strategies to combat the problem. | * **EIN-4.C.1 -** HIPPCO (Habitat destruction, invasive species, population growth, pollution, climate change, and over exploitation) describes the main factors leading to a decrease in biodiversity. * **EIN-4.C.4** - Global climate change can cause habitat loss via changes in temperature, precipitation, and sea level rise. |

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## Materials and resources

Materials can be found at <https://trench-ed.github.io/#resources>.

**Resources for introducing approaches**

While the activities are designed to guide students through the data collection, analysis, and interpretation, additional background knowledge in presenting and analyzing data may facilitate this process. We highlight some of the resources available online below.

Presenting biological data: <https://openoregon.pressbooks.pub/mhccmajorsbio/chapter/presenting-data/>

<https://www.biologyforlife.com/graphing.html>

Regressions:

<http://www.colby.edu/bio/statistics-and-scientific-writing/regression-analysis/>