# Does Overfishing Impact the Genetic Diversity of Fish?

## Materials

**For the leader:**

Computer

Projector

Fish Genetic Diversity Patterns Table

**For the activity:**

Graphing paper

Pencils/pens

Fish Genetic Diversity Data Table

Fish Genetic Diversity Figure

Fish Genetic Diversity Cards

## Overview

When we look at evolution, at the base level, we are investigating and observing changes in the allele frequency in a population over time. Alleles are different versions of a gene, in which are the sequences that codes for a trait (…ATTCGAA…) on a chromosome. A population naturally has a range of alleles that occur in different frequencies. Therefore, when scientists are interested in looking at changes in the genetic diversity of a population (and potential evolutionary changes that have or are occurring), they too look at the allele frequency within a population.

Greater genetic diversity within a population enables the population to adapt to a changing environment. If there are greater numbers of alleles in the population, then there is a higher chance that multiple individuals of that population will have the allele(s) that are suited for the new environmental conditions. Therefore, more individuals of the population would survive to produce offspring that also have the allele(s). Conversely, a loss in genetic diversity would mean that the population would be less likely to survive in the changing environment, as there would be a smaller chance of individuals having the allele(s) suited for the new environment. Thus a loss in genetic diversity can leave a population more vulnerable to a changing environment.

There are a number of factors that impact the genetic diversity of a population. The size of a population has a large influence on the amount of genetic diversity that exists within the population. The larger the population size, the greater there is a chance of different alleles developing and being passed along to offspring. This is also why a population bottleneck (a sharp reduction in the size of a population due to environmental events or human activities) can have such a dramatic impact on the genetic diversity of a population. For example, the large decline in the number of cheetahs due to changing climates ~10,000 years ago reduced the population size initially and then over-hunting in Africa reduced the population size further over the past few centuries. Cheetahs now have some of the lowest genetic diversity of organisms on Earth today; approximately 99% of genes are the same in related Cheetahs as opposed to on average 80% for other organisms.

Because we know that human activities can produce a population bottleneck, scientists became interested in looking at whether overfishing was having an impact on the genetic diversity of fish. A fish population is considered "overfished" when the size of the fish population is too low, aka it is below a predetermined threshold that is necessary to maintain for the future health and success of the fish population (a good resource about overfishing is: http://www.fishwatch.gov/features/overfishing_overfished_same_thing.htm). Overfishing could result in a population bottleneck as large numbers of individuals are removed from the population. However, fish populations are so large to begin with, even those populations that are being overfished still have millions of individuals within the population.

Early studies used a Before-After approach to investigate the question of a relationship between genetic diversity and overfishing. Some studies found a decrease in genetic diversity after overfishing, while other studies found no change in the genetic diversity of fish populations after overfishing. Unfortunately, the way the early studies were conducted was poor, their experimental design meant that they had low statistical power and thus would not able to see an effect even if one existed. Therefore, Pinsky & Palumbi (2013) used a Control-Impact approach to look at 11,000+ genes (rather than 5-10) across 140 species (rather than 1) to determine if there was a relationship between overfishing and genetic diversity. They demonstrated that overfished fish populations had lower genetic diversity than fish populations that have not been overfished.

This lesson has been developed to compliment the work published in: Pinsky, M.L. and S.P. Palumbi. 2013. Meta-analysis reveals lower genetic diversity in overfished populations. Molecular Ecology 23: 29-39.

**Motivating Questions:**

- **Is there evidence that overfishing is impacting the genetic diversity of fish populations? If so, what is the evidence?**

## Take Home Message

Overfishing can remove many individuals from a population, which can lead to a population bottleneck, which can result in a loss of genetic diversity in the fish population.

NOTE – This lesson assumes that your students have an understanding of DNA, genetic diversity, and population bottlenecks.

## Structure

The students will be exposed to data on genetic diversity (number of alleles) and overfishing for a variety of fish groupings. Students will be assigned a fish group to investigate the potential relationship between overfishing and genetic diversity. They will combine their data as a class to look for overall patterns across fish groups, to discuss data interpretation questions, and to make predictions of the potential impact on the genetic diversity of a fish group based on overfishing.

## Time Required

One 45-minute class period

## Activity Outline

| | |
|---|---|
| **Engage**: Students will participate in a brainstorming session about overfishing and the potential impacts of overfishing on the genetic diversity of fish. | 10 minutes |
| **Explore**: Students will interpret data for a fish group to explore the potential relationship between overfishing and genetic diversity and then combine their data as a class to look for the overall patterns. | 25 minutes |
| **Make Sense**: Through a class discussion students will reflect upon the data to process what they have learned about the potential impacts of overfishing on the genetic diversity of fish populations and therefore the potential impacts on characteristics of fish within those populations. | 10 minutes |
| **Total:** | **45 minutes** |

## Audience

High school students ($9^{th}$-$12^{th}$ grade)

## New Jersey Core Curriculum Content Standards - Science

| Content Area | Content Statement | CPI# |
|---|---|---|
| Science Practices: | Interpretation and manipulation of evidence-based models are used to | 5.1.12.A.2 |

| | | |
|---|---|---|
| Understand Scientific Explanations | build and critique arguments/explanations. | 5.1.12.A.2 |
| | Revisions of predictions are based on explanations are based on systematic observations, accurate measurements, and structures data/evidence. | 5.1.12.A.3 |
| Science Practices: Reflect on Scientific Knowledge | Refinement of understanding, explanations, and models occurs as new evidence is incorporated. | 5.1.12.C.1 |
| | Data and refined models are used to revise predications and explanations. | 5.1.12.C.2 |
| | Science is a practice in which an established body of knowledge is continually revised, refined, and extended as new evidence emerges. | 5.1.12.C.3 |
| Science Practices: Participate Productively in Science | Science involves practicing productive social interactions with peers, such as partner talk, whole-group discussions, and small-group work. | 5.1.12.D.1 |
| | Science involves using language, both oral and written, as a tool for making thinking public. | 5.1.12.D.2. |
| Life Science: Heredity and Reproduction | Inserting, deleting, or substituting DNA segments can alter the genetic code. An altered gene may be passed on to every cell that develops from it. The resulting features may help, harm, or have little or no effect on the offspring's success in its environment. | 5.3.12.D.2 |
| Life Science: Interdependence | Stability in an ecosystem can be disrupted by natural or human interactions. | 5.3.12.C.2 |

# Preparation (20 minutes)

1. Write the motivating questions up on the board:

   **Q. Is there evidence that overfishing is impacting the genetic diversity of fish populations? If so, what is the evidence?**

2. Write the Engage questions on the board:
   a. What do you know about genetic diversity?
   b. What is a population?
   c. What could be the relationship between genetic diversity in a population and population size?
   d. What questions do you have about genetic diversity in a population and population size?
   e. What do you know about the impacts of overfishing on fish populations?
   f. What impact(s) could overfishing have on the genetic diversity within a population?
3. Write the Make Sense questions on the board and keep them covered until the end of the lesson:
   a. Were the overall observed patterns in the data what you expected in terms of the relationship between overfishing and genetic diversity? Why or why not?
   b. Were the results from each fish group what you expected? Why or why not?
4. Write (or project) the not completed Fish Genetic Diversity Patterns Table on the board.
5. Make a copy of the Fish Genetic Diversity Data Cards and cut out the individual fish groups to pass out to each small group.

# Engage (10 minutes)

1. Have the students think to themselves and write down their thoughts about the first two Engage questions on the board:
   a. What do you know about genetic diversity?

   b. What is a population?

2. After a few minutes bring the class back together and ask for some volunteers to share what they were thinking about. These questions should be a review for them (based on what you have covered previously in class).
3. Next show the students the next two Engage questions and have them discuss with a partner:
   c. What could be the relationship between genetic diversity in a population and population size?
   d. What questions do you have about genetic diversity in a population and population size?
4. After a few minutes bring the class back together and ask for volunteers to share their thoughts or questions about genetic diversity and population size. Be accepting of all responses and questions, as this is just a brainstorming activity to get the students thinking. Depending on the questions, answer those that you feel are necessary for the students to understand the lesson but do not answer all of them. Encourage the students to think about how they can answer their own questions.
5. Explain to the students that when a fish population is labeled as "overfished" that means that the size of the fish population is too low, aka it is below a predetermined threshold that is necessary to maintain for the future health and success of the fish population (a good resource about overfishing is: http://www.fishwatch.gov/features/overfishing_overfished_same_thing.htm). With this definition in mind, as a whole class discuss the final two Engage questions.
   e. What do you know about the impacts of overfishing on fish populations?
   f. What impact(s) could overfishing have on the genetic diversity within a population?
6. Once the conversation slows down, ask the students:
   a. How can we determine the genetic diversity of a population? – *Count the number of alleles that are similar or different across individuals within a population.*
   b. How can we use this method to determine if overfishing impacts the genetic diversity of fish populations? - *Look at the genetic diversity of a fish population before and after overfishing OR compare the genetic diversity of overfished and not overfished fish populations. These are two ways to look at the impact of an event. The first, Before-After, is done when scientists measure a variable (e.g., genetic diversity) before an event, again after the event, to then compare the data to draw conclusions about the impact of the event. The second, Control-Impact, is when scientists have two groups of the same or similar individuals and keep one as is (control group) and change something within the second group (impact group). Then scientists compare the data to draw conclusions about the consequence of the variable that was changed.*
7. Give the students 30 seconds to think the questions over before taking any responses. When it is time, allow students to contribute their thoughts. Again be accepting of all answers to encourage them to brainstorm.

## Explore (25 minutes)

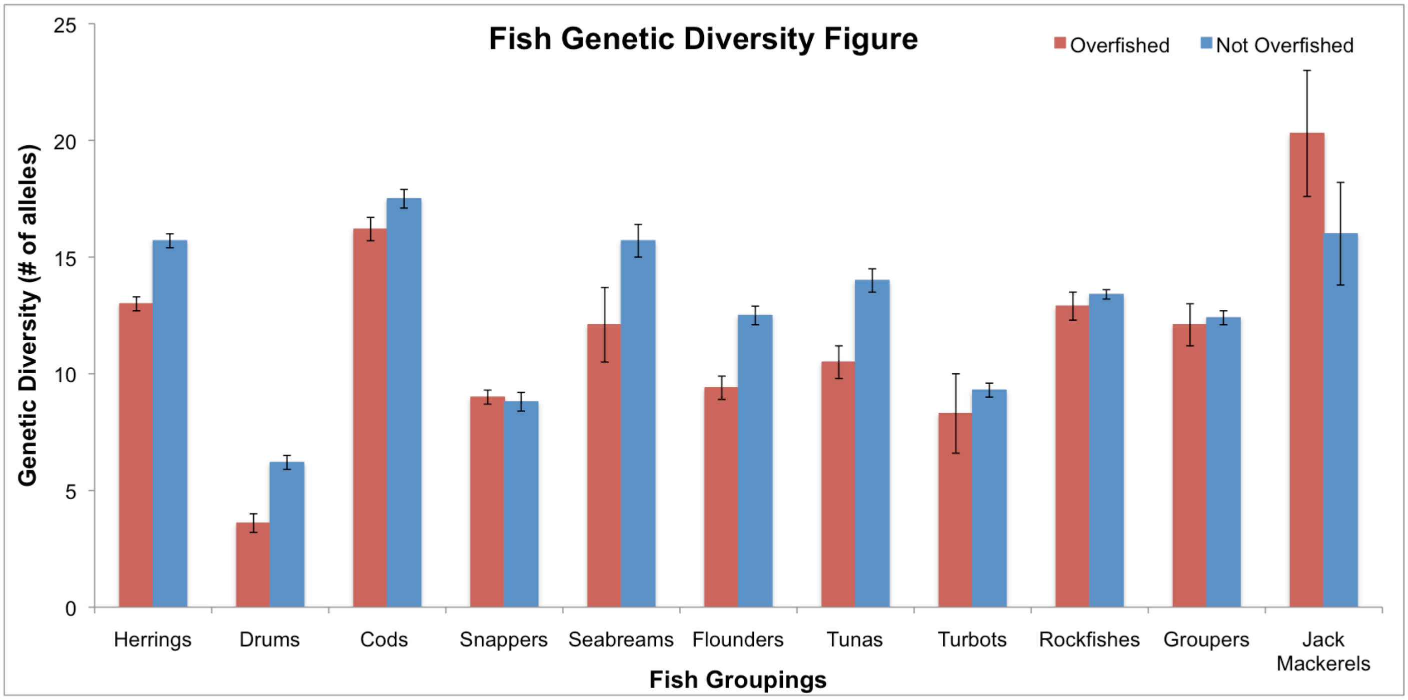
1. Scientists at Rutgers and Stanford Universities were interested if overfishing a fish population would produce a bottleneck and therefore a loss in genetic diversity within the fish population. Because they could not go back in time to sample the fish populations before fishing, instead they look at fish populations that were not overfished and those that were overfished to compare the genetic diversity (Pinsky and Palumbi 2013).

2. Tell the students that will be working in small groups to analyze at genetic diversity (number of alleles) datasets from 11 different fish groups, which were used by Drs. Pinsky and Palumbi, to determine if overfishing has had an impact on the genetic diversity of fish populations.
3. Each group will be given a different fish group from the Fish Genetic Diversity Data Cards to investigate. Listed on each data card is genetic diversity data for the overfished and not overfished populations in the group. The students need to work together to plot this data, answer the prompting questions (1. What conclusions did you draw from the figure? and 2. What does your figure tell us about the relationship between overfishing and genetic diversity?), and draw conclusions from data with respect to the relationship between overfishing and genetic diversity. The students will present their data visualization and conclusions to the class at the end of their 5 minutes.
4. Split the class into 11 groups and pass out the "Fish Genetic Diversity Data Cards" so that each small group receives one.
5. As the students are talking through their data and creating their data visualization, circulate and answer questions as needed.
6. After five minutes have passed (or as the students begin to wrap-up their work), have each group report to the class what they were interpreting and their responses to the two prompting questions:
    a. What conclusions did you draw from the figure?
    b. What does your figure tell us about the relationship between overfishing and genetic diversity?
7. As the students are presenting, complete the "Fish Genetic Diversity Patterns Table." In the end, it should resemble the table below:

| | **Less Diversity in Overfished than Not Overfished** | **No Difference in Diversity between Overfished and Not Overfished** | **Less Diversity in Not Overfished than Overfished** |
|---|---|---|---|
| **Herrings** | X | | |
| **Drums** | X | | |
| **Cods** | X | | |
| **Snappers** | | | X |
| **Seabreams** | X | | |
| **Flounders** | X | | |
| **Tunas** | X | | |
| **Turbots** | X | | |
| **Rockfishes** | X | | |
| **Groupers** | X | | |
| **Jack Mackerels** | | | X |

8. Once all of the groups have reported out, have the students take a moment to write down a description in their own words of the overall pattern across fish species. Encourage the students to look carefully at the data and make sure they site what data/evidence they are using to form their conclusions about the overall pattern in the data.

    NOTE – It may be helpful to project the Fish Genetic Diversity Figure for the students to look at in addition to the Fish Genetic Diversity Patterns Table. The standard error bars are plotted onto the figure, in case you are interested in leading a discussion with your students about how scientists would begin to investigate whether averaged values are statistically different or not. If the error bars of two data points do not overlap (i.e., Herrings (*Clupeidae*)) it is likely that the difference is statistically different. However, if the error bars of two data points do overlap (i.e., Jack Mackerels (*Trachurus*)) it is unlikely that the difference is statistically different. It is important to remind the students that only by running statistical analyses would scientists be able to determine which differences in the data are statistically significant.

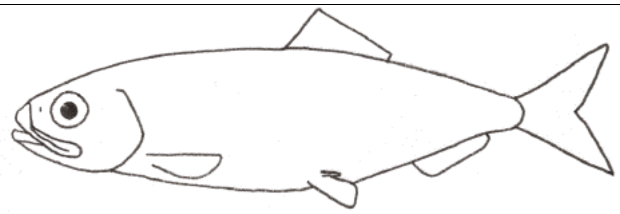
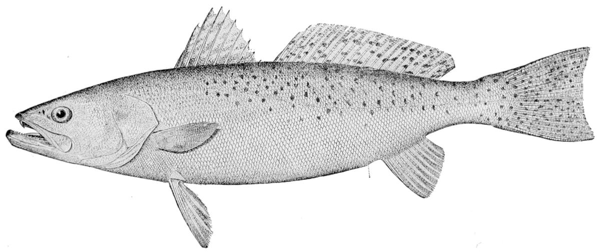


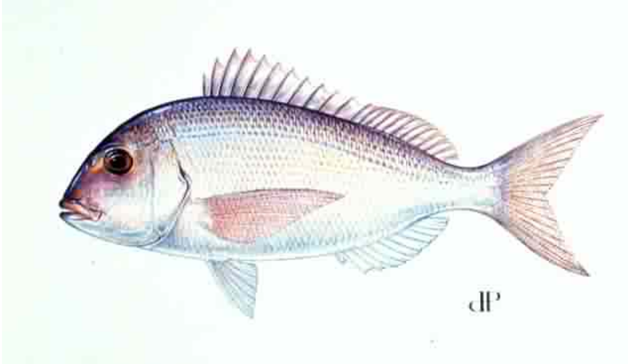
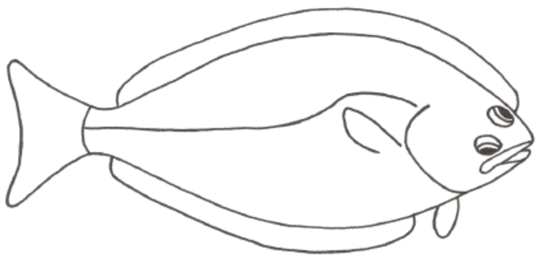
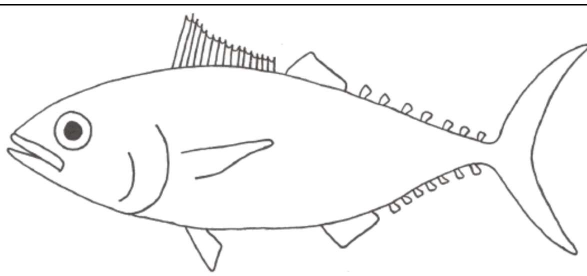
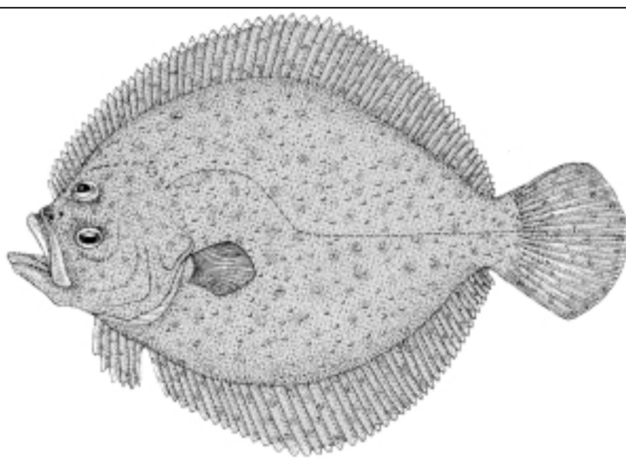

## Make Sense (10 minutes)

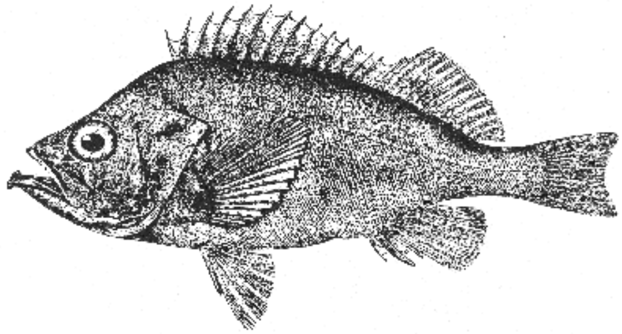
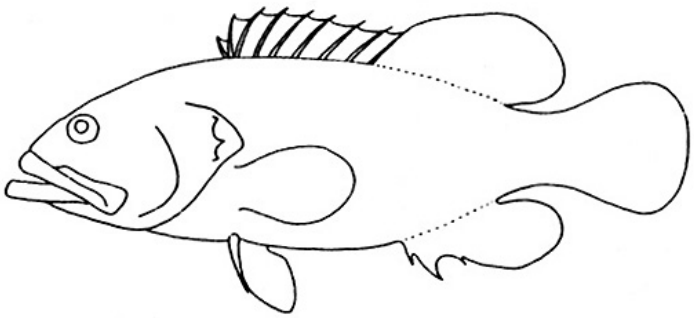
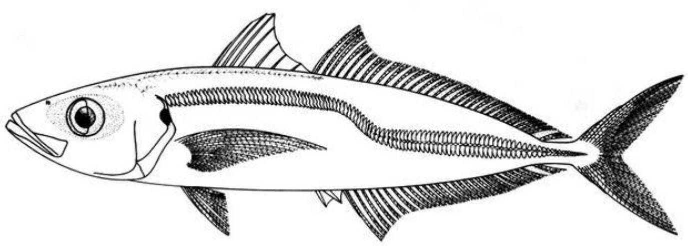
1. After a few minutes, have the students think to themselves and write down their thoughts about the Make Sense questions on the board. Encourage the students to site what data/evidence they used to draw their conclusions:
    a. Were the overall observed patterns in the data what you expected in terms of the relationship between overfishing and genetic diversity? Why or why not?
    b. Were the results from each fish group what you expected? Why or why not?
2. After a few minutes have the students share with a partner their thoughts to the above two questions.
3. After a few minutes ask for volunteers to share what they discussed about the observed relationship between overfishing and genetic diversity. Be accepting of all responses and questions, as this is a processing activity to get the students to think about how they have spent the last 40 minutes learning about a real world example of what impacts genetic diversity in a population.
4. Once the discussion slows down, point to the motivating questions and ask:

    **Q. Is there evidence that overfishing is impacting the genetic diversity of fish populations? If so, what is the evidence?**
5. As a class, have the students review what evidence they used to make conclusions about the relationship between overfishing and genetic diversity. This is your opportunity to make sure the students understand the "take home message" of the section.
6. Ask if the students have any final questions about the activities and concepts of the day.

# Fish Genetic Diversity Data Cards

| | |
|---|---|
|  Burke Museum: http://www.burkemuseum.org/static/FishKey/clup.html | **Herrings (Clupeidae)**<br>Overfished: 13 alleles<br>Not Overfished: 15.7 alleles |
|  Wikipedia/Bulletin of the United States Fish Commission: http://commons.wikimedia.org/wiki/File:Cynoscion_nebulosus.jpg | **Drums (*Cynoscion*)**<br>Overfished: 3.6 alleles<br>Not Overfished: 6.2 alleles |
|  Wikipedia/NOAA: http://commons.wikimedia.org/wiki/File:Atlantic_cod.jpg | **Cods (Gadidae)**<br>Overfished: 16.2 alleles<br>Not Overfished: 17.5 alleles |
|  Zipcodezoo.com: http://zipcodezoo.com/Photos/Lutjanus_bohar_7.jpg | **Snappers (*Lutjanus*)**<br>Overfished: 9 alleles<br>Not Overfished: 8.8 alleles |

| | |
|---|---|
|  Virginia Tech, Dept. of Fisheries and Wildlife Sciences: http://filebox.vt.edu/users/midavis1/pubs.htm | **Seabreams (*Pagrus*)**<br>Overfished: 12.1 alleles<br>Not Overfished: 15.7 alleles |
|  Burke Museum: http://www.burkemuseum.org/static/FishKey/pleuro.html | **Flounders (Plueronectidae)**<br>Overfished: 9.4 alleles<br>Not Overfished: 12.5 alleles |
|  Burke Museum: http://www.burkemuseum.org/static/FishKey/tuna.html | **Tunas (Scombridae)**<br>Overfished: 10.5 alleles<br>Not Overfished: 14 alleles |
|  Fish and Agriculture Organization of the United Nations: http://www.fao.org/fishery/culturedspecies/Psetta_maxima/en | **Turbots (Scophthalmidae)**<br>Overfished: 8.3 alleles<br>Not Overfished: 9.3 alleles |

| | |
|---|---|
| <br>Gulf of Maine Research Institute: http://www.gma.org/fogm/Sebastes_marinus.htm | **Rockfishes (*Sebastes*)**<br>Overfished: 12.9 alleles<br>Not Overfished: 13.4 alleles |
| <br>Online Keys: http://www.online-keys.net/infusions/keys/keys_print.php?key_no=25 | **Groupers (Serranidae)**<br>Overfished: 12.1 alleles<br>Not Overfished: 12.4 alleles |
| <br>Discover Life: http://www.discoverlife.org/mp/20p?see=I_RR993&res=640 | **Jack Mackerels (*Trachurus*)**<br>Overfished: 20.3 alleles<br>Not Overfished: 16 alleles |

## Fish Genetic Diversity Data Table

| Taxon | Common Names | Genetic Diversity – Overfished | Standard Error (+/-) - Overfished | Genetic Diversity – Not Overfished | Standard Error (+/-) – Not Overfished |
|---|---|---|---|---|---|
| **Clupeidae** | **Herrings** | 13 | 0.3 | 15.7 | 0.3 |
| ***Cynoscion*** | **Drums** | 3.6 | 0.4 | 6.2 | 0.3 |
| **Gadidae** | **Cods** | 16.2 | 0.5 | 17.5 | 0.4 |
| ***Lutjanus*** | **Snappers** | 9 | 0.3 | 8.8 | 0.4 |
| ***Pagrus*** | **Seabreams** | 12.1 | 1.6 | 15.7 | 0.7 |
| **Pleuronectidae** | **Flounders** | 9.4 | 0.5 | 12.5 | 0.4 |
| **Scombridae** | **Tunas** | 10.5 | 0.7 | 14 | 0.5 |
| **Scophthalmidae** | **Turbots** | 8.3 | 1.7 | 9.3 | 0.3 |
| ***Sebastes*** | **Rockfishes** | 12.9 | 0.6 | 13.4 | 0.2 |
| **Serranidae** | **Groupers** | 12.1 | 0.9 | 12.4 | 0.3 |
| ***Trachurus*** | **Jack Mackerels** | 20.3 | 2.7 | 16 | 2.2 |

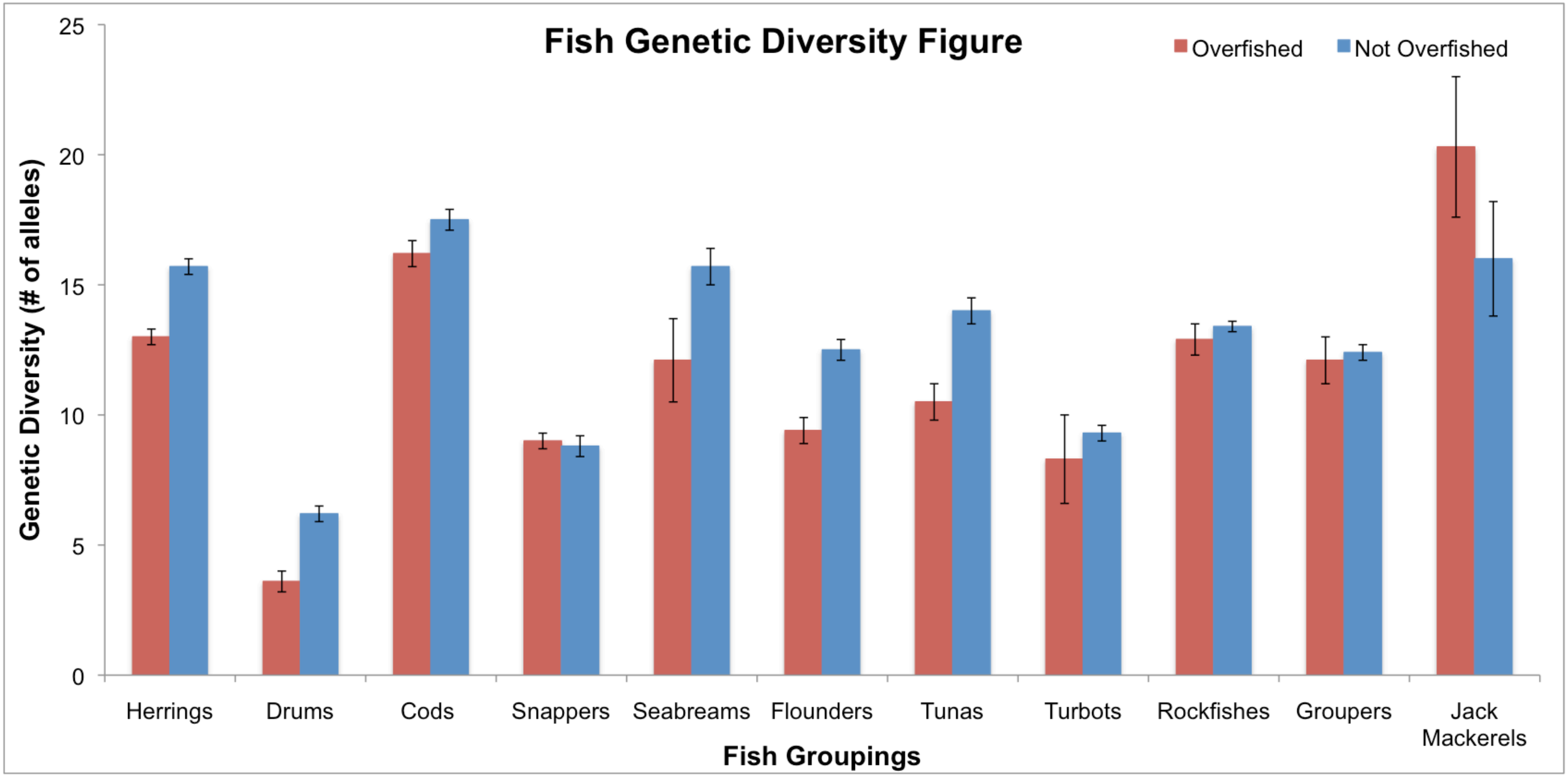
# Fish Genetic Diversity Patterns Table (not completed)

| | Less Diversity in Overfished than Not Overfished | No Difference in Diversity between Overfished and Not Overfished | Less Diversity in Not Overfished than Overfished |
|---|---|---|---|
| **Herrings** | | | |
| **Drums** | | | |
| **Cods** | | | |
| **Snappers** | | | |
| **Seabreams** | | | |
| **Flounders** | | | |
| **Tunas** | | | |
| **Turbots** | | | |
| **Rockfishes** | | | |
| **Groupers** | | | |
| **Jack Mackerels** | | | |

# Fish Genetic Diversity Patterns Table (completed)

| | Less Diversity in Overfished than Not Overfished | No Difference in Diversity between Overfished and Not Overfished | Less Diversity in Not Overfished than Overfished |
|---|---|---|---|
| **Herrings** | X | | |
| **Drums** | X | | |
| **Cods** | X | | |
| **Snappers** | | | X |
| **Seabreams** | X | | |
| **Flounders** | X | | |
| **Tunas** | X | | |
| **Turbots** | X | | |
| **Rockfishes** | X | | |
| **Groupers** | X | | |
| **Jack Mackerels** | | | X |

# Fish Genetic Diversity Figure



# Common Core State Standards Connections: ELA/Literacy and/or Math

*English Language Arts*

| | |
|---|---|
| SL.11-12.5 | Make strategic use of digital media (e.g., textual, graphical, audio, visual, and interactive elements) in presentations to enhance understanding of findings, reasoning, and evidence and to add interest. |
| RST.11-12.1 | Cite specific textual evidence to support analysis of science and technical texts, attending to important distinctions the author makes and to any gaps or inconsistencies in the account. |
| RST.11-12.7 | Integrate and evaluate multiple sources of information presented in diverse formats and media (e.g., quantitative data, video, multimedia) in order to address a question or solve a problem. |

*Mathematics*

| | |
|---|---|
| MP.2 | Reason abstractly and quantitatively. |
| HSN.Q.A.1 | Use units as a way to understand problems and to guide the solution of multi-step problems; choose and interpret units consistently in formulas; choose and interpret the scale and the origin in graphs and data displays. |
| HSN.Q.A.3 | Choose a level of accuracy appropriate to limitations on measurement when reporting quantities. |

# Next Generation Science Standards

*Natural Selection and Evolution, HS-LS4-3* – Apply concepts of statistics and probability to support explanations that organisms with an advantageous heritable trait tend to increase in proportion to organisms lacking this trait.

| Science & Engineering Practice | Disciplinary Core Ideas | Crosscutting Concepts |
|---|---|---|
| *Analyzing and Interpreting Data* - Apply concepts of statistics and probability (including determining function fits to data, slope, intercept, and correlation coefficient for linear fits) to scientific and engineering questions and problems, using digital tools when feasible. | *LS4.B: Natural Selection* - Natural selection occurs only if there is both (1) variation in the genetic information between organisms in a population and (2) variation in the expression of that genetic information—that is, trait variation—that leads to differences in performance among individuals.<br>*LS4.B: Natural Selection* - The traits that positively affect survival are more likely to be reproduced, and thus are more common in the population.<br><br>*LS4.C: Adaptation* - Natural selection leads to adaptation, that is, to a population dominated by organisms that are anatomically, behaviorally, and physiologically well suited to survive and reproduce in a specific environment. That is, the differential survival and reproduction of organisms in a population that have an advantageous heritable trait leads to | *Patterns* – Different patterns may be observed at each of the scales at which a system is studied and can provide evidence for causality in explanations of phenomena. |

| | | |
|---|---|---|
| | an increase in the proportion of individuals in future generations that have the trait and to a decrease in the proportion of individuals that do not.<br>*LS4.C: Adaptation* - Adaptation also means that the distribution of traits in a population can change when conditions change. | |

*Natural Selection and Evolution, HS-LS4-4* – Construct an explanation based on evidence for how natural selection leads to adaptation of populations.

| Science & Engineering Practice | Disciplinary Core Ideas | Crosscutting Concepts |
|---|---|---|
| *Constructing Explanations and Designing Solutions* - Construct an explanation based on valid and reliable evidence obtained from a variety of sources (including students' own investigations, models, theories, simulations, peer review) and the assumption that theories and laws that describe the natural world operate today as they did in the past and will continue to do so in the future. | *LS4.C: Adaptation* - Natural selection leads to adaptation, that is, to a population dominated by organisms that are anatomically, behaviorally, and physiologically well suited to survive and reproduce in a specific environment. That is, the differential survival and reproduction of organisms in a population that have an advantageous heritable trait leads to an increase in the proportion of individuals in future generations that have the trait and to a decrease in the proportion of individuals that do not. | *Cause and Effect* – Empirical evidence is required to differentiate between cause and correlation and make claims about specific causes and effects. |