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The Mystery of Ocean Acidification

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THE MYSTERY OF OCEAN ACIDIFICATION

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Grade Level
High School

Subject area
Life Science, Biology, Chemistry, or Environmental Science

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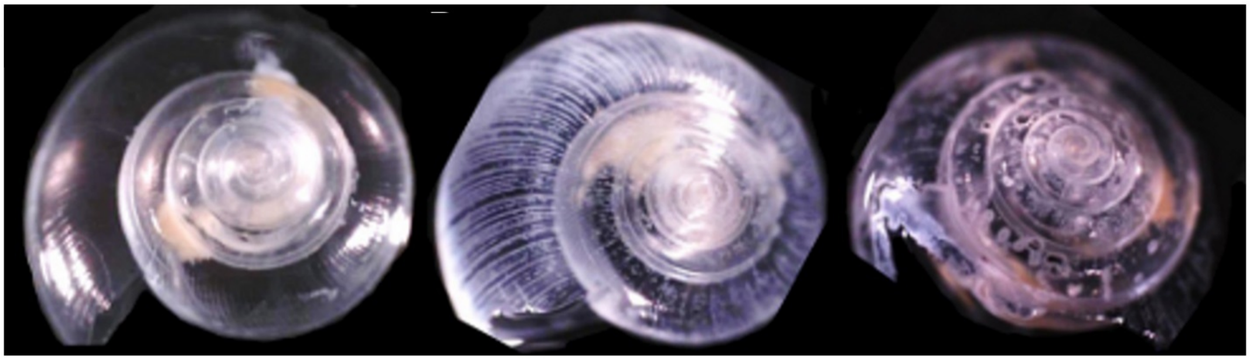
Contents of Lesson Plan

~~~The Mystery of Ocean Acidification~~~



Focus: The chemical processes of ocean acidification and potential impacts on biological organisms. A case study activity highlighting Antarctica and the impact of ocean acidification on the abundance of a species of pteropod (open-ocean snail).

Grade levels/Subject: HS life science. Also, applicable to HS chemistry, earth science, physical science, and marine biology/science with differentiation.

VA Science Standards addressed: HS life science (*see appendix 1* for non-life science SOL's met)

Life Science

LS. 1: D: models and simulations are constructed and used to illustrate and explain phenomena; F: Dependent variables, independent variables, and constants are identified; G: Variable are controlled to test hypotheses; H: Data are organized and communicated through graphical representation, interpreted, and used to make predictions; I: Patterns are identified in data and are interpreted and evaluated; J: Current applications are used to reinforce life science concepts

LS. 6: A: Carbon cycle, C: complex relationships within marine ecosystems

LS. 8: A: Relationship between predators and prey

LS. 9: B: Characteristics of marine ecosystems

LS.10: B: Climate changes

LS. 11: E: Environmental issues

Learning objectives/outcomes:

- Students will outline ocean chemistry processes, and identify key points of Antarctic geography and biology of polar species
- Students will synthesize scientific information from the internet and reproduce in their own words
- Students will record and graph real scientific data using excel
- Students will interpret graphs and make predictions about future trends based on graphical information

Total length of time required for the lesson: 135mins or approx. three, 45min classes
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Keywords, vocabulary:

- Chemistry:
  - Solubility: The amount of a substance that will dissolve for a given amount of a solvent to give a saturated solution under specified conditions.
  - Acid: Ionic compounds (a compound with a positive or negative charge) that break apart in water to form a hydrogen ion (H+). The strength of an acid is based on the concentration of H+ ions in the solution. The more H+ the stronger the acid.
  - Base: Ionic compounds that break apart to form a negatively charged hydroxide ion (OH-) in water. The strength of a base is determined by the concentration of Hydroxide ions (OH-). The greater the concentration of OH- ions the stronger the base.
  - pH: hydrogen ion concentration = -log[H+].
- Biology:
  - Pteropod: Pelagic (open ocean) planktonic (drifting) snails. Some species have a shell made of aragonite (calcium carbonate, $CaCO_3$) and a 'foot' that has developed into wings. Pteropod in Latin means 'wing (ptero) foot (pod)." These pelagic gastropods are commonly referred to as a sea butterfly due to their wings that give them a distinct swimming behavior unique to pteropods.
- Climate change:
  - Fossil Fuel: A natural fuel such as coal or gas, formed in the geological past from the remains of living organisms.
  - Global warming: A long-term increase in Earth's average temperature.
  - Ocean acidification: A result of human induced (anthropogenic) increases in dissolved carbon dioxide into the ocean. As dissolved carbon dioxide increases, ocean pH decreases and there is a coincident decrease in carbonate and subsequently aragonite (made of carbonate).

Background information: There is a mystery to be solved! Teacher presents students with the challenge of identifying the Who, What, When, Where, Why, and How of ocean acidification. Ocean acidification is a pertinent topic when discussing the general concept of seawater chemistry. Hence, this lesson plan uses ocean acidification as a method to apply more traditional chemistry concepts (i.e., solubility, acids-bases). The lesson also focuses on a case study in Antarctica and the potential effects of ocean acidification on an open ocean plankton, the pteropod (tero-pod) species *Limacina helicina*, whose shell is easily dissolved in ocean acidification conditions.

The class will begin with an ocean acidification gallery walk in which students work in pairs or small teams to scan QR codes with iPads/iPhones. Students will record their findings from each website they are directed to in a provided worksheet and then report their findings as a class. This starter activity will cover the "**What** is ocean acidification?" The teacher will then show a powerpoint to review the concept of ocean acidification (**What** and **When**) and explain **Why** ocean acidification is happening. The powerpoint also discusses ocean acidification in Antarctica and how it could affect a species of pteropod, *Limacina helicina* (**Where** and **Who**). Students will participate in a *data nugget* activity for much of class to learn "**How** is it happening?" Class will conclude by students reviewing the 5 W's of ocean acidification with a think-pair-share activity.

Student handouts and other materials needed:

- Ocean Acidification vocabulary QR-code gallery walk worksheet
- Pre-made pteropod abundance graphs (if desired)
- Data Nugget summary questions (as worksheet or written on board)

Materials and supplies, A/V/Tech support

- QR-codes, posted around classroom walls (starter activity)
- iPads and/or smartphones available for students (starter activity)
- Powerpoint slides available (mini lecture)
- Data nugget (core activity)
- Graphing app/program available for students (core activity)
- Large post-it notes or index cards (closing activity)

Classroom/lab study setup: Desks are clumped in groups of four to accommodate group work. No chemicals will be needed.

Procedure:

1. Announce plan for day, the hook! (< 5mins)

   A. News clip on ocean acidification by ABC: https://www.youtube.com/watch?v=fJbyC-eqrfs

2. Starter activity: QR Gallery Walk (30mins: 5min explanation and set up, 20min for activity, 5min for recap)

   a. Students complete QR website vocabulary activity on iPads/iPhones by scanning codes hung around classroom

   b. Teacher checks in with students/groups during activity

   c. As a class, students share thoughts on what ocean acidification is based on what they learned in activity

3. Teacher shows powerpoint slide illustrating ocean acidification and Antarctica (30mins)

   a. Students listen (notetaking optional) to lecture reviewing the concept of ocean acidification and how it is changing Antarctica and affecting pteropods

      I. Youtube video on OA for summary (embedded in PPT): https://www.youtube.com/watch?v=MgdlAt4CR-4

   b. Teacher emphasizes relationship that pteropods have on Antarctic food web, the 'so what?"

   c. Teacher recaps (within lecture) the 5 W's of ocean acidification from QR activity and powerpoint to provide context for data nugget activity

4. How is it happening? Teacher introduces the data nugget (30mins)

   a. Teacher shows on powerpoint/white board how the data nugget is organized

I. *See appendix 4* for graphing information in excel

b. Teacher models plotting DIC variable vs. pteropod abundance in excel to class

I. Provide a discussion of independent vs. dependent variables, if necessary

II. Ask students to write down a hypothesis based on what they have learned about pteropods and ocean acidification

5. Students (pairs or groups) use selected variable and graph vs. pteropod abundance (15mins)

a. Teacher assigns a different variable (from six available) to each group

*Differentiation: Teacher can also print graphs ahead of time and have students only interpret the graphs rather than generating their own

I. *See appendix 5* for premade graphs

6. Students compare results with classmates and make conclusions based on results (15mins)

a. Students print or expand graph on computer to show classmates, compare simultaneously (10mins)

b. Questions are answered to draw conclusions on results (5mins)

I. *See appendix 6* for guiding questions

II. Can be done with the entire class or within groups as a worksheet

7. Closure: Have we solved the mystery of Ocean Acidification? (10mins)

a. Students answer the 5 W's of Ocean Acidification with their neighbor in a think-pair-share format (5mins)

b. Student groups volunteer to share their 5 W's with the class (3mins)

c. Students individually write something they are still curious about learning in regards to ocean acidification (i.e., I wonder…) before they leave class (2mins)

Assessment: The starter activity (QR code gallery walk) will be a formative assessment gauging students' familiarity to seawater chemistry and ocean acidification. The graphs and interpretations presented in class will be a formative assessment of students' abilities to infer data and make comparisons and interpretations. The closing think-pair-share will be an informal, formative assessment gauging students' grasps of the key concepts of ocean acidification and the activity.

Differentiation: A variety of teaching techniques will be employed to address different student learning types including chunk & chew, lecture, video, demonstration, and independent and group activities. The QR activity can act as a general introduction to ocean acidification preceding the data nugget activity or can act as its own lesson for ocean acidification depending on the level of the class and available time to dedicate to the entire lesson. The data nugget will provide an opportunity for students to graph and interpret results based on their individual abilities. For example, in non-honors/AP classes, students will only be presented one dependent and independent variable for the graphing activity while honors/AP students will be required to work with multiple variables (e.g., pH, temperature, etc.). The teacher can also print the premade graphs out ahead of time rather than having students graph the variables on their own to accommodate different class levels. To introduce multiple independent students will be introduced to one variable at a time to scaffold the complexity of the material. Assessment can be diversified depending on the level of the course (i.e., graph interpretation could be written as a report or presented to the class).

References:

A. See QR websites handout for sites used
B. Gas Laws information: http://chemistry.bd.psu.edu/jircitano/gases.html
C. Acid-Base information: http://lrs.ed.uiuc.edu/students/erlinger/water/background/ph.html
D. Climate Change information: http://www.nasa.gov/audience/forstudents/5-8/features/nasa-knows/what-is-climate-change-58.html
E. References for educational powerpoint: see citations in slideshow as well as…
    a. Powerpoint chemistry section: https://windward.hawaii.edu/facstaff/miliefsky-m/ocn%20201/ocn%20201%20ppt/007-Chemistry.ppt
    b. Pteropod information:
        i. Bednaršek, N., Feely, R. a, Reum, J.C.P., Peterson, B., Menkel, J., Alin, S.R., Hales, B., 2014. Limacina helicina shell dissolution as an indicator of declining habitat suitability owing to ocean acidification in the California Current Ecosystem. Proc. Biol. Sci. 281, 20140123. doi:10.1098/rspb.2014.0123
        ii. Busch, D.S., Maher, M., Thibodeau, P., McElhany, P., 2014. Shell Condition and Survival of Puget Sound Pteropods Are Impaired by Ocean Acidification Conditions. PLoS One 9, e105884. doi:10.1371/journal.pone.0105884
    c. Antarctic information and data nugget data accessed from: www.pallter.edu
    d. OA summary video by NOAA: https://www.youtube.com/watch?v=MgdlAt4CR-4
    e. Pteropod swimming video by NOAA: : https://www.youtube.com/watch?v=6H_VDhXiFk4

Appendix 1. Additional SOL's: life science, earth science, physical science, and marine biology/science.

1. Chemistry

CH.1: A: Designated laboratory techniques; D: Manipulation of multiple variables, using repeated trials; E: Accurate recording, organization, and analysis of data through repeated trials; G: Mathematical manipulations; H: Use of appropriate technology; I: Construction and defense of scientific viewpoint; J: Use of current applications to reinforce chemistry concepts

CH.3: E: reaction types; F: Reaction rates, kinetics, and equilibrium

CH.4: C: solution concentrations; D: acid/base theory

CH.5: A: pressure, temperature, and volume; B: partial pressure and gas laws

2. Earth Science

ES. 2: The student will demonstrate an understanding of the nature of

science and scientific reasoning and logic (all sub-sections a-d).

ES. 10: The student will investigate and understand that oceans are

complex, interactive physical, chemical, and biological systems and are subject to long- and short-term variations (sub-sections a-c).

ES. 11: The student will investigate and understand the origin and evolution of the atmosphere and the interrelationship of geologic processes, biologic processes, and human activities on its composition and dynamics (sub-sections c, d).

3. Physical Science

PS. 1: The student will demonstrate an understanding of scientific

reasoning, logic, and the nature of science by planning and conducting

investigations (sub-sections e, f, g, h, i, j, n).

PS. 2: The student will investigate and understand the nature of

matter (sub-sections b, c, d, e, f).

PS. 4: The student will investigate and understand the organization

and use of the periodic table of elements to obtain information (sub-sections a, c).

PS. 7: The student will investigate and understand temperature scales, heat, and thermal energy transfer (sub-sections a, b, d).

4. Biology

Bio. 1: The student will demonstrate an understanding of scientific

reasoning, logic, and the nature of science by planning and conducting

investigations (all sub-sections).

Bio. 2: The student will investigate and understand the chemical and

biochemical principles essential for life (sub-sections a, b, d).

Bio. 7: The student will investigate and understand how populations

change through time (sub-sections b, e).

Bio. 8: The student will investigate and understand dynamic equilibria within populations, communities, and ecosystems (sub-sections a, b, d).

Appendix 2. Student handouts

QR code websites:

Carbonate, website:

http://www.britannica.com/science/carbonate

Carbonic acid, video (only watch first half without signing up, don't have to):
http://study.com/academy/lesson/carbonic-acid-formation-structure-chemical-equation.html

20 Questions about OA, article (2 pages):

http://study.com/academy/lesson/carbonic-acid-formation-structure-chemical-equation.html

Ocean acidification, blog:

https://theotherco2problem.wordpress.com/what-happens-chemically/

Ocean acidification and calcification, website tutorial:

http://www.whoi.edu/home/oceanus_images/ries/calcification.html

Acid-Base, learning website:

http://www.visionlearning.com/en/library/Chemistry/1/Acids-and-Bases/58

Gas laws, buzzfeed video (can just watch under 2min. introduction):

https://www.youtube.com/watch?v=WdasR4BvelU

Partial Pressure, Dalton's Law (About.com education):

http://chemistry.about.com/od/workedchemistryproblems/a/partialpressure.htm

Solubility (education website):

https://www.boundless.com/chemistry/textbooks/boundless-chemistry-textbook/solutions-12/factors-affecting-solubility-94/gas-solubility-and-temperature-404-7627/

Pteropods and ocean acidification (educational video, 2mins):

https://www.youtube.com/watch?v=MzpmUHdwLr0

QR-code gallery walk

Directions: You are on a hunt to solve the mystery of ocean acidification! To understand the process, search around the room for 10 QR-codes. At each station, scan the code with your iPad/iPhone app. Watch, read, listen to the website/video you are sent to. Based on what you learned from the website, write down the name of the topic and its definition (1-2 sentences).

Download QR app at: https://itunes.apple.com/us/app/qr-code-reader-and-scanner/id388175979?mt=8

1) Topic: Solubility

Definition:

2) Topic: Pteropods

Definition:

3) Topic: Ocean acidification effects on calcification

Definition:

4) Topic: Gas laws

Definition:

5) Topic: Partial pressure

Definition:

6) Topic: 20 questions on ocean acidification
Definition:

7) Topic: Carbonate
Definition:

8) Topic: Acids and bases
Definition:

9) Topic: Ocean Acidification
Definition:

10) Topic: Carbonic Acid
Definition:

Answers

Directions: You are on a hunt to solve the mystery of ocean acidification! To understand the process, search around the room for 10 QR-codes. At each station, scan the code with your iPad/iPhone app. Watch, read, listen to the website/video you are sent to. Based on what you learned from the website, write down the name of the topic and its definition (1-2 sentences).

Download QR app at: https://itunes.apple.com/us/app/qr-code-reader-and-scanner/id388175979?mt=8

1) Topic: 20 Questions about OA

Definition: Sentences highlighted in bold within article. I.e., OA is a progressive increase in the acidity of the ocean over an extended period.

2) Topic: Acid-base

Definition: (not best answer but probably what they'll come up with based on website, try to emphasize pH in class recap as well) Acids taste sour, are corrosive to metals, change litmus (a dye extracted from lichens) red, and become less acidic when mixed with bases. Bases feel slippery, change litmus blue, and become less basic when mixed with acids.

3) Topic: Carbonate

Definition: Carbonate, any member of two classes of chemical compounds derived from carbonic acid or carbon dioxide.

4) Topic: Carbonic acid

Definition: weak acid formed from reaction of carbon dioxide dissolved in water

5) Topic: ocean acidification

Definition: The pH of surface seawater has fallen from 8.2 to 8.1, (a pH of 7 is neutral) in a few hundred years, after remaining constant for millions of years, due to humans pumping carbon dioxide into the atmosphere that is dissolving in the ocean.

6) Topic: ocean acidification and calcification, shells

Definition: to build shells, marine organisms need Calcium and carbonate. Rising atmospheric CO_2 causes hydrogen ions to increase so it may require more energy for organisms to pump them out, impacting their ability to make shells.

7) Topic: Gas Laws

Definition: List gas laws as written in video.

8) Topic: partial pressure

Definition: the partial pressure of each gas is the pressure that gas would exert if it was the only one occupying that volume of space

9) Topic: solubility

Definition: The amount of a substance that will dissolve for a given amount of a solvent to give a saturated solution under specified conditions.

10) Topic: pteropods

Definition: a plankton that is impacted by ocean acidification

Appendix 3. Teacher guide (*italic text* provides more information for each aspect of the lesson; blue text indicates additional/optional steps for teachers)

1. Announce plan for day, the hook! (5mins) *Focusing on seawater chemistry and a process related to this called ocean acidification (OA). There's a mystery to be solved!*

a. News clip on ocean acidification by ABC:

https://www.youtube.com/watch?v=fJbyC-eqrfs

*Can prompt with questions, gauge student familiarity with topics

2. Starter activity: QR Gallery Walk (30mins: 5min explanation and set up, 20min for activity, 5min for recap)

First: handout worksheet, iPads; read through directions with class

*introduction to key concepts of seawater chemistry and OA, students will search for the terms and concepts to better understand the mystery of OA

*ensure students can successfully download QR app

a. Students complete website vocabulary activity on iPads/iPhones by scanning codes hung around classroom: *10 stations so students will most likely need to work in teams. Some of the websites require sound so encourage headphones or to keep voices down. Students will need to identify the key topic of each station and write a definition, which they can come up with as a team.*

b. Teacher checks in with students/groups: *Make sure they watch all videos in entirety (see appendix 2, QR website sheet for times of videos).*

*Some stations will take longer than others so encourage students if they're waiting to finalize topics and definitions already learned about in activity

c. As a class, students share thoughts on what ocean acidification is based on what they learned in activity

**Can also have students share answers for definitions. Generate list of topics and definitions as class (see appendix 2, QR code answer key in this document).*

3. Teacher shows powerpoint slide illustrating ocean acidification and Antarctica (30mins)

a. Students listen (notetaking optional) to lecture reviewing the concept of ocean acidification and how it is changing Antarctica and affecting pteropods

I. Youtube video on OA for summary (embedded in PPT): https://www.youtube.com/watch?v=MgdlAt4CR-4

b. Teacher emphasizes relationship that pteropods have on Antarctic food web, the 'so what?"

c. Teacher recaps (within lecture) the 5 W's of ocean acidification from QR activity and powerpoint to provide context for data nugget activity

*An extended version of the powerpoint to provide additional background to seawater chemistry is available on slide 18.

4. How is it happening? Teacher introduces the data nugget (30mins)

a. Teacher shows on powerpoint/white board how the data nugget is organized

I. *See appendix 4* for graphing information in excel

See "For Teacher" tab within data nugget excel sheet

Data nugget organization: One variable for teacher demo, six variables for student teams

b. Teacher models plotting DIC variable vs. pteropod abundance in excel to class

I. Provide a discussion of independent vs. dependent variables, if necessary

II. Ask students to write down a hypothesis based on what they have

learned about pteropods and ocean acidification

5. Students (pairs or groups) use selected variable and graph vs. pteropod abundance (15mins)

a. Teacher assigns a different variable (from six available) to each group

*Differentiation: Teacher can also print graphs ahead of time and have students only interpret the graphs rather than generating their own

I. *See appendix 5* for premade graphs (also available in data nugget excel sheet)

6. Students compare results with classmates and make conclusions based on results (15mins)

a. Students print or expand graph on computer to show classmates, compare simultaneously (10mins)

b. Questions are answered to draw conclusions on results (5mins)

I. *See appendix 6* for guiding questions

II. Can be done with the entire class or within groups as worksheet

7. Closure: Have we solved the mystery of Ocean Acidification? (10mins)

a. Students answer the 5 W's of Ocean Acidification with their neighbor in a think-pair-share format (5mins)

b. Student groups volunteer to share their 5 W's with the class (3mins)

I. Guiding answers to 5 W's:
What? *OA is an increase in the acidity of the ocean over an extended period.* ***Why?*** *Increasing amounts of atmospheric CO_2 from human activities dissolve into the ocean through air-sea exchange and photosynthesis/respiration.*

Where? *All over the world's oceans but regions that are colder and already have large concentrations of CO_2 stored in their waters will be most affected, such as Antarctica.*
When? *Right now! We're already seeing the effects of OA along the west coast and in the polar regions. The oceans will only continue to become more acidic if humans do not reduce their CO_2 emissions now.*
Who? *Calcifying organisms that use calcium carbonate to build their shells, such as pteropods, corals, and clams.*
How is OA affecting pteropods? *Rising dissolved CO_2 causes hydrogen ions to increase so it may require more energy for pteropods to pump them out, and decreases carbonate ion availability, impacting a pteropod's ability to make its shell.* In Antarctica, scientists still have not solved the mystery but it is important to start making observations now so scientists can make better predictions for the future of the Antarctic ecosystem.

c. Students individually write something they are still curious about learning in regards to ocean acidification (i.e., I wonder…) before they leave class (2mins) *Use this feedback as to reconnect to and remind students of lesson at beginning of next class*

I. Can use index cards, white/chalk board, large post-it note, email for responses

Assessment: The starter activity (QR code gallery walk) will be a formative assessment gauging students' familiarity to seawater chemistry and ocean acidification. The graphs and interpretations presented in class will be a formative assessment of students' abilities to infer data and make comparisons and interpretations. The closing think-pair-share will be an informal, formative assessment gauging students' grasps of the key concepts of ocean acidification and the activity.

Differentiation: A variety of teaching techniques will be employed to address different student learning types including chunk & chew, lecture, video, demonstration, and independent and group activities. The QR code gallery walk can act as a general introduction to ocean acidification preceding the data nugget activity or can act as its own lesson for ocean acidification depending on the level of the class and available time to dedicate to the entire lesson. The data nugget will provide an opportunity for students to graph and interpret results based on their individual abilities. For example, in non-honors/AP classes, students will only be presented one dependent and independent variable for the graphing activity while honors/AP students will be required to work with multiple variables (e.g., pH, temperature, etc.). The teacher can also print the premade graphs out ahead of time rather than having students graph the variables on their own to accommodate different class levels. To introduce multiple independent students will be introduced to one variable at a time to scaffold the complexity of the material. Assessment can be diversified depending on the level of the course (i.e., graph interpretation could be written as a report or presented to the class).

Appendix 4. Excel plotting directions

1. Walk students through data nugget.

   a. Students will be shown:

      I. 'Description' tab showing where data came from and what it means

         1. Emphasize these data come directly from the United States Antarctic

         Program. This is how these data are presented to scientists when they are analyzing them. Variables include (go through each):

            a. CO_2: Carbon dioxide, units in micro-atmospheres (μatm).

            b. DIC: Dissolved Inorganic Carbon; includes all the major carbon

               species (i.e., CO_2, carbonate, carbonic acid, carbonate). Units in μmol/kg.

            c. Alkalinity: The sum of cations and anions in seawater,

               essentially is the opposite of DIC, acts as the oceans buffer against increases in CO_2. Units in μmol/kg.

            d. pH: The measure of acidity (dissolved hydrogen ions) in

               seawater, unitless.

            e. CO_3^{2-}: carbonate, important building block for marine

               organisms with shells, one of the ions in aragonite, units in mol/kg.

            f. Aragonite: A parameter that compares the concentration of

               aragonitic carbonate relative to the concentration of all calcium carbonate in seawater, unitless.

            g. Temperature: A common measurement when studying

               seawater. A decrease in temperature can increase the solubility of carbon dioxide in seawater. Measured in degrees Celsius (°C).

            h. Pteropods: Specifically studying a shelled pteropod species

               known as *Limacina helicina.*

      II. 'Students-DIC' tab:

         1. Show students the different columns. Remind them what DIC means.

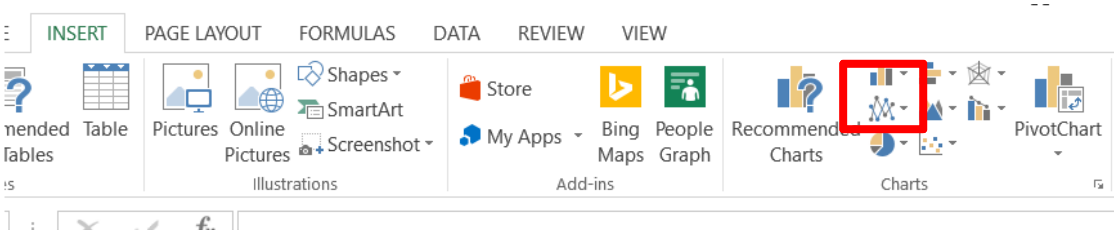
2. Teacher demonstrates graphing DIC variable with pteropod abundance.

a. Right click on an empty cell in the data sheet

Year	DIC	LimacinaNum
1993	2143.818	4.0168
1994	2110.693	7.012472727
1995	2122.351	24.73730508
1996	2118.691	91.59254545
1997	2136.637	36.60546479
1998	2146.253	1.567781818
1999	2184.691	55.85998734

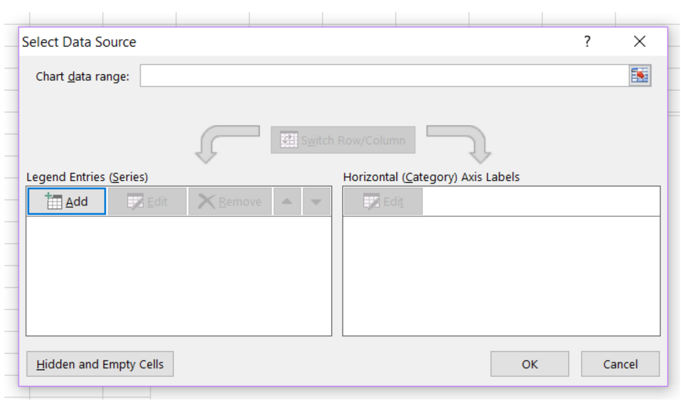
Emphasize the independent variable (time) versus the dependent variables (DIC and pteropod abundance) and their corresponding axes (time = x-axis, DIC and pteropods = y-axes).

b. In the drop-down menu, select 'insert' and within 'charts' select a 'line chart' (highlighted in red). Options will appear for different line plots. Select 2D line plot (top left option). Note: The type of graph will be changed so the type of line plot selected does not actually matter.

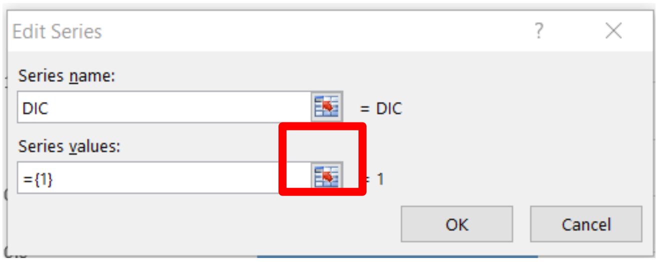


c. An empty chart will appear. Right click on the chart and from the drop-down menu, click on 'select data'.

d. The box below will appear. Click on the 'add' tab (highlighted in blue).



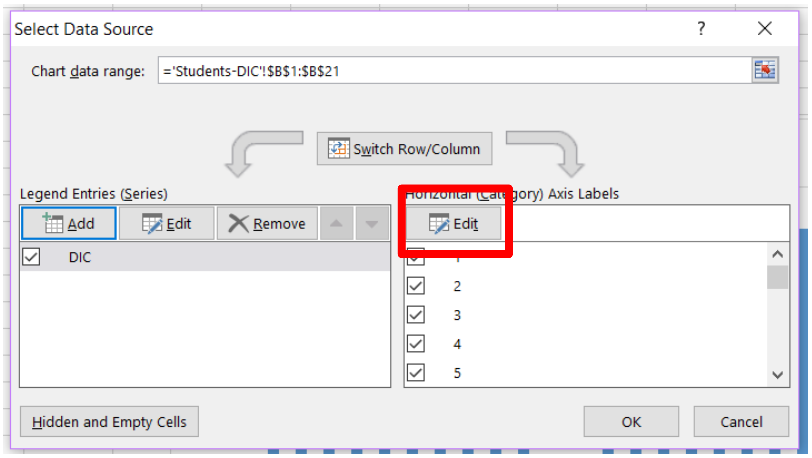
e. Type in the variable name (for demo, use DIC). For 'series values', click on the box with the red highlighted cell (highlighted in red).



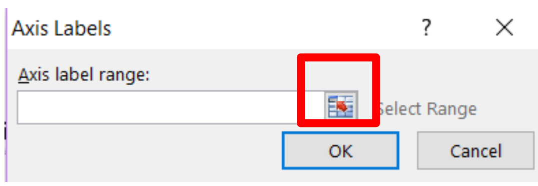
f. Use your cursor to highlight (by holding down left-click on mouse) the entire DIC column (dependent variable, y-axis), including the header. Press the 'enter' key on keyboard to select data.

Year	DIC	LimacinaNum
1993	2143.818	4.0168
1994	2110.693	7.012472727
1995	2122.351	24.73730508
1996	2118.691	91.59254545
1997	2136.637	36.60546479
1998	2146.253	1.567781818
1999	2184.691	55.85998734
2000	2169.451	54.64976596
2001	2174.662	48.63395833
2002	2139.633	168.4823137
2003	NaN	53.45919355
2004	NaN	53.89176667
2005	2130.763	2.724052632
2006	2136.212	27.44945
2007	2113.969	68.24983333
2008	2147.026	127.3380308
2009	2140.155	133.9825
2010	2157.338	29.272
2011	2100.926	302.9238966
2012	2142.716	45.66156098

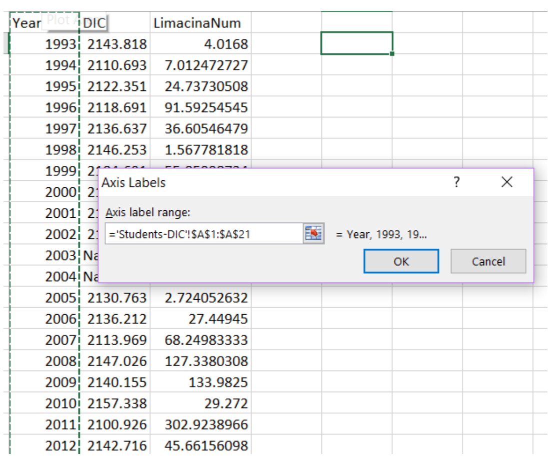
g. A screen will appear with the added DIC data you selected. Now select the horizontal (x-axis) category by clicking on the 'edit' tab (highlighted in red).



h. An 'axis labels' box should appear.

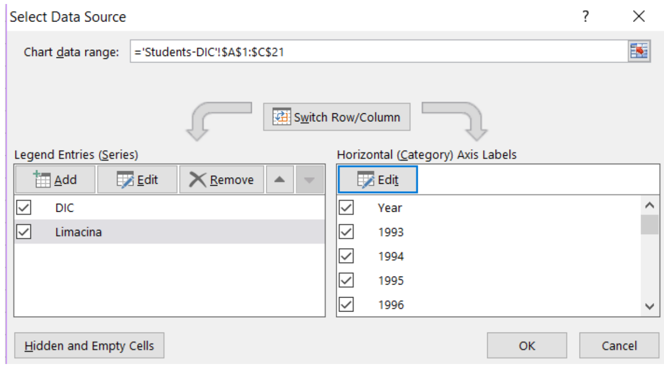


i. Like before, click on the box with the red highlighted cell and then select the 'year' column in your data. This is the independent variable plotted on the x-axis.

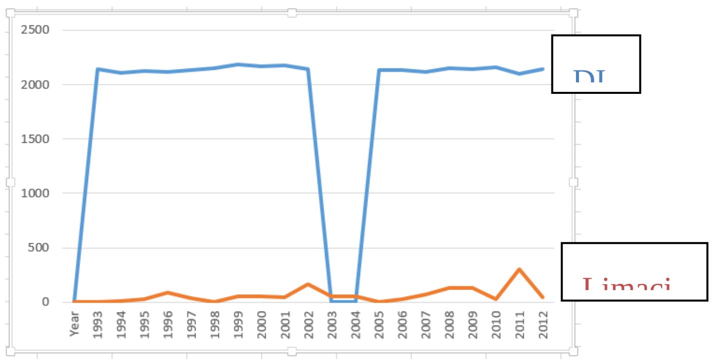


j. Repeat steps d through i again for the column 'LimacinaNum' in the data sheet.

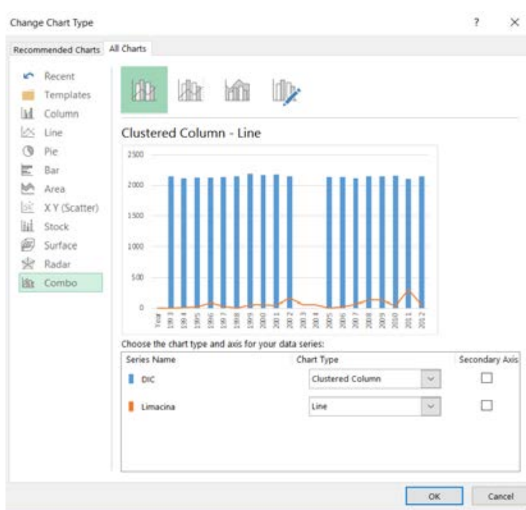
Your data source box should appear as below. Click 'ok'.



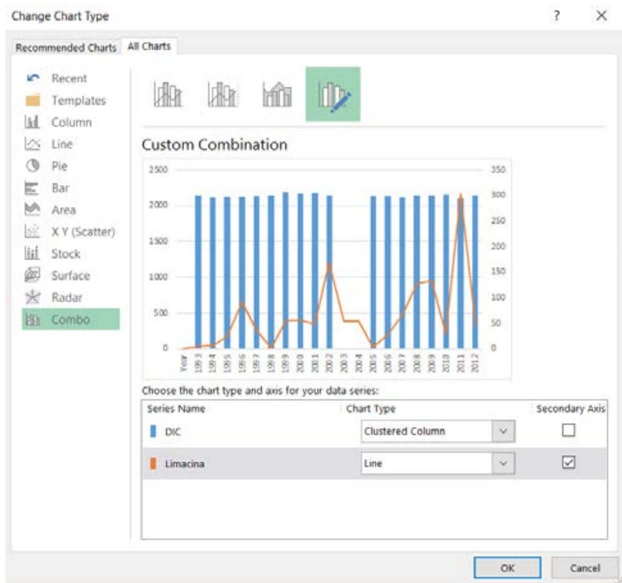
k. Your graph will appear something like below (yuck!). Now we need to adjust the plot to create a combination plot to compare DIC and pteropod abundance over the time-series in a way that can be easily interpreted.



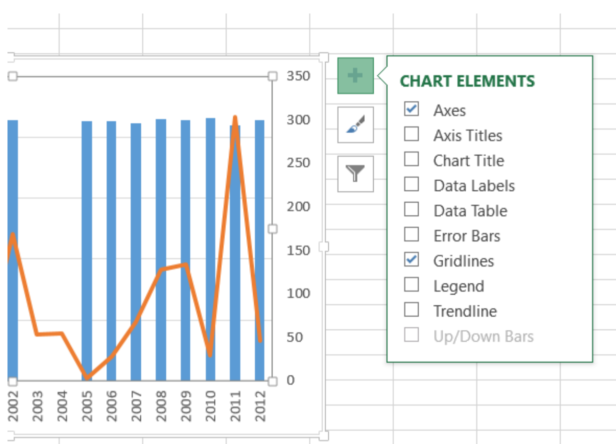
l. Right-click on the white space within the plot (not the lines). From the drop-down menu, select 'change chart type'.



m. In the bottom box under 'chart type' select 'clustered column' for DIC and 'line' for *Limacina*. There will be 2 y-axes because we're plotting two variables overtime so select *Limacina* as secondary axis so its data labels appear on the right side of the graph. If your graph looks like the one below, then select 'ok'.



n. We now need to make axis labels on the graph and add a title. On the top right of the graph, there should be 3 icons. Click the top right icon with '+'. Click on the boxes next to 'Axis Titles' and 'Chart Title'. Note: It appears the way to select axes labels has changed with the latest version of excel. If the '+' icon is not available in your version, right-click on an empty space on the graph (not on the bars or lines) and there should be an option in the drop-down menu for axes labels or format axes.



p. Type the appropriate axis title for the x and y-axes and graph title. See the '*data nugget*' excel worksheet under 'For Teachers' tab for examples of graph titles and appropriate axis titles (with units!) for each variable.

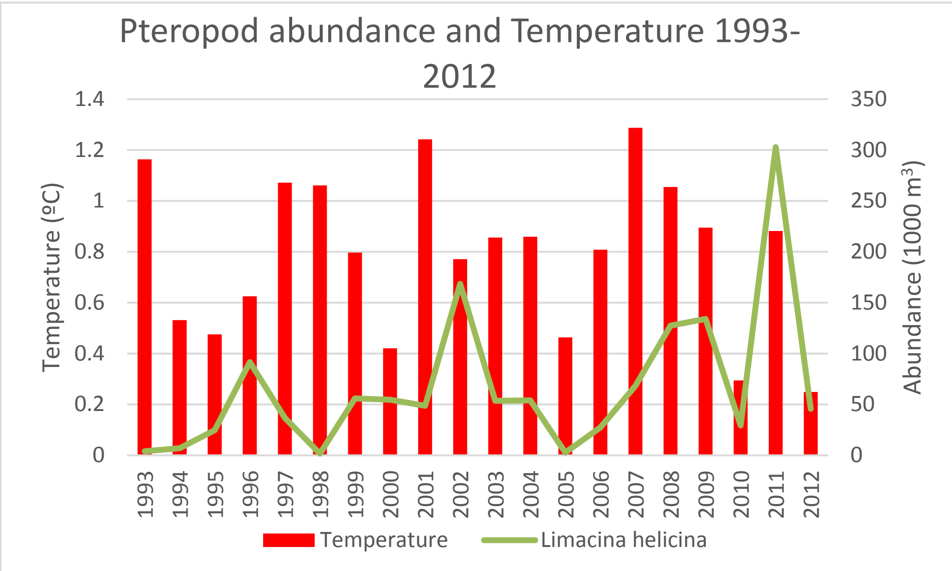
q. Students may want to adjust the y-axis range for easier interpretation. This can be done by right-clicking on the axis and the selecting "format axis" on the drop down menu.

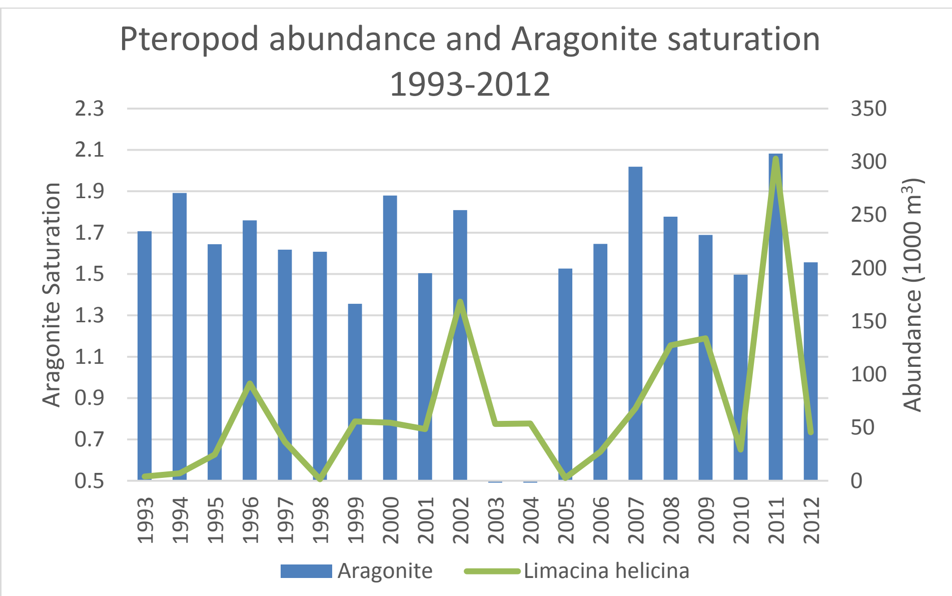
3. Teacher assigns a variable from list to each group to graph. Students generate hypotheses. Students graph the variable with pteropod abundance as a function of time (1993-2012).

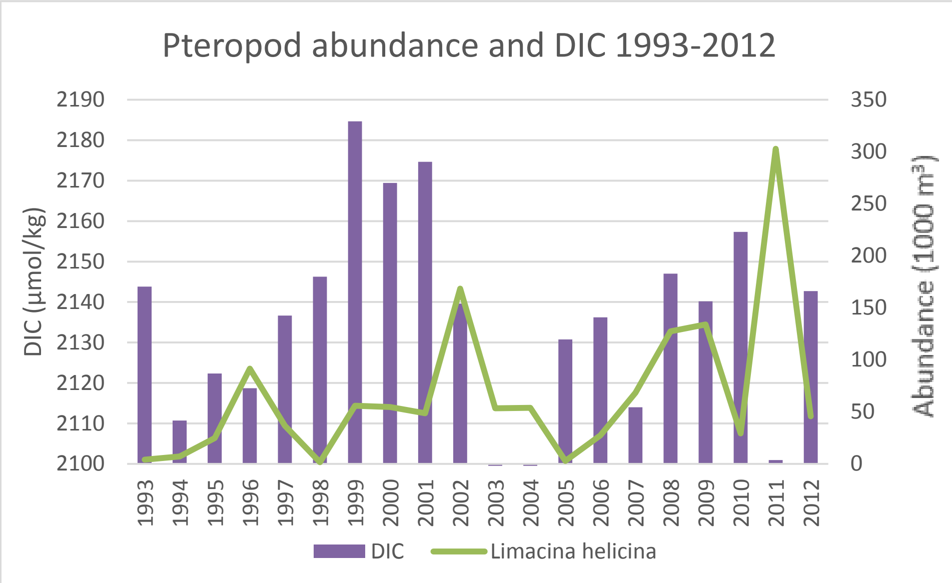
4. Students print or share their graph to classmates so that students can compare results of different variables.

5. Teacher assigns discussion questions for groups to complete or asks questions as a class for all to answer as general discussion.

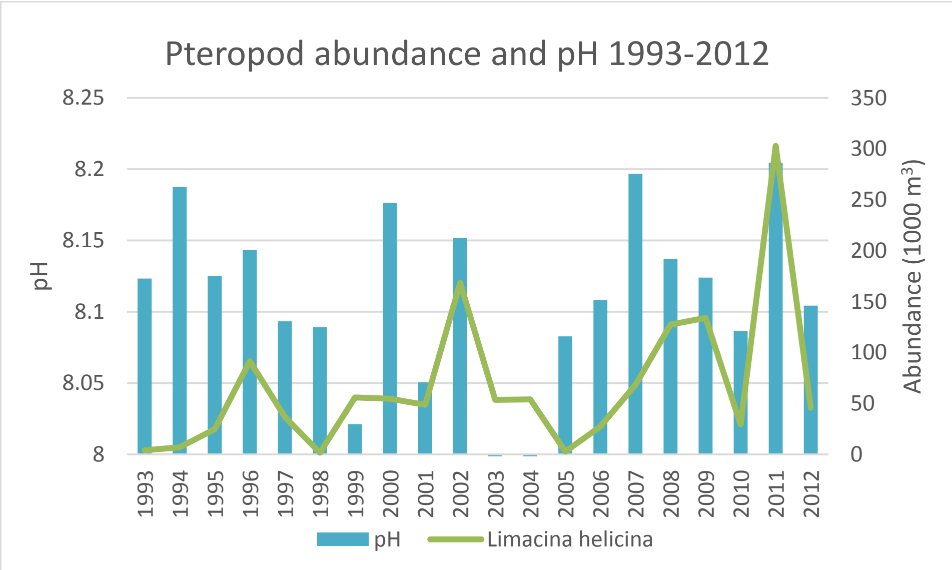
Appendix 5. Premade graphs for data nugget

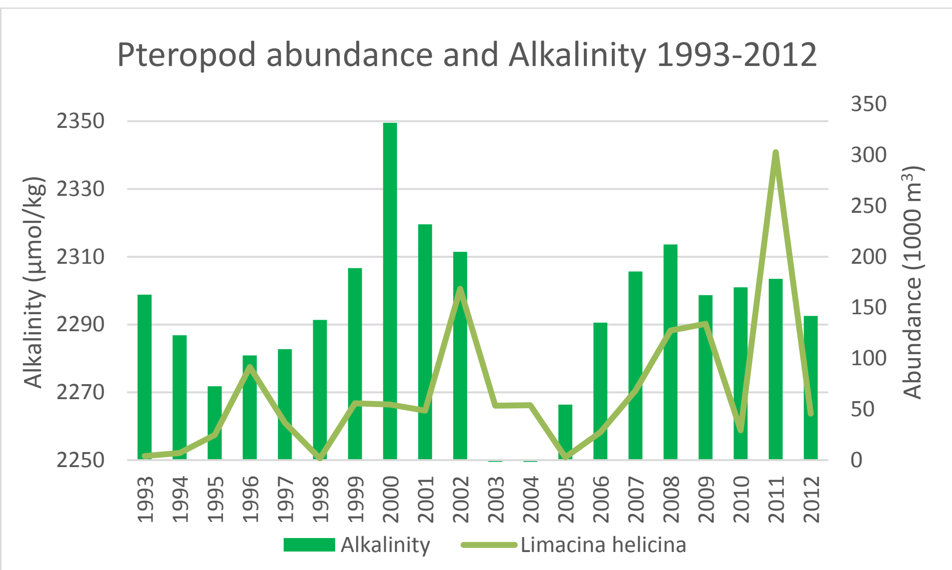


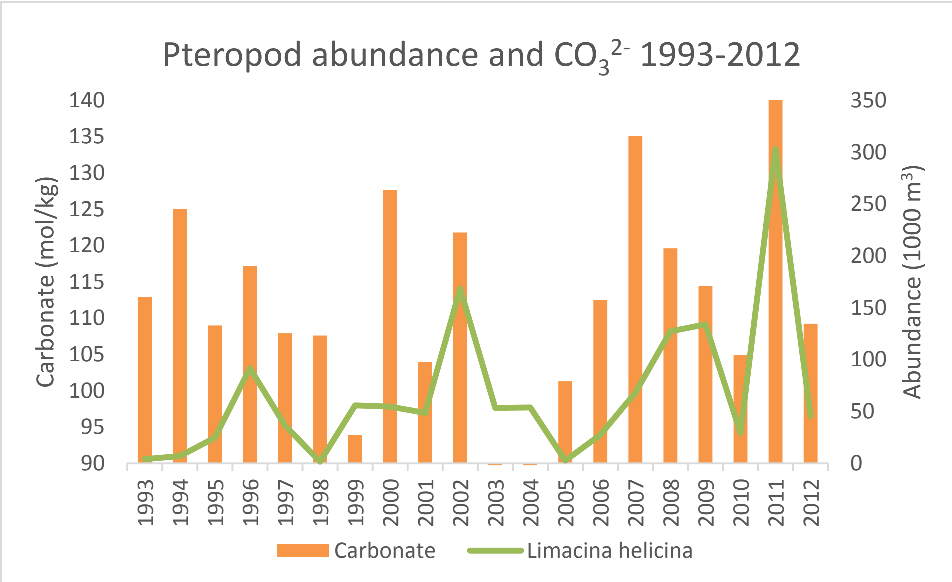


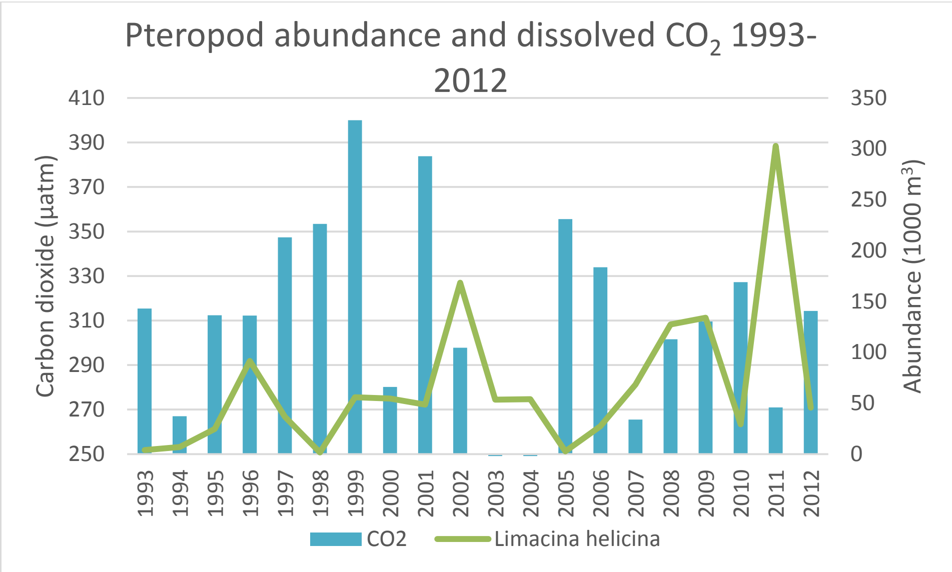


Pteropod abundance and DIC 1993-2012
DIC (µmol/kg)
Abundance (1000 m³)
2190
2180
2170
2160
2150
2140
2130
2120
2110
2100
350
300
250
200
150
100
50
0
1993
1994
1995
1996
1997
1998
1999
2000
2001
2002
2003
2004
2005
2006
2007
2008
2009
2010
2011
2012
DIC
Limacina helicina


Pteropod abundance and pH 1993-2012
pH
Abundance (1000 m³)
8.25
8.2
8.15
8.1
8.05
8
350
300
250
200
150
100
50
0
1993
1994
1995
1996
1997
1998
1999
2000
2001
2002
2003
2004
2005
2006
2007
2008
2009
2010
2011
2012
pH
Limacina helicina


Pteropod abundance and Alkalinity 1993-2012
Alkalinity (µmol/kg)
Abundance (1000 m³)
2350
2330
2310
2290
2270
2250
350
300
250
200
150
100
50
0
1993
1994
1995
1996
1997
1998
1999
2000
2001
2002
2003
2004
2005
2006
2007
2008
2009
2010
2011
2012
Alkalinity
Limacina helicina


Pteropod abundance and CO3 2- 1993-2012
Carbonate (mol/kg)
Abundance (1000 m3)
140
135
130
125
120
115
110
105
100
95
90
350
300
250
200
150
100
50
0
1993
1994
1995
1996
1997
1998
1999
2000
2001
2002
2003
2004
2005
2006
2007
2008
2009
2010
2011
2012
Carbonate
Limacina helicina


Pteropod abundance and dissolved CO2 1993-2012
410
390
370
350
330
310
290
270
250
Carbon dioxide (µatm)
350
300
250
200
150
100
50
0
Abundance (1000 m3)
1993
1994
1995
1996
1997
1998
1999
2000
2001
2002
2003
2004
2005
2006
2007
2008
2009
2010
2011
2012
CO2
Limacina helicina

Appendix 6. Discussion questions and answers

Guiding questions for analyzing data:

Choose questions based on students' abilities, differentiation

a. Describe the data table, what are the variables?

Introduce some of these words in the teacher graphing demo: oscillating, varying, variability. These are common vocabulary to describe trends in time-series data. Students should identify years of high/low pteropod abundance in relation to the graphing variable.

b. What could be your independent and independent variables? Why?

Discuss why pteropod abundance and the environmental variable are both dependent variables (answer: they're both varying as a function of time, the independent variable). To expand upon this question and add a higher order of thinking, ask students how they would interpret a graph of pteropod abundance vs. environmental variable (answer: pteropod would be dependent variable because we're assuming that the environmental variable may be controlling pteropod abundance in some way). This concept could also be expanded to address correlation by asking students to graph these variables against each other, graph a trend line, and calculate a correlation coefficient.

c. **AP LEVEL ONLY**: What ways could you graph these data? What type of graph best shows the data? Why?

This question is getting at the type of graphs used to interpret data. Ask students why they were asked to make a combination plot of the variables rather than two bar graphs or two line plots (answer: want to show data as clearly as possible, when two lines are used it can be difficult to parse apart the two variables, especially if they are highly variable). To expand upon this question, ask students to play around with different graphing options and make a 'better' graph than the original one presented. What makes it better? Is there one right way to present data graphically (answer: no!).

d. How does each environmental variable vary pteropod abundance?

General: Pteropod abundance appears to be high the same years carbonate and aragonite are high. This makes sense because pteropods need carbonate and aragonite to build their shells. It is difficult to identify any major trends with pH, DIC, and alkalinity with pteropod abundance. Pteropod abundance is low years when carbon dioxide is high. This makes sense because more carbon dioxide makes the waters more acidic, which can cause pteropod shell dissolution and may decrease their abundance.

1. pH: There is not enough variability with pH to identify a relationship with pteropod abundance. There does appear but be a slightly lower pH concentration at the beginning of the time series (1993-1998) and pteropod abundance is also low during these years

2. CO_2: pteropod abundance is generally high when CO_2 concentrations are low

3. CO_3^{2-}: pteropod abundance is generally high when carbonate is high

4. DIC: There is not enough variability with DIC to identify a relationship with pteropod abundance. There does appear to be a slightly lower DIC concentration at the beginning of the time series (1993-1998) and pteropod abundance is also low during these years

5. Alkalinity: There is not enough variability with Alkalinity to identify a relationship with pteropod abundance. There does appear but be a slightly lower Alkalinity concentration

at the beginning of the time series (1993-1998) and pteropod abundance is also low during these years

6. Aragonite: Pteropod abundance is generally higher same years when aragonite is high

7. Temperature: Temperature oscillates throughout the time-series and does not appear to have a strong relationship with pteropod abundance (i.e., pteropod abundance is high when temperature is low some years but high when temperature is high other years)

e. Do any of the environmental variables appear to have a similar trend? Why might this be?

DIC, Alkalinity, and pH do not vary over 20-year time-scales (try 50 years!) so they appear to have similar trends. Carbonate is a component of aragonite so we would expect them to have similar trends. IF your class does not see these trends, emphasize that often time it is difficult to identify long-term trends, especially in relation to biology. This is when statistics comes into play!

f. Based on what you've learned so far in class, what could you hypothesize about how these variables will change overtime?

DIC and CO_2 will increase in the future as atmospheric CO_2 increases. pH, aragonite, and carbonate will decrease as the ocean continues to dissolve more CO_2. Temperature will increase overtime due to global warming and increases in atmospheric CO_2. Alkalinity will decrease as sea ice melts, decreasing the concentration of dissolved ions in seawater by diluting them.

g. Were your hypotheses correct? Why or why not?

Can have the class go around and share group hypotheses, discuss why they were correct/incorrect.

h. Based on what you learned about ocean acidification, why may pteropod abundance decrease as pH decreases?

More carbon dioxide will dissolve into the ocean and make it more acidic (pH decrease), which will dissolve pteropod shells.

i. Based on your results, what do you predict to happen to pteropods in Antarctica in the next 5 years, 50 years, next 100 years?

We will not see much of a change over 5 years as it takes longer time periods to see the effects of ocean acidification. In 50 years, pteropods will decrease as the ocean will be more acidic. In 100 years, pteropods could continue to decrease, potentially become extinct, or adapt and evolve to these changes in seawater from ocean acidification and maintain their population.