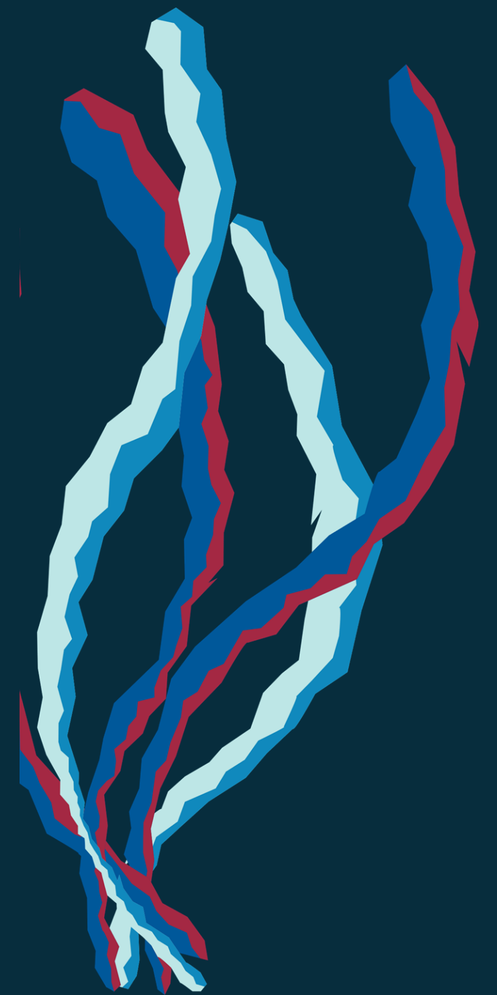
Multiple Stressors

Outline

1. LAND ACKNOWLEDGEMENT
2. STRESSORS
3. OCEAN ACIDIFICATION
4. MARINE HEAT WAVES
5. MULTIPLE STRESSORS
6. OYSTER FARMER ACTIVITY



Land Acknowledgement

NANOOS, WOAC, and University of Washington’s EarthLab acknowledge that many others reside on different territories revoked from Indigenous peoples, and we invite you to take a moment to reflect on the lands you occupy, and their original stewards and consider within this lecture the land and water rights of that region. This lecture was created on land that touches the shared waters of all tribes and bands within the Duwamish, Puyallup, Suquamish, Tulalip, and Muckleshoot nations. We are consciously supportive of the rights to fish, acquire resources, and maintain relationships with the land through reciprocity shared between Indigenous peoples and the Earth since time immemorial.

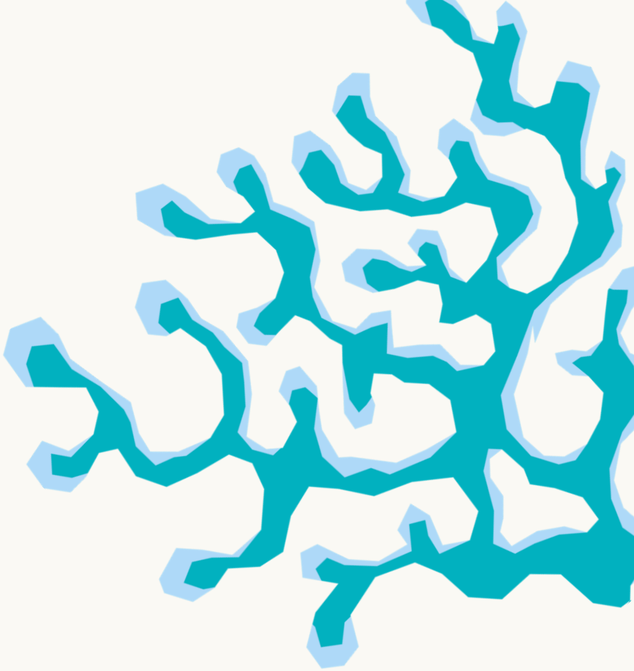
Warm-up Activity

<u>Stressor:</u> a threat to an organism that causes disturbance to its baseline status (homeostasis).

Can you think of some examples of stressors that you felt today?

Brainstorm with a partner and list them on your worksheet!

Warm-up Activity



<u>Stressor:</u> a threat to an organism that causes disturbance to its baseline status (homeostasis).

Now, can you think of some examples of stressors in the ocean? What can cause stress to organisms in the ocean?

Brainstorm with a partner and list them on your worksheet!

Examples of marine stressors:

- Ocean acidification (OA)
- Marine Heat Waves (MHWs)
- Harmful Algal Blooms (HABs)
- Hypoxia (low oxygen)
- Pollution
    - Excess nutrients, oil spills, marine debris, noise, etc.

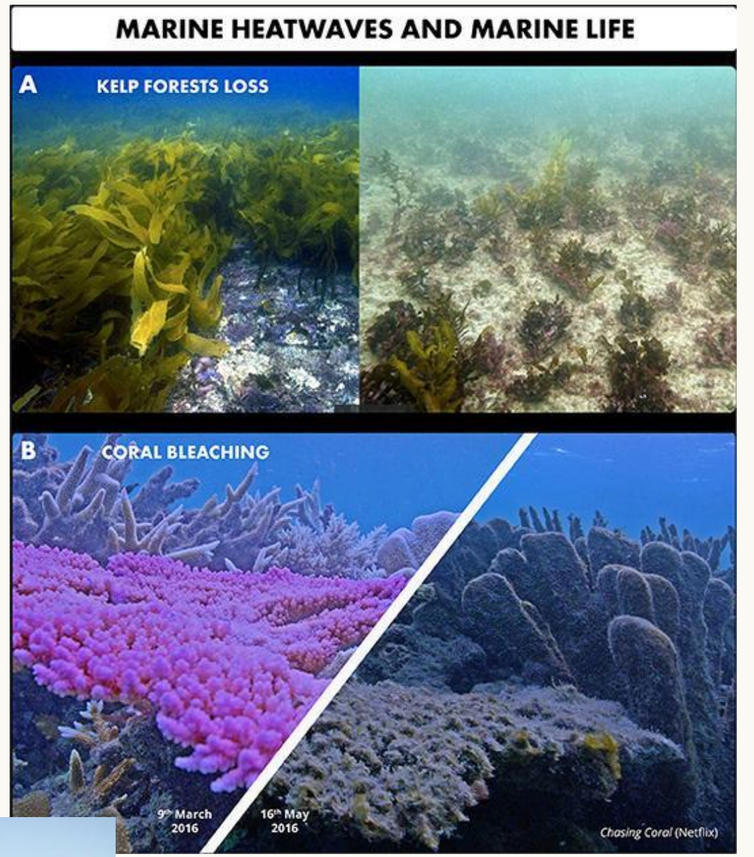
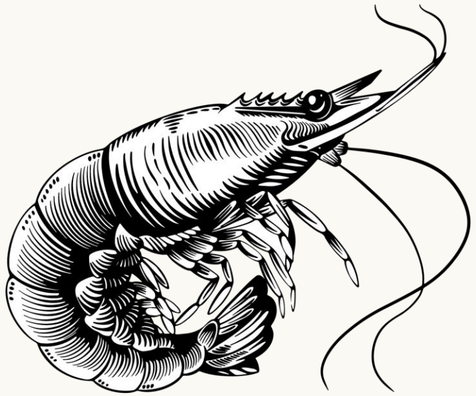


Image: Chasing Corals, Netflix

Image: NOAA Marine Debris Program



What do we mean by multiple stressors?

A single stressor in the ocean can have negative impacts on marine organisms and ecosystems, such as slower growth rates or species decline.

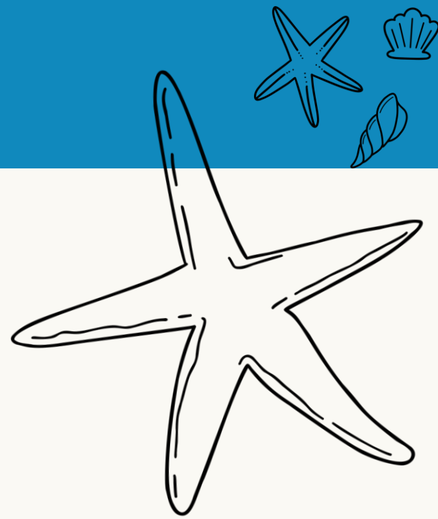
What if another stressor gets added to the mix?

When 2 or more stressors combine or occur at the same time:

- Harmful effects from each stressor can add up
- The presence of 1 stressor can intensify the effects of the other stressor
  - Think of it as going **from bad to worse**

This can lead to tipping points where an ecosystems collapses because it cannot cope or adapt to the rapid changes

Vocabulary Review



Temperature: a measure of hotness or coldness

pH: a scale from 0-14 that measures how acidic or basic a solution is

Calcium carbonate: chemical compound needed for organisms to build structures like shells and skeletons

Homeostasis: the process or ability for an organism to maintain a stable, balanced state despite disturbances

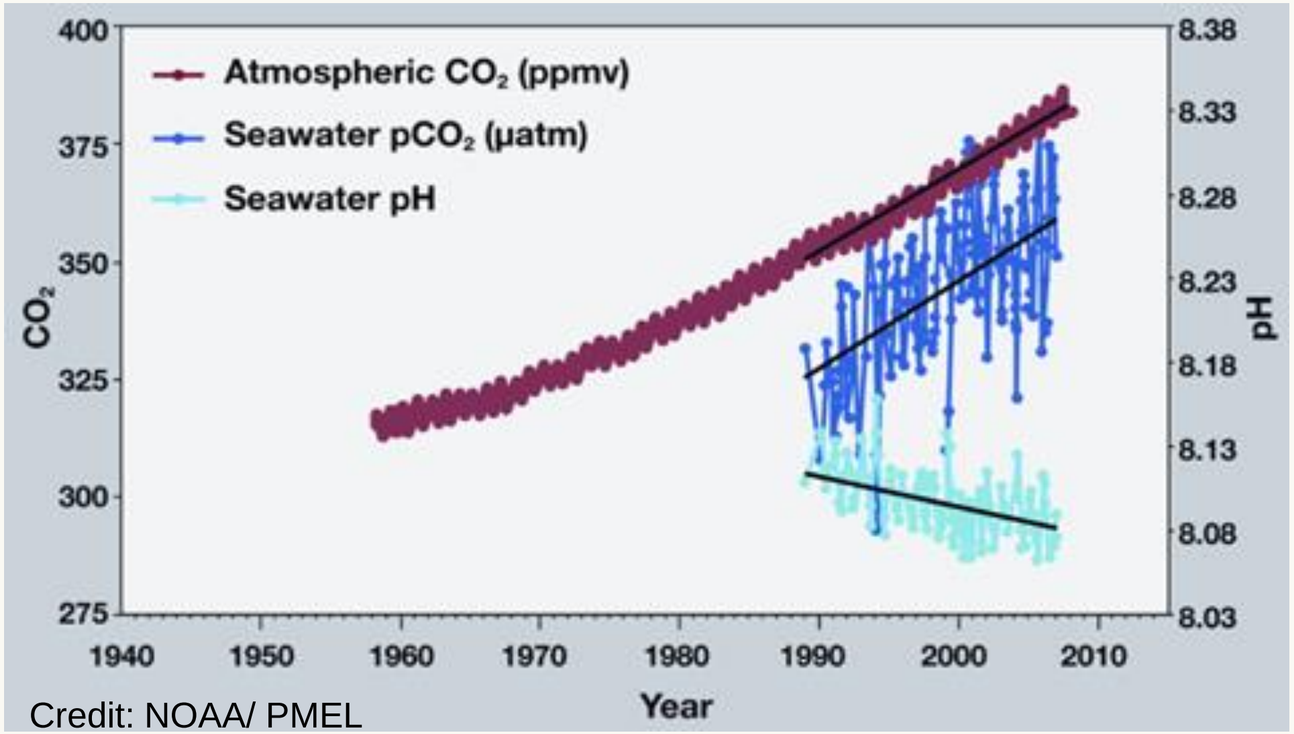
First, let’s consider OA...

What do you already know about OA?

Try to list some things on your worksheet

What is ocean acidification?

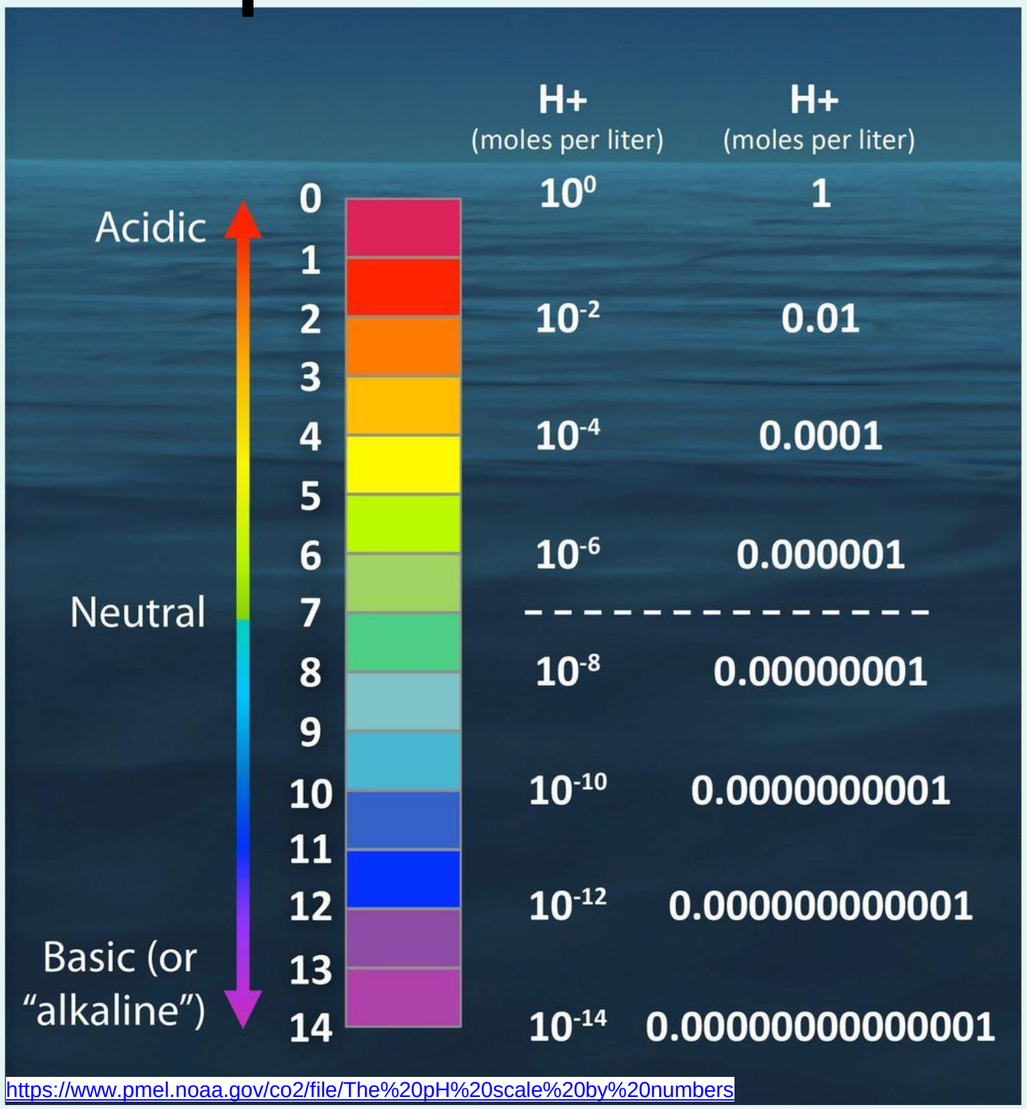
"Ocean Acidification is the **ongoing change** in the **chemistry** of the ocean **caused** primarily by the **ocean's absorption of carbon dioxide** from the atmosphere." – NANOOS



Credit: NOAA/ PMEL

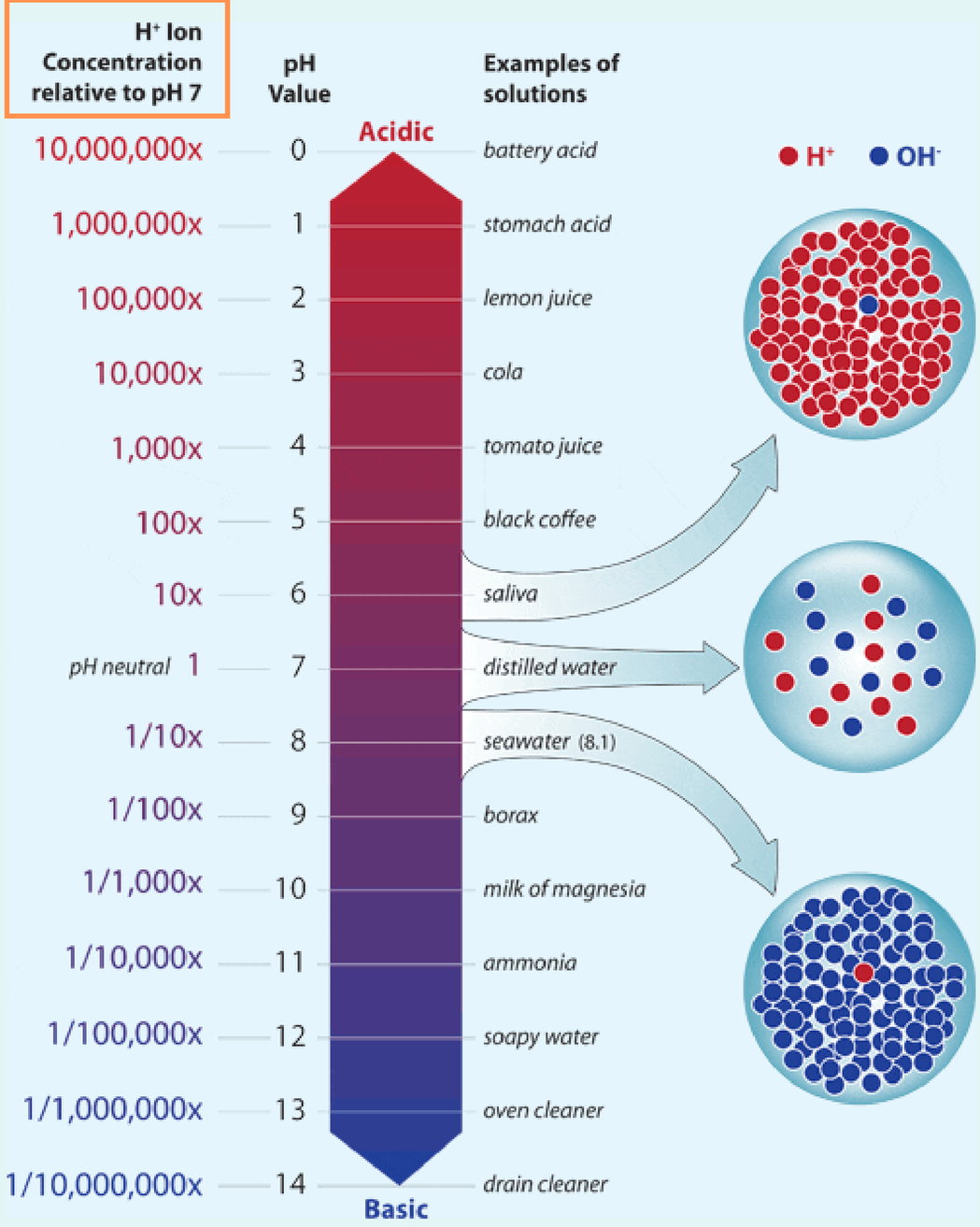
"Ocean acidification refers to a **reduction in the pH of the ocean over an extended period of time**, caused primarily by uptake of carbon dioxide (CO_2) from the atmosphere." – NOAA

pH scales



https://www.pmel.noaa.gov/co2/file/The%20pH%20scale%20by%20numbers

pH is on a log scale!



Remember a small change in pH results in a big change in the environment!

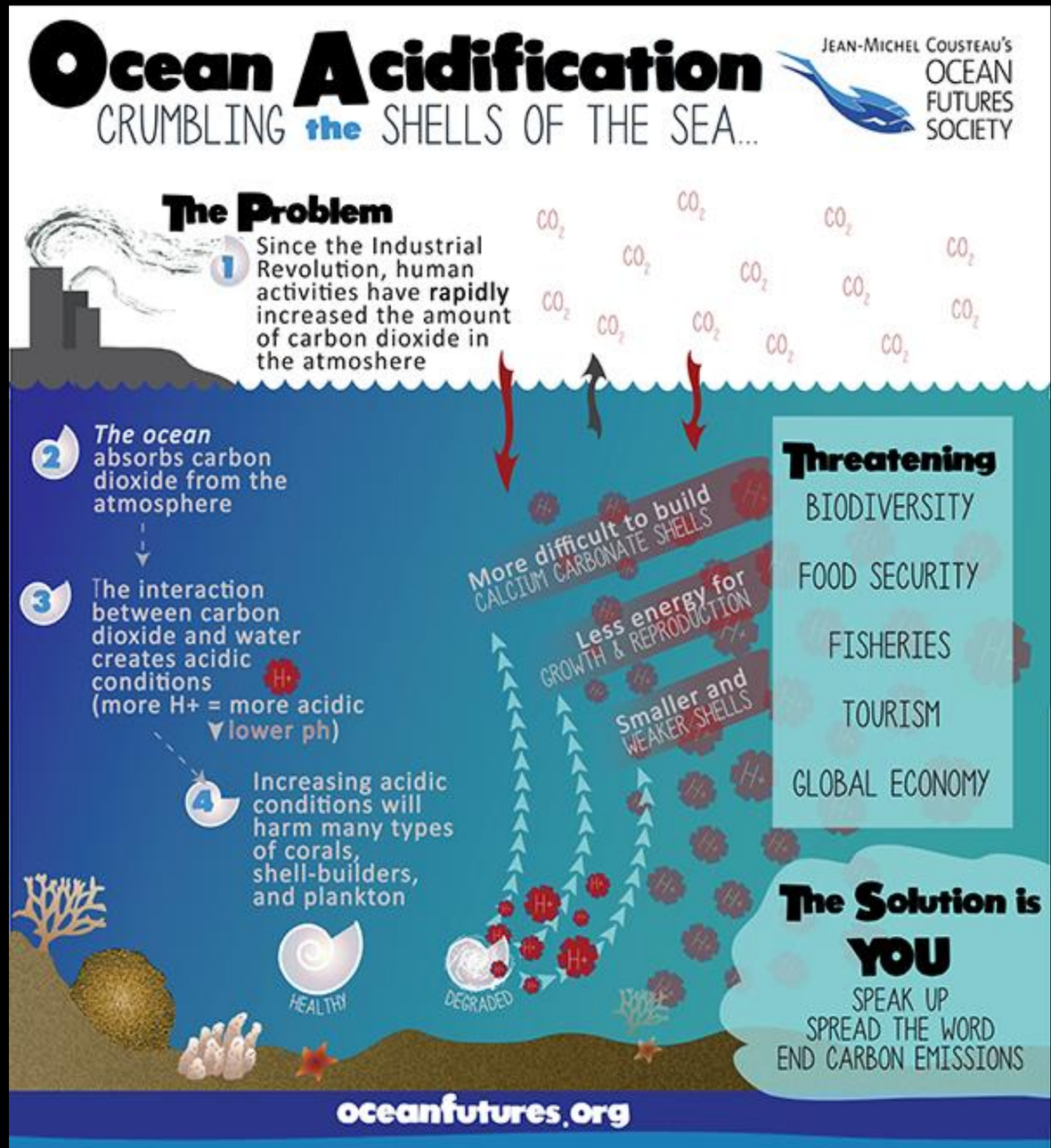
Why is OA a problem?

Calcifying organisms like shellfish, crab, corals, and tiny drifting “pteropods” rely on calcium carbonate to build their structures.

OA decreases the amount of carbonate ion available to them over time.

<u>Less carbonate results in:</u>

- More difficulty building structures
- Less energy for growth, reproduction, and survival



Pteropods

aka sea butterflies

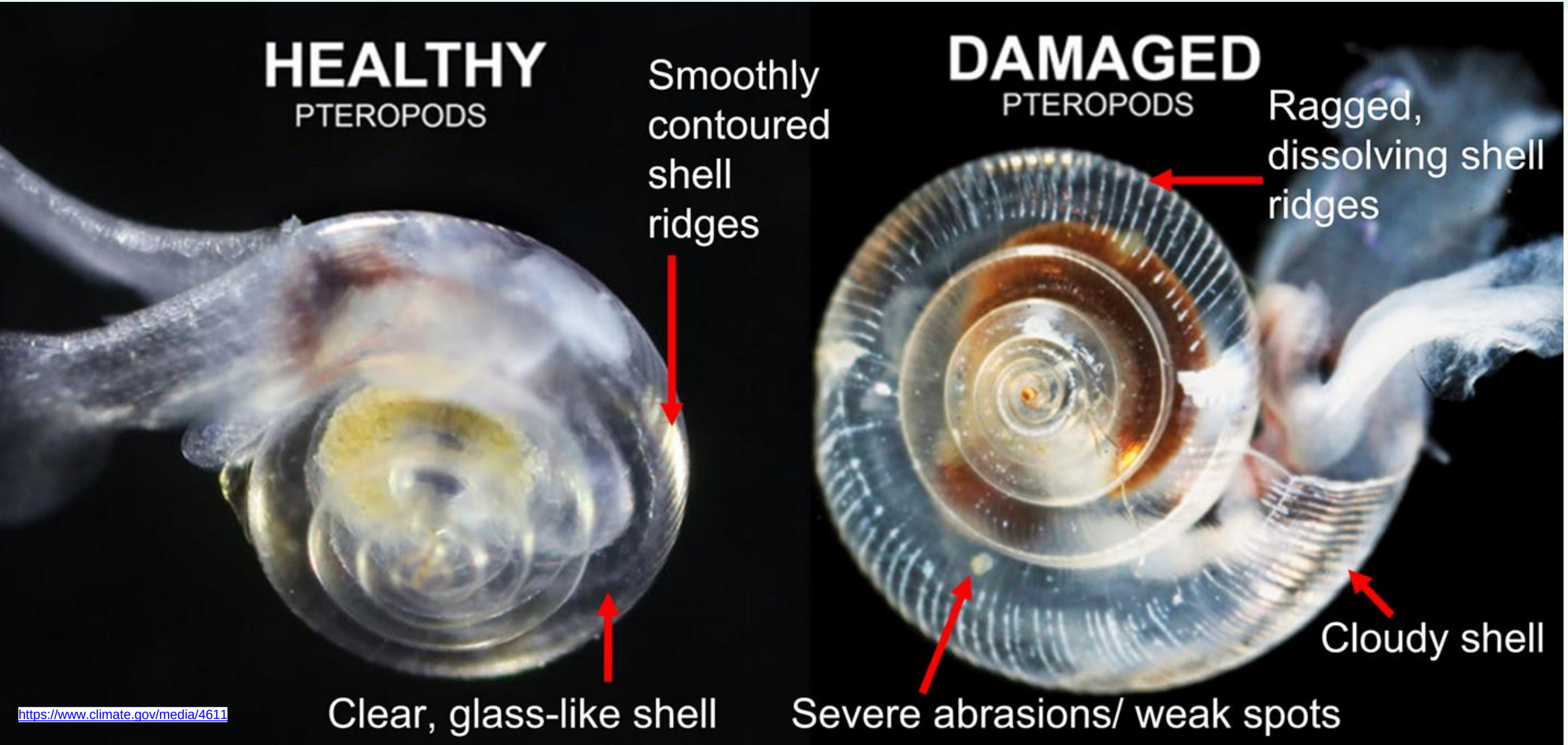
- Important food source in many marine food webs
- Act as indicators of OA

<u>On your worksheet:</u>

- What observations can you make about these pteropods?
- What is different about their shells?

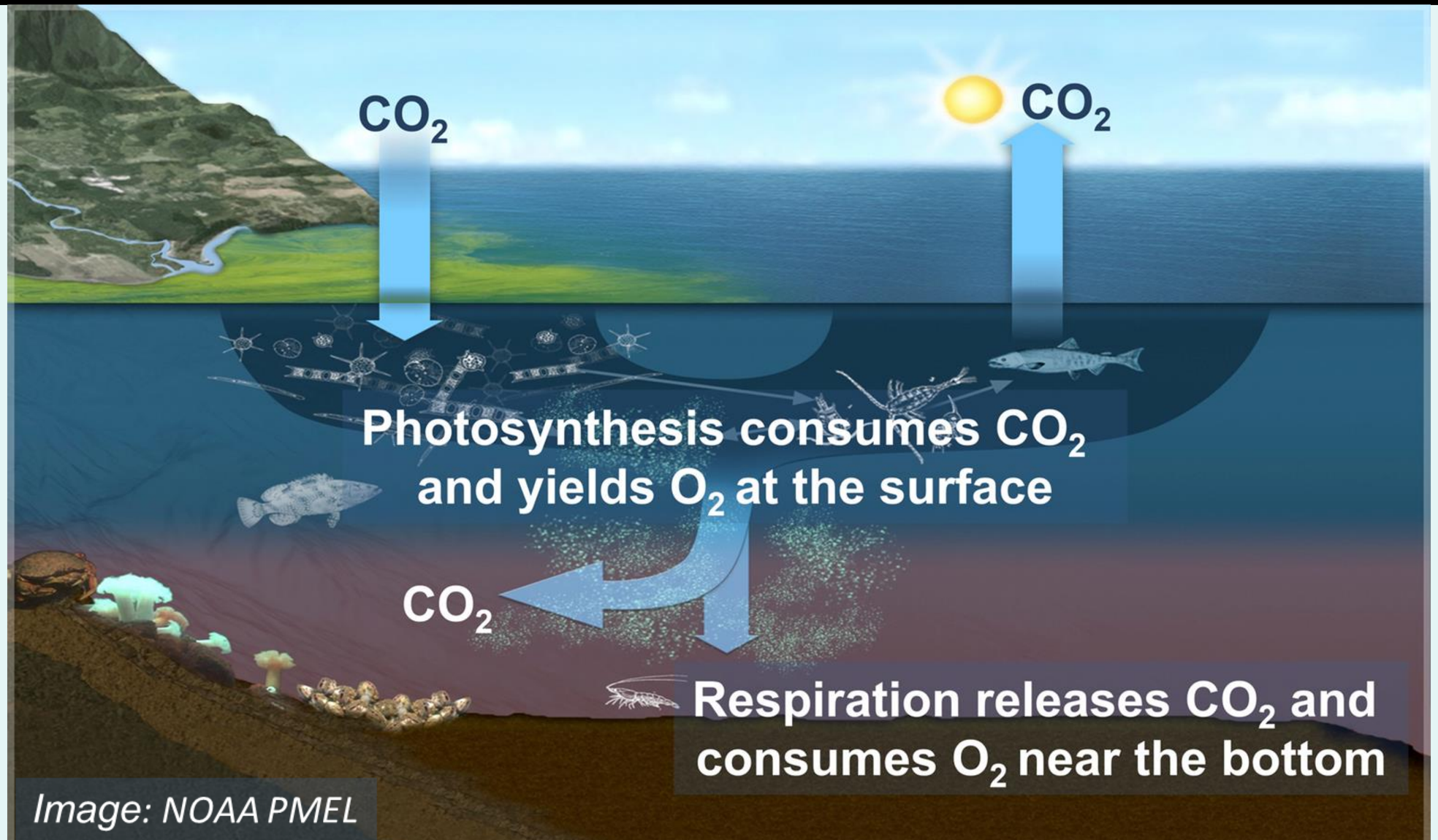
https://journals.plos.org/plosone/article?id=10.1371/journal.pone.0105884

Spotting the differences

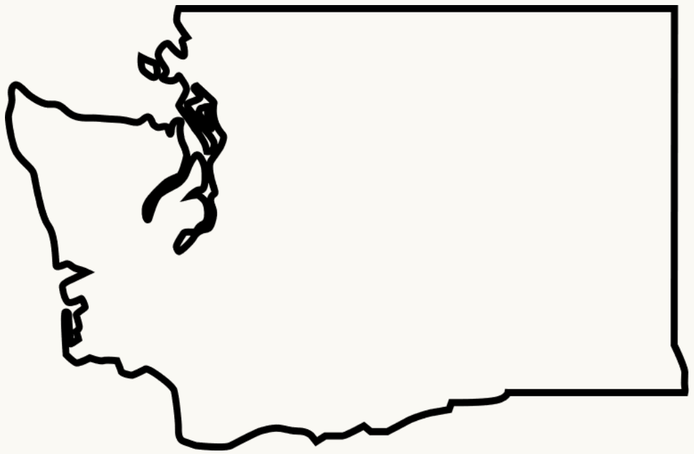


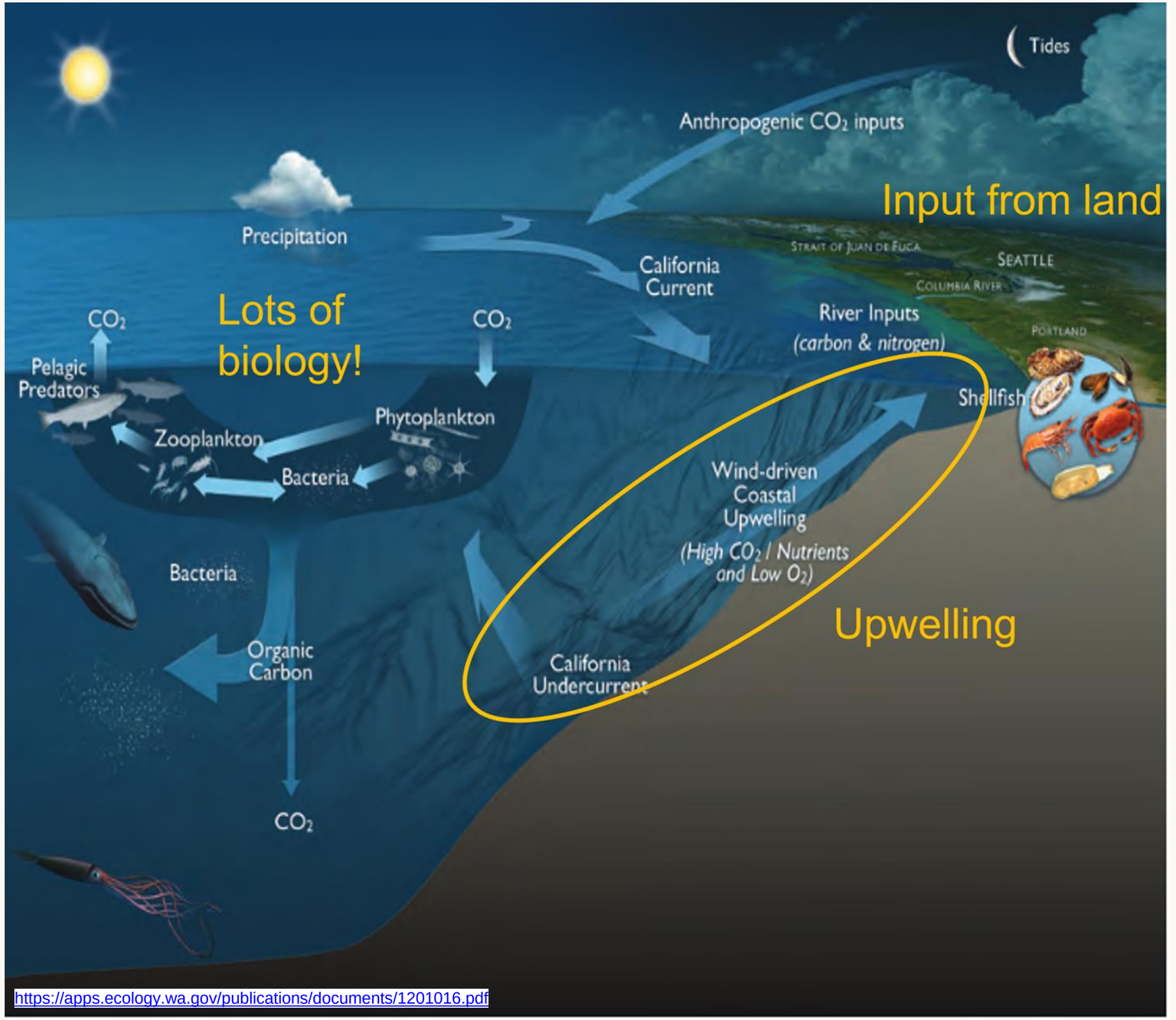
https://www.climate.gov/media/4611

OA is linked to hypoxia: processes that fuel increased respiration yield higher CO_2, lower pH, and lower oxygen



What makes Washington marine waters unique?





https://apps.ecology.wa.gov/publications/documents/1201016.pdf

Figure 1.9: Schematic diagram of the pathways for carbon uptake and remineralization in the coastal waters of Washington State.

Puget Sound and PNW marine waters are particularly vulnerable to OA due to many factors specific to our region:

1. Amount of global CO_2 in our atmosphere from cars etc.

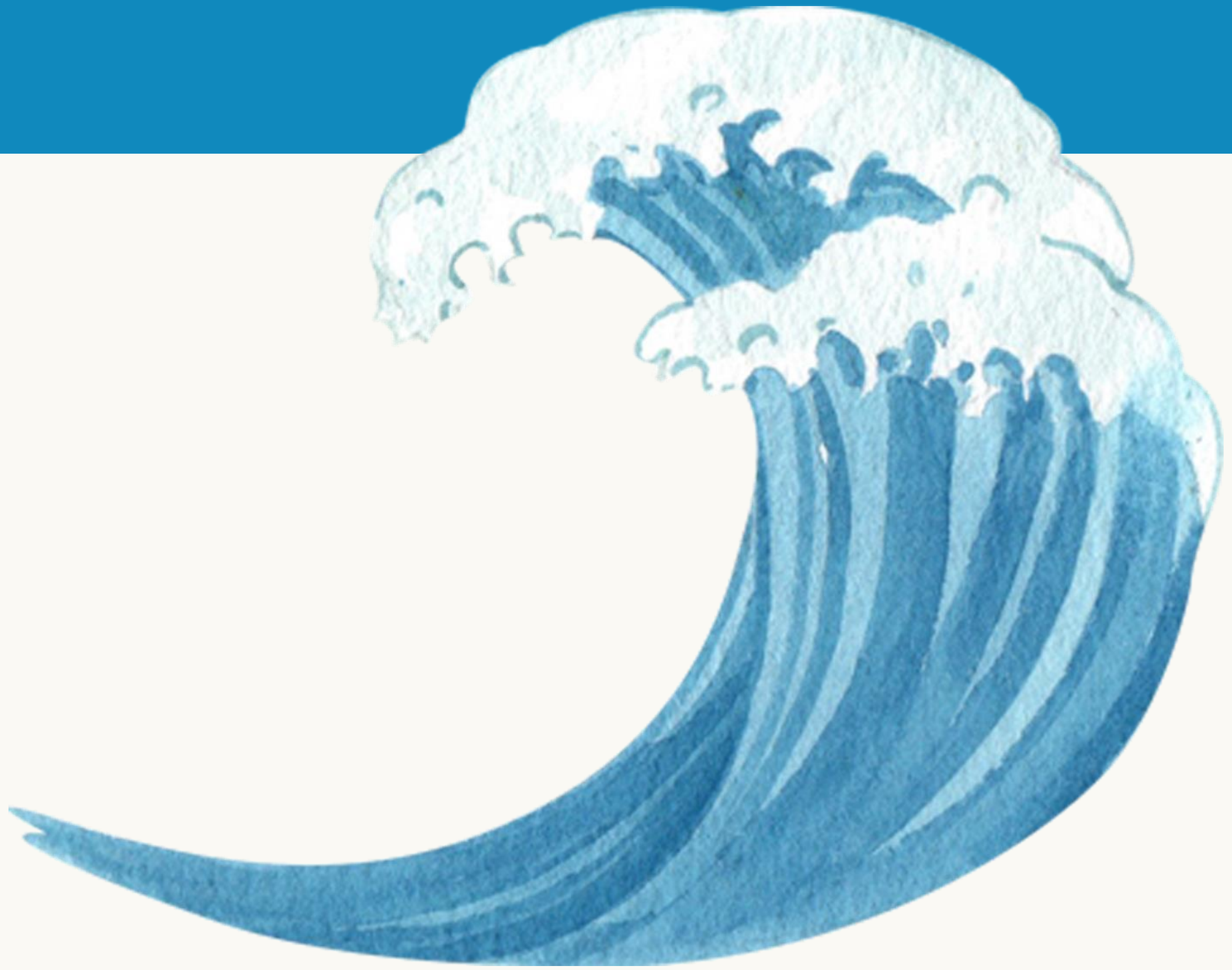
2. Currents off our coast that bring deep water to the surface (upwelling), that are typically corrosive (CO_2–rich, low pH), oxygen-poor, and nutrient-rich

3. High rates of plankton production in the surface (takes up CO_2) that eventually decompose at depth (releases CO_2); decomposition also reduces oxygen content

4. Human activities on land, such as runoff of nutrients and other pollutants from our watersheds and cities, that flow into Puget Sound and coastal waters

In isolation, any 1 of these factors may not tip the balance but when added together they make our waters more susceptible to OA

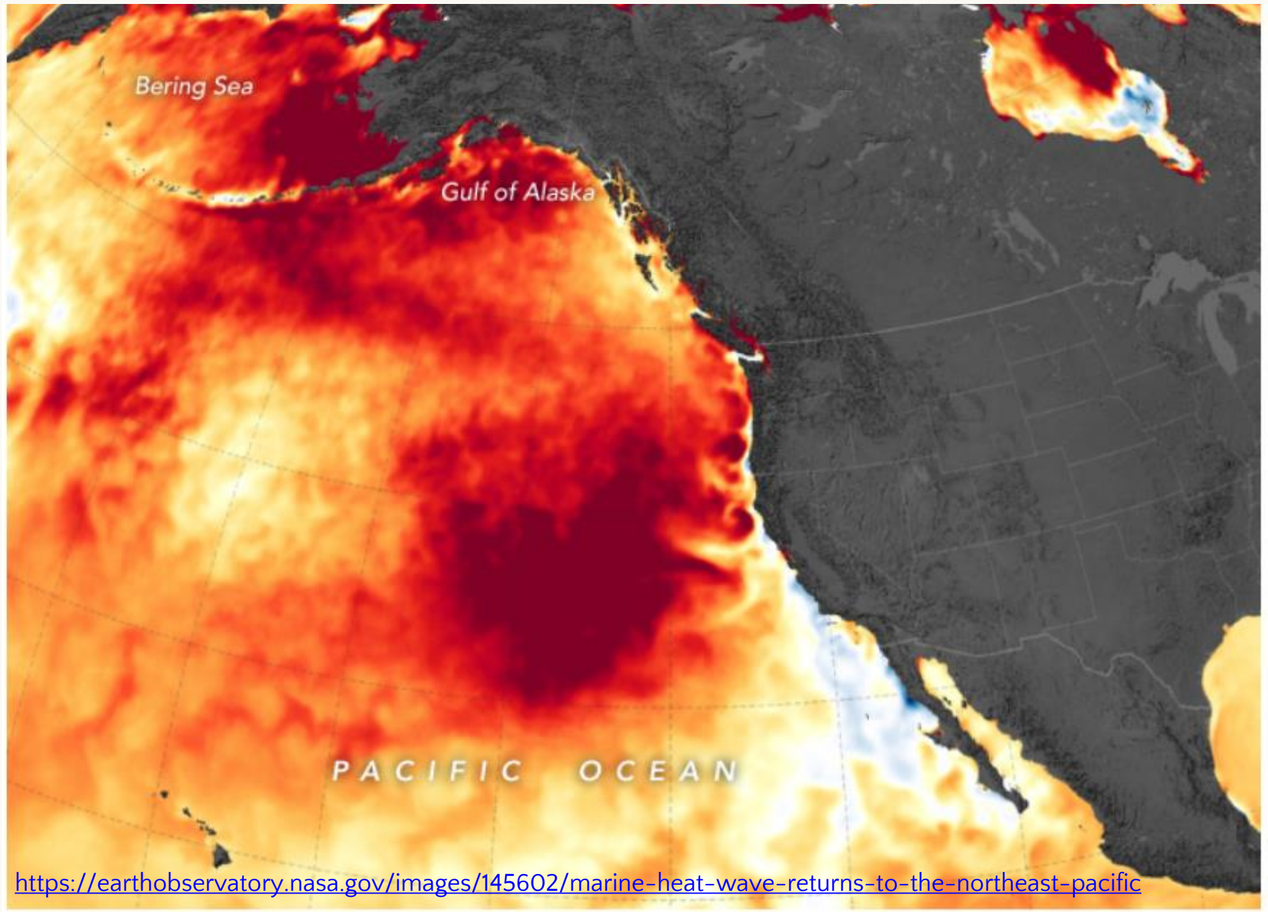
Now, let’s consider seawater temperature



How do we see warmer than average ocean temperature?

Climatology: long-term “normal” established for a certain location at a specific time of year

Anomaly: difference from “normal”



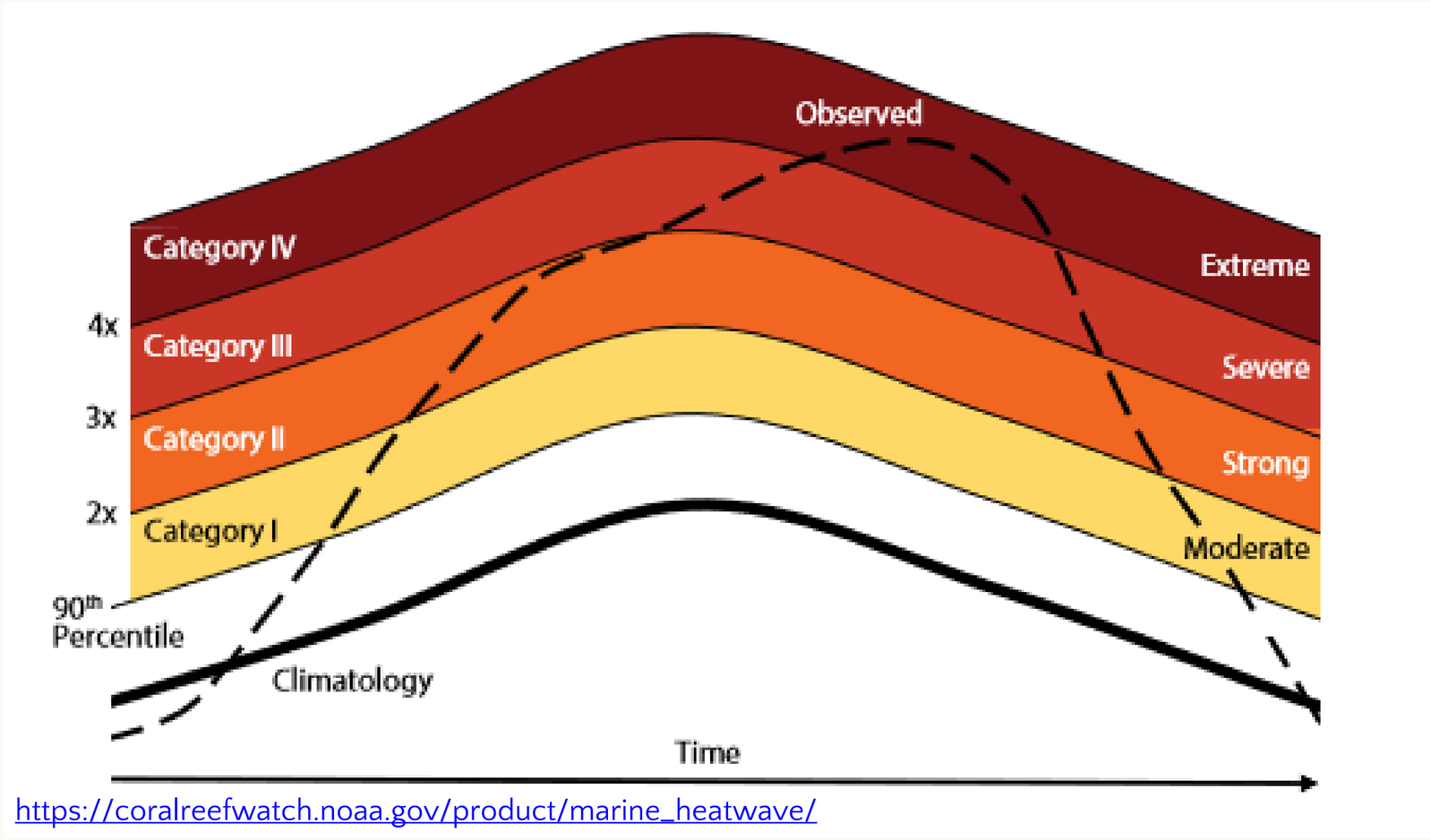
https://earthobservatory.nasa.gov/images/145602/marine-heat-wave-returns-to-the-northeast-pacific

White represents normal

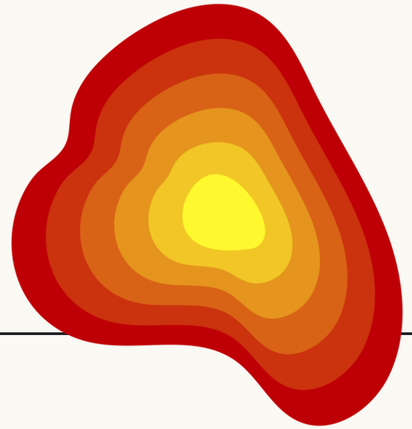
Red is warmer than normal

Blue is colder than normal

What are Marine Heat Waves?



https://coralreefwatch.noaa.gov/product/marine_heatwave/



A MHW occurs when sea surface temperatures are abnormally high and is defined by its intensity and duration.

MHWs in the News...

Looking Back At The Blob: Record Warming Drives Unprecedented Ocean Change

September 26, 2019

Temperatures of up to 7 degrees Fahrenheit above normal disrupted the marine ecosystem in both expected and surprising ways.

JUNE 4, 2024 Editors' notes

Rocky shores of Pacific Northwest show low resilience to changes in climate

by Steve Lundeberg, Oregon State University

OCEANS

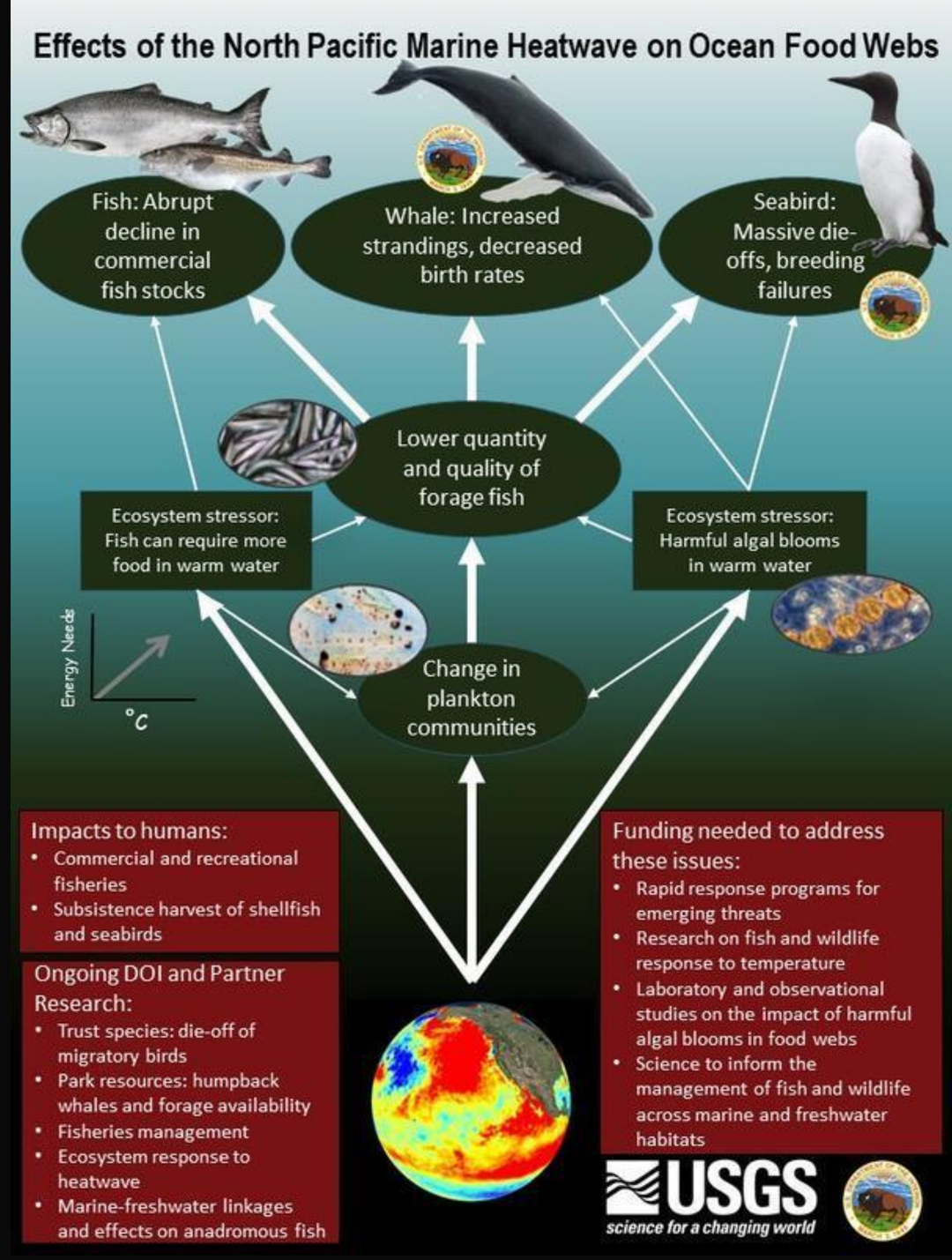
AUGUST 31, 2023

Protect Our Oceans

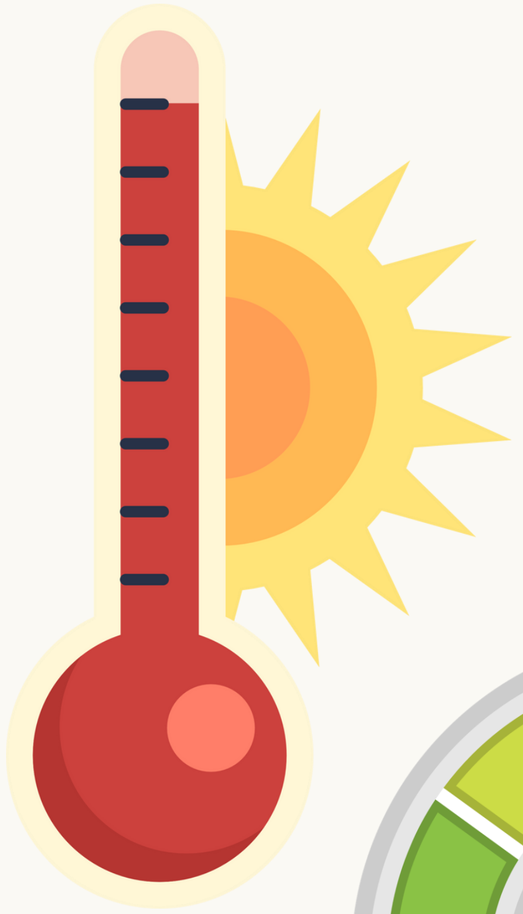
A marine heat wave is taking a toll on the Pacific Northwest

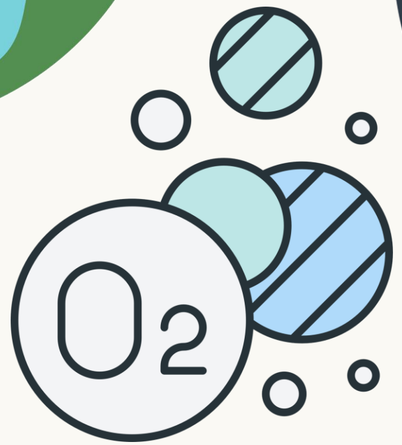
Marine heat waves disrupt the ocean food web in the northeast Pacific Ocean

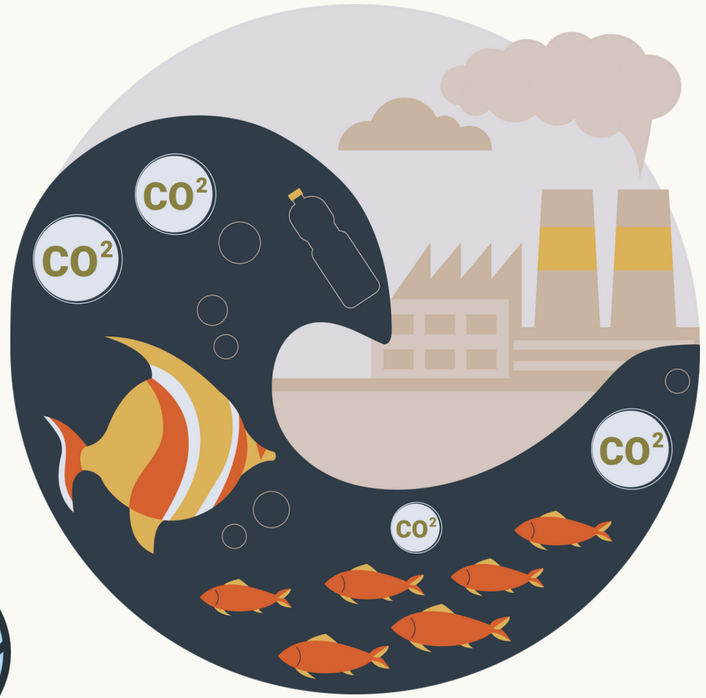
March 13, 2024



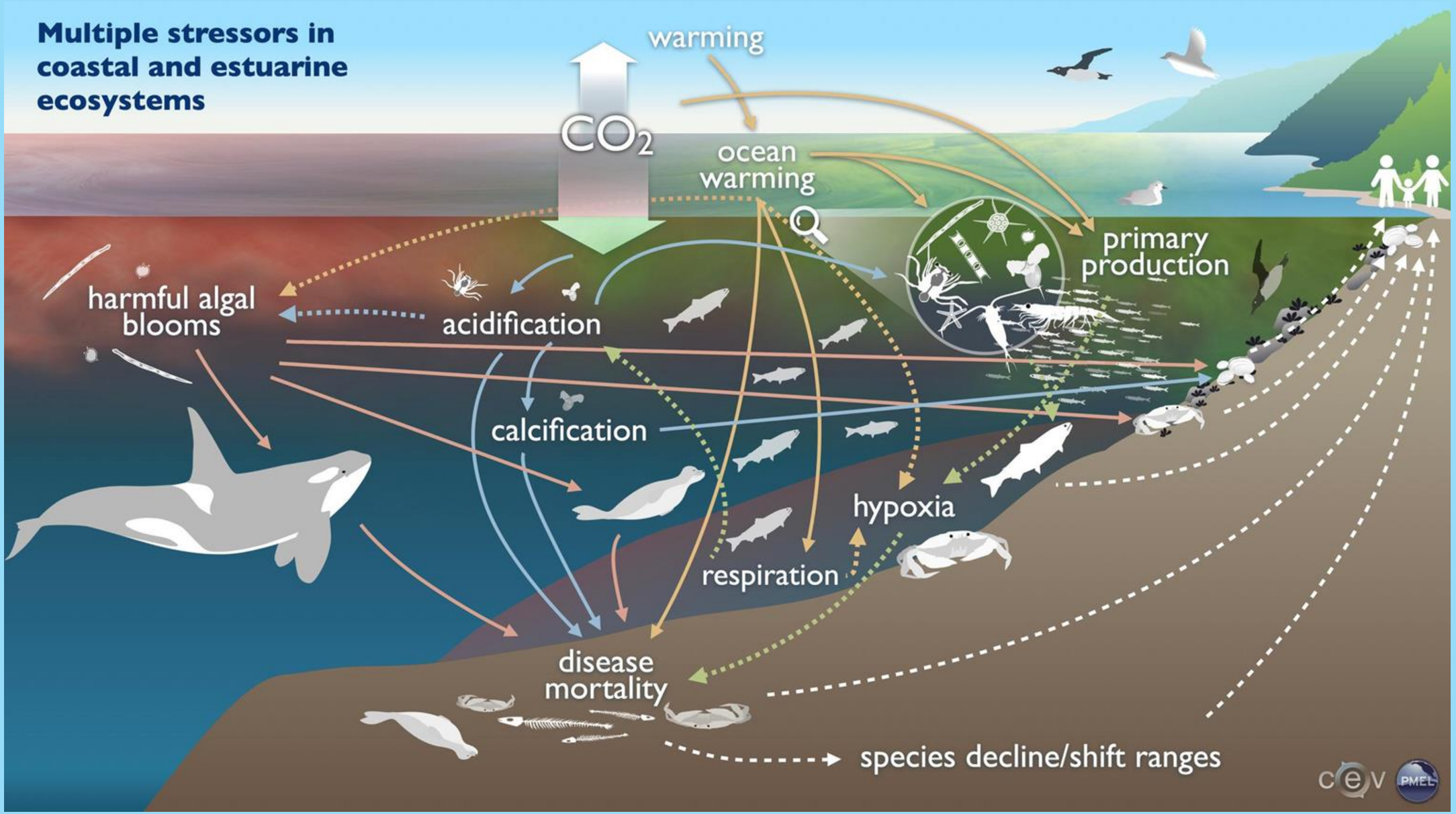
Now, let’s think about multiple stressors!







Multi-stressors and their potential impacts



How do we measure stress in the ocean?

- Monitoring water quality using pH, salinity, temperature, dissolved oxygen, pollutants, etc.
- Collecting data on growth and mortality rates
- Comparing marine species sizes from past to present
- Shell composition: is it thick? thin? brittle?

Why we care

Food security + scarcity

Seafood is a vital and culturally important food source for humans! Shellfish also serve as important organisms in many marine food webs

Biodiversity + ecosystems

Coral reefs support habitats for marine organisms, like fish and mollusks, to live in and hide from predators

Culture + economy

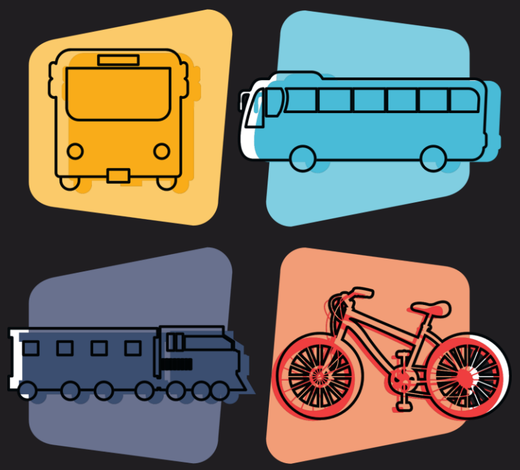
Including preserving Indigenous peoples' way of life, fisheries vitality, and regional tourism

Quinault Indian Nation razor clamming; photo credit: David Ruck

Taylor Shellfish Farms worker; photo credit: Ted S Warren/ Alamy

https://dialogue.earth/en/ocean/ocean-acidification-us-pacific-shellfish-farms

How can y’all help?



- Reduce, reuse, recycle!

  → minimize your carbon footprint

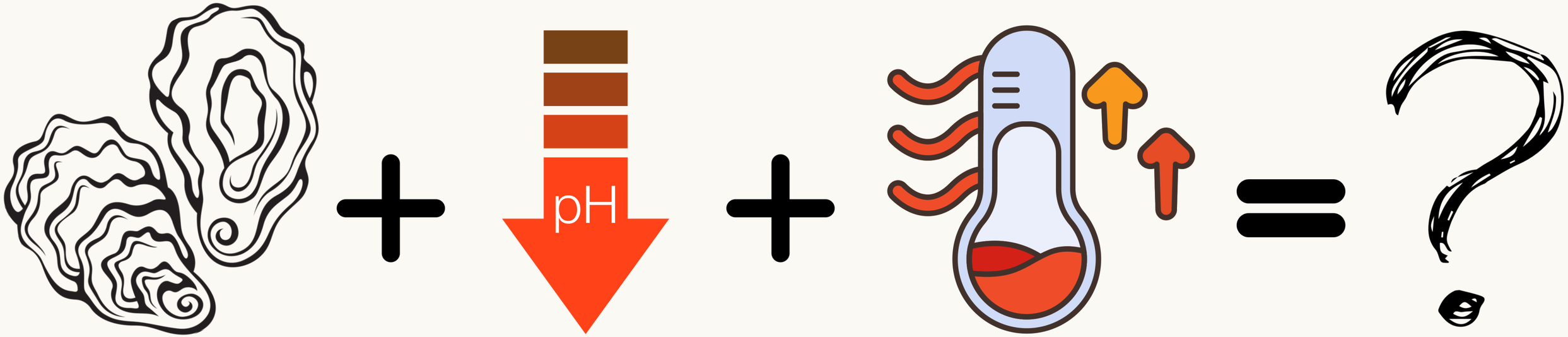
- Walk, bike, or take public transportation instead of driving

- Talk to friends, family, community, and policy makers about how human-driven climate change is affecting our Earth’s oceans

Think-Pair-Share:

Imagine you are a shellfish in the Pacific Northwest and the water around you starts getting warmer and more acidified.

How do you think these changes will affect you?



Oyster Farmer Activity Prep

pH isn’t the only OA variable that is relevant to shellfish.

Omega (Ω), the saturation state, of aragonite describes the level of calcium carbonate saturated in seawater available for aragonite, which shellfish use for their shells.

Oyster seed, baby oysters grown at Taylor Shellfish in Dabob Bay. (Photo:KUOW/Ruby de Luna)

https://www.kuow.org/stories/Baby-oysters-cant-build-healthy-shells

Saturation states

Think of saturation state like making hot chocolate:

Supersaturated: Too much powder mix (undissolved clumps)

Saturated: when no more cocoa powder will dissolve in the liquid

Undersaturated: Not enough powder mix (watery cocoa)

Oyster Farmer Activity Prep

pH isn't the only OA variable that is relevant to shellfish.

Omega (Ω), the saturation state, of aragonite describes the level of calcium carbonate saturated in seawater available for aragonite, which shellfish use for their shells.

If Ω > 1.5 then larval oysters are **safe** (saturated)
If Ω < 1.5 then larval oysters **will likely not survive** (undersaturated)

If Ω aragonite is **below 1**, conditions are **corrosive** (undersaturated) and aragonite shells will begin to get etched and dissolve.

Also need safe pH and temperature ranges for larval oysters:
Multiple stressors!

Aragonite crystal

Pretend you're an oyster farmer!

…and want to find out if you should plant larval seed today.

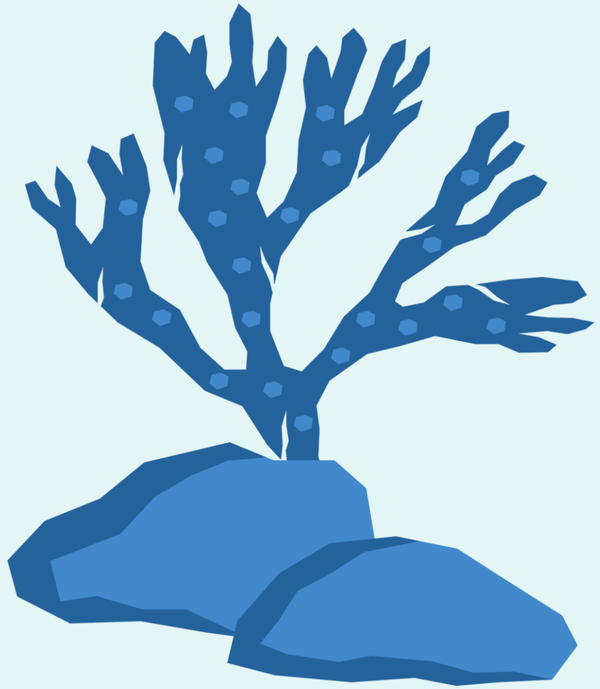
Use instructions on worksheet to navigate NANOOS Visualization System (NVS) to view data for:

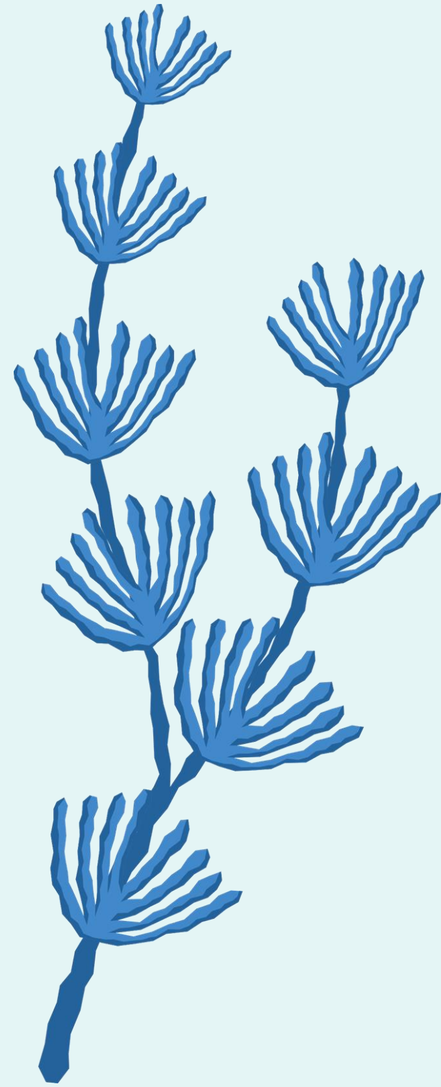
- $\Omega_{aragonite}$
- sea temperatures
- pH

Computer Activity Time!

Want to learn more?

- NANOOS: Multi-stressors publications
- NANOOS: Education resources
- 6 Things we know about OA in PNW
- Pacific Marine Heatwave





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WOAC
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Acknowledgements

NANOOS

Name:_____ Date:_____

Multiple Stressors Worksheet

Draw or use your own words to describe what stress means to you.

List some examples of personal stressors:

1.

2.

3.

List some examples of stressors in the ocean:

1.

2.

3.

4.

What do you already know about ocean acidification? Is there anything about it that is confusing to you?

What observations can you make about the healthy vs. unhealthy pteropods? What is different about their shells?

Name:_____ Date:_____

Fill in the blank definitions:

Ocean acidification is the ongoing _____ in the ocean, which is primarily caused by the ocean's_____ from the atmosphere.

Marine heat waves occur when _____ are unusually _____ than normal and are characterized by their _____ and duration.

What are multiple stressors? Why are they bad for marine organisms?

Think-Pair-Share activity:

Think about the scenario on your own for a few minutes, then turn to a neighbor and talk about it together.**Imagine you are a shellfish in the Pacific Northwest and the water around you starts getting warmer and more acidic. How do you think these changes will affect you?**

Circle the appropriate answer:

When Ω > 1.5, are larval oysters **safe/not safe** and likely **will/will not** survive.

When Ω < 1.5, are larval **safe/not safe** and likely **will/will not** survive.

Computer Activity Instructions

The Northwest Association of Networked Ocean Observing Systems (NANOOS), the regional association of U.S. Integrated Ocean Observing System (U.S. IOOS) for the U.S. Pacific Northwest, developed the NANOOS Visualization System (NVS) to provide users with a rich interface to access observations, forecasts, and satellite overlays from a wide range of ocean and coastal assets.

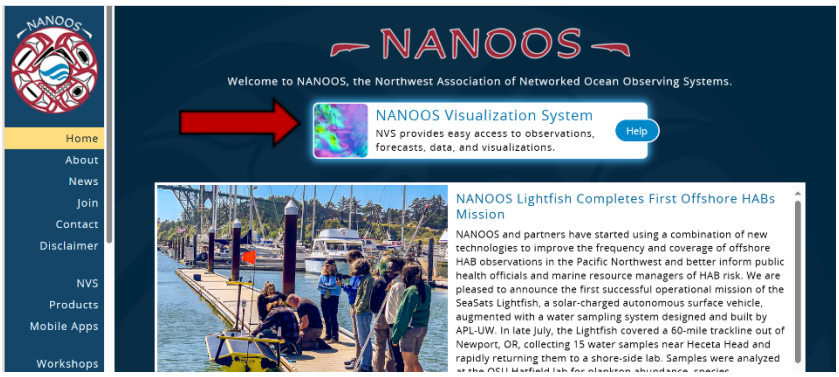
Pretend you are an oyster farmer, and you want to find out if you should plant larval seed today based on data from NVS. Use the table below as you go through the activity.

Location	Date	Time	$\Omega_{aragonite}$	pH	Temp: Normal? Anomaly?

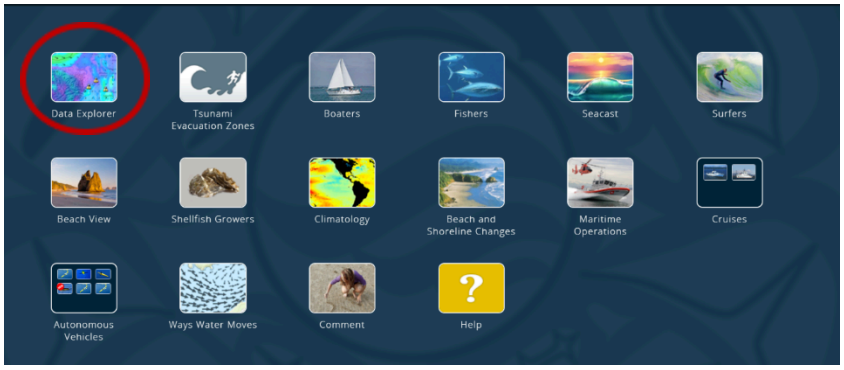
Let's check the saturation state of aragonite!

1. Go to www.nanoos.org (NANOOS Homepage)

2. Navigate to NANOOS Visualization System (NVS)

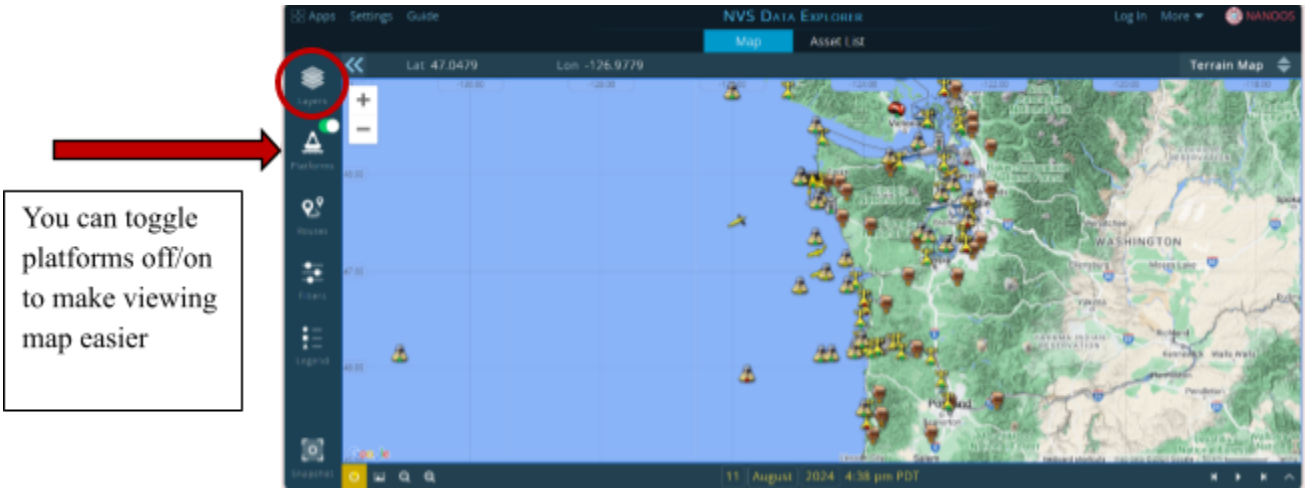


3. Click on Data Explorer App (circled in red below)



4. Zoom in on the Washington coastline from tip of Olympic Peninsula to Columbia River (can click and drag to move around on the map).

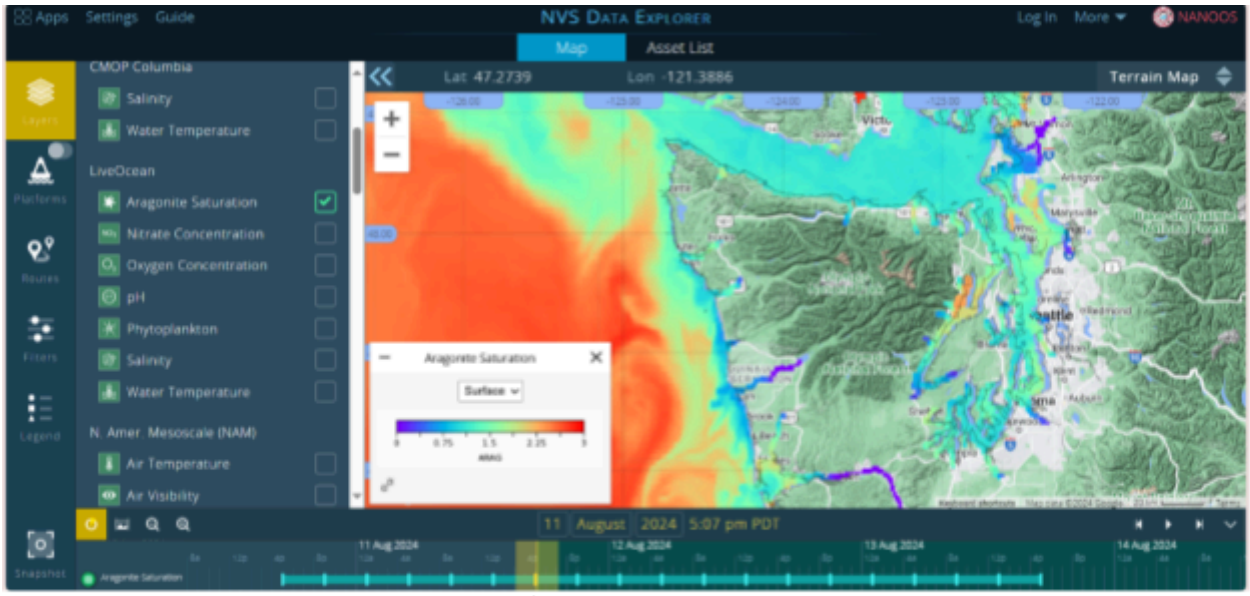
5. On left-hand side of screen, click on “Layers” to open its menu (can also toggle platforms off/on to make the area easier to see)



6. In the “Layers” menu, scroll down to “Models” and click on the “+” to see more options.

7. Under LiveOcean, click the box next to “Aragonite Saturation”
    - Did you notice any color changes on your map? Does it look similar to the one below?

        - If not, or if you’re having trouble: Ask for help and/or click here!



Click and drag the yellow marker along the different days and times to view forecasted data over next 3 days

8. Based on your map and the colors you can observe, do you see any locations that would be safe to plant larval seed today? (use color scale to estimate values for the saturation state of aragonite)

    - Write down 2-3 safe and/or unsafe locations along with their estimated values!

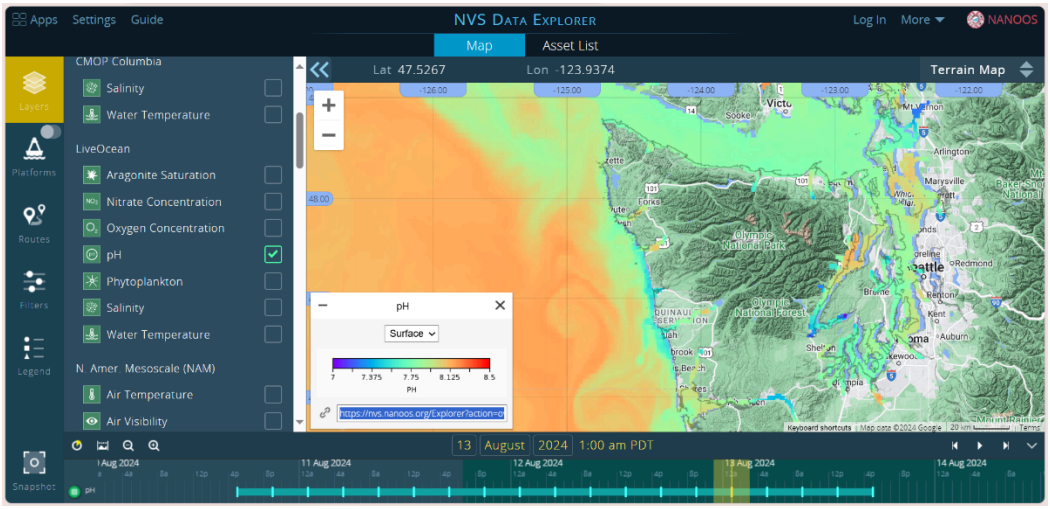
    - What does the data look like tomorrow or 2 days from now?

9. Are the $\Omega_{aragonite}$ values the same at the surface and bottom? (use drop-down menu on the color scale to switch between depths)

Now, let's check the forecast for pH!

10. Go back to the "Layers" menu and navigate to options under "Models"

11. Under LiveOcean, uncheck the box next to "Aragonite Saturation" and check the box next to "pH"



- If you're having trouble navigating to the pH forecast: Ask for help or **go here**

12. Based on your map, what is the estimated pH for the locations you wrote down in the last part? (use color scale to estimate values for pH)

    - What does the data look like tomorrow or 2 days from now?

13. Are the pH values the same at the surface and bottom? (use drop-down menu on the color scale to switch between depths)

Now, let's check temperature!

14. Go back to www.nanoos.org (NANOOS Homepage) and navigate to NVS

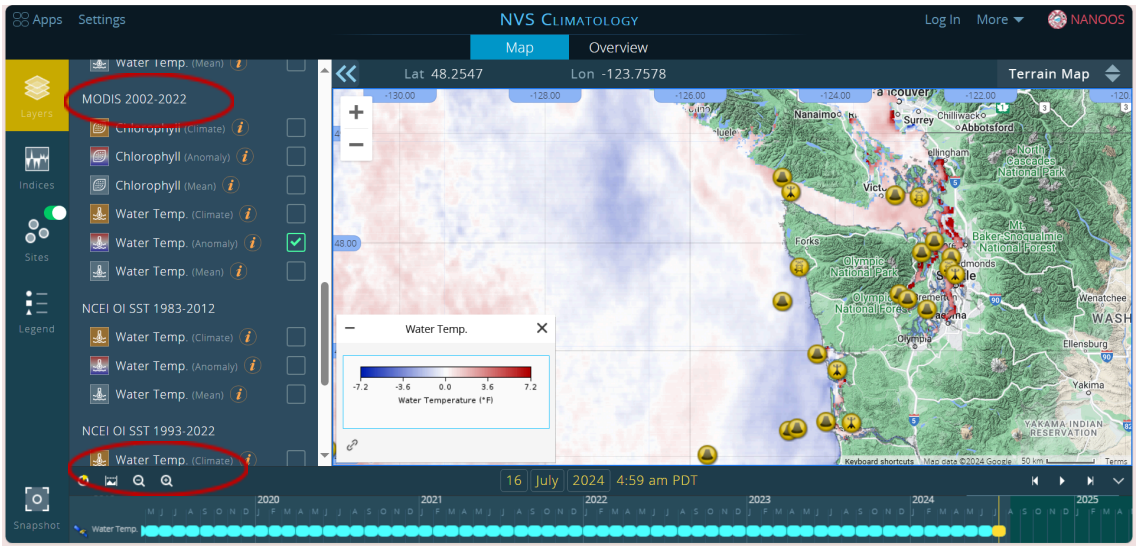
15. Click on Climatology App (circle in red)

16. Go to “Layers” menu (left hand side of screen)

17. In Layers menu, look under “Models” then scroll down until you find “MODIS 2002-2022” or “NCEI OI SST 1993-2022”

18. Check a box for Water Temp. (Climate), (Anomaly), or (Mean). Take time to explore the different options and what they look like on the map!

    - Having trouble viewing water temperatures? Ask for help or **try here!**



19. Make observations and record water temperature data for your chosen locations on your table. Make a note if the water temperature is normal or abnormal and by how many degrees.

Reflection time:

20. Now that have collected all of your data. Which day(s), if any, do you think would be best to plant larval seeds? Why or why not?

21. Did you learn anything new today? What did you find most interesting? Is there anything you are confused by?

Teacher Supplemental

Multiple Stressors curriculum

Preparation tips:

- Familiarize yourself with instructions for NVS computer activity and check links below to ensure they are working and showing NANOOS modeled/forecasted data properly
    - Ω of aragonite
    - pH
    - Temperature
        - Students might need to click select closest data point (near bottom of screen) for sea temps to appear

- Provide online or printed version of multiple stressor worksheet for each student

- Review lesson plan slides and additional materials prior to class time, if needed

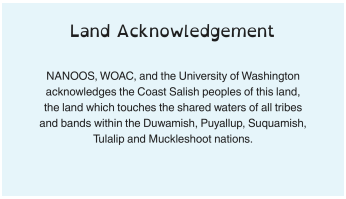
Additional Resources: (if needed)

- Multi-stressors: Publications (nanoos.org)
- Multi-Stressor Observations and Modeling to Build Understanding of and Resilience to the Coastal Impacts of Climate Change (scientific paper)
- Integrated Multi-Stressor Observations, Modeling, and Experiments to Inform Management in the Northern California Current
- NANOOS: What is Ocean Acidification?
- Six things we know about OA in PNW coastal waters
- Ocean acidification: How US Pacific shellfish farms are coping (dialogue.earth) (article)
- Ocean acidification | National Oceanic and Atmospheric Administration (noaa.gov) (article)
- LiveOcean Homepage (washington.edu) (LiveOcean model + forecasts)
- NANOOS Partnerships for Assessing OA in the PNW (scientific paper)
- Shell Condition and Survival of Puget Sound Pteropods Are Impaired by Ocean Acidification Conditions | PLOS ONE (scientific paper)
- Northwest Bivalve Shellfish and Marine Snails in a Changing Climate (USDA article)
- Ocean Acidification's impact on oysters and other shellfish (noaa.gov) (video)
- The ongoing marine heat waves in U.S. waters, explained (NOAA article)
- Pacific Marine Heatwave (USGS article)
- Marine Heat Wave tracker (interactive tracker)

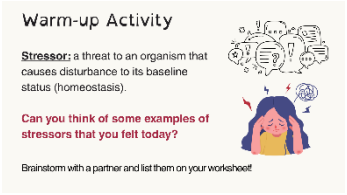
Overview of Slides

Slide 1: Title/introducing multiple stressors

Slide 2: Agenda

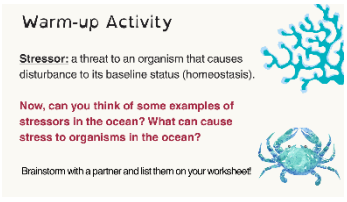


Slide 3: Land Acknowledgement



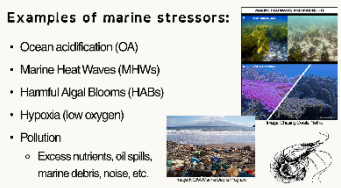
Slide 4: Warm-up Activity part 1

Direct students to list some examples of personal stressors on their worksheets.



Slide 5: Warm-up Activity part 2

Now, have students list some examples of ocean stressors.

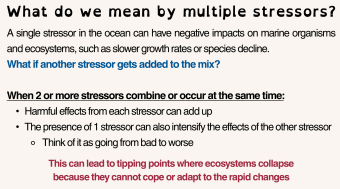


Slide 6: Examples of marine stressors

Sources:
Example stressors: https://www.nanoos.org/products/multi-stressors/home.php

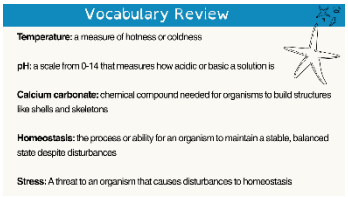
Top image (MHWs):
https://kids.frontiersin.org/articles/10.3389/frym.2022.712528
Photo credit: Chasing Corals, Netflix

Bottom image (marine debris):
https://www.nanoos.org/products/marine_debris/marine_debris.php
Photo credit: NOAA Marine Debris Program



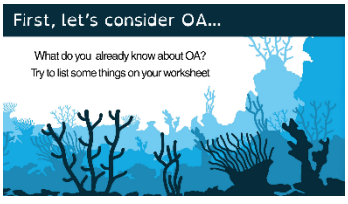
Slide 7: What does multiple stressors mean?

When 2+ stressors combine or occur simultaneously, their effects can be additive and/or synergistic. Focus on organisms becoming increasingly stressed and vulnerable to the point where they cannot adapt or cope anymore.



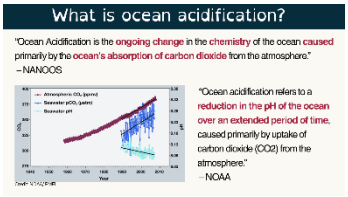
Slide 8: Vocab review slide

Source: Google searches (and common knowledge)



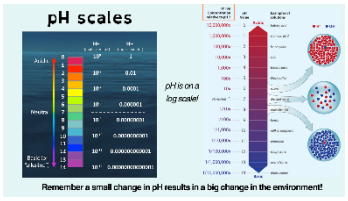
Slide 9: Transition to ocean acidification

Direct students to jot some thoughts and ideas they already have about OA on their worksheet.



Slide 10: What is OA?

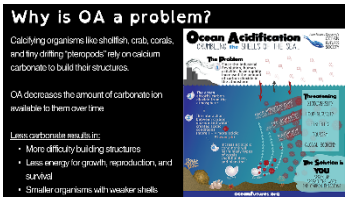
Source:
https://www.nanoos.org/products/oa/ocean_acidification.php
Graph credit: NOAA/PMEL



Slide 11: pH scales

Sources:
Left pH scale:
https://www.pmel.noaa.gov/co2/file/The%20pH%20scale%20by%20numbers
Credit: PMEL/NOAA

Right pH scale:
https://www.whoi.edu/know-your-ocean/ocean-topics/how-the-ocean-works/ocean-chemistry/ocean-acidification/the-ph-scale/
Credit: Woods Hole Oceanographic Institution



Slide 12: Why is OA a problem?

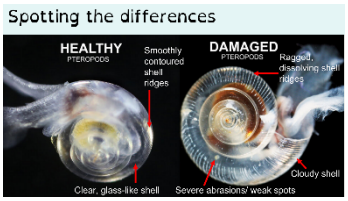
Source:
infographic: https://www.oceanfutures.org/news/blog/ocean-acidification-crumbling-shells-sea

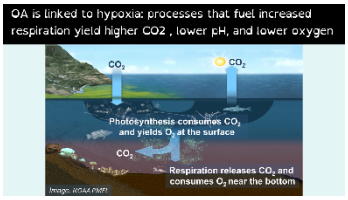
Slide 13: Pteropods—shell dissolution from OA

Have students write down some observations about the healthy vs. damaged shells on their worksheets.

Sources:
https://journals.plos.org/plosone/article?id=10.1371/journal.pone.0105884

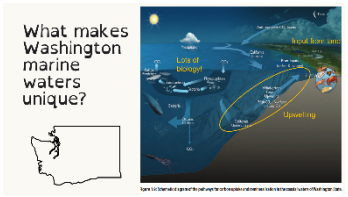
For more info on pteropods and OA:
https://www.seadocsociety.org/blog/tag/pteropods
Image credit: The SeaDoc Society





Slide 15: OA linked to Hypoxia

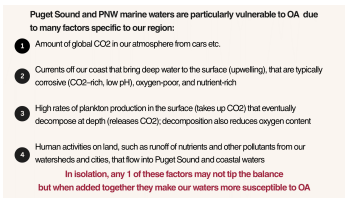
Image Credit: NOAA/PMEL



Slide 16: What makes WA marine waters unique?

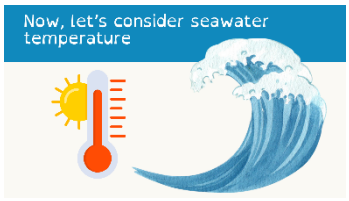
Source:

https://apps.ecology.wa.gov/publications/documents/1201016.pdf
(page 29)

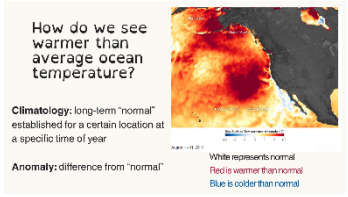


Slide 17: WA waters + factors increasing OA vulnerability

Source:
https://oceanacidification.uw.edu/our-work/about-ocean-acidification/



Slide 18: Transition to sea temperatures and MHWs

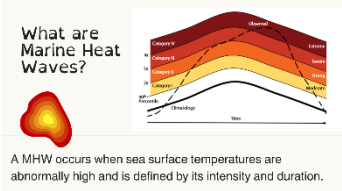


Slide 19: How we see warmer than avg. sea temps

Sources:
Info from NANOOS MHW lesson plan:

https://www.nanoos.org/education/pdfs/marine_heatwaves.pdf

Image: https://earthobservatory.nasa.gov/images/145602/marine-heat-wave-returns-to-the-northeast-pacific

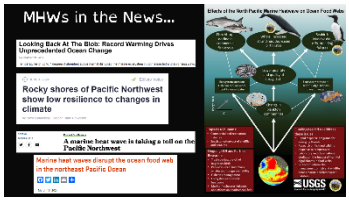


Slide 20: What are MHWs?

Sources:
Info from NANOOS MHW lesson plan:

https://www.nanoos.org/education/pdfs/marine_heatwaves.pdf

Image: https://coralreefwatch.noaa.gov/product/marine_heatwave/

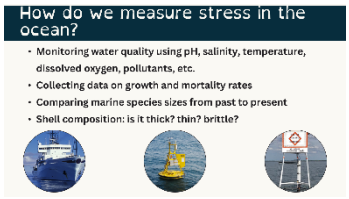


Slide 22: Transition back to multiple stressors

Slide 23: Multi-stressors and their potential impacts in coastal and estuarine ecosystems

Caption: "Infographic illustrating the climate-driven stressors in coastal and estuarine ecosystems (warming, hypoxia, and acidification) and their potential influences on other processes such as primary production, respiration, and calcification and ecological phenomena like harmful algal blooms, disease, and other species impacts."

Infographic credit: Hunter Hadaway and Simone Alin
Source:
Alin, Simone R.; Newton, Jan; Feely, Richard A.; Greeley, Dana; Herndon, Julian; and Kozyr, Alex (2023). A multi-stressor data product for marine heatwave, hypoxia, and ocean acidification research, including calculated inorganic carbon parameters from the southern Salish Sea and northern California Current System from 2008-02-04 to 2018-10-19 (NCEI Accession 0283266). NOAA National Centers for Environmental Information. Dataset. https://doi.org/10.25921/5g29-q841..



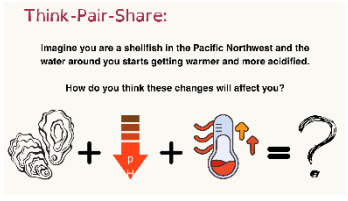
Slide 24: How do we measure stress in the ocean?

Source:
Info: NANOOS OA salmon race and intertidal lesson plans
oa-salmon_race.pdf (nanoos.org)
OA and Intertidal Slidedeck.pptx (nanoos.org)

Images: https://www.nanoos.org/about_nanoos/ocean_observing.php

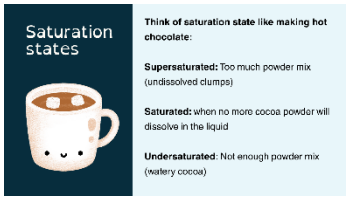
Slide 26: How can you help?

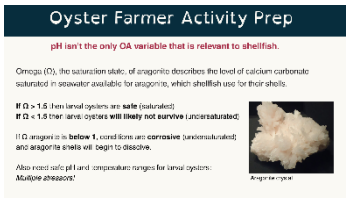
Lead students in discussion about anthropogenic-driven climate change and what each person can do to help combat it



Slide 27: Think-Pair-Share

Have students think about prompt on their own for a few minutes, then turn to a neighbor and discuss/share ideas.





Slide 31: Transition to oyster farmer computer activity

Direct students to instructions on worksheet for how to access NVS data.

Sources:
Top image: Oyster growing in Samish Bay, Puget Sound. **Credit:** Puget Sound Partnership
https://www.nanoos.org/products/oa/ocean_acidification.php?section=oa_in_pnw

Middle image: Pacific oyster grower Yaquina Bay, OR. **Credit:** NOAA

Bottom image: "Oyster seed – larvae that have grown shells and are able to permanently attach to a surface – at a hatchery in Louisiana." **Credit:** Louisiana Sea Grant/Flickr, CC BY

https://dialogue.earth/en/ocean/ocean-acidification-us-pacific-shellfish-farms/