# Pre-module questions

After the introduction provided by your instructor, please answer these initial questions and record your responses. Clearly explain the reasoning for your answer with examples from what you have learned in class and your reading.

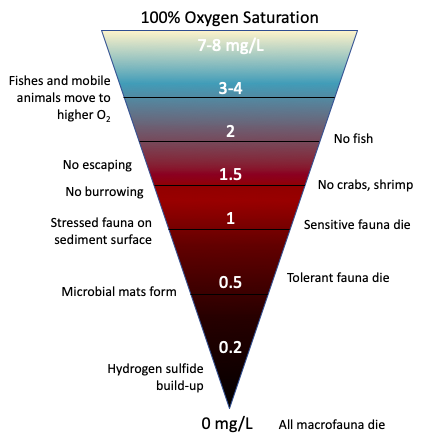
1. What do you know about what causes algal blooms and “fish kills”?
2. What environmental factors add or remove dissolved oxygen from natural bodies of water?
3. What are some other environmental factors that should be considered when studying fish kills?

Activity A: Hypoxic events in the Chesapeake Bay

In this activity, you will analyze a time series of dissolved oxygen concentrations, looking for low oxygen events in the Chesapeake Bay. When oxygen concentrations fall below 2 mg/L, conditions are called **hypoxic**. When concentrations are approximately 0 mg/L, conditions are **anoxic**. Water quality data are available from the Chesapeake Bay Program at <https://www.chesapeakebay.net>, collected since 1984. Data for a single station (CB4.1C) in the mesohaline region of the Chesapeake Bay, a few miles south of the Chesapeake Bay Bridge, are provided for 2010-2019.

The data available are: sample date and time, dissolved oxygen concentration (DO), water temperature, salinity, nitrate concentration (NO3-), phosphate concentration (PO4-3), chlorophyll concentration (ChlA), pheophytin concentration (Pheo), particulate organic carbon (POC) and total suspended solids (TSS) for both surface and bottom depths at station CB4.1C. Some of the data will be used in this activity and the other data will be used for further analysis in the following activities.

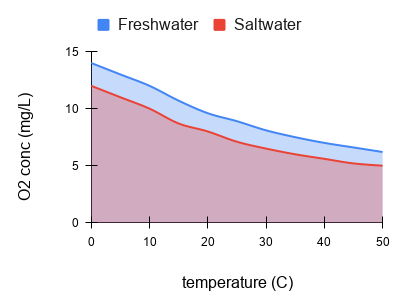
1. Create one plot with both surface DO and bottom DO over time from 2010-2019. (Plot both surface and bottom data on the y-axis with time on the x-axis.)
2. Describe the patterns observable in the plot. Look at patterns over time as well as patterns seen comparing surface and bottom plots.
3. How many hypoxic (DO < 2 mg/L) events occur in the data set? When (specify month(s) and year) and where (surface, bottom) do they take place?
4. The figure below shows the impacts of dissolved oxygen concentrations on organisms. Compare the surface and bottom DO concentrations found in your data to those in the figure. How do the conditions for living change in surface and bottom waters given the patterns in the data described above?



**Hypoxic < 2 mg/L** **Anoxic = 0 mg/L**

Modified from https://www.vims.edu/research/topics/dead\_zones/impacts/index.php

1. Of the two DO data sets, which do you think is more revealing about any processes and/or problems that are occurring around the station being studied? Explain.
2. What physical and/or biological processes should be investigated to decide what was happening at this location in the Bay? What other data do you think you need to analyze to decide?
3. Let’s look in more detail at two variables you may have considered in your answer to Question 6: temperature and salinity. Create two graphs, one showing surface and bottom temperature over time, the other showing surface and bottom salinity over time (2010-2019).
4. For each graph, describe the patterns over time as well as patterns seen comparing surface and bottom plots.
5. Use the figure below to estimate the approximate maximum and minimum DO concentrations expected in water at the ranges of temperature and salinity found in your plots.



Expected oxygen concentrations (100% saturation) in freshwater and saltwater (35 ppt) at different temperatures.

1. Based on your data and analysis, do temperature or salinity differences alone explain the pattern of DO concentrations found in our data? Explain our reasoning.

# Activity B: Investigating physical properties of surface and bottom water in an estuary

In Activity A, you investigated DO change over time and between surface and bottom water. To further understand the patterns you observed, you also considered the effect of temperature and salinity on oxygen solubility and found that the low DO concentrations in the bottom waters could not be explained by temperature or salinity alone. Next, you will investigate the effects of temperature and salinity on additional physicalproperties of the surface and bottom water in the estuary: **density** and **stratification**.

Water temperature and salinity both contribute to density. Generally, an increase in temperature will decrease the density and an increase in salinity will increase the density. The combination of these two variables thus must be considered to determine the density of a water sample. When temperature, salinity, and pressure are known, density can be calculated using the equation of state (e.g., Gill 1982).

1. Calculate the density of surface and bottom waters at your station. Your spreadsheet contains a simplified version of the equation of state (neglecting effects of pressure) in the first row of the density columns (cells J2 & K2). It calculates density based on the temperature and salinity found at the surface and bottom of the station on the first sample date (01-11-2010). To calculate surface and bottom densities for all sample dates, copy and paste the formula into the remaining cells in column J (surface density) and K (bottom density).

1. Create one plot with both surface density and bottom density over time from 2010-2019.
2. Describe the patterns in the data you plotted:
3. What similarities and differences do you see between the surface and bottom densities?
4. Identify several months/years where the surface and bottom densities are most similar. Also identify several months/years where the surface and bottom densities differ the most.
5. What else can you infer about the water column when the surface and bottom densities are the most similar? And the most different?
6. Scientists often use the difference between surface and bottom densities to characterize the degree of stratification in the water column: a greater density difference between the surface and the bottom indicates stronger stratification; a smaller density difference indicates stronger mixing. In the next column on your working spreadsheet (L), calculate the difference between surface and bottom water densities for each sample date (subtract surface from bottom density; Excel equation format: =Cell2-Cell1, where Cell2 is the bottom density and Cell1 is the surface density on each sample date).
7. Create a plot of density difference over time from 2010-2019.
8. Study the patterns in density difference over time:
   1. Describe the patterns in this new graph
   2. Identify several dates where density difference is smallest and greatest. How do those months/years compare to those you found in Question 3b? Do your findings in this comparison make sense? Explain.
   3. Explain what the changes in density difference over time tell you about how stratified or well-mixed the water is during each season.
9. To more easily compare two variables in a time series, you can plot the two variables on two different y-axes with time on the x-axis. Creating a second y-axis will allow the two variables to have different scales, as appropriate for their magnitude. Plot *bottom* DO and density difference over time to look for a pattern relating the two variables. See Microsoft Support (n.d.) in reference list for more guidance.
10. Study the new plot and describe any patterns and relationships you notice between the bottom DO and density difference (degree of stratification or mixing).
11. From your interpretation of the data and the background provided, how do you think the density differences might be related to the fluctuations of bottom DO?
    1. Draft a conclusion and support it with an explanation using appropriate and sufficient evidence from the data sets we’ve studied so far, tied to your understanding of relevant science background.
    2. What physical and/or biological processes should be investigated to decide what was happening at this location in the Bay? What other data do you think you need to analyze to decide?

Gill, A. E. 1982. Atmosphere-Ocean Dynamics. Academic Press, San Diego, CA

Microsoft Support, n.d., Add or remove a secondary axis in a chart in Excel, <https://support.office.com/en-us/article/add-or-remove-a-secondary-axis-in-a-chart-in-excel-91da1e2f-5db1-41e9-8908-e1a2e14dd5a9>

# Activity C: How can we responsibly manage the Bay to limit future hypoxic events?

In this activity, you will look for variables that can be responsibly managed to limit future hypoxic events. Since the first colonial settlement on the shores of the Chesapeake Bay in 1607, human activities in and around the bay and its watershed have had an effect on its health.

In the late 1970s, Congress funded a five-year study to analyze the Chesapeake Bay’s rapid loss of wildlife and aquatic life. These initial research findings, published in the early 1980s, led to the formation of the Chesapeake Bay Program as the means to track changes and restore the Chesapeake Bay. The data you are analyzing was collected through this program.

Physical variables, like temperature, salinity, and density can’t always be managed or controlled by communities (unless there are industrial-scale water release mechanisms), but biological variables can potentially be managed. What variables might be managed by nearby communities to reduce the incidence of hypoxic events in the Chesapeake Bay?

1. In the last tab of the spreadsheet, called “Activity C data,” there are additional variables that were measured along with the DO and density that we’ve already explored.
   1. From that list of variables, select one that you think may be related to the concentration of dissolved oxygen in the bottom water. In making your decision, think carefully about what would make sense (both biologically as well as surface or bottom). Explain what variable and depth (surface or bottom) you chose and why it makes sense to compare it to bottom DO. Predict what relationship you expect to find between the variable and bottom DO.
   2. Plot the selected variable and bottom DO over time, using two different y-axes (like you did in Activity B for density difference and bottom DO).
2. Describe the patterns in the new plot. Compare and describe any patterns and relationships you notice between the bottom DO and the new variable.
3. Do the patterns you see make sense based on what you know about dissolved oxygen in aquatic ecosystems? Explain why (or why not).
4. Record important patterns and points made from other plots shared by groups in your class.
5. With partners or in small groups, compare the patterns observed and discuss which of the variables appear to have the strongest relationship to hypoxic events. Include your reasons for selecting the strongest relationships.
6. Making use of all the data sets you have studied in Activities A, B, and C, conclude and explain in detail what factors lead to hypoxic events in the Chesapeake Bay. Be sure to include relevant and sufficient evidence from all activities.
7. Given your response to Question 6, explain what you think communities can do and responsibly manage to prevent the hypoxic events.

# Activity D (optional): Providing statistical evidence

The work you completed in Activities A-C are good first steps to analyze data and begin to make sense of the results and the phenomenon studied. With such a robust data set, a next step could be to perform statistical analyses to quantify some of the observations you can make and determine how significant they are. Your instructor may provide their own approach to some options for analyses. For this exercise, we include instructions to complete a cross correlation analysis and Student’s t-test.

For multiple time series variables that we suspect are correlated, one can perform cross correlations associated with different time shifts (or lags) to determine which lag results in the highest correlation between the data sets. With the correlation coefficients from such analyses, one can then test for the statistical significance of the best correlation coefficient using the Student’s t test on the correlation coefficient (Zar 2010). This activity is designed to use a publicly available Excel spreadsheet (Kyd 2020) that includes statistical calculations. You need to add the time series from this module to analyze.

1. For an Excel spreadsheet set up to conduct a cross correlation analysis, go to [Kyd (2020)](https://exceluser.com/1069/use-automated-cross-correlations-in-excel-to-find-leading-indicators-part-1/) and follow instructions to request and download the example spreadsheet. The website also contains an explanation of the statistical method and interpretation of results. Once you have received the file, proceed with the steps below.
2. In the “Data” tab of the Cross correlation spreadsheet, add the time series data from your Chesapeake Bay data set you wish to analyze to the raw data table by copying and pasting the following:
   1. sample dates of your time series into the “Date” column
   2. density difference into the Data1 column; change the column heading to reflect new data (Note: make sure you paste the **values** only, not the equation; use paste special!)
   3. DO bottom into the Data2 column; change the column heading to reflect new data
   4. expand the “Date text” column to match up with the data set (copy and paste the formula from one of the cells into all remaining cells in the column)
3. Move to the “Report” tab, which contains the results of the cross correlation analyses. Notice that the Excel file template is set up for smaller data sets; therefore, the graph will most likely be difficult to read. To correct this, move the graph to an area below the statistical analyses and expand the size of the graph until you can clearly see your data and labels.
4. In the “Report” tab, investigate the results of the cross correlation analyses with guidance from your instructor (if needed, [Kyd (2020)](https://exceluser.com/1069/use-automated-cross-correlations-in-excel-to-find-leading-indicators-part-1/) also provides instructions on how to interpret the results).
   1. Which time shift produced the best correlation? Is this correlation negative or positive?
   2. For the best correlation, use a t-test to calculate the p-value of the correlation coefficient. Your instructor will provide more detailed instructions; briefly, calculate the t statistic (Zar 2010), then use Excel’s two-tailed t-test function (=T.DIST(t, n-2,2)) to determine the p-value. What is the p-value for the highest correlation coefficient?
   3. In words, what do the results from 4a. and 4b. indicate about the relationship between density difference and bottom DO?
5. With the results of the cross correlation analysis, revise your conclusion and explanation composed in Activity C (Question 6) to incorporate these new findings.

Kyd, C., 2020, Find Leading Indicators Using Automated Cross Correlations in Excel Part 1, ExcelUser.com. https://exceluser.com/1069/use-automated-cross-correlations-in-excel-to-find-leading-indicators-part-1/

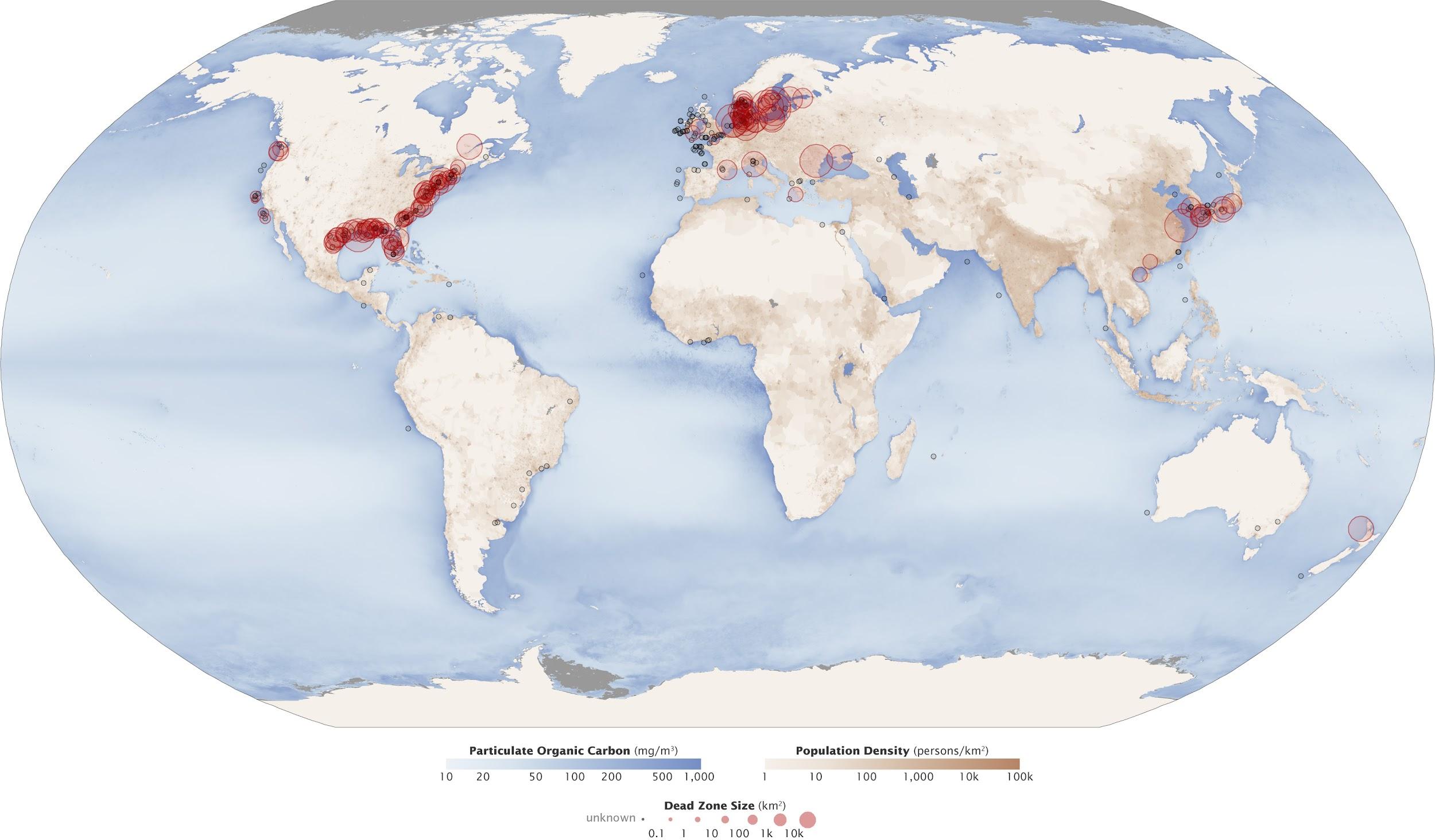
Zar, J.H., 2010, *Biostatistical Analysis*, 5th ed., Pearson, NJ, 944 pp.

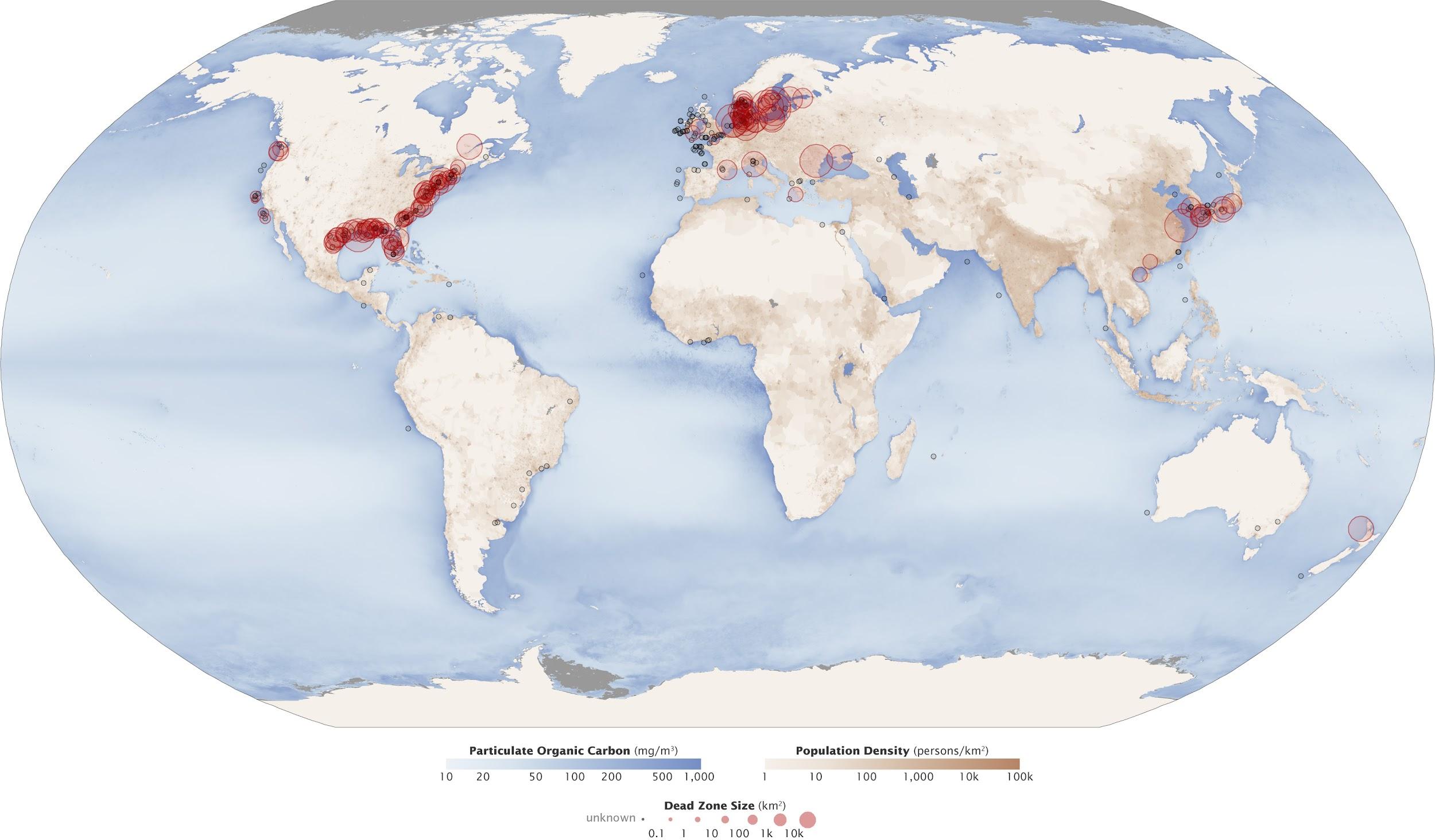
# Activity E (optional): Hypoxia around the globe and the effect of climate change

In Activities A-C, you have studied one site within a coastal water body that has been challenged by anthropogenic impacts. The good news is that the problems were eventually recognized and attempts have been made to address them and improve the overall ecosystem in part to protect fisheries.

However, the Chesapeake Bay is not the only coastal water body where hypoxic zones can form. In this section you will determine how common the problem of hypoxia is around the globe, and how climate change might affect it.

1. Study the accompanying map that shows the locations of known “dead zones” across the globe mapped with the variations in sea floor particulate organic carbon (POC). Describe all the patterns you see in the occurrence of high concentrations of POC across the oceans.





<https://earthobservatory.nasa.gov/images/44677/aquatic-dead-zones>

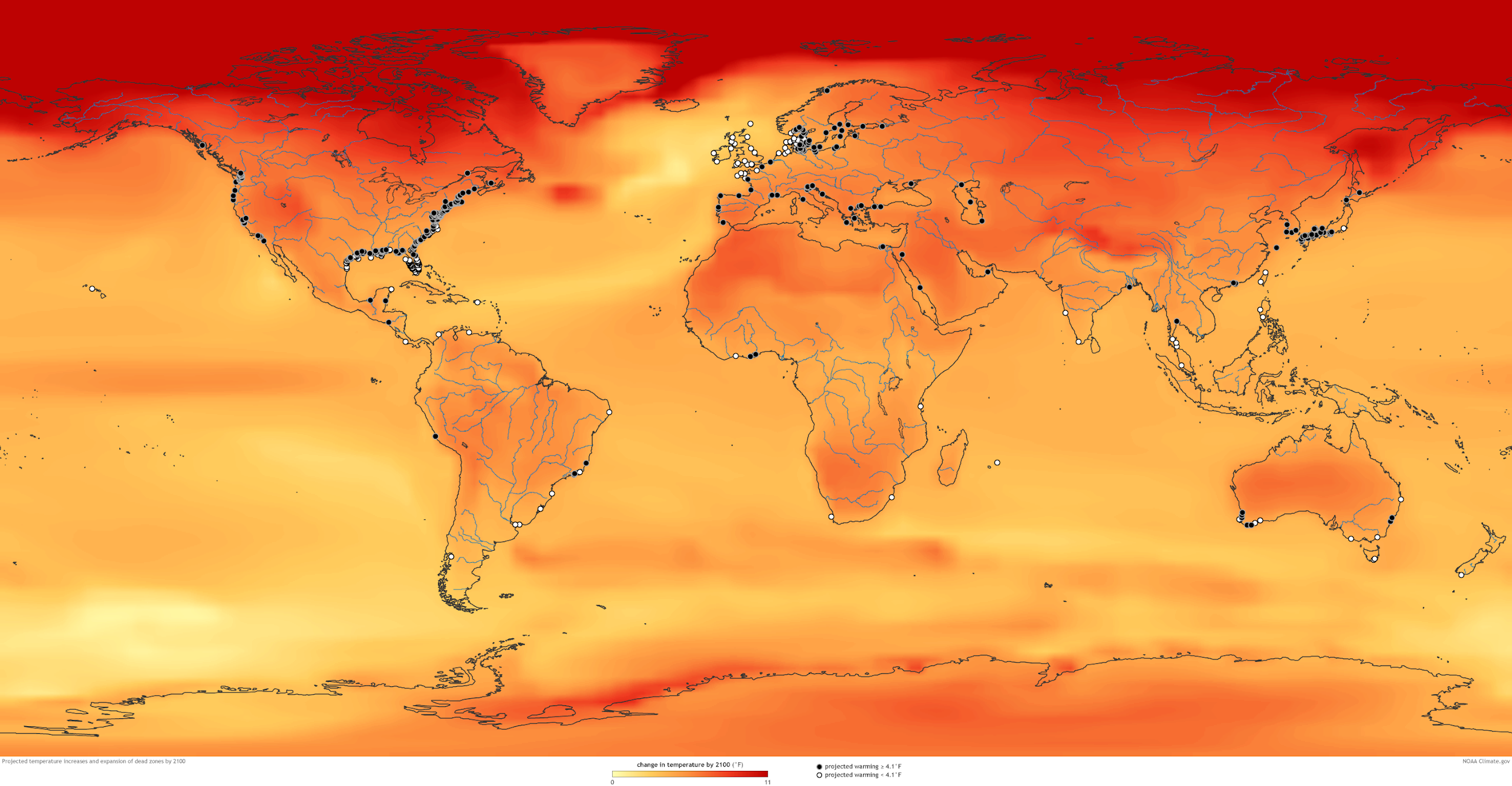
1. What can explain the higher particulate organic carbon (POC) in various locations? Explain your response.
2. What patterns do you see in the occurrence of “dead zones”? Describe below. If the map is available online at <https://earthobservatory.nasa.gov/images/44677/aquatic-dead-zones>, it can be magnified so you can zoom into different locations.
3. Compare the occurrences of high POC concentrations and dead zones. Where are they both high and where is one high and not the other?
4. Why might some higher POCs not be associated with documented dead zones? Explain your response.
5. Where would you expect dead zones resulting from human activities to likely occur? Explain your response.
6. What might be the impact of these dead zones on the ecosystems and human activities?
7. In your opinion, what can be done to reduce this phenomenon?

The rapidly changing climate and increasing global temperatures is another way we have impacted the environment. The ocean is like the heart of the climate, moving heat, moisture, nutrients, and life, connecting the ocean floor with the atmosphere with the coastlines and continents. Consider this while you study the maps below.

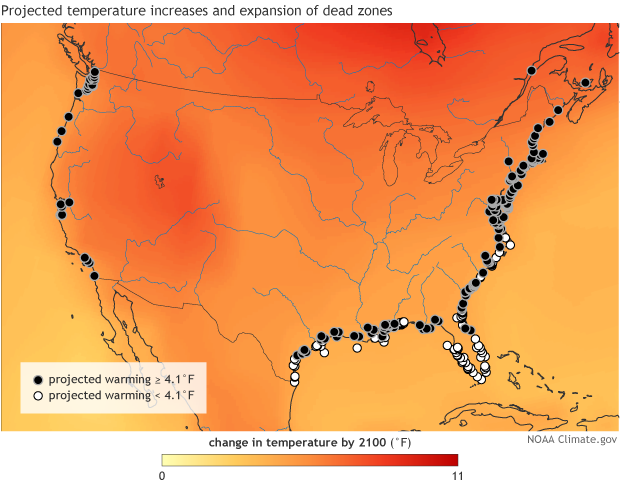
The maps below show the predicted end-of-century increases in sea surface temperatures. To see the larger version of the maps, visit this site:<https://www.climate.gov/news-features/featured-images/climate-change-likely-worsen-us-and-global-dead-zones>.

On that site, click on the map of the United States to see the larger global map; you can click on the global map to zoom in even more.

1. What impact could these changes have on concentrations of dissolved oxygen?



Projected changes in global air temperature by 2100 considering a middle-of the road fossil-fuel-use scenario. Black and white dots indicate knowne continental dead zones. 94% projected to experience at least 4.1 °F increase. Median global air temperature projected to be 4.1°F (2.3°C) warmer than the 1980-1999 average. From https://www.climate.gov/news-features/featured-images/climate-change-likely-worsen-us-and-global-dead-zones



Projected changes in air temperature in the US region by 2100 considering a middle-of the road fossil-fuel-use scenario. 65% projected to experience at least 4.1 °F increase.

1. Note the occurrences of “dead zones” in the map (black and white dots). What are the possible future problems of dead zones with these predicted temperature increases? Explain your answer using appropriate evidence from the above map and previous steps in this unit that tie to your understanding or relevant science concepts.