DO pH-VARIABLE HABITATS PROVIDE REFUGE FOR STONE CRABS FROM COASTAL ACIDIFICATION?

ANSWER KEY

ACTIVITY 1

1. Explain the relationship between pH and pCO_2. Use the plot you created as evidence.
   When pH is low, pCO_2 is elevated. A higher level of CO_2 dissolved in the seawater results in a reduction of seawater pH.

2. Explain the relationship between pH and temperature. Use the plot you created as evidence.
   When pH is lower, temperature is usually elevated.

3. What other environmental variables do you hypothesize may influence seawater pH? Explain your reasoning for this prediction.
   Responses could include: precipitation, coastal runoff, photosynthesis, respiration. Answers will vary, but in general, precipitation and runoff could introduce excess organic material and thus reduce coastal pH. Photosynthetic activity during the day will increase seawater pH as photosynthesis removes CO_2 from the water, while respiration at night will reduce pH due to the release of CO_2.

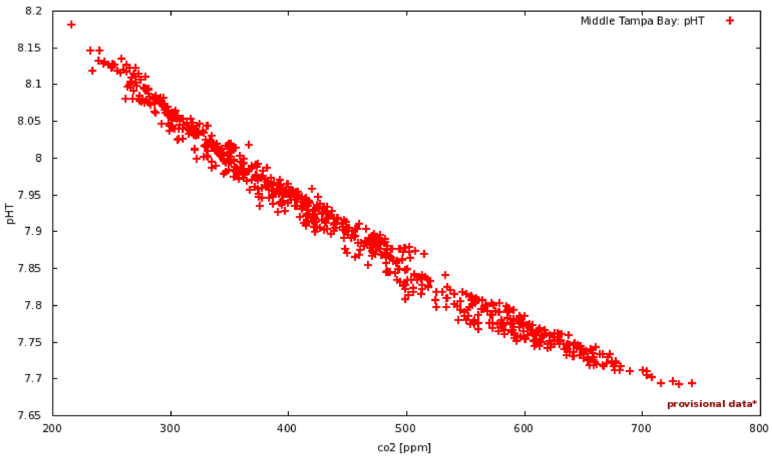

FIGURE 1. The relationship between pH and pCO_2 in Tampa Bay during July 2021 from the USGS LOBO monitoring site in Tampa Bay, FL (http://tampabay.loboviz.com/).

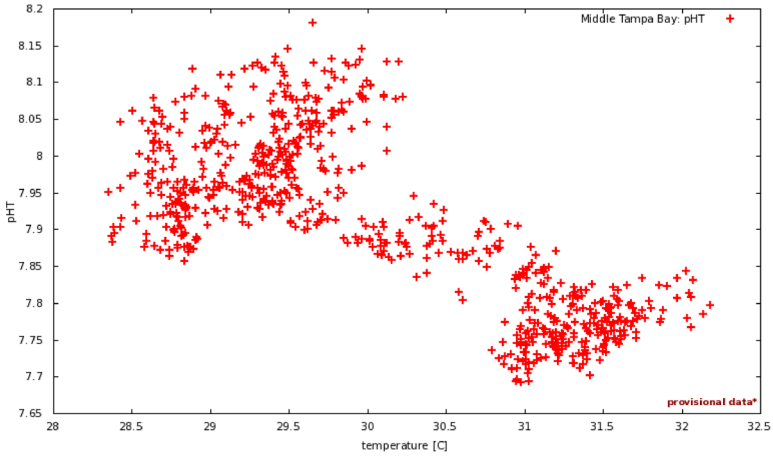

FIGURE 2. The relationship between pH and temperature in Tampa Bay during July 2021 from the USGS LOBO monitoring site in Tampa Bay, FL (http://tampabay.loboviz.com/).

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ACTIVITY 2

1. Explain how pH changed within each field site. Use the calculations and plot you created as evidence.
   pH is more variable for the seagrass site, where there are greater diel changes due to biological activity such as photosynthesis and respiration.

2. Explain the relationship between pH and photosynthesis and respiration. Use the plot you created as evidence.
   During the day, the seagrass photosynthesizes and absorbs more CO_2, resulting in higher pH. During the night, biological respiration is dominant, resulting in the production of CO_2 and thus lower seawater pH.

3. Warmer water holds less CO_2 than colder water but the results in Activity 1 from the data buoy show the opposite trend. Explain why this might be happening.
   Other factors can impact changes in seawater pH, especially within coastal systems like bays and estuaries. Biological activity, freshwater runoff, tidal cycles, and seasonal changes complicate the carbonate system of estuarine systems along the Gulf of Mexico (see McCutcheon et al. 2021). Coastal pCO_2 levels are estimated to be increasing by 2.35–3.20 µatm yr^{-1} (see Osborne et al., 2022), driven largely by metabolic activity/respiration biological activities and a shift toward more heterotrophic processes. While warmer temperatures do reduce CO_2 solubility in the ocean, some studies indicate that increasing atmospheric CO_2 concentrations can influence or contribute to this phenomenon (see Lohrenz et al., 2018; Kealoha et al., 2020). Furthermore, this region is thought to be a CO_2 source in the summer due to seasonal cycles in nutrient loading (Kealoha et al., 2020).

4. Hypothesize how pH might impact the reproductive success of stone crabs; use the plot and prior knowledge to formulate a hypothesis.
   Research has shown that reduced pH can reduce stone crab hatching success by ~28%. Hypotheses will vary.

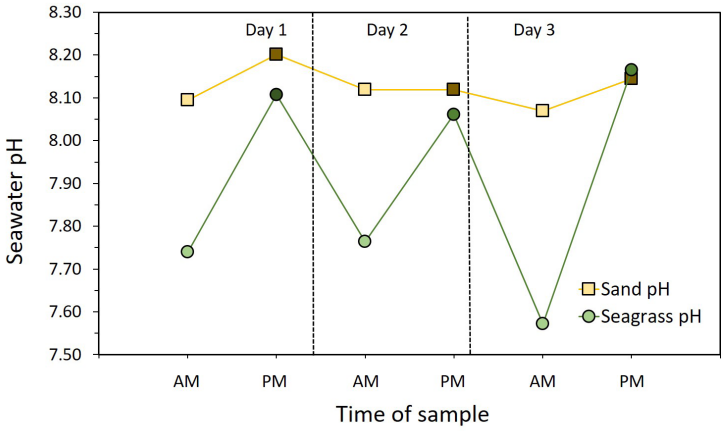

FIGURE 3. The field pH during the 2020–2021 study. The yellow line and dots represent the sand site. The green line and dots represent the seagrass site. The lighter circles represent the sunrise samples while the dark circles represent the sunset samples.

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ACTIVITY 3

1. What can cause reduced seawater pH? List one natural and one anthropogenic cause.
   Increased CO_2 emissions, excess nutrients, freshwater input, storm events, seasonal changes, etc.

2. Which treatment resulted in higher hatching success? Use the averages and plot as evidence.
   The crabs in the control exhibited higher hatching success.

3. Discuss which treatment might lead to lower reproductive success for the population. Use the averages, plots, and prior knowledge to formulate your hypothesis.
   Reduced pH conditions might result in lower reproductive success in stone crabs.

4. If the average legal-sized female stone crab with a 102 mm carapace width has an annual fecundity around 2 million eggs (Ros et al., 1981; Hogan and Griffen, 2014), use the average hatching success from this study to estimate how the reduction in hatching success in reduced pH may affect the fecundity of a single crab in one reproductive season.
   With the annual fecundity of 2 million eggs, the number of embryos hatched in reduced pH conditions is 1,065,400. Reduced pH conditions decrease the number of embryos hatched by 934,600.

$$2 \times 10^6(.5327) = 1{,}065{,}400$$

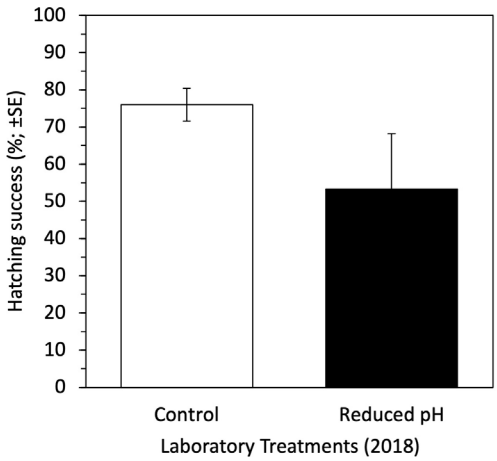

FIGURE 4. The average hatching success during the 2018 laboratory study for the control (white bar; seawater pH = 8.0) vs. the reduced pH treatment (black bar; pH = 7.6). The bars represent the standard error for the subset of data used in this lesson.

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ACTIVITY 4

1. Which treatment and habitat had higher hatching success? Use the averages and plot as evidence.
   Reduced pH and seagrass

2. Discuss which treatment and habitat might lead to higher reproductive success for stone crabs. Use the averages, plots, and prior knowledge to formulate a hypothesis.
   Reduced pH and seagrass

3. Is any variation in hatching success observed in crabs from the sand and seagrass habitats? If so, what could be the reason for these differences?
   Yes, more variation in the seagrass. This could be related to the more variable pH conditions and individual crab tolerance of those daily changes.

4. Predict what these results may indicate for the stone crab fishery under future climate conditions.
   Exposure to more variable habitats like seagrass may serve as a refuge from extremes in seawater pH associated with climate change.

5. Based on these results, what management actions would you recommend in order to mitigate the impacts of climate change on stone crabs?
   Suggestions could include: invest in seagrass restoration, management, and preservation/conservation; limit or reduce stone crab harvest in or near seagrass habitats. Maintaining a healthy seagrass habitat could benefit stone crab populations by allowing them to acclimate to extremes in seawater pH. This could result in greater fecundity and hatching success as climate change continues to threaten coastal habitats. Limiting harvest in seagrass habitats might allow for more crabs to reproduce and could result in subpopulations that are more resilient to extremes in pH, especially if the resilient larvae are transported into new habitats. Seagrasses are potential refugia where stone crab reproductive success may not be impacted by future extremes in seawater pH. Therefore, limiting harvest in seagrass could enhance stone crabs' resilience to reduced pH over that of other habitats/populations that have not been exposed to pH variability similar to that of seagrass habitats.

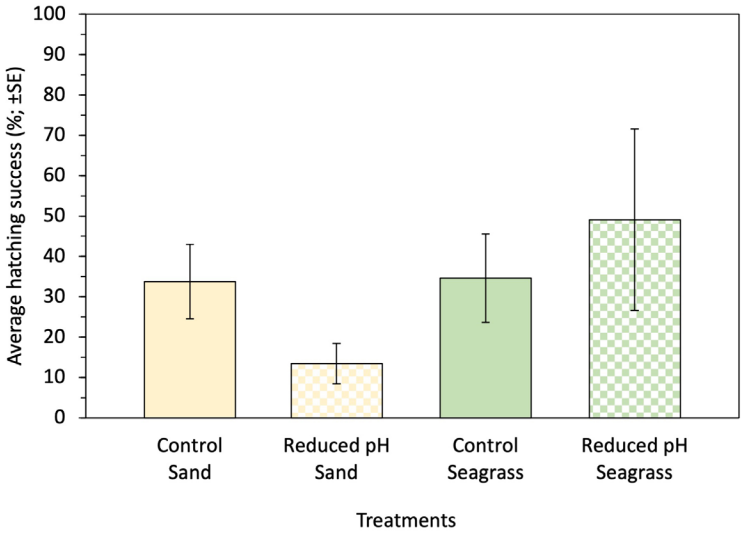

FIGURE 5. Average hatching success during the 2020–2021 study for sand habitat crabs (yellow bars) and seagrass habitat crabs (green bars). The sand habitat had less variable pH while the seagrass habitat had more variable pH. After conditioning within the field sites and extrusion of a new egg mass, crabs were then transferred back to a laboratory setting where they were placed within a control (solid bars; pH = 8.0) or a reduced pH treatment (checkered bars; pH = 7.6). The bars represent the standard error for the subset of data used in this lesson.

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