Mysterious Die-off of Wild Oysters in San Francisco Estuary

San Francisco Bay is an estuary: a dynamic body of water where freshwater flowing from rivers meets and mixes with saltwater from the ocean. In the San Francisco Estuary, water from the Sacramento and San Joaquin Rivers flows together with water from smaller rivers, and meets and mixes with the saltwater from the Pacific Ocean. The watershed of San Francisco Estuary is huge and includes all kinds of habitats from densely populated cities, to agricultural fields, to the vast wilderness of the Sierra Nevada Mountains. Rain that falls within this huge region eventually makes its way into the San Francisco Estuary. The force of the tide brings tremendous amounts of saltwater into the estuary from the Pacific Ocean twice each day; the saltwater all flows in through the 1 mile wide opening at the Golden Gate.

Offshore of China Camp State Park in San Rafael, the water reflects the dynamic nature of the estuary; the amount of salt and sediment in the water is constantly changing. Even the temperature and pH change as the proportion of salt and freshwater shift. The animals and plants that live at China Camp are adapted to change. This State Park, which is also part of NOAA's National Estuarine Research Reserve System, includes tidal salt marsh habitat, where plants like pickleweed can live flooded with saltwater, and rocky intertidal habitat, where animals like oysters can survive despite being cemented to rocks that are sometimes in the air and sometimes under water. Scientific surveys in 2010 documented that China Camp was home to a thriving population of wild native oysters. Native oysters are not as abundant as they were historically in the estuary, but they still support diverse food webs and protect shorelines. Many scientists, policy makers, and landowners hope to encourage more oysters to grow in the estuary as a way to encourage healthy food webs and protect shorelines from waves and storms. Therefore, scientists study the oysters at China Camp to understand how they might restore them or expand their populations in other parts of the estuary.

Unexpectedly, in 2011 a mass mortality event left all the oysters at China Camp dead. What killed the oysters? Scientists used the data they had available – data collected day in and day out by government-funded monitoring programs – to search for evidence and piece together an explanation of what killed the oysters. What story do you see in the data?

Part 1: Documenting a Die-off

Data is available on oyster population density (how many oysters are living in randomly placed quadrats) from February 2009 through June 2011 at four locations within China Camp. These data were being collected as part of a graduate student fellowship project and then, fortuitously, as part of a short-term research project examining the relationship between oysters and water quality. After the die-off, scientists continued monitoring one site, Bullhead Flat, to track what they hoped would be the eventual recovery of China Camp's oysters.

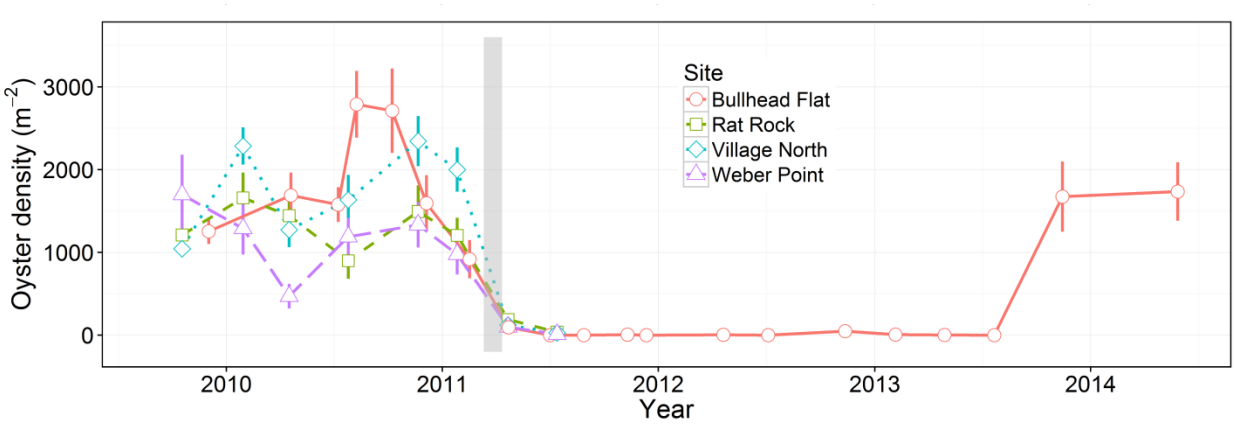


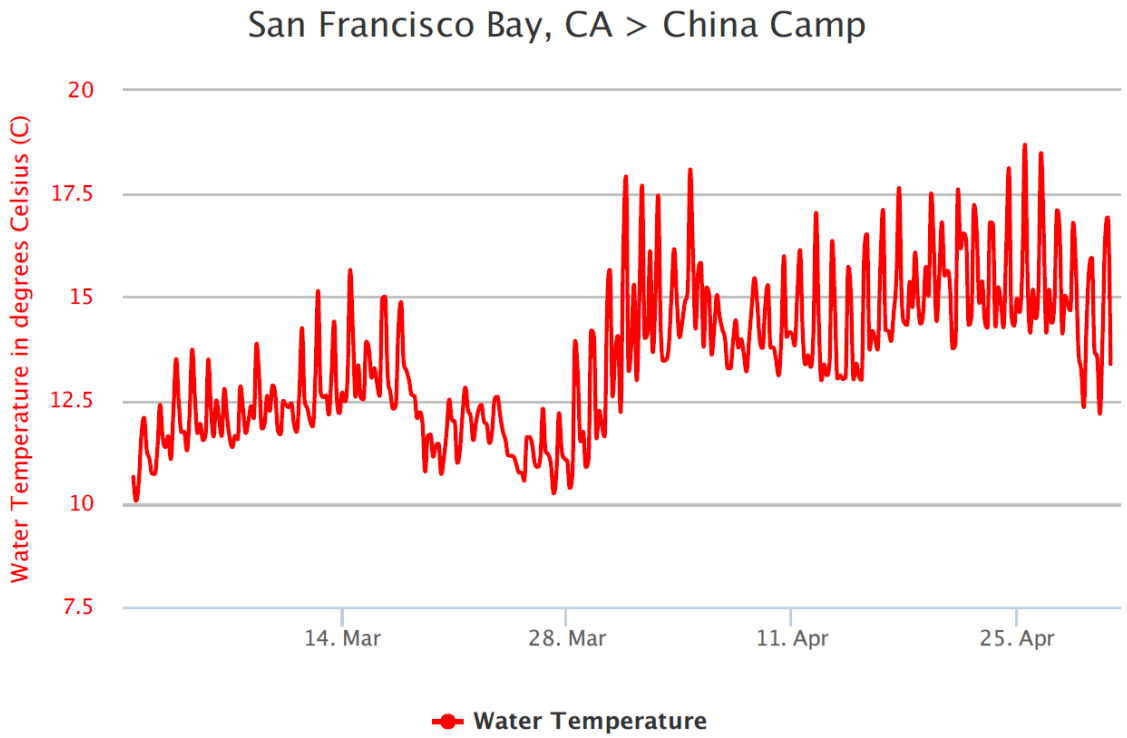
Figure 1: Oyster populations before and after the die-off at China Camp State Park, part of NOAA's National Estuarine Research Reserve System. Figure reprinted with permission from Cheng et al. 2016.

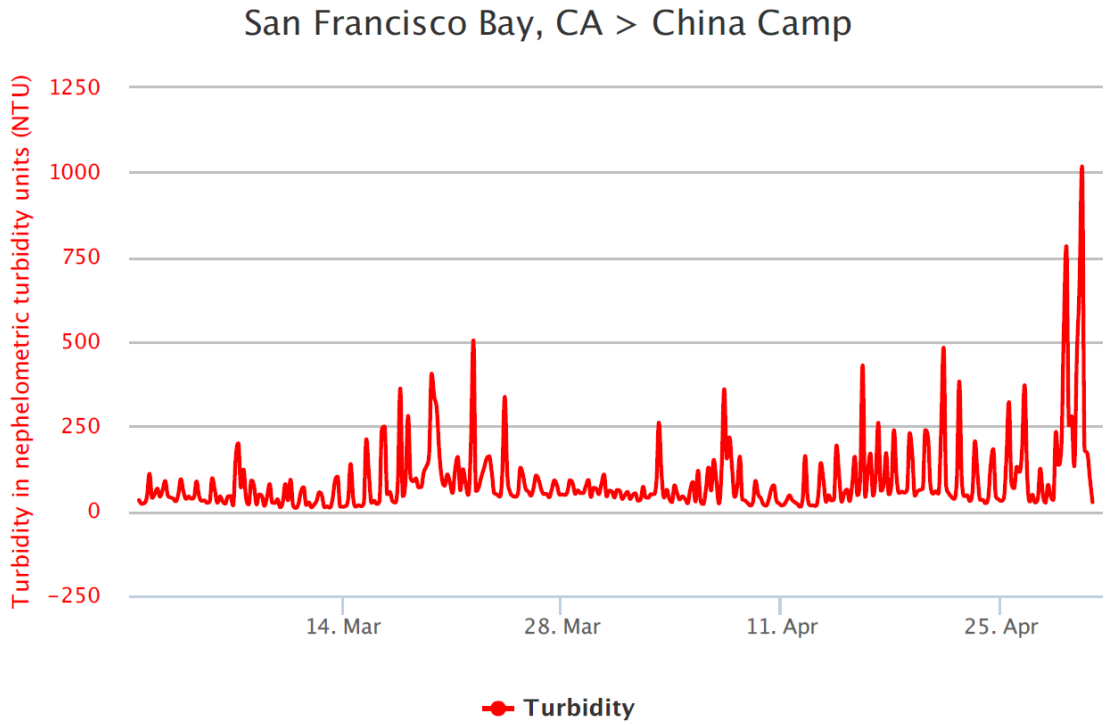
1. What does the graph of oyster population density tell you about the oyster die-off?

Part 2: Constructing an Explanation:

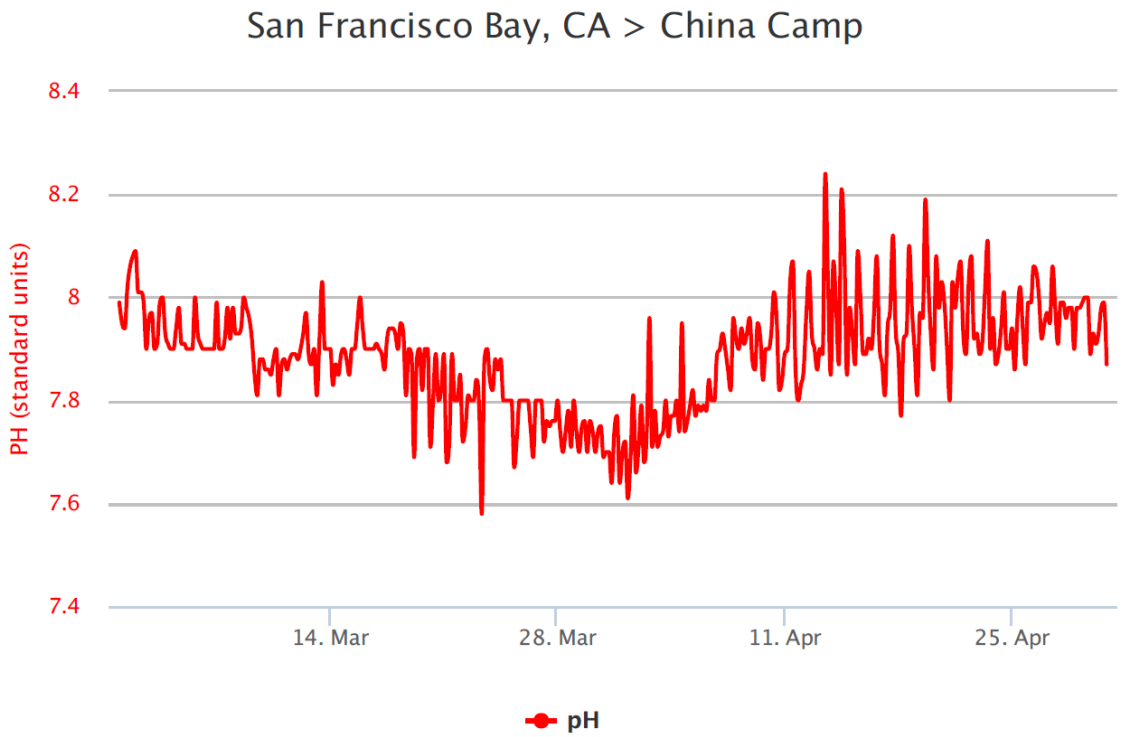
In their search for an explanation for the die-off, scientists turned to data collected at China Camp by an automated water quality station. It collects data on seven water quality parameters, including salinity, temperature, turbidity (a measure of how murky the water is), and pH, every 15 minutes. The graphs of these data from March-April 2011 are presented on the next two pages. Examine each graph carefully. Look for patterns within each graph and between the graphs. Do you see any evidence that might suggest what caused the oyster die-off?

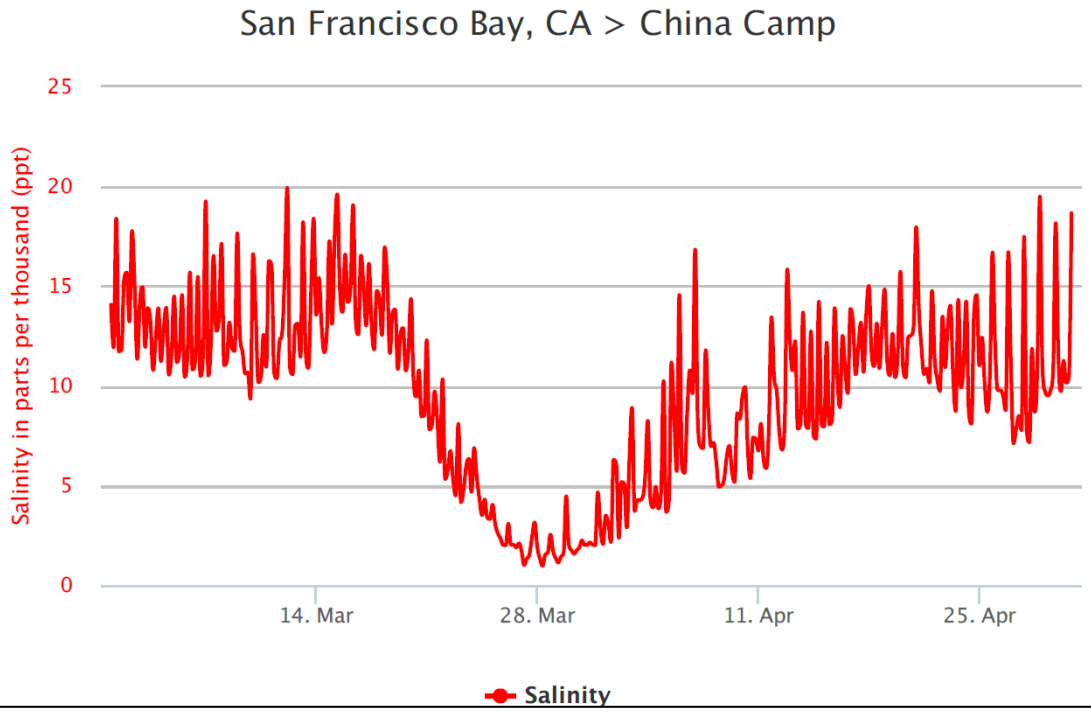
2. Based on the evidence you have (from the graphs provided), present an explanation for what may have caused the oysters to die?





Note: Graphs are from 2011. The oyster die-off occurred sometime in the time frame plotted here.





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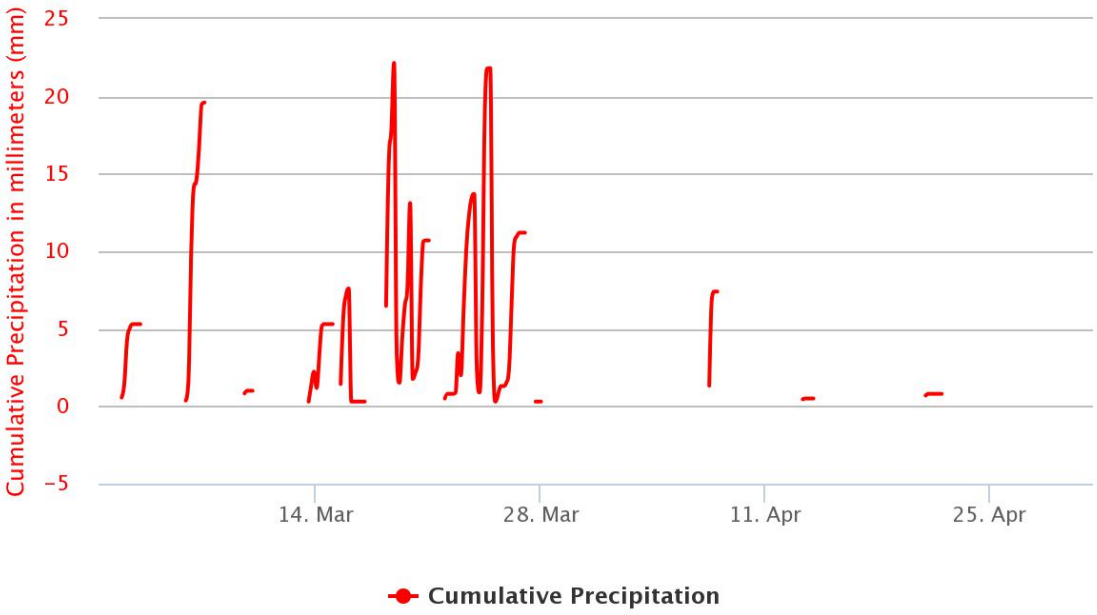
Scientists also looked at weather data to look for explanations of the patterns they saw in the water quality data. There is no National Estuarine Research Reserve weather station at China Camp, but there is one about 25 miles away at Rush Ranch. Rush Ranch is also within the San Francisco Estuary watershed. Graphs of precipitation (rainfall) for March 1 through April 30th and for all of 2011 are included on the next page. (Hints for reading these graphs: (1) the scale on the graph is in millimeters: 25.4 millimeters is 1 inch; (2) Dates with no rainfall are shown as no data (not printed as zeroes).)

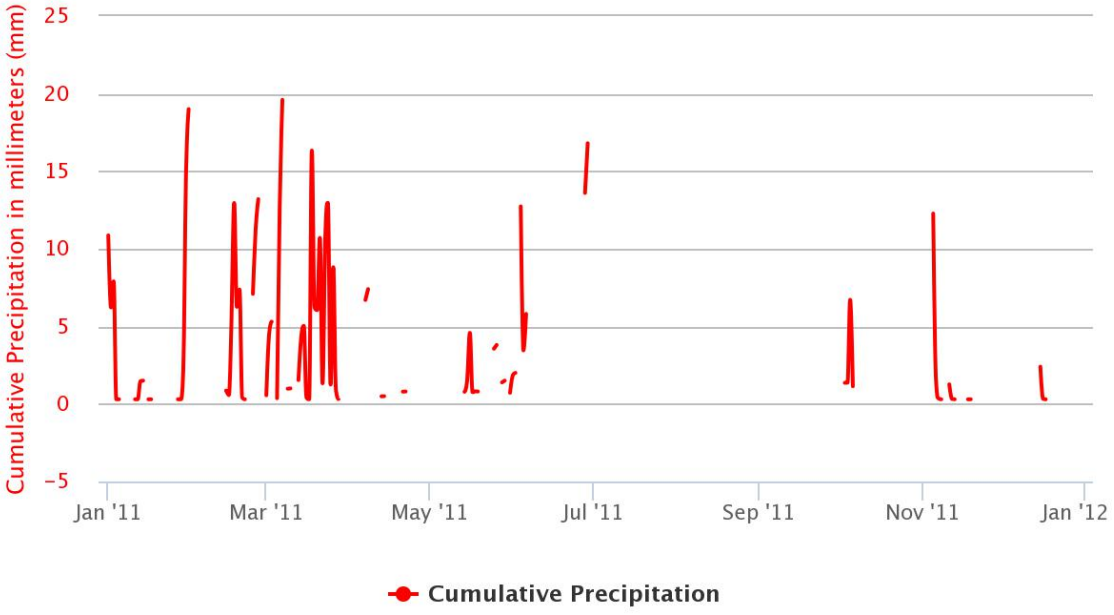
3. Does the rainfall data add to your explanation of what may have caused the oysters to die?

4. Describe one or more ways you could you test whether your explanation could be correct? (Assuming you are a professional scientist with access to scientific tools.)

San Francisco Bay, CA > Rush Ranch
3/1/2011 - 4/30/2011



San Francisco Bay, CA > Rush Ranch
1/1/2011 - 12/31/2011



Part 3: Evaluating your Explanation Using Additional Evidence

After developing a possible explanation for the oyster die-off, the scientists working on this project reviewed previously published information and conducted new experiments in controlled lab environments to test how oysters responded to changes in water quality parameters (including salinity, water temperature, and pH). They found the following:

Parameter	Level	Duration	Result
Low salinity	Below about 6 ppt	For 8 or more days	Causes death
High water temp.	Above 37.6 C	For 1 or more hours	Causes death
High pH	Above 7.9	For 52 days	Stressful, but not deadly

Table 1: Known oyster responses to extremes in water quality parameters. References for all data are listed at the end of lesson plan.

5. Does this additional evidence support the explanation you developed in questions 2 and 3? How? If it does not support your explanation, how could you revise your explanation based on the additional evidence?

Extension: Using the data available online at coast.noaa.gov for the "CA-San Francisco Bay – China Camp" water quality station, can you determine if there have been more recent storms that may have put the recovering oyster population at China Camp in danger?

Additional Resources and References:

This science this lesson plan refers to has been published in several peer-reviewed articles, including:

Cheng, B. S., Komoroske, L. M. and Grosholz, E. D. (2016), Trophic sensitivity of invasive predator and native prey interactions: integrating environmental context and climate change. Funct Ecol. doi:10.1111/1365-2435.12759

Cheng, B. S., Chang, A. L., Deck, A., Ferner, M. C. (2016) Atmospheric rivers and the mass mortality of wild oysters: insight into an extreme future? Proceedings of the Royal Society B. doi: 10.1098/rspb.2016.1462

Oyster tolerance data presented in the table is published in the following locations:

[*Salinity*] Cheng, B.S., Bible, J.M., Chang, A.L., Ferner, M.C., Wasson, K., Zabin, C.J., Latta, M., Deck, A., Todgham, A.E. & Grosholz, E.D. 2015 Testing local and global stressor impacts on a coastal foundation species using an ecologically realistic framework. Global Change Biology 21, 2488-2499.

[*Water temperature*] Brown, H.M., Briden, A., Stokell, T., Griffin, F.J. & Cherr, G.N. 2004 Thermotolerance and Hsp70 profiles in adult and embryonic California native oysters, Ostreola conchaphila (Carpenter, 1857). J. Shellfish Res. 23, 135-141.

[*Water temperature*] Cheng, B.S., Komoroske, L.M. & Grosholz, E.D. 2016 Trophic sensitivity of invasive predator and native prey interactions: integrating environmental context and climate change. Functional Ecology. DOI:10.1111/1365-2435.12759

[*pH*] Hettinger, A., Sanford, E., Hill, T.M., Russell, A.D., Sato, K.N.S., Hoey, J., Forsch, M., Page, H.N. & Gaylord, B. 2012 Persistent carry-over effects of planktonic exposure to ocean acidification in the Olympia oyster. Ecology 93, 2758-2768.

Scientists that conducted the research mentioned in this lesson plan include Brian Cheng, Andy Chang, Anna Deck, and Matt Ferner; several of these scientists also provided important review of this lesson plan. This lesson was written to be used in 2017 Teachers on the Estuary professional development and research experience by Sarah Davies Ferner at the San Francisco Bay National Estuarine Research Reserve. Questions about the lesson and suggestions for adaptations and improvements can be directed to her at daviess@sfsu.edu.