Effects of ocean acidification on the Copper River sockeye fishery

The PhotosyntheSistahs

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Abstract

Sockeye salmon (*Oncorhynchus nerka*) are an important part of Cordova’s economy and culture, with the majority of the town’s infrastructure revolving around salmon fishing. Sockeye salmon are at risk from ocean acidification, relying heavily on vulnerable prey species such as amphipods and larval fishes. With such an economy, Cordova would benefit greatly from more information on ocean acidification in the Gulf of Alaska where salmon feed. Most existing platforms for monitoring ocean acidification are close to the coast of Alaska, and do not illustrate the conditions experienced by salmon within the Gulf of Alaska. This project will use a combination of moored buoys (long term) and mobile Saildrones (initially) to track changes in pH, aragonite, pCO$_2$, salinity, and temperature in the Gulf of Alaska. The moored and mobile platforms will also monitor plankton abundance and distribution to determine the quantity of food available to sockeye salmon in the area. With a long-term data set and a better understanding of how salmon species respond to changes in prey abundance, fisheries scientists will be better able to manage the sockeye fishery in real-time and for future returns.
Introduction

The importance of salmon to Cordova

The residents of Cordova are inextricably connected and deeply dependent upon salmon. Nearly 26% of Cordova households hold commercial salmon fishing permits, compared with only 2.4% of Alaskan households (CFEC permit data 2018). The overall number of people affected by the industry is considerably higher: in a 2017 letter to the Alaska Board of Fisheries the mayor of Cordova stated that “approximately $1,000,000,000 of commercial fisheries infrastructure has been built and maintained in Cordova... 90% of Cordova’s economy can be directly attributed to the harvest, processing, and delivery of [salmon].” This shows the importance of salmon to the community and illustrates the potential for economic instability if salmon were threatened or reduced.

Cordova has always had a deep connection with salmon. To the early Eyak people, salmon were vital for all aspects of life, including trading, eating, and making clothing. Salmon skin could be made into tough, waterproof leather for coats and shoes (Barnes, 2018). Alaskan culture is deeply connected with salmon fishing as it is one of the oldest subsistence means in Alaska. (Native Village of Eyak, 2016) Lately, Native Alaskans have found themselves short of the salmon they use for subsistence and to supply their elders. One representative at the Native Village of Eyak said, “Our culture is greatly impacted by fishing, we have been living on fish for generations. Our elders need the salmon to feed on, it is their traditional food, without it, some have fallen into depression. Not being able to connect to the wilderness anymore through subsistence is hard for them.”
The commercial salmon fishing permits in Cordova are split between gillnetting (239 permits) and seining (81 permits). While both of these fisheries target different species of salmon throughout the season, the main target species for commercial gillnetters and resident subsistence users is sockeye salmon (*Oncorhynchus nerka*) from the Copper River. The future of the sockeye fishery is therefore of great concern to the town of Cordova.

*Introduction to ocean acidification*

Ocean acidification is caused by excess carbon dioxide (CO$_2$) entering the ocean. The carbon dioxide combines with water to form carbonic acid, which loses a hydrogen ion to form bicarbonate ions. These bicarbonate ions lose an additional hydrogen to become carbonate ions, and the increase in free hydrogen ions lowers the pH of seawater, causing it to become more acidic (Figure 1a)

This process endangers organisms with calcified skeletons, such as pteropods and decapods. These organisms build skeletons using the CaCO$_3$ molecule. In the case of ocean acidification, however, the carbonate ions (CO$_3$) recombine with the H$^+$ ions, leaving fewer carbonate ions available to create CaCO$_3$ (Figure 1b). With less CaCO$_3$, calcifying organisms are unable to build and maintain a calcified skeleton (Denman et. al. 2011; Fabry et. al. 2008). Aragonite is a common form of CaCO$_3$, so its saturation state ($\Omega_{arag}$) is often used as a measure of ocean acidification. Lower values mean that there is less CaCO$_3$ available (Fabry et. al., 2008). Table 1 shows some common measures of ocean acidification, including $\Omega_{arag}$, $\Omega_{calc}$ (the saturation state

![Figure 1](image_url)

Figure 1. (a) The process of CO2 mixing with H2O to form carbonate and hydrogen ions. (b) The formation of calcium carbonate from carbonate and calcium ions. (Figures by Helen Laird)
of calcium), pH, temperature, and salinity. All values, except for temperature, are decreasing, meaning Alaskan waters are becoming less basic and have less available CaCO$_3$.  

### Ocean acidification and sockeye salmon

Ocean acidification affects both salmon and their food supply and poses a serious threat to Cordova’s economy and way of life. Acidification has been shown to directly affect the nervous systems of marine fishes (Feely et al., 2012), and ongoing research at the University of Washington suggests that it impairs navigation and predator response in salmon (Gallagher et al., 2016). Accurate navigation is particularly important for salmon, who migrate from the open ocean to spawn in their natal streams.

The sockeye food supply is also threatened. Larval crabs, krill, amphipods, and larval fish are all at risk from ocean acidification; combined, they make up 92% of the diet of sockeye salmon in Southeast Alaska (Table 2; Feely et al. 2012; Gallagher et al. 2016; Gardner et al. 2018; Hunt et al. 2015; Rata et al. 2017).

The effects of ocean acidification on these prey species have been measured in controlled studies, but they have not yet been measured in the Gulf of Alaska under natural conditions. Changes to the salmon populations depend on which prey species are most affected by ocean acidification.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Change in parameter</th>
<th>Change for Gulf of Alaska</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\Omega_{\text{arag}}$</td>
<td>c.2000-1900 to c.2100-2000</td>
<td>-0.31 to -0.79</td>
</tr>
<tr>
<td>$\Omega_{\text{calc}}$</td>
<td>c.2000-1900 to c.2100-2000</td>
<td>-0.50 to -1.26</td>
</tr>
<tr>
<td>pH</td>
<td>c.2000-1900 to c.2100-2000</td>
<td>-0.10 to -0.34</td>
</tr>
<tr>
<td>Temperature</td>
<td>c.2000-1900 to c.2100-2000</td>
<td>1.25 to 3.40</td>
</tr>
<tr>
<td>Salinity</td>
<td>c.2000-1900 to c.2100-2000</td>
<td>-0.07</td>
</tr>
</tbody>
</table>

Table 1. Modeled average changes in aragonite, calcium, pH, temperature, and salinity from the past (1880-1889) to the present (2003-2012), and the present to the future (2095). Source: Table 2, Mathis et. al. (2015).
Acidification. For example, if amphipods decline sockeye populations could decline since amphipods make up such a large portion of the sockeye diet. Another factor is diet diversity: chum salmon, which have a more varied diet, could potentially outcompete sockeye salmon if there are major changes in prey availability. These variables mean that it is necessary to monitor the plankton population and the ocean conditions in the areas where sockeye salmon feed, starting as soon as possible to better record any changes.

<table>
<thead>
<tr>
<th>Prey</th>
<th>Species</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Chum</td>
</tr>
<tr>
<td>Calanoid copepods</td>
<td>3.0</td>
</tr>
<tr>
<td>Larval crabs</td>
<td>3.1</td>
</tr>
<tr>
<td>Euphausiids (krill)</td>
<td>6.1</td>
</tr>
<tr>
<td>Hyperiid amphipods</td>
<td>28.0</td>
</tr>
<tr>
<td>Tunicates</td>
<td>30.1</td>
</tr>
<tr>
<td>Fishes</td>
<td>28.3</td>
</tr>
</tbody>
</table>

Table 2. Index of relative importance, indicating the dominant prey eaten by Pacific salmon of similar average lengths sampled in northern British Columbia and southeastern Alaska. Rare items were omitted. Source: Table 16.2, Quinn et al. (2018).

Research Plan for Ocean Observation

What observations are needed?

The NOAA PMEL Carbon Program operates several observation arrays for ocean acidification, but there are none in the Gulf of Alaska where sockeye salmon feed during their time at sea (Figure 2). Very limited data exists about this open water habitat due to the difficulties in maintaining stationary buoys and the high cost of research vessel time to access this area.
This proposed project will expand the existing array of ocean acidification monitoring in the Gulf of Alaska by adding three new moored ocean buoys to the west of the currently observed area and organizing three yearly Saildrone surveys of the area to monitor the oceanographic conditions and composition of the plankton population in critical salmon feeding habitat.

With detailed information on the distribution of plankton, we will be able to monitor the presence and abundance of important sockeye prey species such as larval decapods, euphausiids, and amphipods, and record detailed measurements of pCO2, pH, temperature, salinity, and aragonite. When combined, these measurements will show whether the sockeye salmon food supply is threatened and add to the growing global network of long-term climate data.
Instrumentation needed and how to access, gather, and analyze data

Our ocean observing platform will consist of three moored buoys placed in the Gulf of Alaska and Saildrones completing three tracks over the first three years of the study. The moored buoys and the Saildrones will collect the same oceanographic data. Saildrones are a relatively new scientific instrument that have been used around the world to gather information in harder to reach areas. Saildrones can hold up to 16 scientific instruments (Figure 3) and collect both atmospheric and oceanographic data. We will specifically be using a CO$_2$ system, thermsalinograph, and honeywell durafet to measure pCO$_2$, water temperature, salinity, aragonite, and pH; it will also be equipped with a plankton camera to monitor plankton abundance. The mobility of the saildrone allows us to gather information in a large area where sockeye salmon are known to feed. This would give us the opportunity to receive information on sockeye salmon prey.

Figure 3. Intrumentation array for the Saildrone with atmospheric and ocean sensors. This study will use the CO$_2$ system, the pH sensor, and the thermsalinograph to measure ocean acidification in the Gulf of Alaska. Source: saildrone.com
Saildrone observations will be done over three years, covering a different area each year. Each Saildrone will zig zag away from the coast of Alaska until it reaches the moored buoys. It will then turn and head back to the starting point (solid lines, Figure 4). The reason we would be placing it in this area is so that we can research the Gulf of Alaska where sockeye salmon go to grow and feed. As we go to the sockeye salmon’s main feeding areas we would use the Saildrone to test for pCO₂, temperature of the water, salinity, and pH. Throughout the expedition the Saildrones will be collecting measurements of pCO₂, pH, water temperature, salinity, and aragonite saturation, as well as performing photographic plankton surveys. Data is sent via satellite in real time; with this detailed information we will compare Saildrone data to buoy data to better understand how they differ. After three years we will only use the buoys, redeploying the Saildrones only in the event of a sudden change.

The three moored buoys will be similar to the NOAA PMEL buoys already in place to the East, and would be located near Attu, Unalaska, and about 400 miles southeast of Unalaska to best surround the sockeye range (triangles, Figure 4). The buoys will also use plankton...
cameras and test for pCO2, water temperature, salinity, aragonite saturation, and pH to show how the area is being affected by ocean acidification and how that affects the prey of sockeye salmon.

Funding the project

Running a ship to collect data can cost up to $30,000 per day. In contrast, Saildrones cost an average of $2,500 per day to run (Voosen, 2018). Government funding is low; according to AAAS there was a 17% reduction in funding for basic research in 2017, so we will apply for both government and private grants. This will include the Saildrone Award, a free Saildrone mission that awards 30 days of drone-powered data collection, and the NOAA grant NOAA-NFA-NFAPO-2018-2005418, which supports healthy oceans, climate adaptation/mitigation, and resilient coastal communities. Our project will address these issues by informing the public about the effects of ocean acidification and climate change on Sockeye salmon, an essential part of the local economy, ecology, and way of life.

Community Involvement

Outreach

It is critical that the Cordova community is aware of the potential threat to the salmon population. If the citizens of Cordova are aware of the problem then we are one step closer to solving it. We are eager learners and quick adapters when it comes to preserving such a vital way of life. Scott Kelly, the Commercial Fisheries director for the Alaska Department of Fish and Game, says “They are very passionate about salmon in Cordova, for a very good reason —
because it's the lifeblood of their community...The fisheries are crucial to that town." (Anchorage Daily News).

We will make it apparent to the community that our way of life may be at risk and that every little bit helps. Simple life decisions that we make every day can be changed to reduce our carbon footprint: eating less red meat, walking to work or school, carpooling, recycling, turning off appliances when they aren’t in use, and speaking up in local management and politics on all levels. For example, in Juneau, there are 300 electric vehicles currently in use, and 1-3 new electric cars are being brought in to Juneau each week (Electric Vehicles, 2018).

To inform the community of our project we will use the Tuesday Night talks, a weekly community lecture series hosted by the Prince William Sound Science Center, and the local radio, KLAM. We will also publish an article in the local newspaper, The Cordova Times, and on the Prince William Sound Science Center website to explain the purpose of our project, the information we will be collecting, what we can conclude from our data, and how locals can make a change.

Other applications of this platform

In our project we use Saildrones to collect ocean acidification data along the coast of Alaska to monitor its effects on prey species of sockeye salmon. A similar plan could be used anywhere in the world; one example is the Okhotsk Sea in Russia. Just as the Gulf of Alaska supports a large salmon fishing industry, the Okhotsk Sea region supports a large Walleye pollock (Gadus Chalcogrammus) fishery: between 1.5-1.7 million metric tons of Walleye pollock are caught every year in Russia (Van Eynde, 2017), making it one of the most abundant commercialized species of fish. Walleye pollock are the most frequently caught fish in the Okhotsk Sea, making up 74% of the commercial catch biomass. Their diet is mainly
zooplankton, including larval crustaceans, krill, and other pelagic fauna (Yamamura et. al., 2001).

Most Walleye pollock caught in the Okhotsk Sea feed near the western Kamchatka Peninsula, where a decline of copepods was observed in 1994 (Pinchuk and Paul, 2000). A Saildrone could be deployed from the Russian city Magadan on the Western side of the Okhotsk Sea, and travel along the coast of Kamchatka Peninsula (Figure 5).

Observing Walleye pollock and measuring the effects of ocean acidification around them, especially at their feeding grounds, is very important. Walleye pollock are a large part of the fishing industry in the Okhotsk Sea, so knowing what is happening with them and their food source is vital for scientists and the fishing industry alike.

**Summary**

Sockeye salmon are a vital part of the economy and traditions of Cordova, with fishing-related infrastructure making up 90% of the economy. However, this species of salmon is particularly vulnerable to the effects of ocean acidification, with 92% of their diet originating in organisms vulnerable to acidification.

This study will use a combination of long-and-short-term monitoring systems to measure ocean acidification and its effects on the salmon food supply in the Gulf of Alaska. Three
moored buoys at the western edge of the sockeye salmon range will measure pCO2, pH, temperature, salinity, and the saturation state of aragonite over a period of twenty years, or more if funding allows. These buoys will be similar to the ocean stations currently moored off the coast of Alaska, and will give steady readings on the state of ocean acidification in the area where salmon feed.

To provide a more detailed look at conditions inside the salmon range we will use Saildrones in three expeditions over three years. The data from these mobile observation platforms will be compared to the data collected by the buoys, which will show any differences between the center of the range and the area monitored by the long-term buoys. We will also use plankton cameras attached to both observation platforms to determine how salmon prey species respond to ocean acidification.

By combining these three types of data we will have a better idea of the future of sockeye salmon prey species, and therefore the future of sockeye salmon. Monitoring changes in the prey species will allow fisheries management to anticipate changes or declines in the sockeye salmon population and provide a better view of the future of salmon fishing in Cordova and the rest of Southcentral Alaska.
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