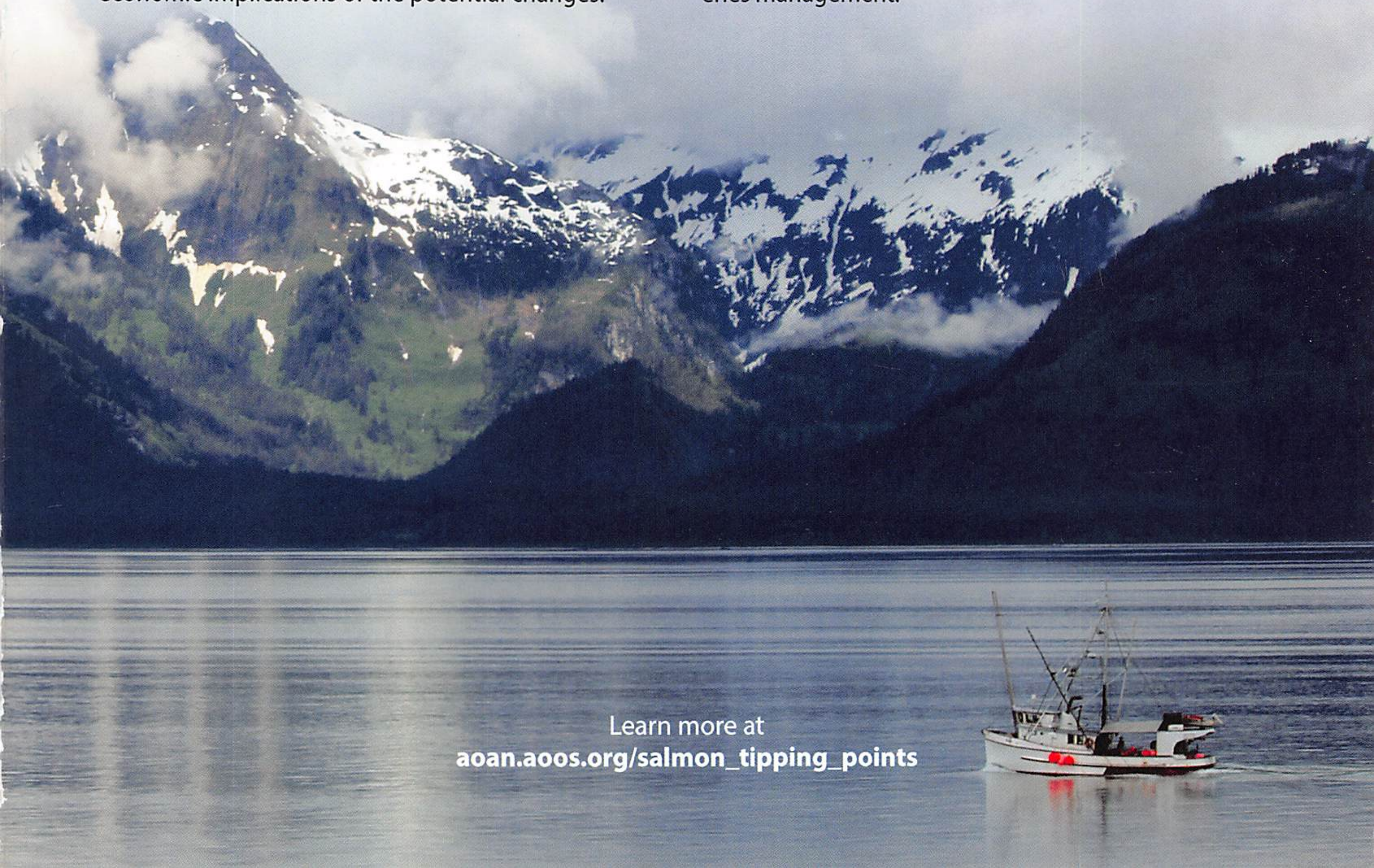
THRESHOLDS IN A CHANGING OCEAN ENVIRONMENT

BIOECONOMIC IMPLICATIONS FOR ALASKA'S SALMON FISHERIES

Alaska is expected to experience ocean acidification (OA) faster than other coastal waters in the United States, primarily due to its colder water, which absorbs more carbon dioxide than warmer waters. Increased ocean acidification is expected to have significant implications for Alaskans dependent on salmon and healthy oceans for subsistence, nutrition, and culture.

With funding from NOAA's Ocean Acidification Program, an interdisciplinary team of researchers formed to explore how salmon may be impacted by a higher-acidity environment and other climate change effects. We wanted to understand the potential for "tipping points" (i.e., environmental thresholds) which, once crossed, are difficult if not impossible to reverse. We focused on ocean conditions in the Gulf of Alaska and potential impacts on pink salmon. Additionally, we wanted to better understand the human ramifications of these effects - how human society might respond and the economic implications of the potential changes.

We focused on pink salmon because of the availability of long-term data, prior success with lab rearing, and commercial significance. Unlike other salmonids, recently emerged pink salmon immediately migrate out to the ocean and will likely experience seawater corrosivity at an earlier life history stage than other salmon species. Given the variation in life cycles among salmon species, we cannot extrapolate outcomes to other species. However, some of the main take-homes from this study apply to many fisheries, including how investments in science can help inform responsive fisheries management.



Learn more at
aoan.aoos.org/salmon_tipping_points

The research included 4 key components

- **Lab study -** We conducted an experiment looking at the direct effect of exposure to future ocean acidification conditions and the indirect effect of reduced food availability on juvenile pink salmon.
- **Fishermen engagement -** We conducted key informant interviews and surveyed commercial salmon permit holders to understand the factors that are most likely to influence fishermen's choices to continue fishing the way they are now, modify their participation, or leave the industry. We circulated the survey to all commercial permit holders in Prince William Sound (PWS), Kodiak, and Southeast Alaska.
- **Salmon data synthesis -** We studied the combined effects of changes in ocean conditions and salmon abundances on the productivity of wild pink salmon in PWS. Our goal was to understand whether wild pink salmon productivity has been associated with changes in ocean acidification, temperature, competition among pink salmon, and interspecific competition with other species of Pacific salmon.
- **Modeling -** We used the results from the other components to develop and test a model looking at how management decisions and implementation of harvest rules affect harvest value given environmental variability, climate-driven regime shifts, and price volatility.

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By integrating multiple areas of research on the impacts of OA and the influence of tipping points on Alaska's fisheries, our goal was to inform decision making of salmon managers to minimize the impacts on salmon populations and those who depend on them.

Take-aways on pink salmon response

- **Negative effects of ocean acidification on PWS pink salmon were not yet detectable in the wild.** This result was based on historical data from a relatively short time series (1980-2013) and used model-derived proxies for ocean acidification.
- The lab study results showed that **juvenile pink salmon had measurable negative impacts when subjected to higher acidity water,** particularly in conjunction with low food availability, which is a potential indirect effect of future OA conditions.
- **The impacts on juveniles in the lab were sub-lethal, resulting in size decrease as well as stress and metabolic increases.** The results indicated that the impacts could scale up to population and fishery issues in the future, particularly when combined with other stressors.
- **While we have not seen ocean acidification effects in pink salmon in the wild yet, it is likely to occur in the future** as the ocean will become more acidic for multiple human generations based on the amount of CO2 already released into the atmosphere.

Take-aways from the biometric analysis and fishermen's survey

- **Wild salmon populations have historically responded to stressors associated with changes in ocean conditions, including warming and competition in the ocean.**
- The data showed evidence that **large-scale hatchery pink salmon releases negatively affect wild pink salmon productivity more than the other variables studied.** This is from 60 years of data on wild pink salmon abundances, hatchery releases, and ecological conditions in the ocean and is likely due to competition between wild and hatchery juveniles in nearshore marine habitats.
- According to the commercial permit holder survey, **the three major decision factors influencing a fisherman's choice to continue fishing, modify participation, or leave the fishery were: resource availability, prices, and harvest volume.** Environmental changes (jellyfish and phytoplankton blooms) were minor decision factors, yet were of concern to fishermen for the long-term viability of their fishing businesses.
- **Fishermen may switch target species or stop fishing when price and/or volume are outside the historic norm,** according to the permit holder survey. Prices significantly influence behavior as well as the variance in the net economic benefits or the annual average future value of the harvest.

The lab study results showed that juvenile pink salmon had measurable negative impacts when subjected to higher acidity water.

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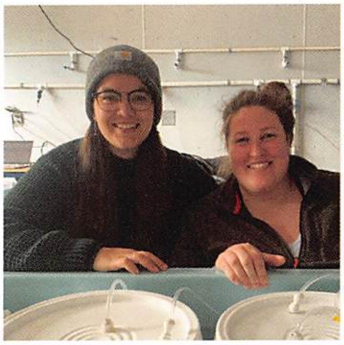
Model results and implications for management and policy

- **As ocean conditions change over time, pink salmon will likely become increasingly vulnerable** due to the increased stress and metabolic demands associated with expected future acidification conditions. This is likely to impact Alaska fisheries.
- **Models show warming and OA will continue to increase, so managing other stressors will become more important to sustain the species and communities that rely on Alaska salmon.** Fisheries managers cannot control warming or OA conditions but can manage other stressors.
- **Our findings highlight the need for salmon management in PWS to consider potential adverse effects of large-scale hatchery production within the context of increasing stressors from ocean change.**
- **In order to maximize economic well-being, management decisions need to consider market price, the number of people fishing, and volume of fish.** The model highlighted these as the top factors to optimize both healthy fisheries and healthy fishing communities.
- **Investments in the ability to track and understand *recruitment variability* are needed to manage fisheries under changing conditions.** While current management focuses on escapement, recruitment variability drives fish population and economic returns. There are benefits to focusing management on increasing recruitment and better understanding environmental factors that affect survival.
- **Delays in adjusting management policies in the face of ocean regime change can lower the financial performance of the fishery.** Delays can also lead to higher chances of fishing moratoriums and lower cumulative recruitment (i.e. lower ecological health). More responsive policy reduces the uncertainty in harvest value and variability in the fishery, though the magnitude depends on specific ecological relationships.

USFWS-Katrina-Mueller

How did the salmon respond?

- Weight and weight-to-length ratios were significantly smaller in fish exposed to future OA conditions.
- Stress hormone levels (cortisol) were significantly higher in fish exposed to future OA conditions and reduced food.
- The routine metabolic rate was significantly higher in fish exposed to future OA conditions and reduced food.
- The otoliths (inner ear bones) of juvenile pink salmon reared under future OA conditions were significantly smaller than the otoliths of fish reared in current day conditions.



UAF Kelley Lab team members at Alutiiq Pride Marine Institute.

Dr. Amanda Kelley builds out an ocean acidification exposure system in the wet lab.

Why it matters

- **Sublethal impacts to salmon from OA can affect fisheries.** While there was no significant effect of direct exposure to future OA conditions on juvenile pink salmon survival, the sublethal (not deadly) effects related to growth, stress, and metabolic rate were significant and could create population-level implications. These potential physiological changes should be incorporated into climate change mitigation and adaptation planning.
- **Subsistence, commercial, and recreational resource users may be impacted by OA.** Juvenile pink salmon lost weight under future OA conditions which could influence the total number of fish needed to meet the needs of harvesters. The increased metabolism of salmon in these conditions may also displace other target species through direct competition for prey.
- **Measurable effects require time.** Previous studies on juvenile pink salmon did not detect any impacts of OA on growth or physiology. However, the previous studies were short (~2 weeks). Our work demonstrated that the impacts of OA began to appear after two weeks of exposure, highlighting the need for laboratory studies to be carried out for longer periods.

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OAP OCEAN ACIDIFICATION PROGRAM

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OCEAN ACIDIFICATION AND ALASKA PINK SALMON

WHAT WE KNOW FROM THE LAB

Background

The increase in carbon dioxide in the atmosphere from human activities is driving a long-term increase in ocean acidity, a process known as ocean acidification (OA). Lab research has shown that OA can have direct, negative impacts on marine organisms by affecting growth, calcification, reproduction, and survival. Ocean acidification can also affect marine food webs as many prey species are sensitive to changes in ocean chemistry. Alaska is naturally predisposed to ocean acidification because of its cold water and other factors. Understanding how species of economic and cultural importance may respond is vital to help inform future fisheries management.

Quick chemistry fact
The more CO_2 generated or injected into seawater, the lower its pH level will be. This is caused by the interaction between CO_2 and H_2O, which results in a release of carbonic acid. Lower pH corresponds to higher acidity.

The research question

The Kelley Lab at the University of Alaska Fairbanks looked at how juvenile pink salmon respond to the direct effect of future ocean acidification conditions and the indirect effect of reduced food availability in the lab setting.

Treatment
Ambient pCO_2 = 400 uatm
Elevated pCO_2 = 1,100 uatm
Reduced food = 1.5% body mass

What we did

Juvenile pink salmon were exposed to treatments with increased pCO_2 (which increases acidity) and reduced food availability at the Alutiiq Pride Marine Institute in Seward, Alaska. Researchers from the University of Alaska Fairbanks measured developmental, physiological, and otolith mineral characteristics over the course of a 6-week period in 2021. The pCO_2 were consistent with conditions expected by the year 2100 under a "behavior as usual" scenario.

Tonsina Creek near Seward shows representative pink salmon habitat in Southcentral Alaska.

Marina Alcantar