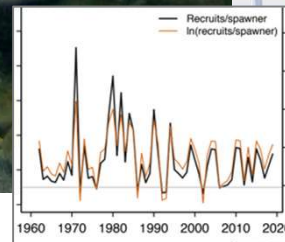
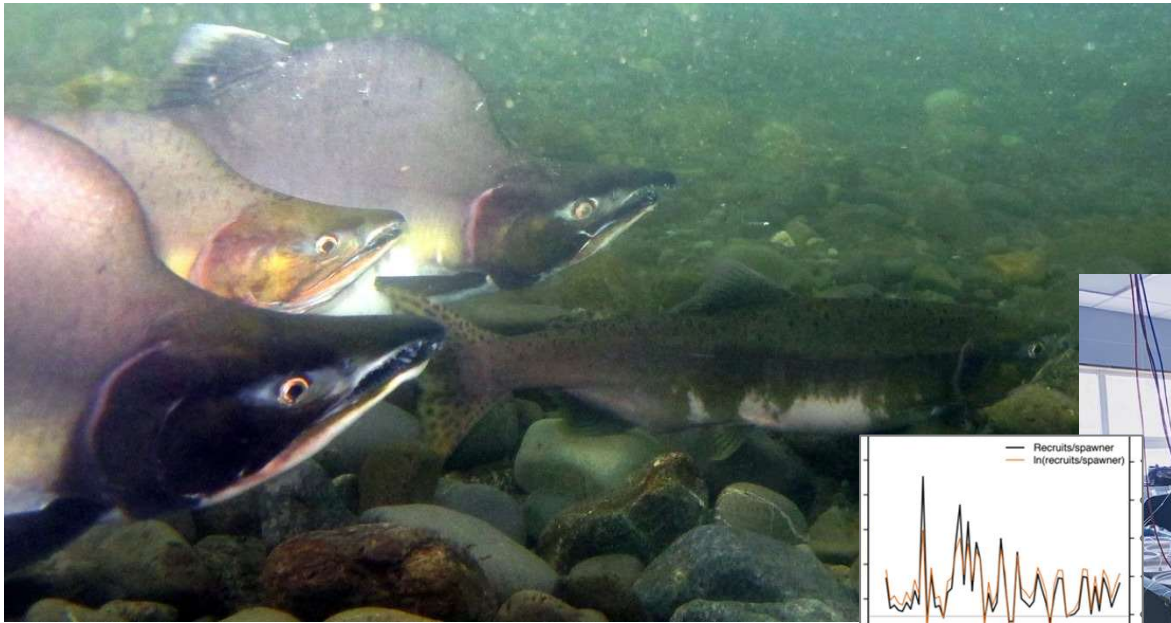


Ocean Acidification and Alaska Pink Salmon



Alaska Board of Fish

October 4, 2023

Darcy Dugan, Alaska Ocean Observing System

Marina Alcantar, University of Alaska Fairbanks

Kevin Berry, University of Alaska Anchorage

Plan for today

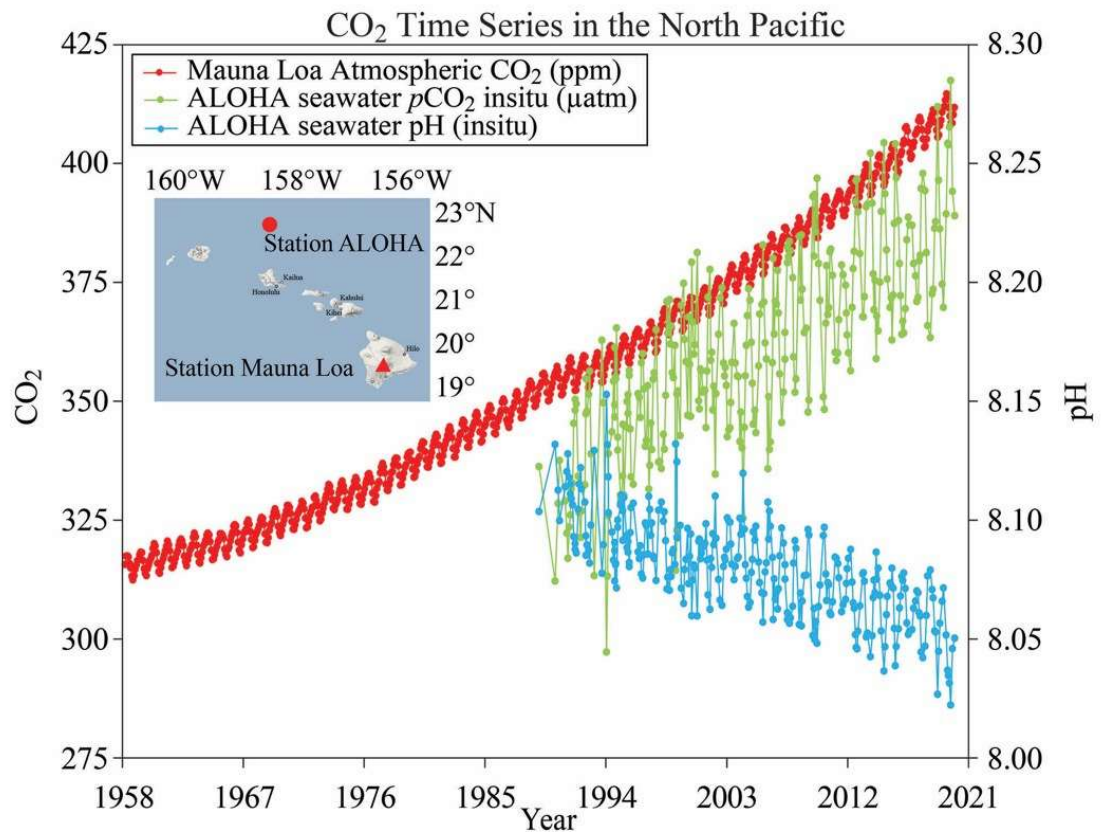
- Refresher and update on ocean acidification
- Results: the Tipping Points Project
 - Pink salmon study – Marina Alcantar (UAF)
 - Bio-economic modeling results – Kevin Berry (UAA)
- Discussion/Q&A (30 min)



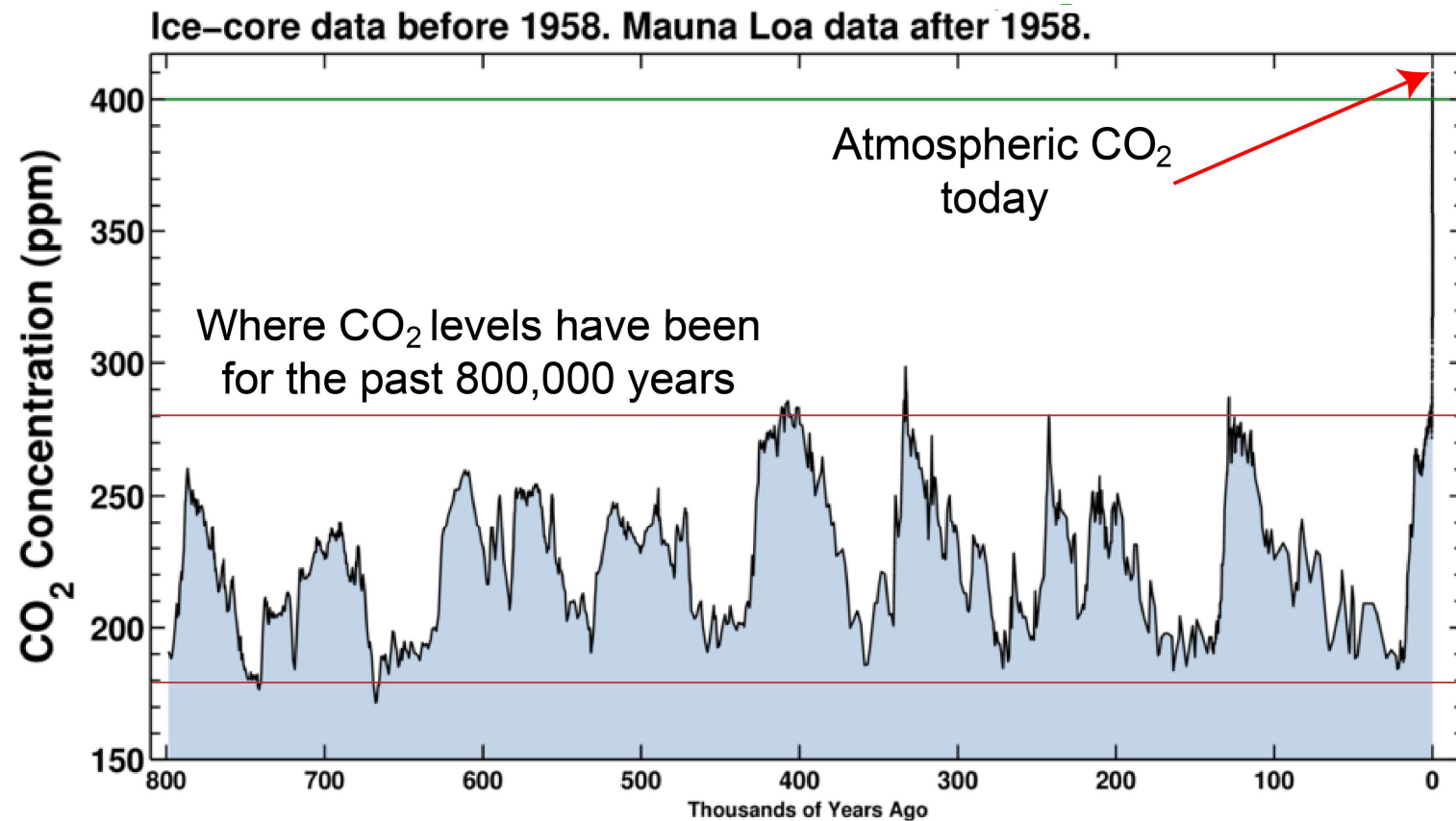
Ocean Acidification: a quick refresher

Ocean water absorbs CO_2 from the atmosphere

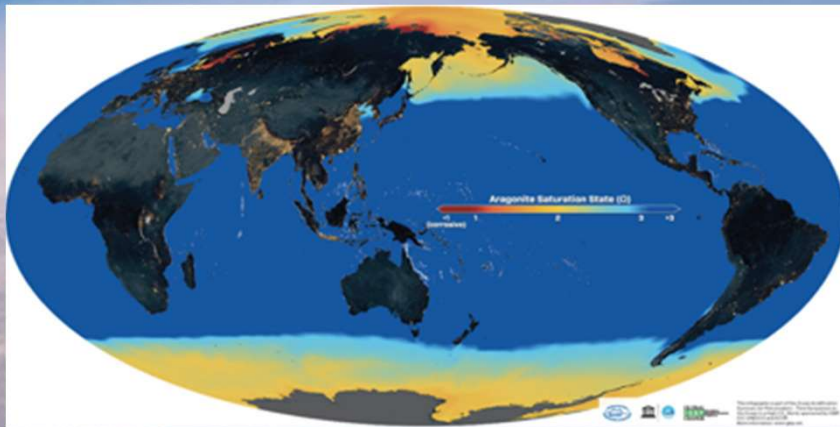
Globally, acidity has increased 26% since the industrial revolution.



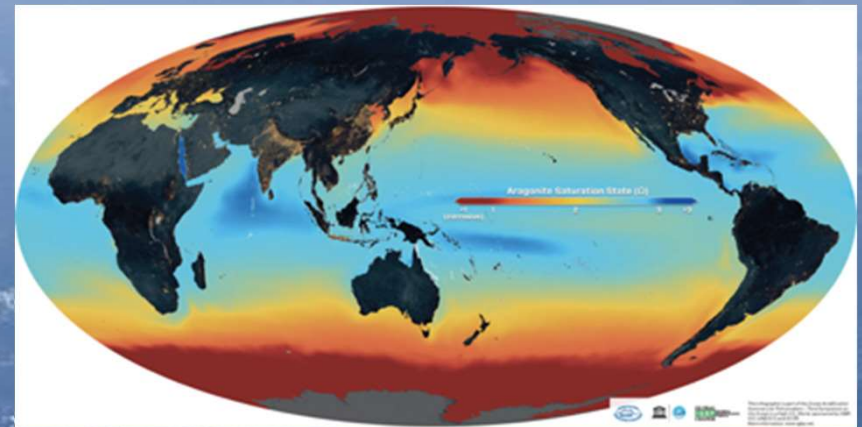
Atmospheric carbon dioxide in context



Alaska waters are more susceptible

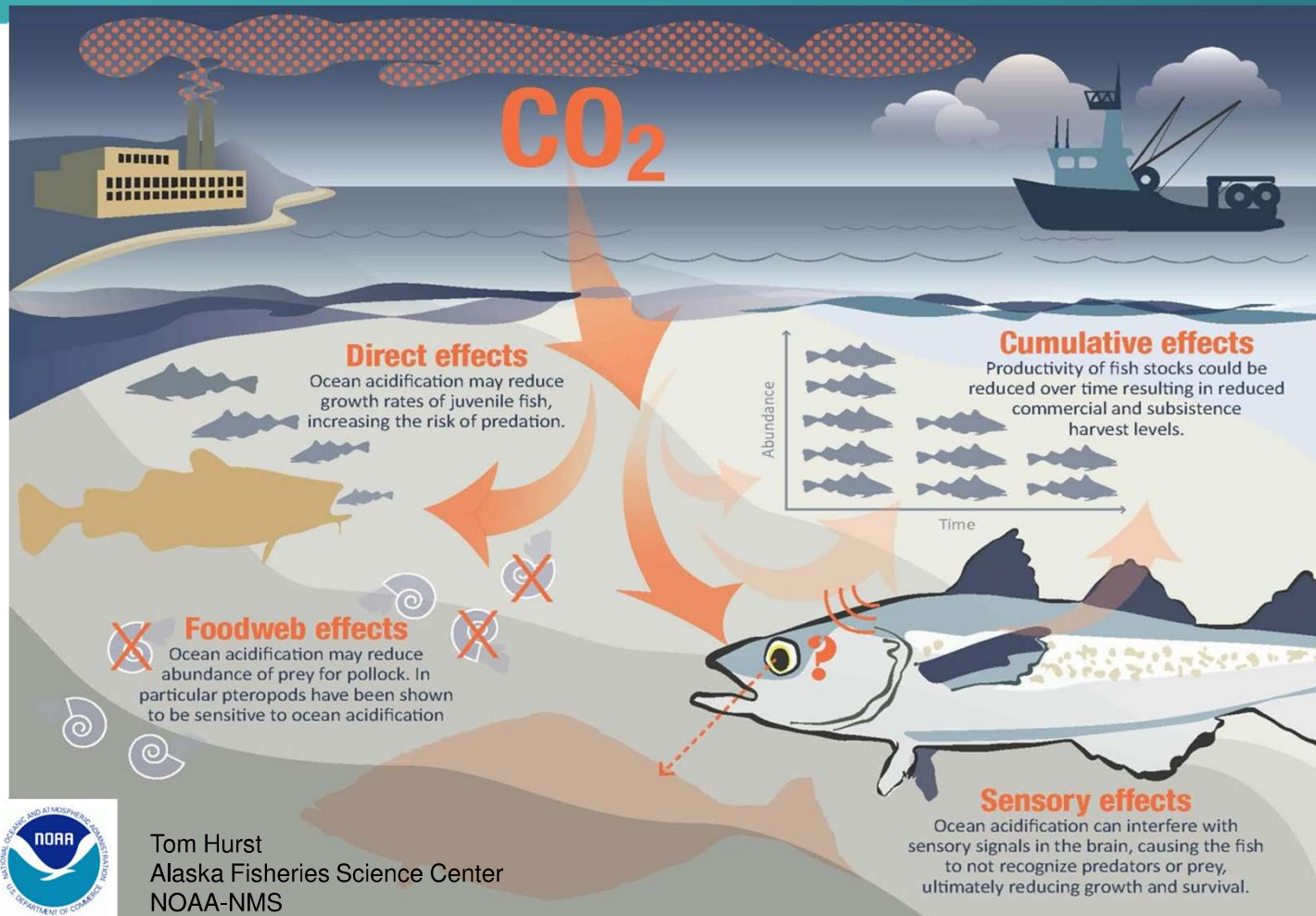


Pre-industrial

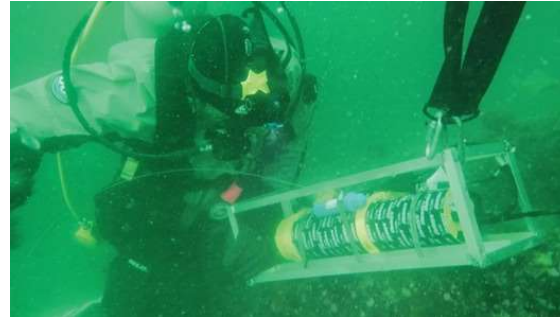
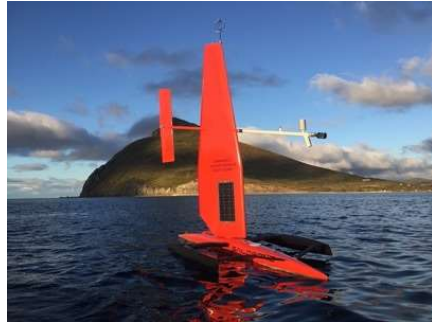


2100

Ocean acidification affects fish



Monitoring: a multi-faceted approach



What are we learning?

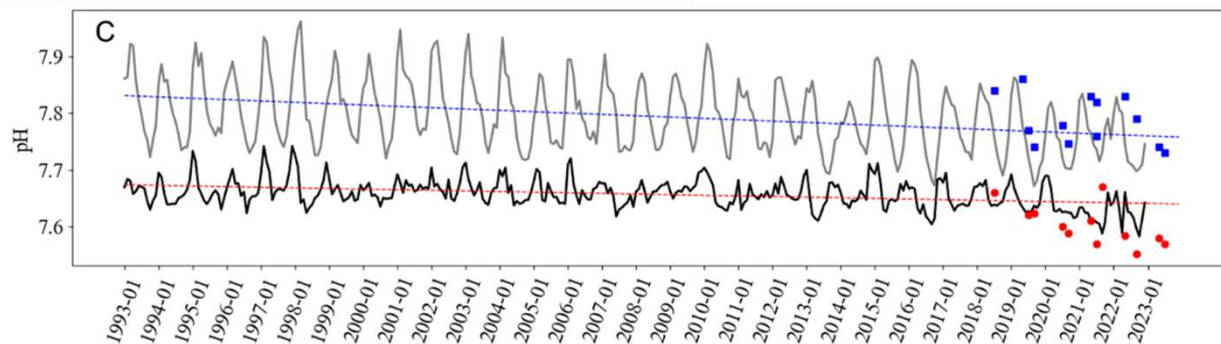
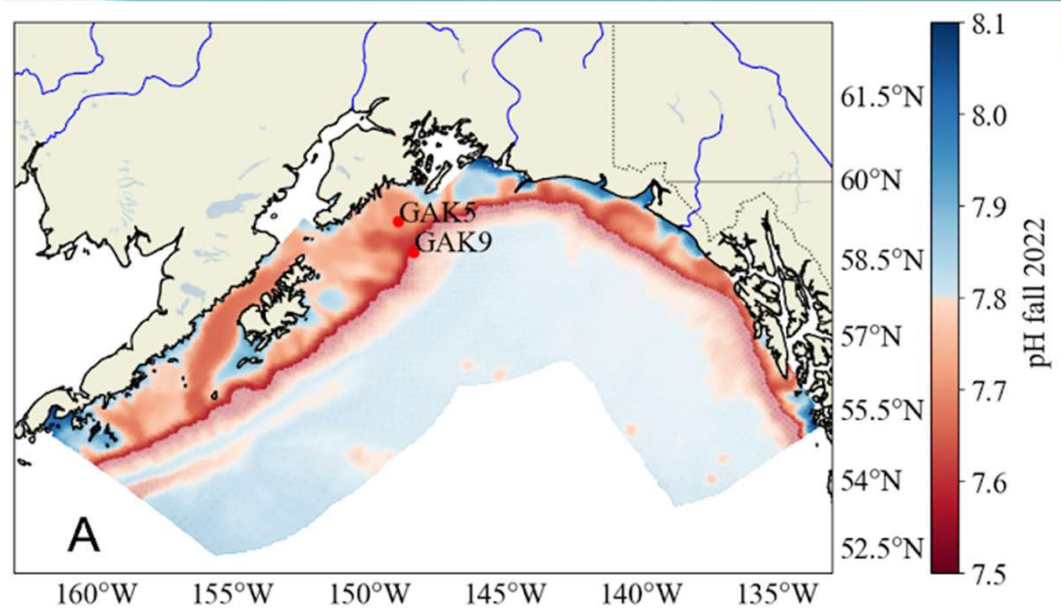
- Corrosive water is occurring now
- Conditions are not uniform
- Seasonal fluxes are large and predictable
- Fall/winter tend to have more acidic conditions
- Glacial melt/freshwater outflow and upwelling are exacerbating factors
- Despite natural variability, we can track a long term change.
- Ocean acidification is happening in tandem with other climate-related changes



What do we know about the Gulf of Alaska

Monitoring and model output show increases in acidity in the past 30 years

Bottom water pH is already exceeding thresholds for some species (< 7.8)



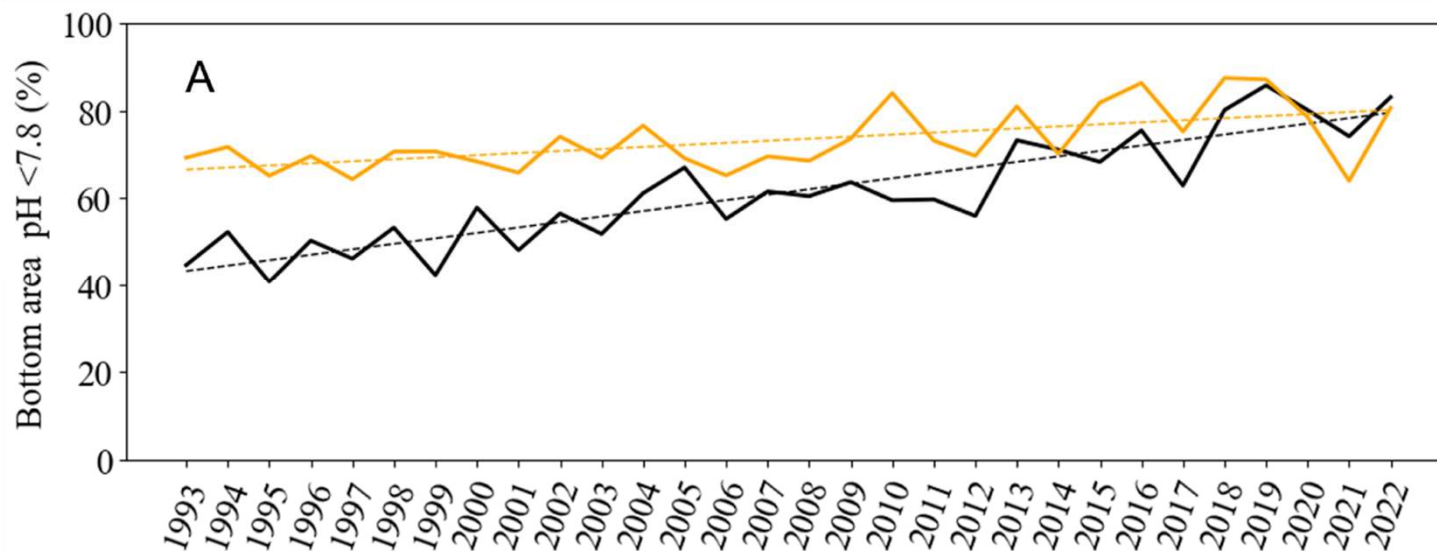
Figures from Claudine Hauri (UAF) submitted for 2023 Ecosystem Status report

The two lines are bottom water pH from 2 locations in the Gulf (GAK5 and GAK 9 on map above)

What do we know about the Gulf of Alaska

- The percent of bottom water with low pH has increased in the past 30 years
- This is shrinking habitat for sensitive species

Percent of seafloor area in the Gulf of Alaska affected by low pH



Black line = western shelf

Yellow line = eastern shelf

Hauri et al, submitted

How will species respond?

Many species respond negatively to more acidic water

Coho salmon: reduced sense of smell to detect predators

Butter clams: shell dissolution

Tanner crab – fewer embryos hatched, slower growth, reduced shell formation

Red king crab – decrease in survival and growth


Cod - reduced growth during the first few weeks after hatching

Pteropods – shell dissolution

Snow crab – appear to be resilient

Pollock - no effect on growth or survival

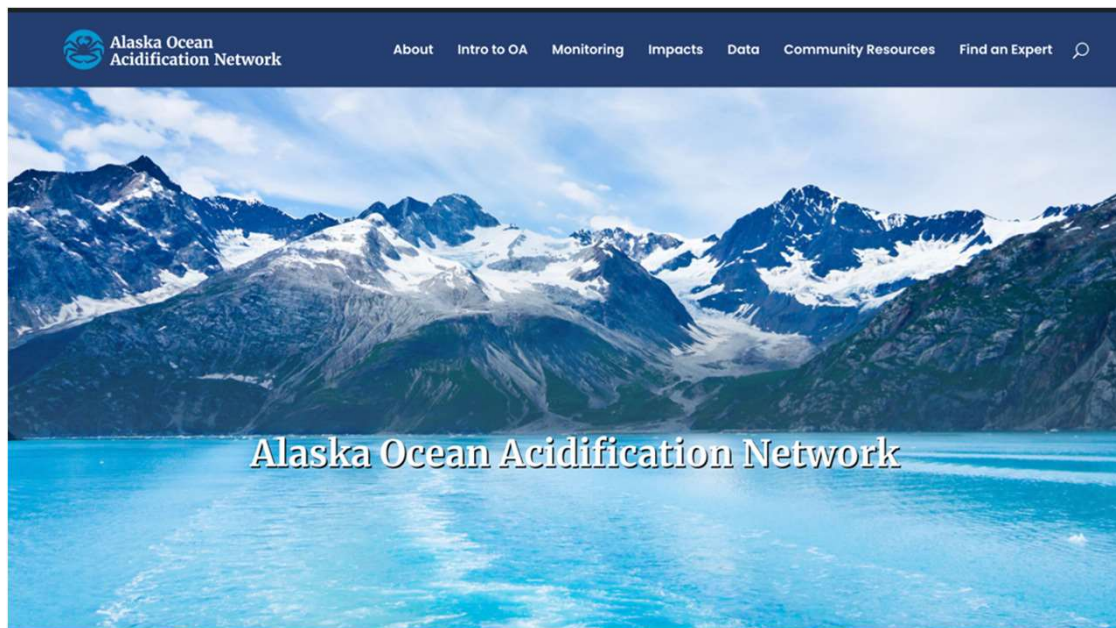
Shrimp – preliminary results show resiliency

Response to Ocean Acidification

Resident marine species		Calcification	Growth	Reproduction	Survival
Red king crab	Embryo	U	U	U	—
	Larvae	▲	U	U	▼
	Juvenile	—	▼	U	▼
	Adult	▲	U	U	U
Pink salmon*		N/A	▼	▼	U
Dungeness crab*		U	▼	—	▼
Blue king crab	Juvenile	▲	▼	U	▼
Golden king crab	Juvenile		▼		▼
Tanner crab	Embryo				▼
	Larvae	▼			▼
	Juvenile	▼	▼		▼
	Adult	▼			▼
Snow crab	Embryo				—
	Larvae	—			—
	Adult	▼			
Pacific Cod	Larvae	▲ ▼			
Northern rock sole*		N/A	▼	U	▼
Walleye pollock*		N/A	—	U	—
Northern shrimp*		U	▼	U	▼
Pteropod**	Juvenile, Adult	▼			▼
Dungeness crab	Larvae		▼		
Pinto abalone	Adult		▼		
Baltic clam*		▼	▼	▼	▼
Common cockle*		▼	▼	U	U
Red sea urchin*		U	U	▼	U


Alaska Ocean Acidification Network



<https://aoan.aooos.org/>

- Engage with communities to expand understanding
- Identify information needs and monitoring priorities
- Share best practices and data
- Explore adaptation and mitigation

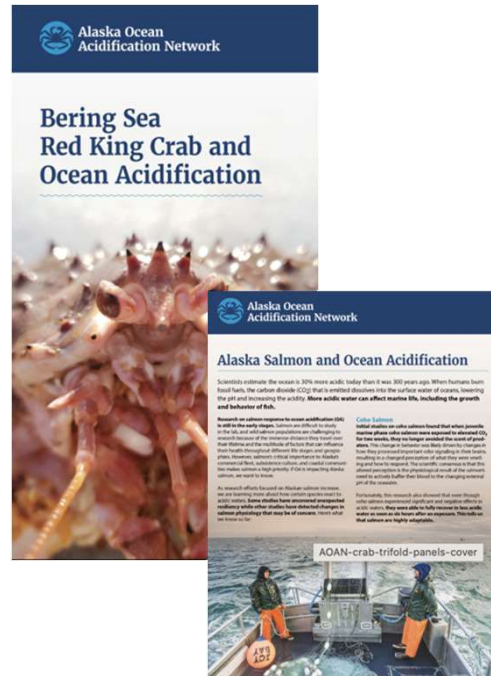
Addressing ocean acidification is an active discussion



Response to Ocean Acidification

Resident marine species		Calcification	Growth	Reproduction	Survival
Red king crab	Embryo	U	U	U	U
	Larvae	U	U	U	U
	Juvenile	U	U	U	U
	Adult	U	U	U	U
Pink salmon*		N/A	U	U	U
Dungeness crab*		U	U	U	U
Blue king crab	Juvenile	U	U	U	U
Golden king crab	Juvenile	U	U	U	U
Tanner crab	Embryo	U	U	U	U
	Larvae	U	U	U	U
	Juvenile	U	U	U	U
	Adult	U	U	U	U
Snow crab	Embryo	U	U	U	U
	Larvae	U	U	U	U
	Adult	U	U	U	U
Pacific Cod	Larvae	U	U	U	U
Northern rock sole*		N/A	U	U	U
Walleye pollock*		N/A	U	U	U
Northern shrimp*		U	U	U	U
Pteropod**	Juvenile, Adult	U	U	U	U
Dungeness crab	Larvae	U	U	U	U
Pinto abalone	Adult	U	U	U	U
Baltic clam*		U	U	U	U
Common cockle*		U	U	U	U
Red sea urchin*		U	U	U	U

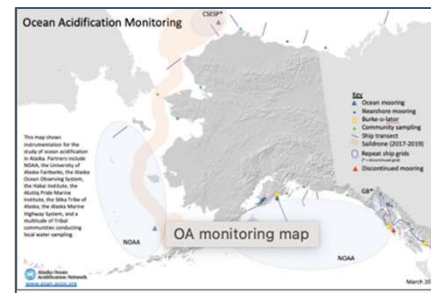
Species response synthesis



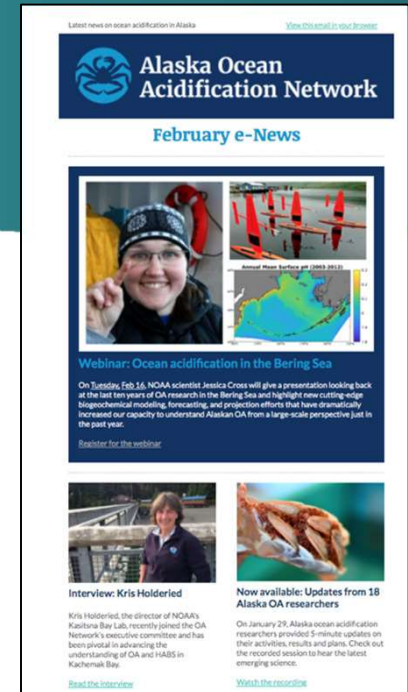
Brochures on species



Presentations and Discussion Series



Instrument map



eNews



Podcast on solutions

Tipping Points project

Questions:

How might salmon be impacted by higher acidity conditions and other climate change effects?

How might management decisions influence how those changes will impact fishing communities?

Components

- Lab study on pink salmon response (higher acidity, reduced food)
- Biometric analysis (60 years of salmon and oceanographic data)
- Commercial fishermen engagement (interviews and survey)
- Bio-economic modeling



Funding source: NOAA's Ocean Acidification Program



The Tipping Points Team



Toby Schwoerer
UAF



Marina Alcantar
UAF



Jan Ohlberger
Univ. Washington



David Finhoff
University of Wyoming



Molly Mayo
Meridian Institute



Darcy Dugan
Alaska Ocean Observing System



Eric Ward
NOAA



Amanda Kelley
UAF



Jeff Hetrick
Alutiiq Pride Marine Institute



Kevin Berry
UAA



NOAA OCEAN ACIDIFICATION PROGRAM



Characterizing the direct and indirect effects of ocean acidification on juvenile pink salmon (*Oncorhynchus gorbuscha*)



Marina Alcantar¹, Shelby Bacus¹, Dr. Peter Westley¹, Dr. Amanda Kelley¹

¹College of Fisheries and Ocean Sciences,
University of Alaska Fairbanks

Rasmuson Fisheries
Research Center

Pink Salmon Response to OA

<u>Ou et al. (2015)</u>	<u>Frommel et al. (2020)</u>
Hatchery fish	Wild caught
Embryo → juvenile	Juvenile (67-87 mm fork length)
Freshwater acidification and OA	Exposed to natural corrosive regime ~1000 $\mu\text{atm } p\text{CO}_2$
450, 1000, 2000 $\mu\text{atm } p\text{CO}_2$	850-2000 $\mu\text{atm } p\text{CO}_2$
OA effects on growth, olfactory responses and anti-predator behavior	No OA effect on mortality, condition factor (Fulton's K), plasma $[\text{Cl}^-]$ or CTmax

Both studies characterize response after 2-week seawater exposure

Full Factorial: OA and Food Reduction

- Conducted for 42 days
- Treatments
 - Ambient $p\text{CO}_2$ (400 μatm) /pH (8.0) x ambient food level (3% body mass)
 - Ambient $p\text{CO}_2$ (400 μatm) /pH (8.0) x reduced food level (1.5% body mass)
 - Elevated $p\text{CO}_2$ (1,100 μatm) /pH (7.6) x ambient food level (3% body mass)
 - Elevated $p\text{CO}_2$ (1,100 μatm) /pH (7.6) x reduced food level (1.5% body mass)
- Temperature was $10^\circ\text{C} \pm 1^\circ\text{C}$



The Complete Picture

Whole organism

- **Mortality**
- **Mass, length, conditional index**
- **Morphological development**
- **Routine metabolic rate**

Tissue

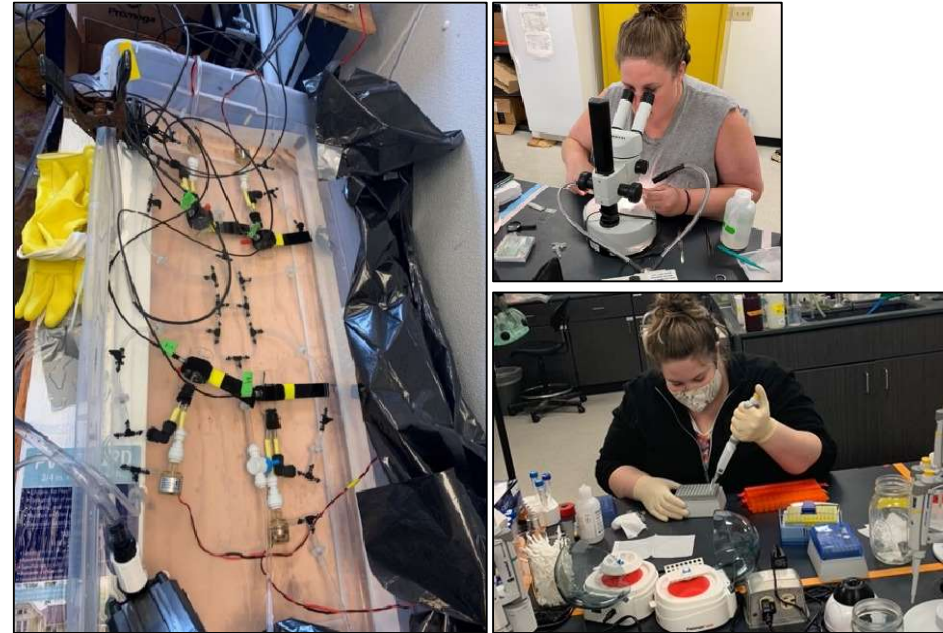
- **Endocrine response**
 - Cortisol levels (stress hormone)

Biomineralogy

- Otolith growth
- **Mineralogy- aragonite vs. vaterite**

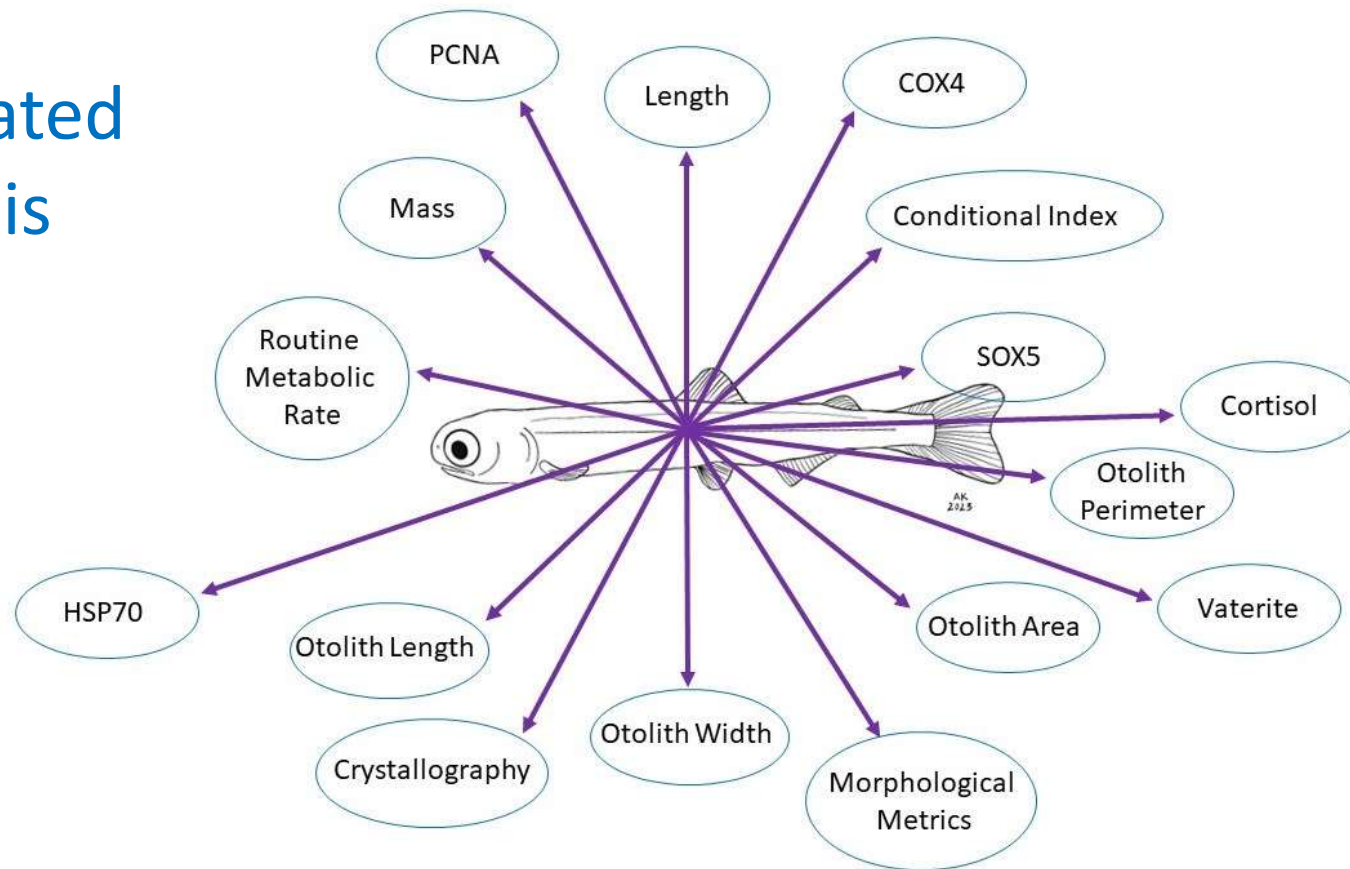
Cellular

- Gene expression
- HSP70, SOX5, COX4, PCNA

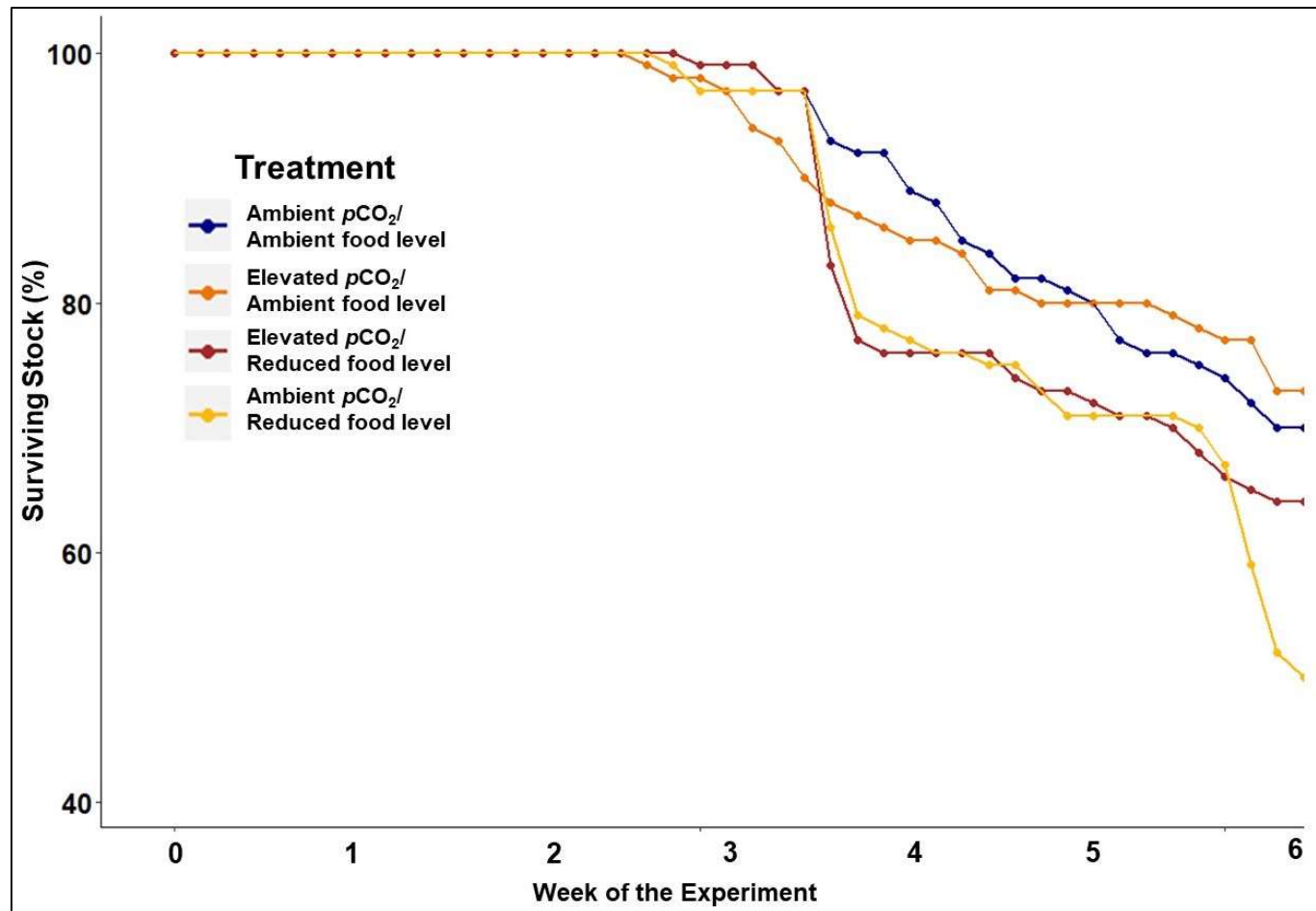


The Complete Picture

Integrated Analysis

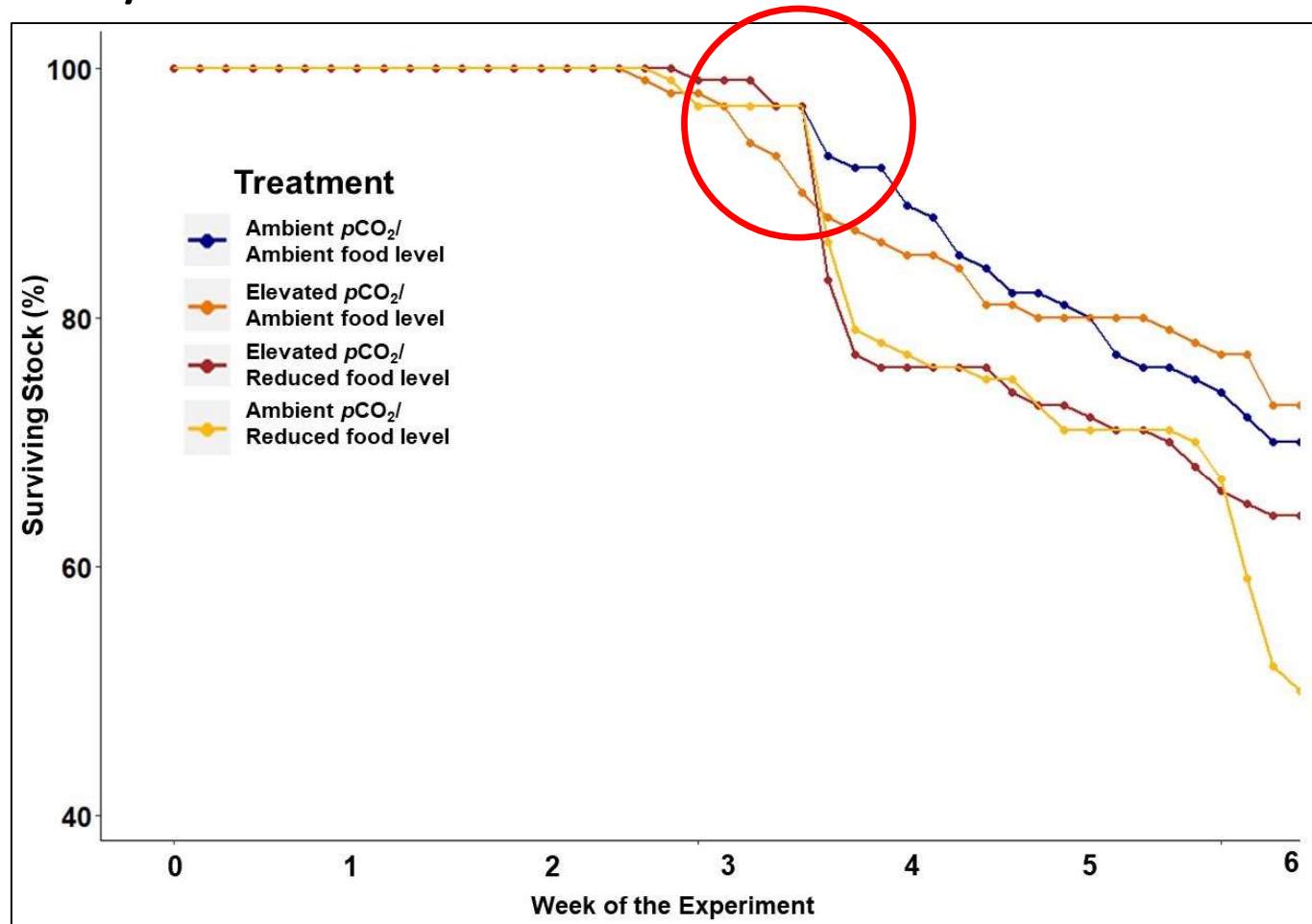


Mortality

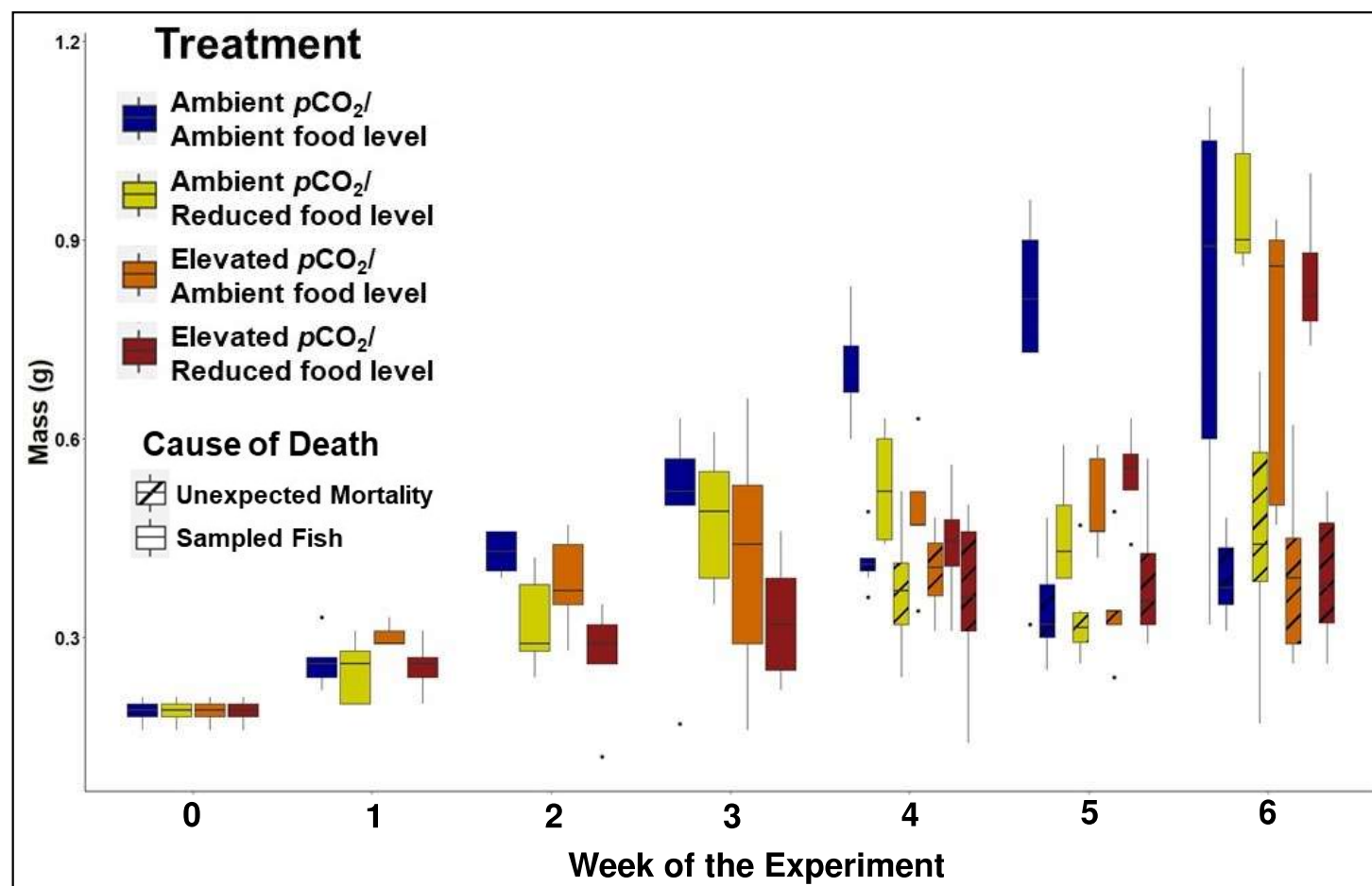


Mortality

***Intense mortality events
began between weeks 3 and 4**

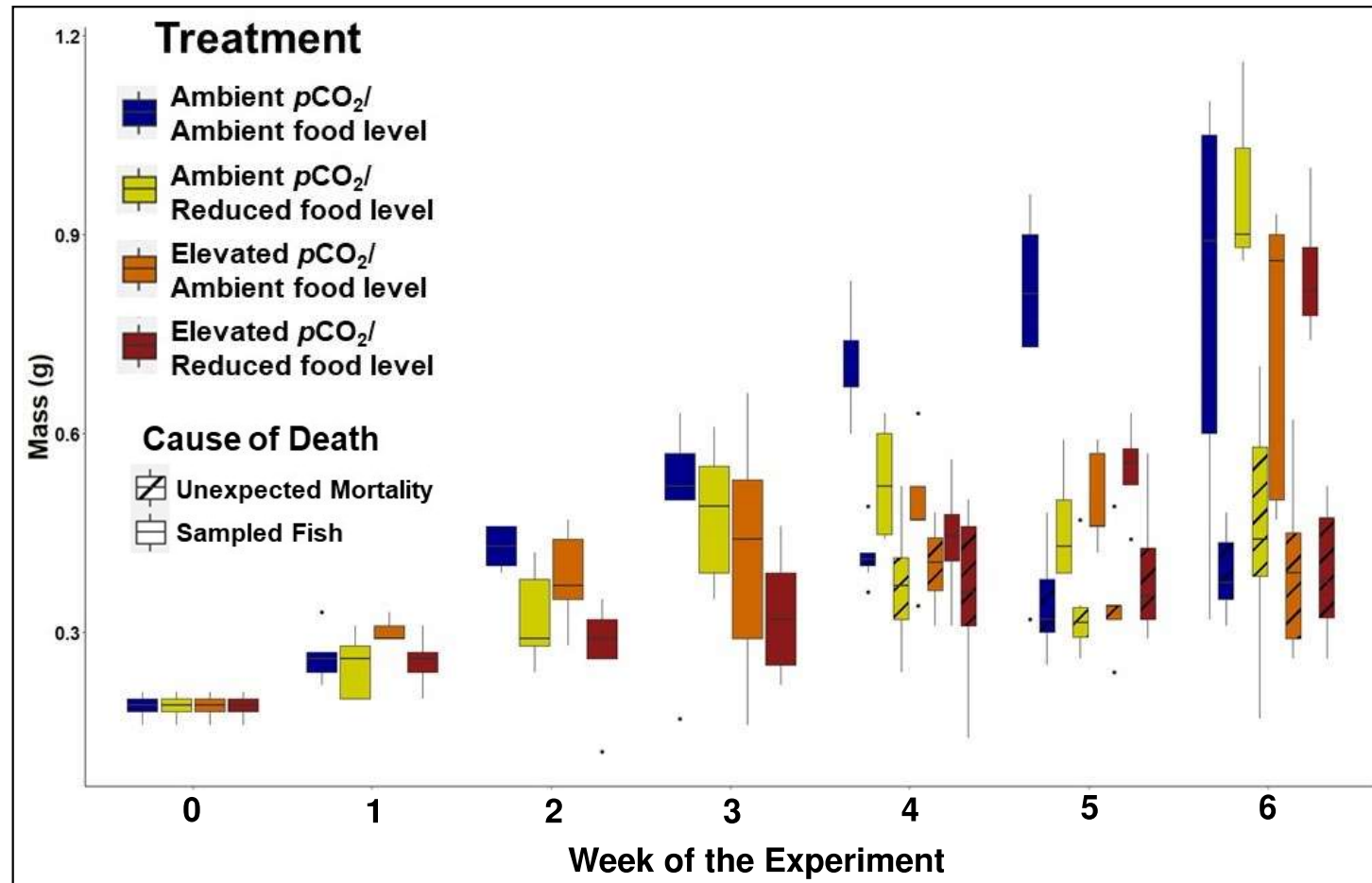


Fish Mass



Fish Mass

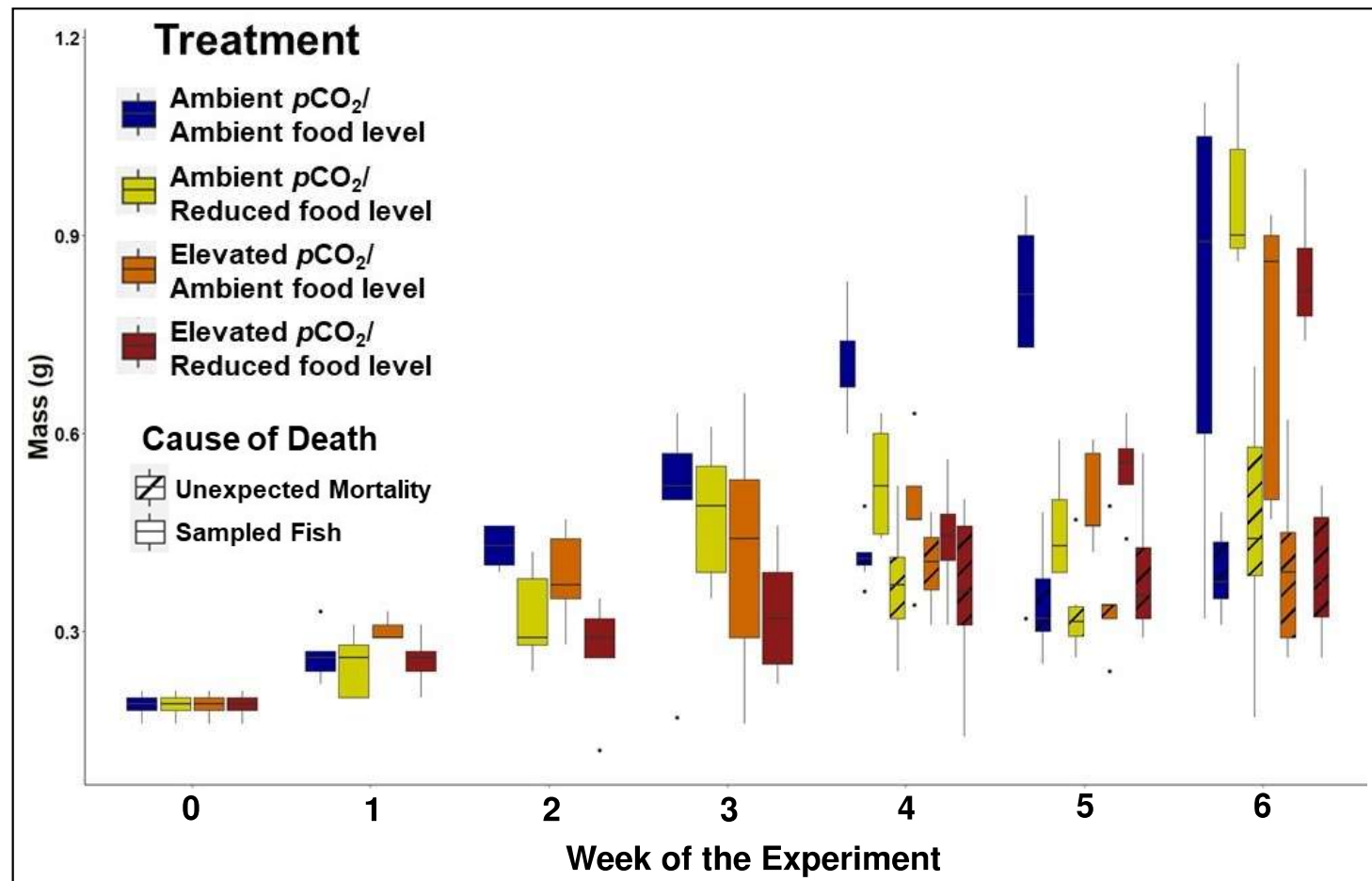
*** $p\text{CO}_2$ exposure and food availability had a significant effect on overall mass**



Fish Mass

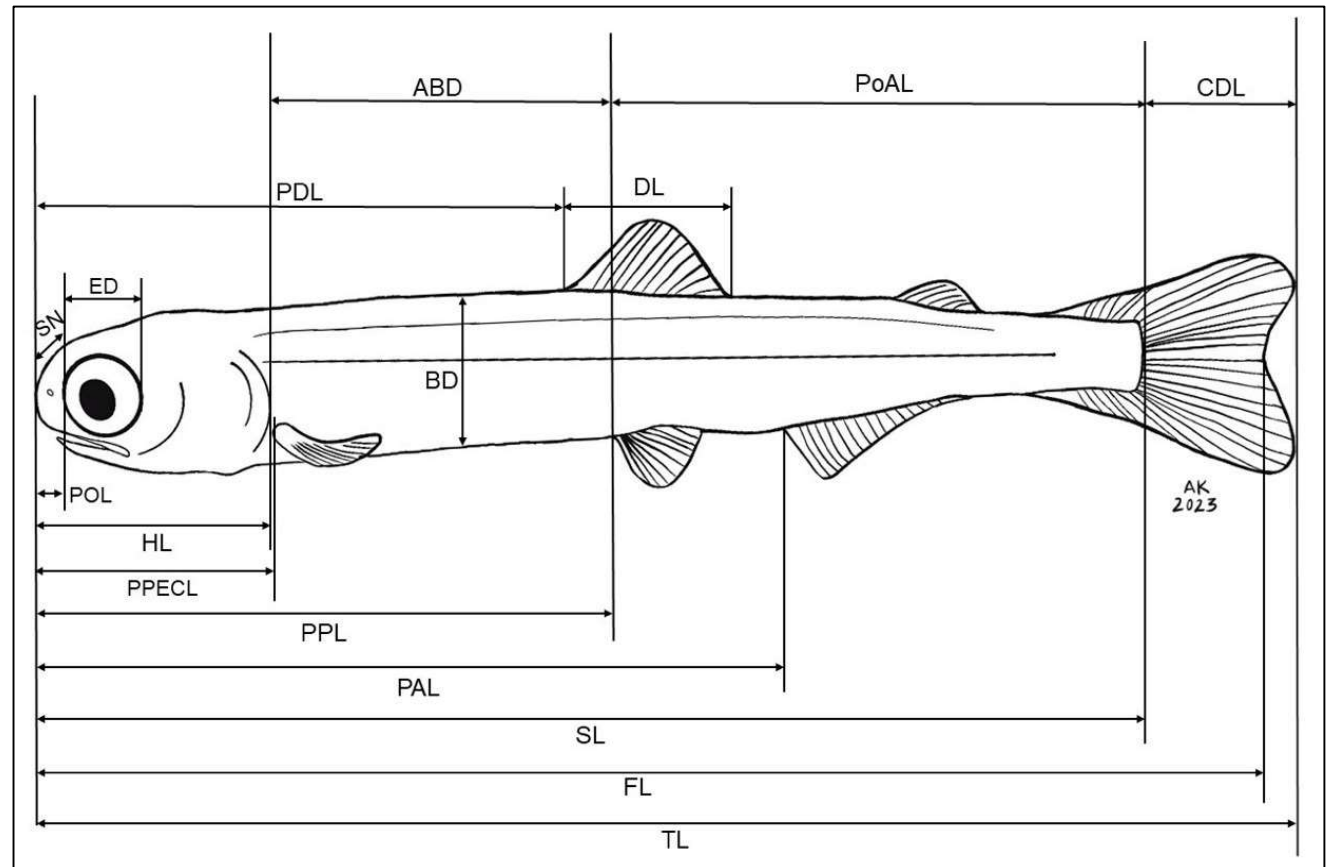
*** $p\text{CO}_2$ exposure and food availability had a significant effect on overall mass**

~ These data are being used by the modeling team to inform future fish quality metrics.

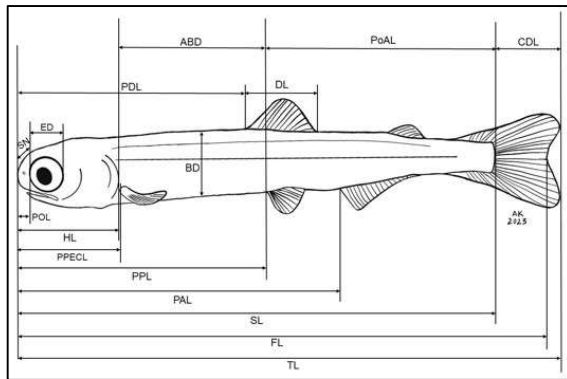


Morphology

- Constrain overall fish shape
- Accounts for inter-individual size variability
- Method from Berghaus et al. (2019)
 - Includes measurements from Huysentruijt et al. (2009)
- Principle component analysis (PCA)



Morphology

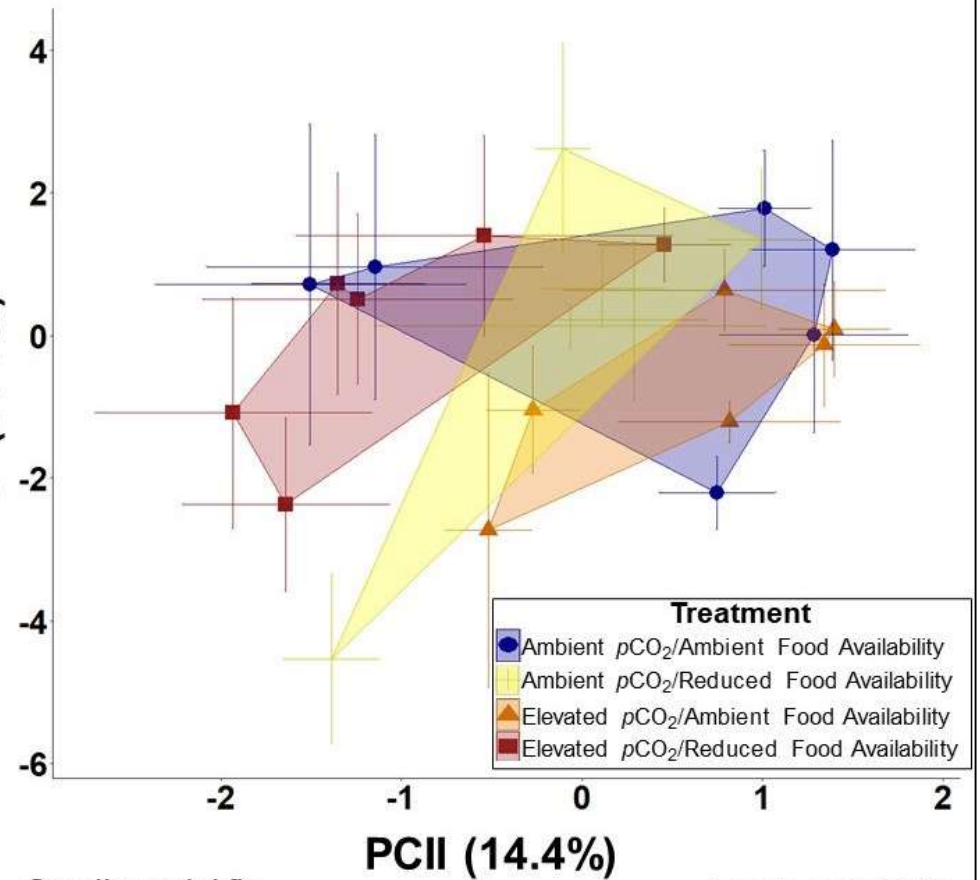


Long body, large pectoral fin, long pre-anal-fin section

Overall body length

Short body, small pectoral fin, short pre-anal-fin sections

PCI (50.5%)

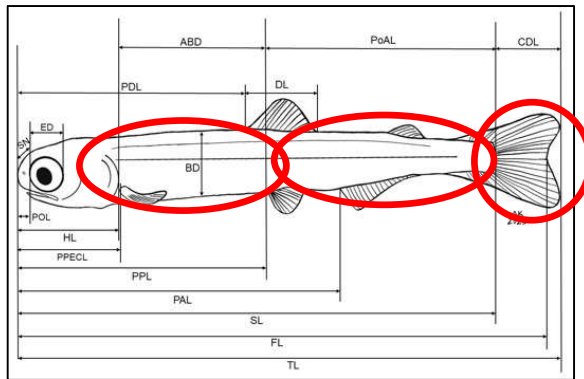


Small caudal fin, shorter abdomen, and post-anal-fin section

Posterior Morphology

Large caudal fin, longer abdomen, and post-anal-fin section

Morphology

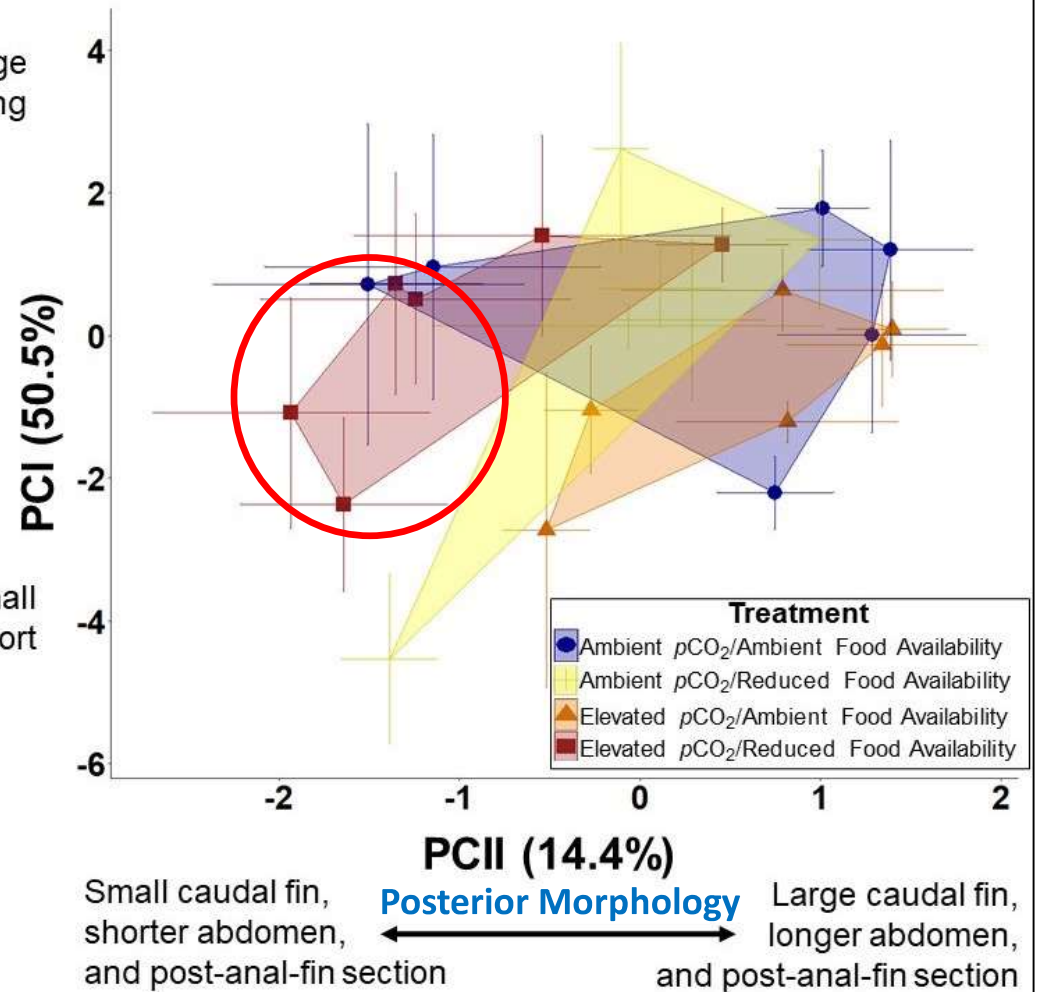


***Juvenile pinks reared under combined elevated $p\text{CO}_2$ reduced food availability conditions had smaller caudal fins, abdominal sections and post-anal-fin sections.**

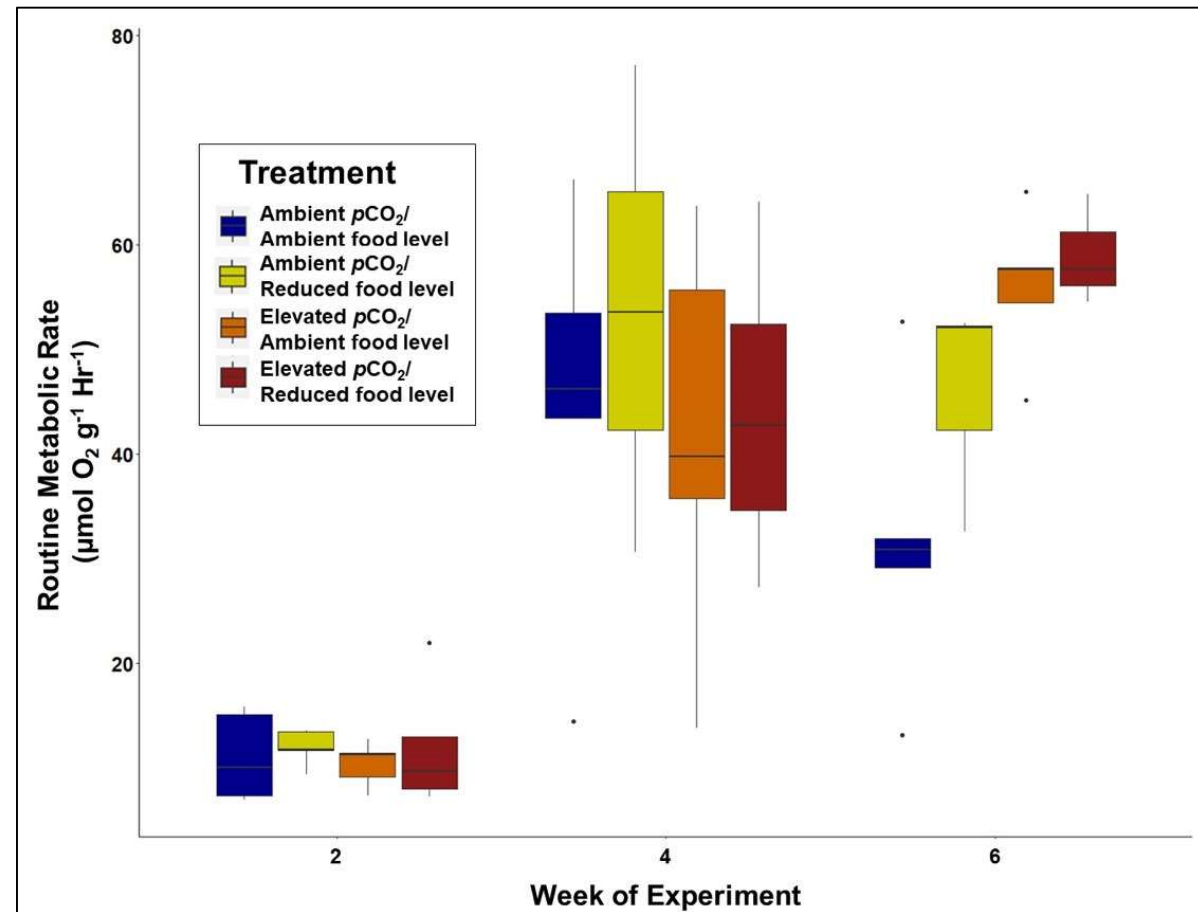
Long body, large pectoral fin, long pre-anal-fin section

Overall body length

Short body, small pectoral fin, short pre-anal-fin sections



Routine Metabolic Rate (RMR)

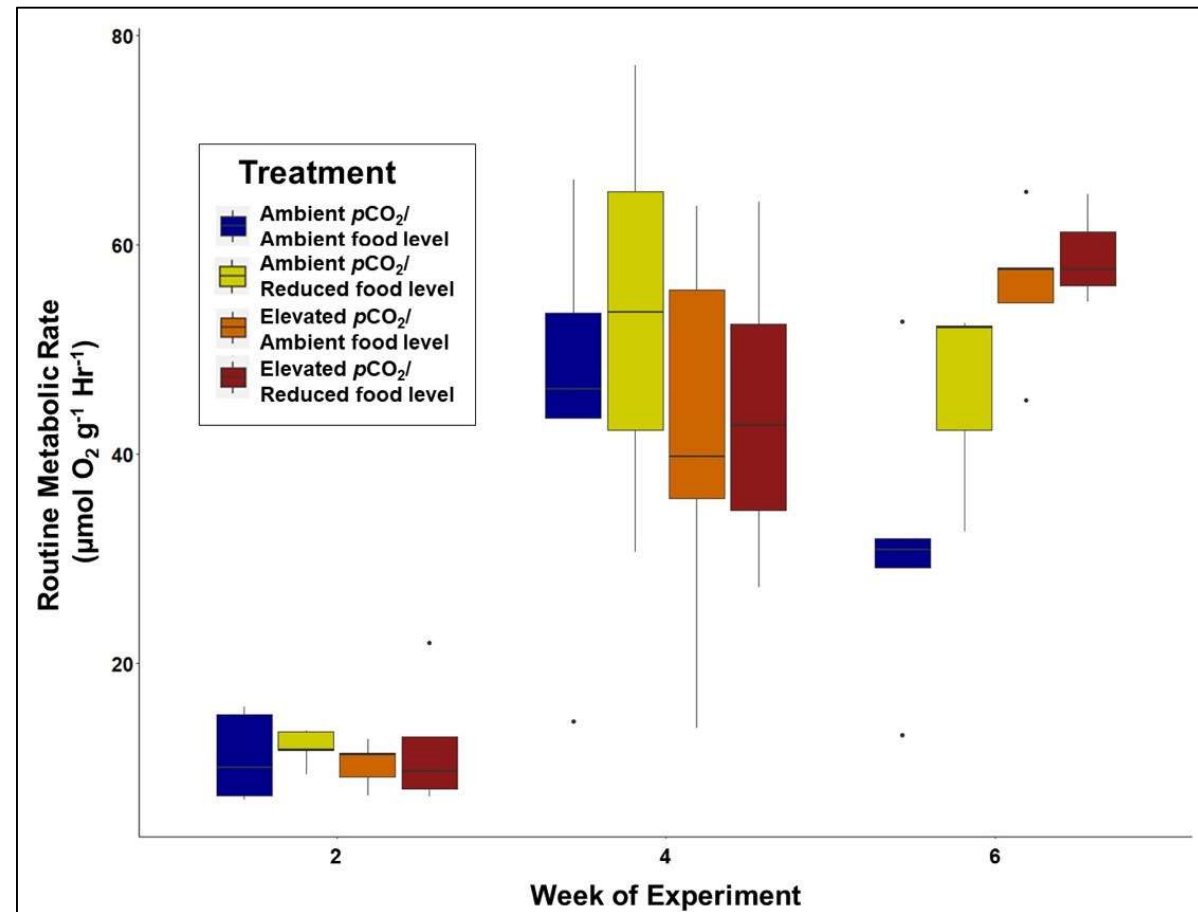


Routine Metabolic Rate (RMR)

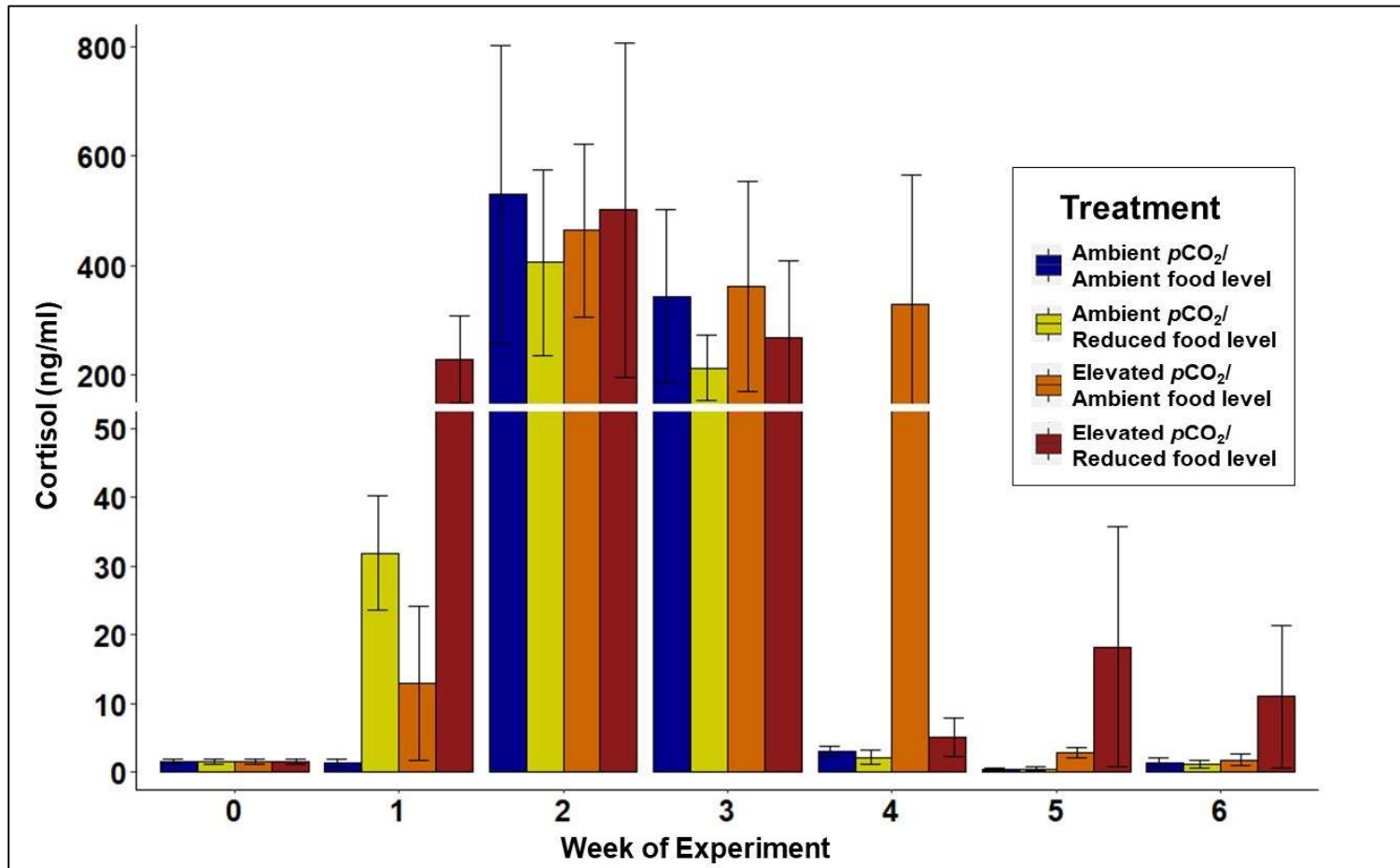
***Significant effect of $p\text{CO}_2$ exposure on RMR**

***Significant effect of food availability on RMR**

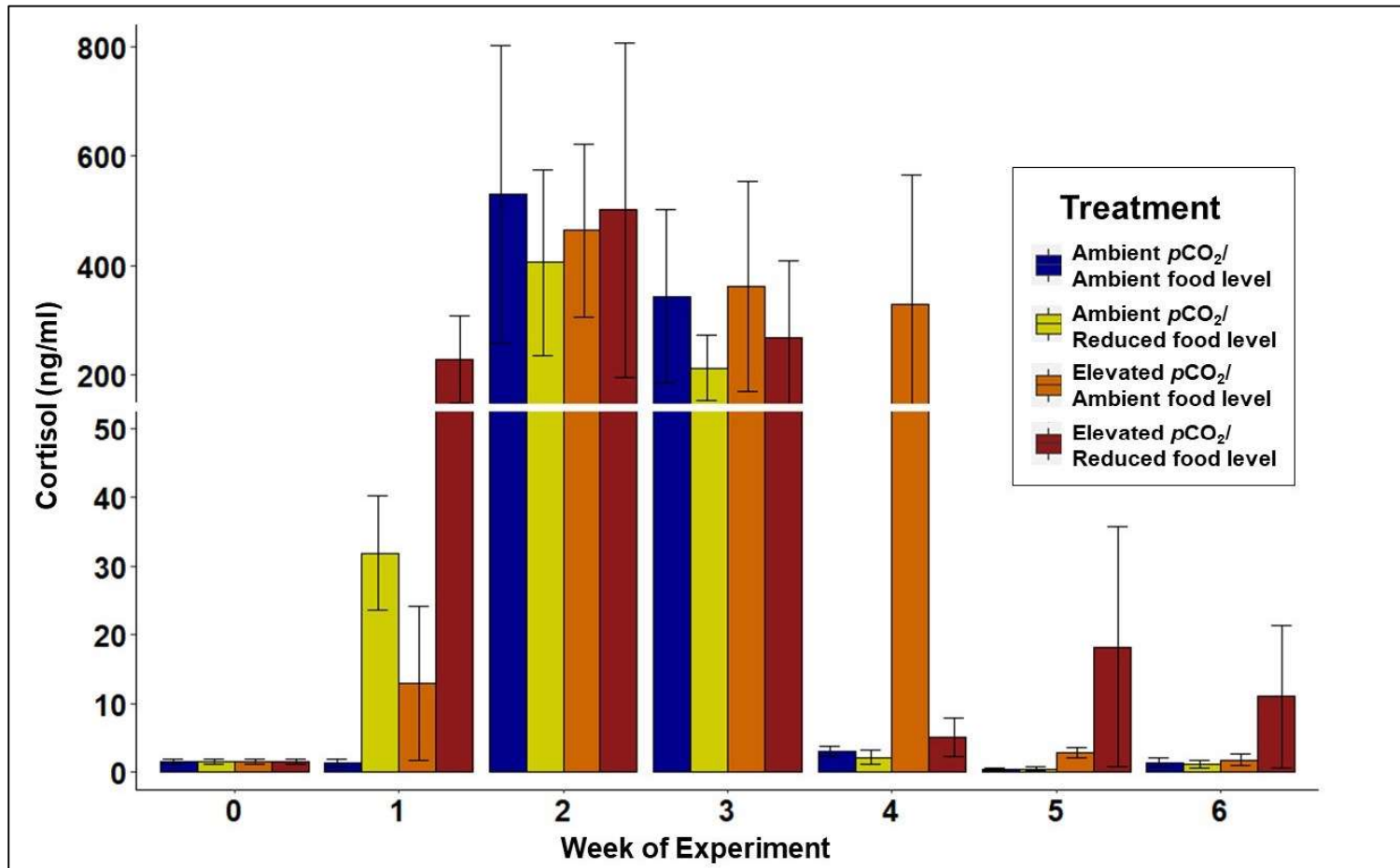
***Significant effect of time on RMR**



Endocrine Response



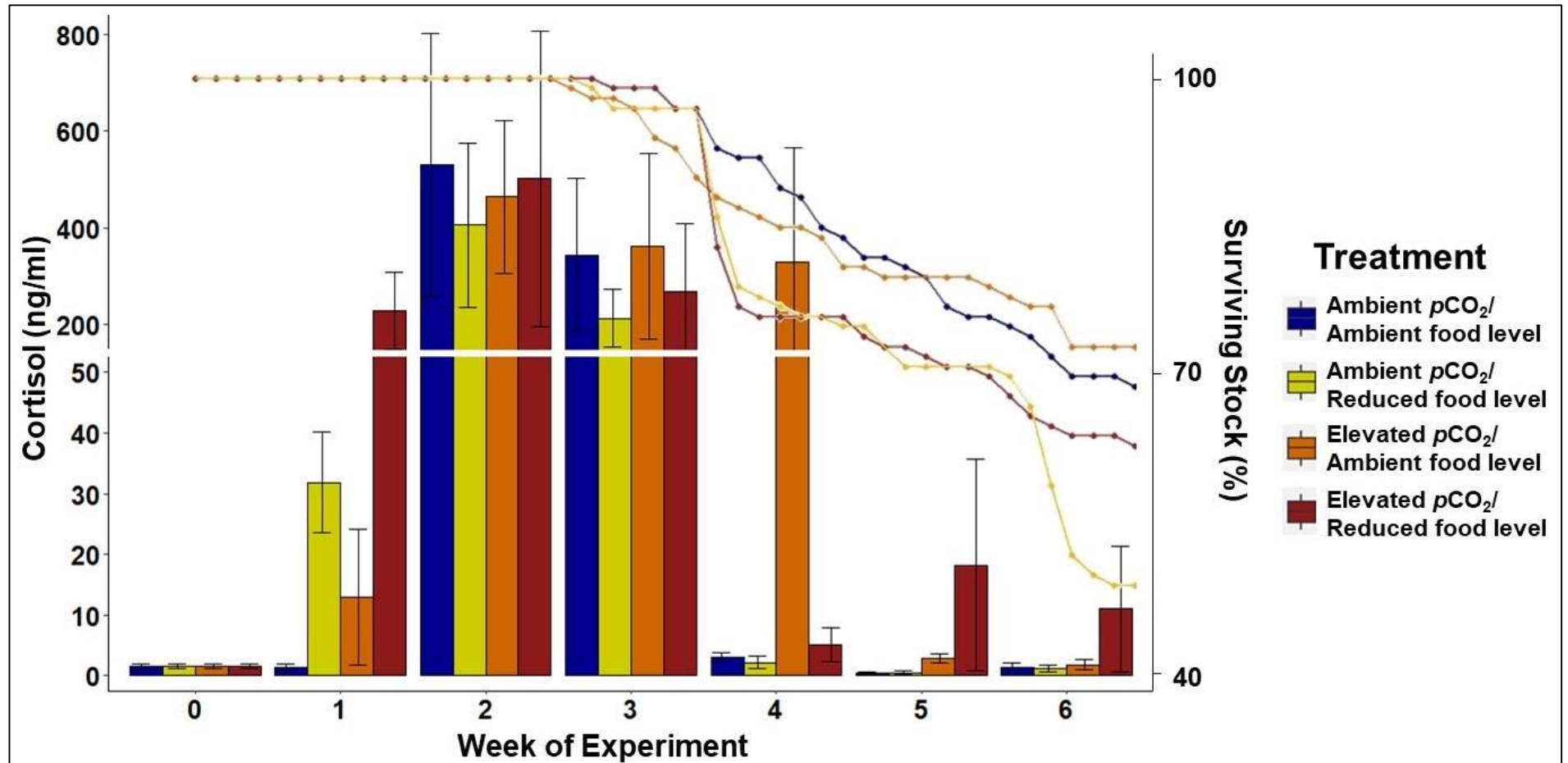
Endocrine Response



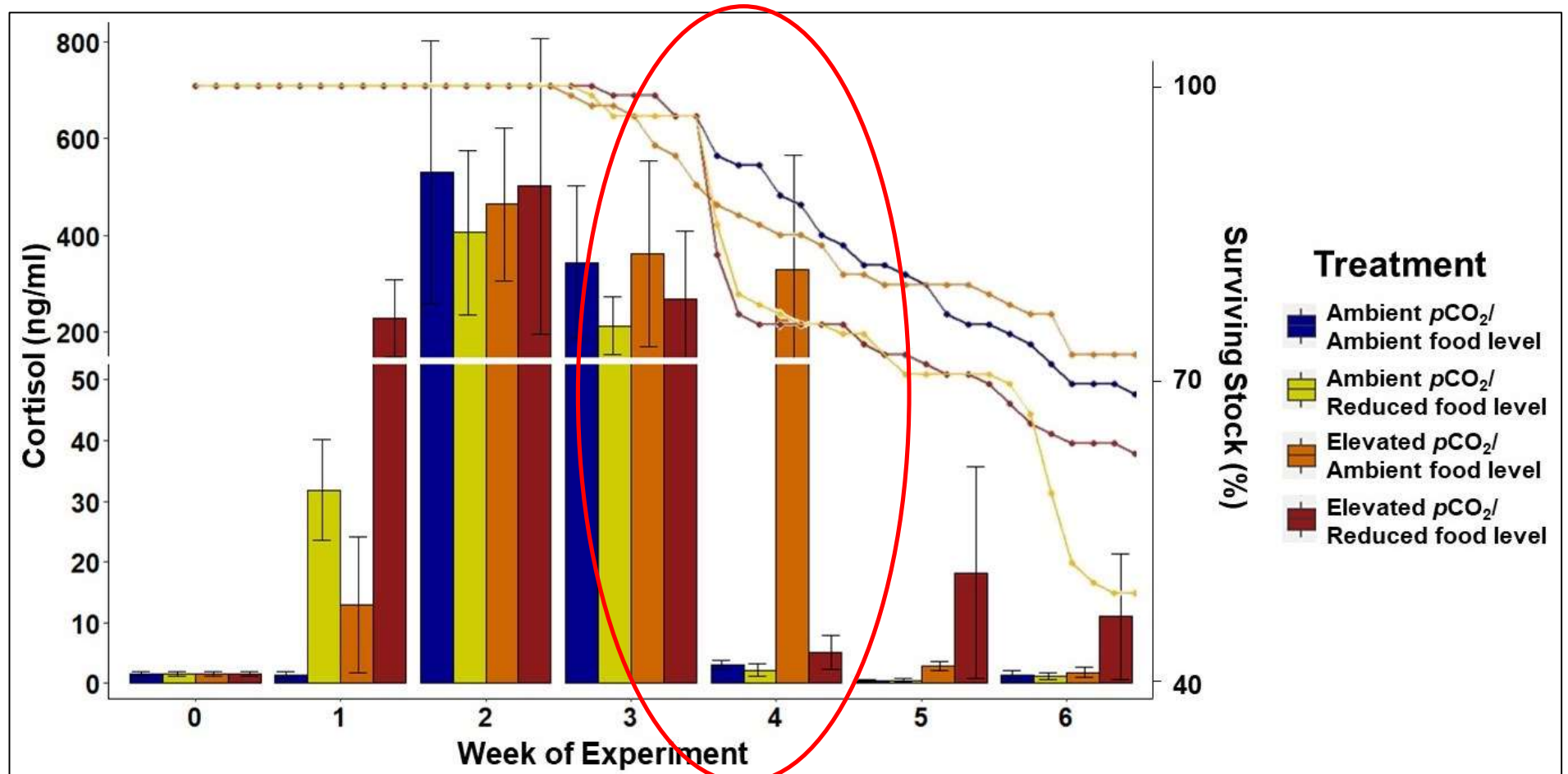
***Significant effect of $p\text{CO}_2$ exposure on cortisol expression**

***Significant effect of time on cortisol expression**

Endocrine Response & Mortality

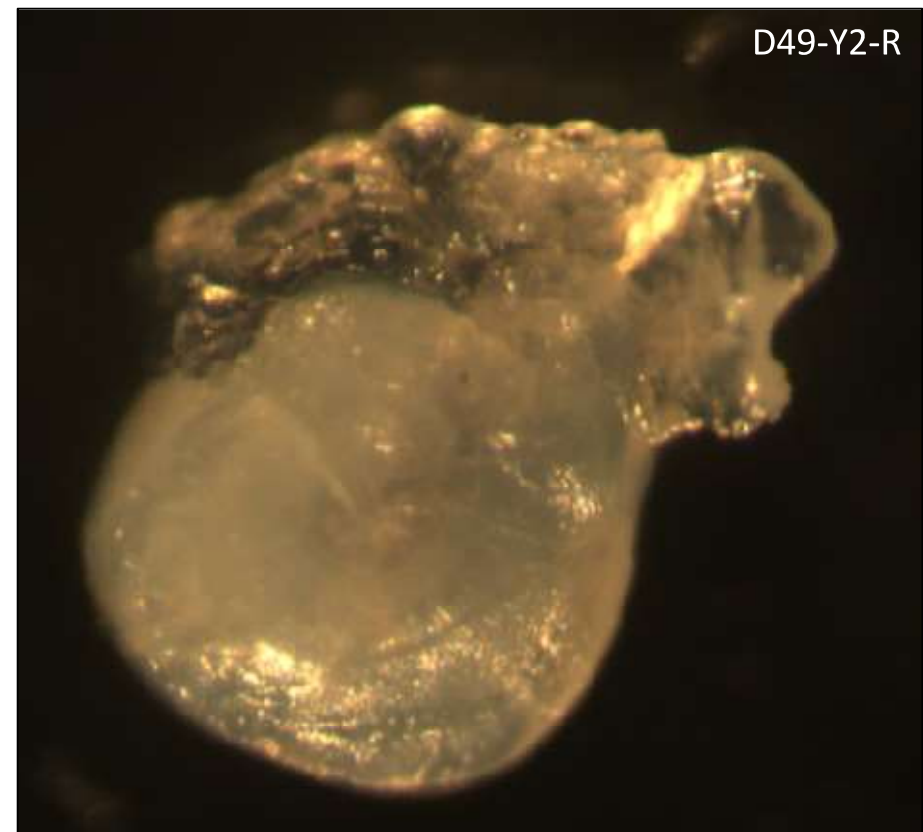


Endocrine Response & Mortality

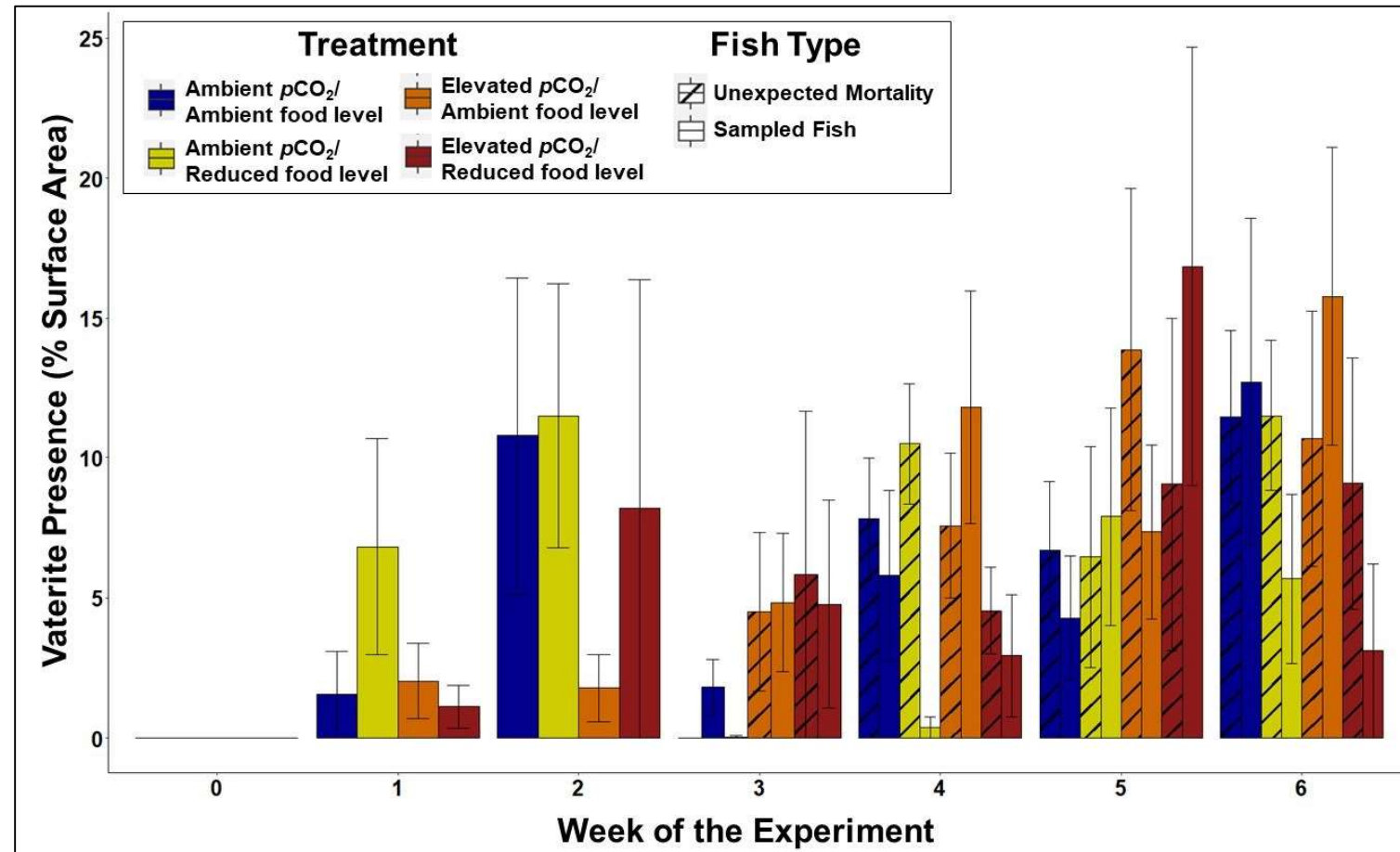


Biomaterialogy- Vaterite vs. Aragonite

- Both polymorphs of calcium carbonate
- Otoliths typically aragonitic
- Vaterite is alternative polymorph
 - Dissolves more easily in seawater
 - Shown to inhibit auditory function
 - Oxman et al. (2007)



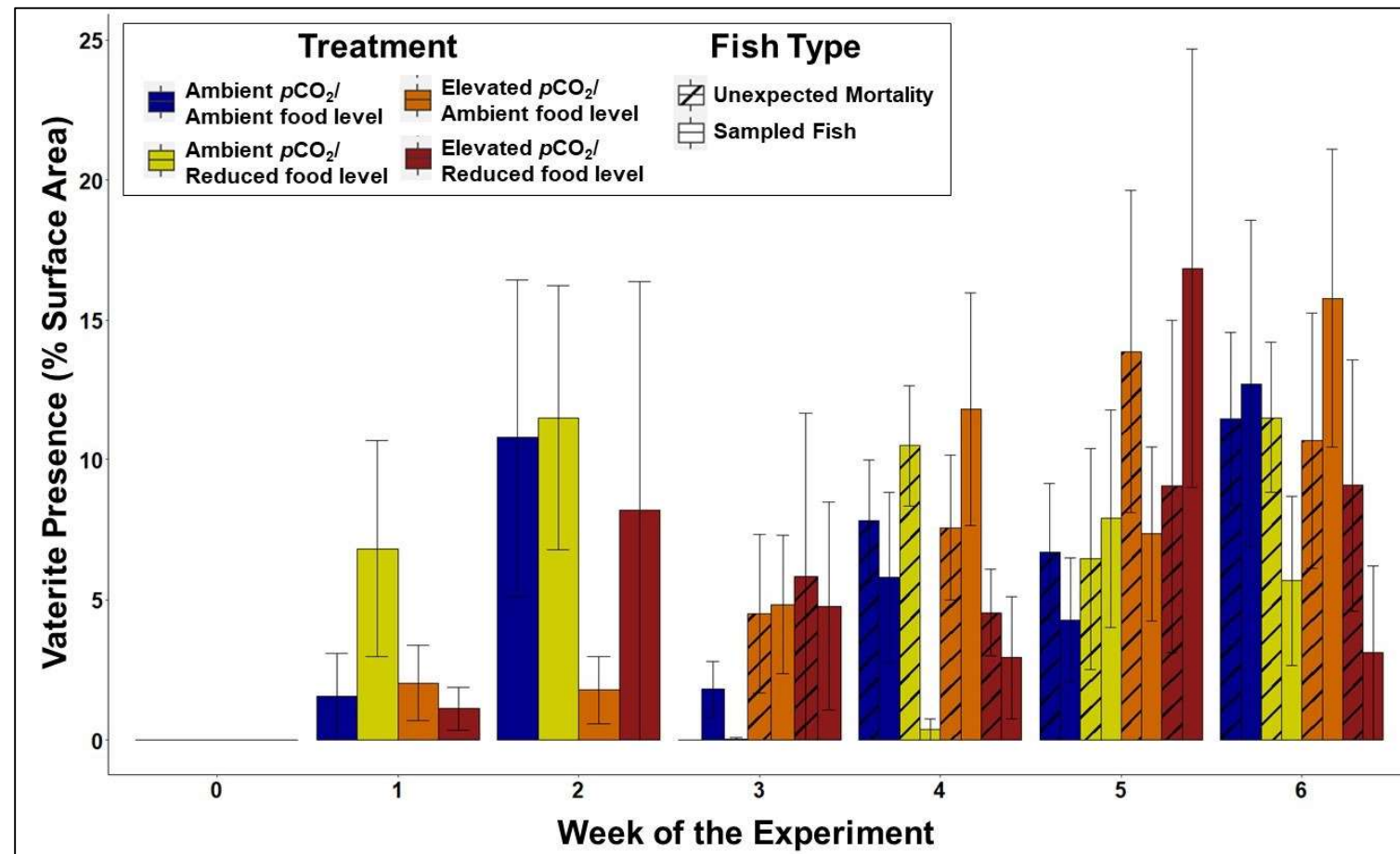
Vaterite Presence



Vaterite Presence

***NO significant effect of $p\text{CO}_2$ exposure or food availability**

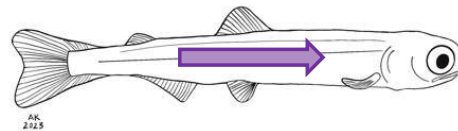
***Significant effect of time on vaterite prevalence**



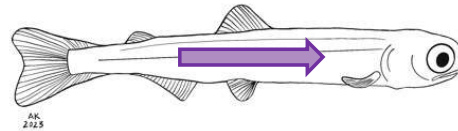
What does it all mean?

Our results

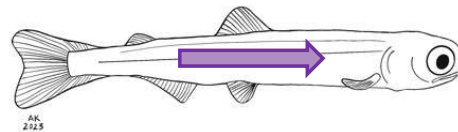
Reduced Mass



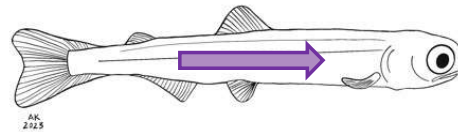
Smaller posterior body sections



Increased routine metabolic rate



Elevated cortisol expression



What it means for pinks

Smaller pink salmon in the future

Reduced predation escape success, velocity

Increased demand for food

Cardiac malformation, reduced cardiac output

References

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- Winemiller, K. O., Leslie, M., and Roche, R. (1990). Phenotypic variation in male guppies from natural inland populations: an additional test of Haskins' sexual selection/predation hypothesis. *Environ Biol Fish* 29, 179–191. doi: 10.1007/BF00002218.

Acknowledgements

Jeff Hetrick, Jacqueline Ramsey, Ricardo De Luna, Mandy Frazier, James Currie, Josianne Haag, Jonah Jossart, Katrin Iken, Sarah Mincks, and Kristin O'Brien

Project video



NOAA OCEAN ACIDIFICATION PROGRAM



Rasmuson Fisheries
Research Center

Project Partners:

The Alaska Ocean Observing System
The Alutiiq Pride Marine Institute
The Meridian Institute
NOAA Fisheries
The University of Wyoming
The University of Alaska Anchorage

Additional questions:
mwalcantar@alaska.edu



Bio-economic Modeling

Integrating information from ocean conditions, salmon fishermen, and 6 decades of pink salmon data



Motivation

- Inform preemptive adaptation management
 - Understand the potential for a tipping point
 - Shift assumptions away from a stable and predictable ecological system
 - Anticipate how commercial fishermen might respond to changes in the fishery
- Reduce the potential for negative implications on communities
- Increase the likelihood of the survival of the species and the fishery

→ This modelling is *not* for forecasting

→ Intended to understand how mechanisms included in the study can impact outcomes

Salmon Synthesis Highlights

- **Negative effects of ocean acidification on PWS pink salmon were not yet detectable in the wild.**
- **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.
- **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.**



Fishermen Engagement Data

- Commercial permit holder survey confirmed 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.



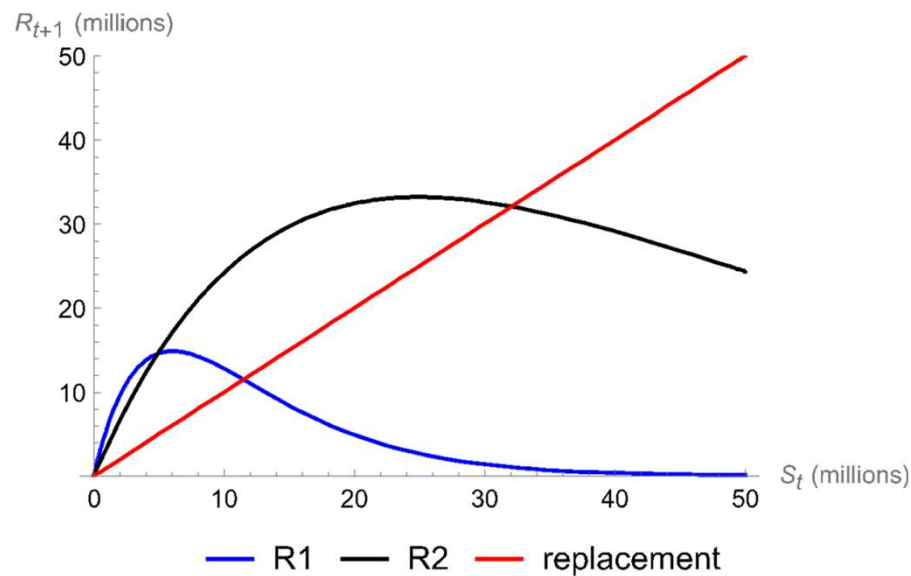
Additional Economic Data for the model

- Ex-vessel value from ADF&G “Statewide Salmon Gross Earnings by Area”
 - Calculated unit prices 1975-2019 from value and volume data
 - Averaged prices before and after 1988/1989 regime shift
- Calibrate cost parameters assuming fishermen on average make 10% profit

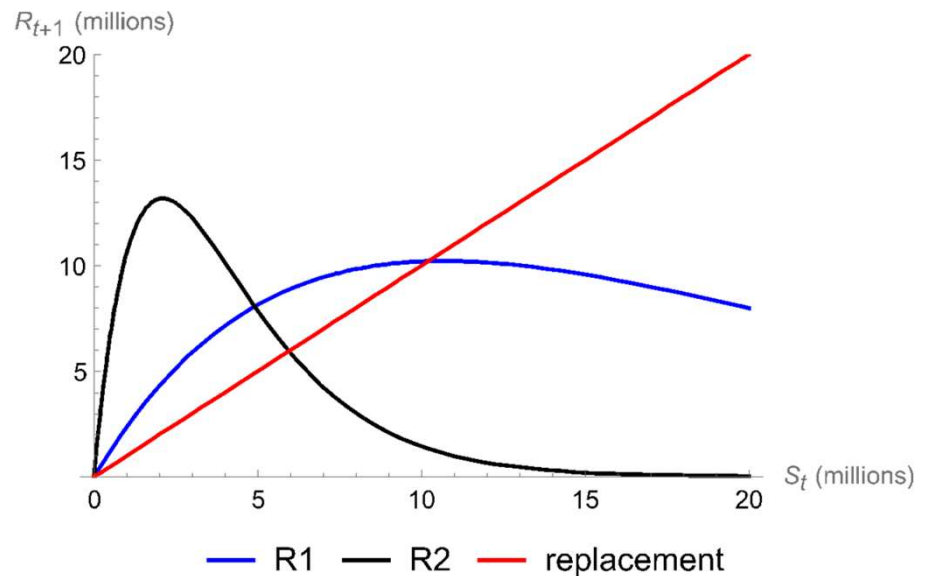


Regime shifts impact productivity

Odd Broodline Growth



Even Broodline Growth



Ricker growth functions from Ohlberger et al

Model Outline



- Question:
 - How do alternative escapement rules perform when considering realistic ecological, environmental and economic features?
- Potential escapement rules:
 - Maximum Sustainable (ecological) Yield: ignore economic parameters
 - Deterministic: ignore the potential for regime shifts
 - Stochastic: determine bioeconomic expected escapement based on regime
- Caveat:
 - This is not a forecast, but a tool for understanding mechanisms

Theory Implications



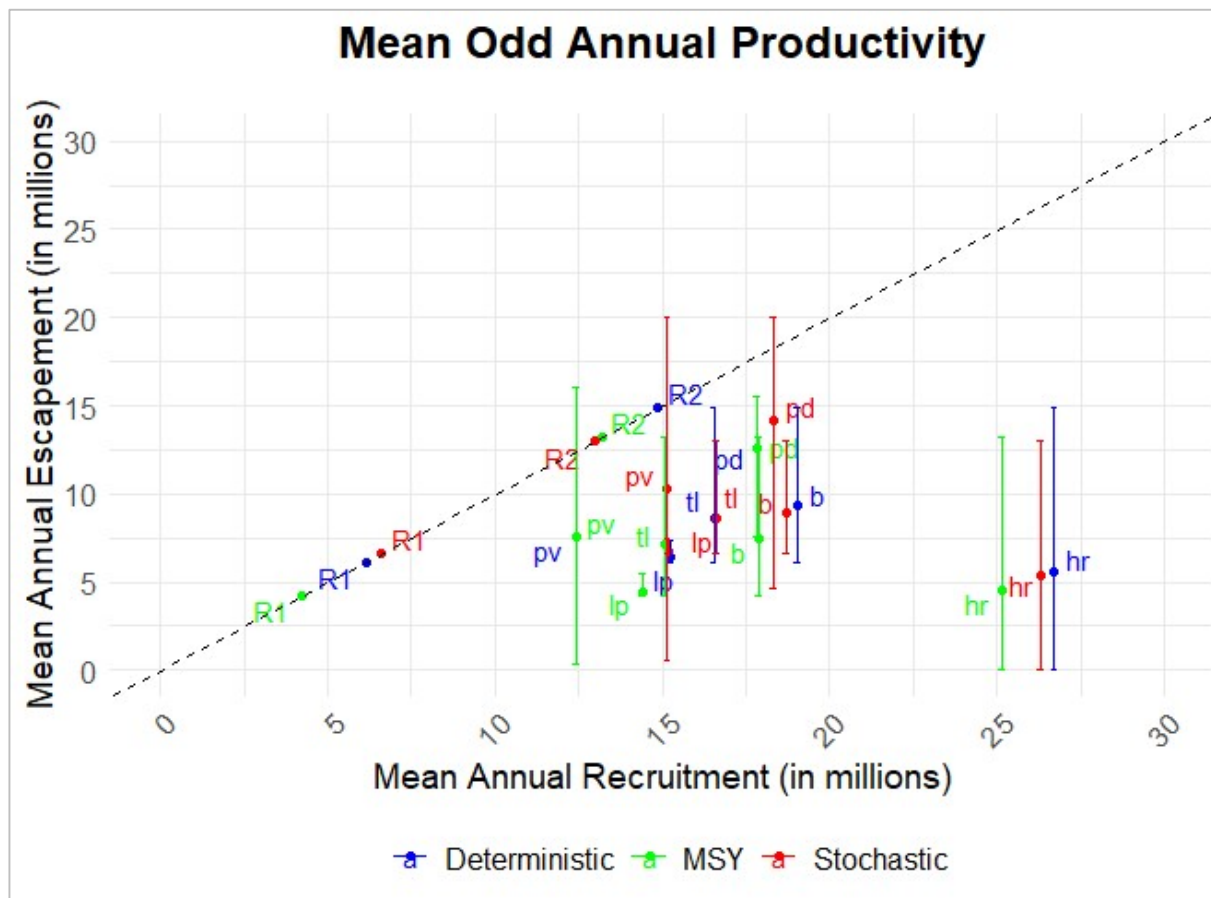
- Maximum Sustainable (ecological) Yield: ignore economic parameters
 - Maximizing natural productivity to protect the resource itself
- Deterministic: ignore the potential for regime shifts
 - Balance the return from the fishery with the next best alternative investment
- Stochastic: determine bioeconomic expected escapement based on regime
 - Balance the value of investment in the fishery against the expected return from marginal escapement

Simulation Scenarios

- In addition to growth changes from R1 and R2, we include
 - Potential for switching between regimes repeatedly
 - Recruitment variation
 - Delayed response from fisheries management
 - Price declines
 - Price variation

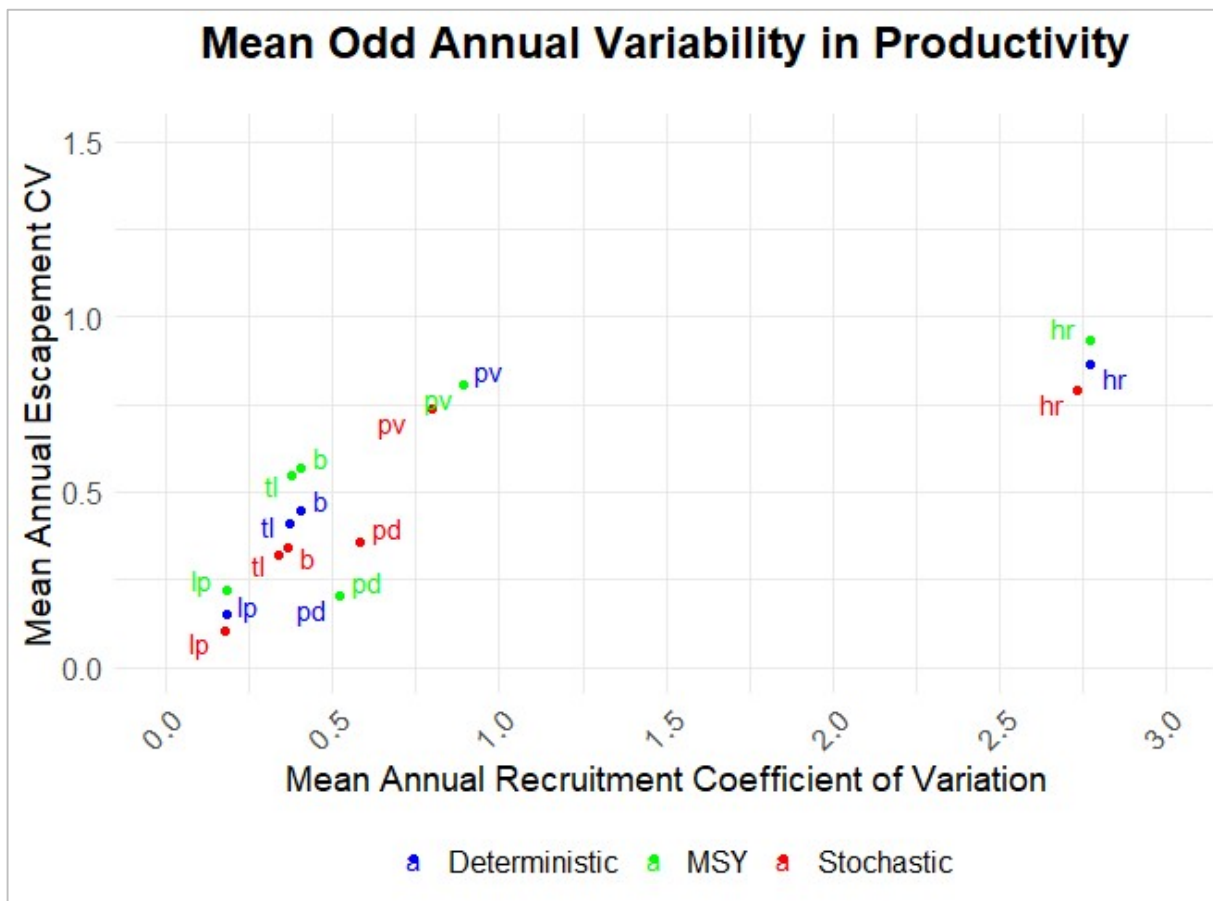
	Escapement in millions of fish			
Brood line Year	Odd		Even	
Regime	R1	R2	R1	R2
MSY Rule	4.228	13.222	4.448	1.807
Deterministic Rule	6.143	14.848	6.179	2.598
Stochastic Rule	6.595	12.971	5.637	2.741

Average escapement varies less with stochastic rules



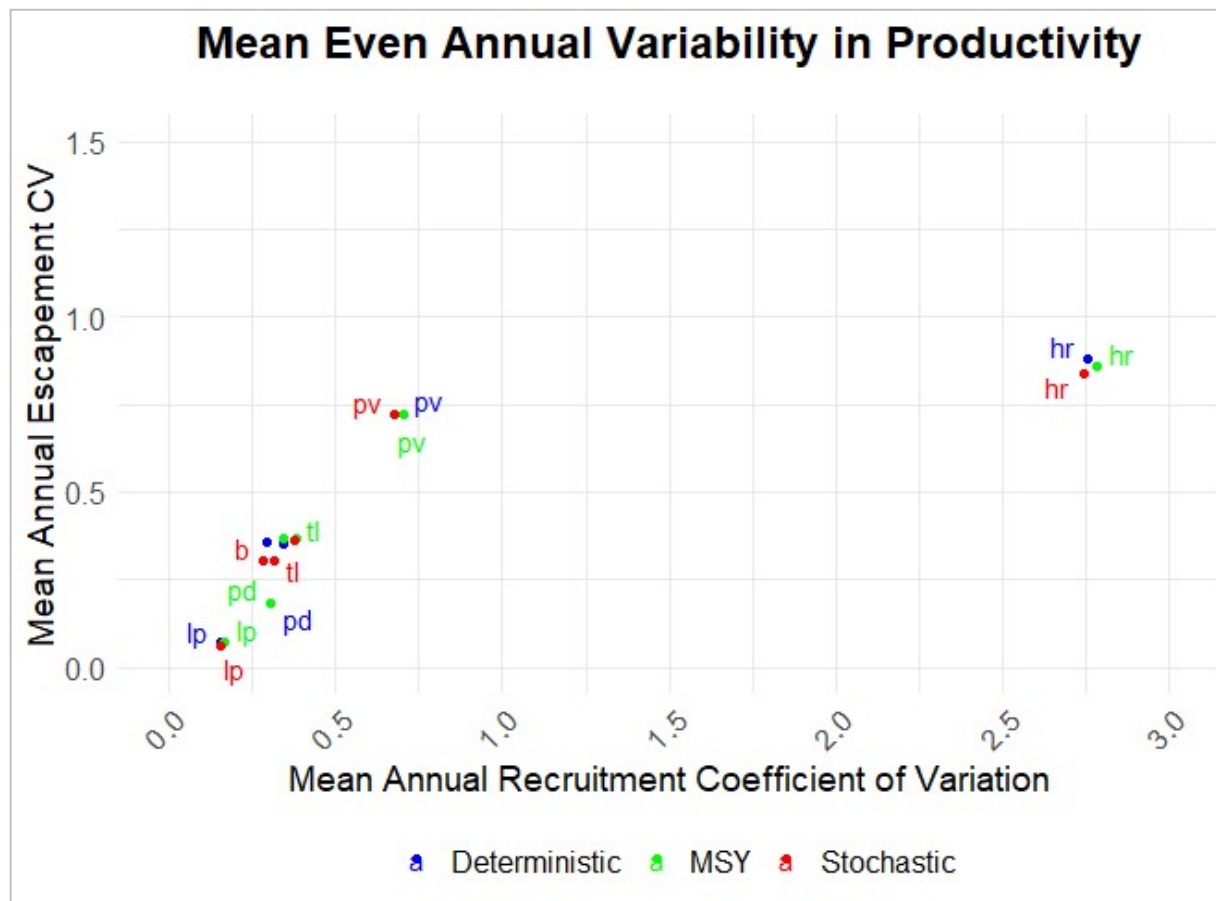
Scenario	Notation
Baseline	b
High recruitment variation	hr
Low probability of transition (R1→R2)	lp
Time lagged management response	tl
Price decline	pd
Price variation	pv

High recruitment scenario is an important outlier



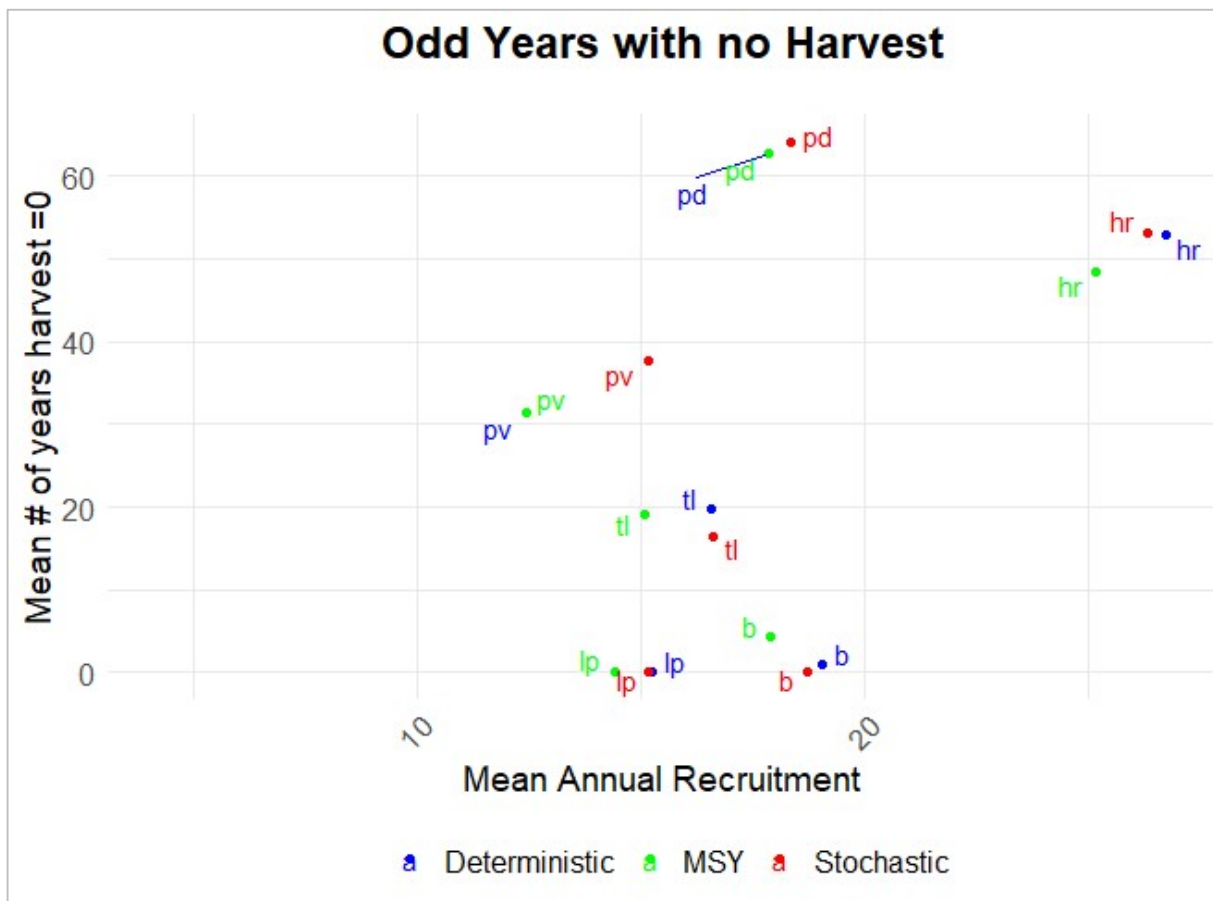
Scenario	Notation
Baseline	b
High recruitment variation	hr
Low probability of transition (R1→R2)	lp
Time lagged management response	tl
Price decline	pd
Price variation	p

High recruitment variation makes a big difference



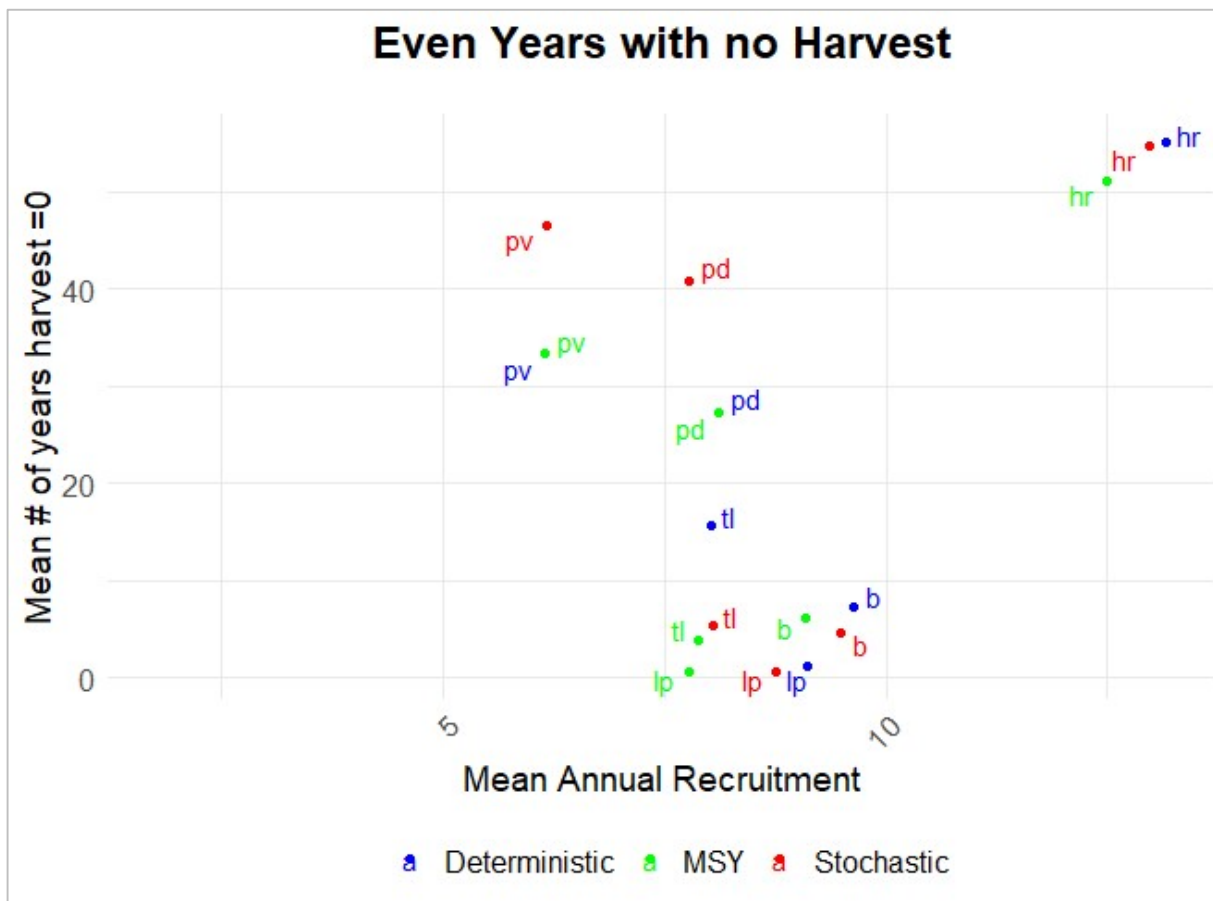
Scenario	Notation
Baseline	b
High recruitment variation	hr
Low probability of transition (R1→R2)	lp
Time lagged management response	tl
Price decline	pd
Price variation	pv

High recruitment variation and prices lead to more years with no harvest



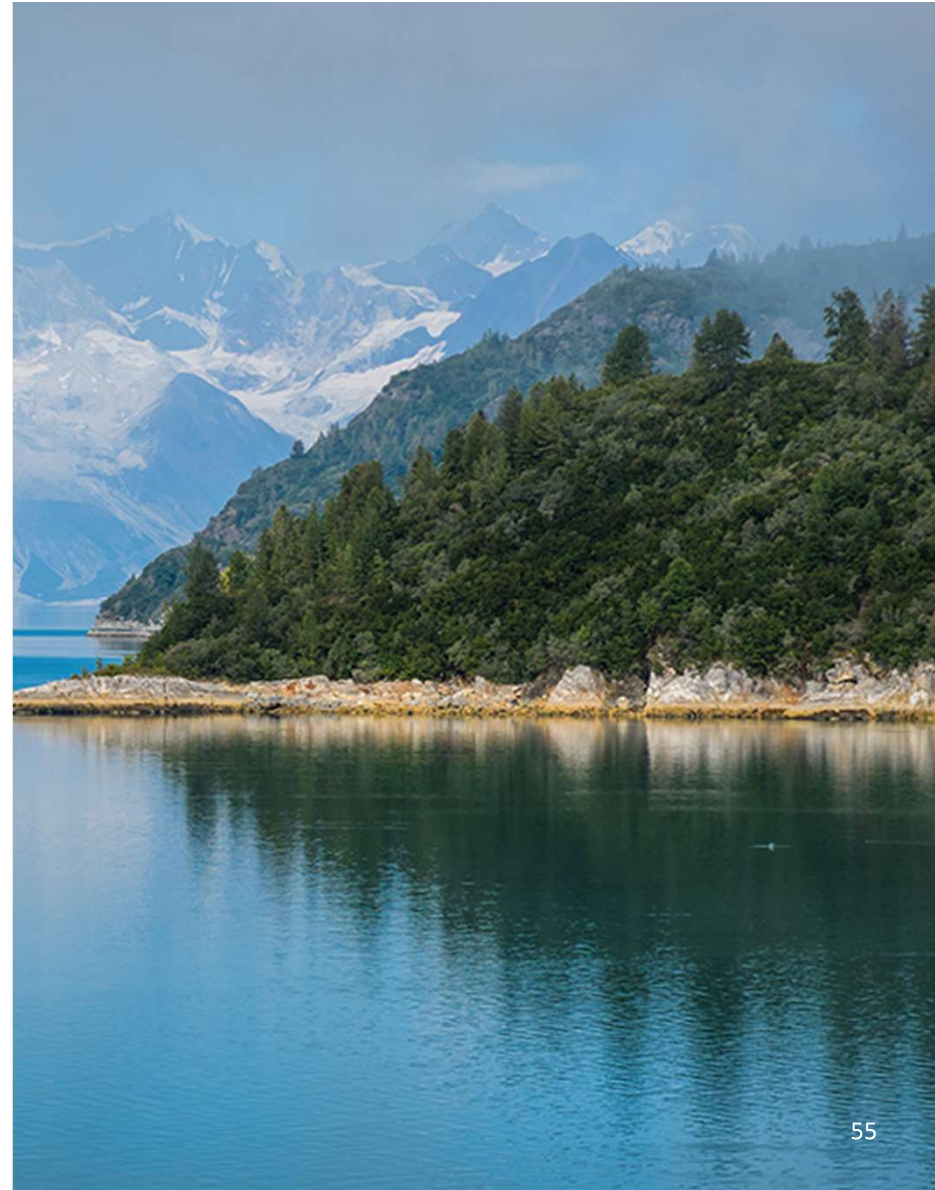
Scenario	Notation
Baseline	b
High recruitment variation	hr
Low probability of transition (R1→R2)	lp
Time lagged management response	tl
Price decline	pd
Price variation	pv

Lagged management response also contributes to years of no harvest



Conclusion

- **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.
- **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.**
- **In order to maximize economic well-being, management decisions need to consider market price, the number of people fishing, and volume of fish.**
- **Investments in the ability to track and understand recruitment variability are needed to manage fisheries under changing conditions.**
- **Delays in adjusting management policies in the face of ocean regime change can lower the financial performance of the fishery.**
- **More responsive policy reduces the uncertainty in harvest value and variability in the fishery**



Thank You!

Prof. Kevin Berry

Associate Professor of Economics

Harold T. Caven Professor of Business and Sustainability

kberry13@Alaska.edu

907-786-4185

Thanks from the Tipping Points team



Toby Schwoerer
UAF



Marina Alcantar
UAF



Jan Ohlberger
Univ. of Washington



David Finhoff
University of Wyoming



Molly Mayo,
Meridian Institute



Darcy Dugan
Alaska Ocean Observing System



Eric Ward
NOAA



Amanda Kelley
UAF



Jeff Hetrick
Alutiiq Pride Marine Institute



Kevin Berry
UAA