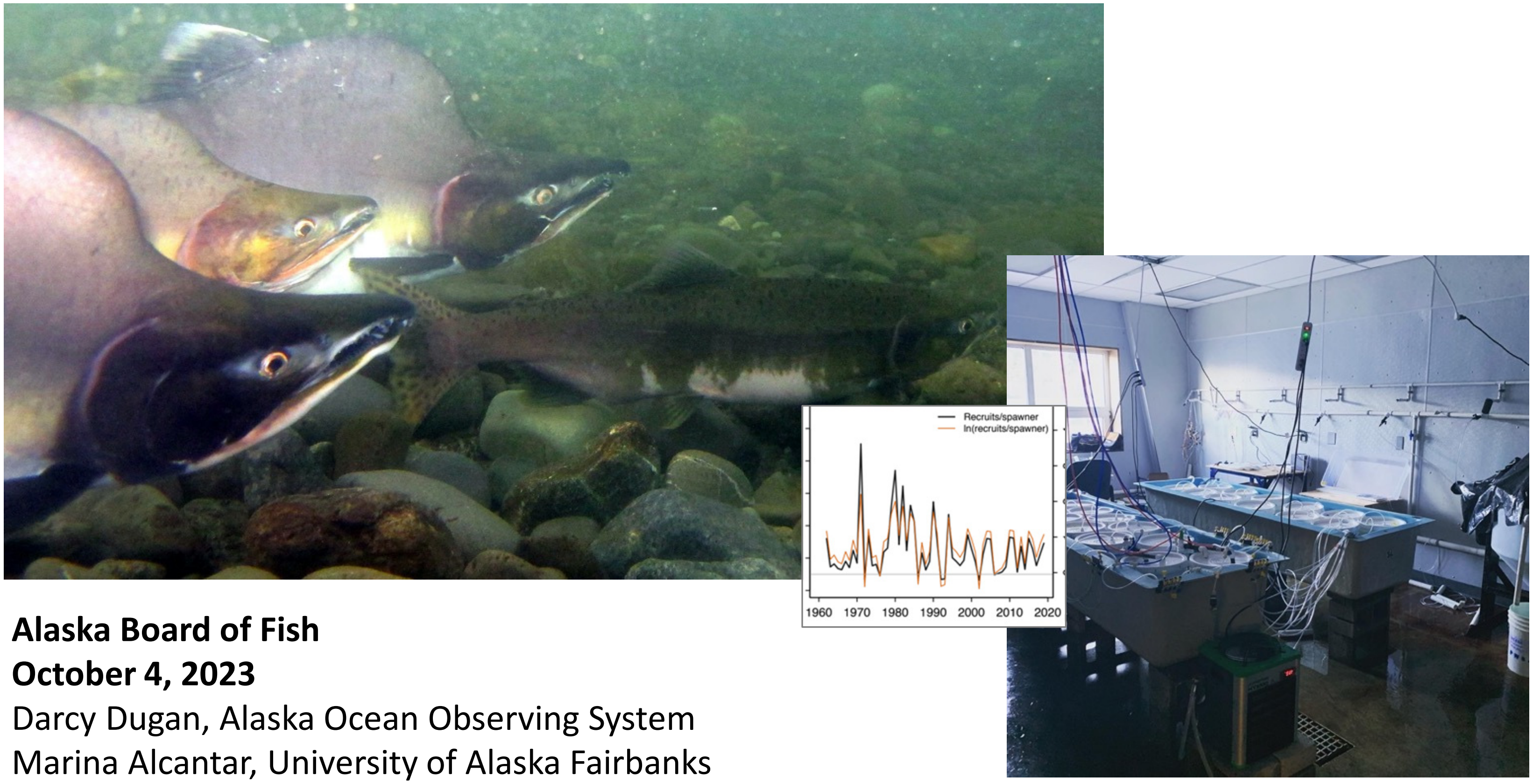
Ocean Acidification and Alaska Pink Salmon



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

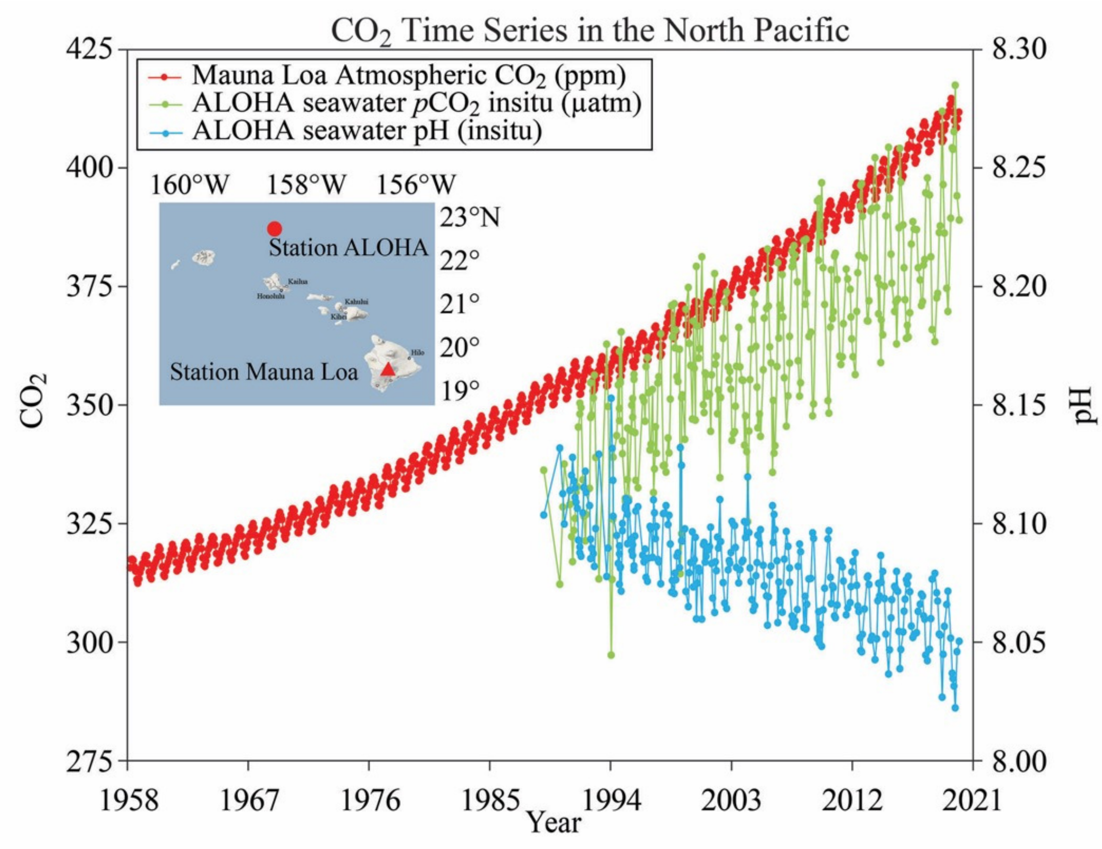
Plan for today

- 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)

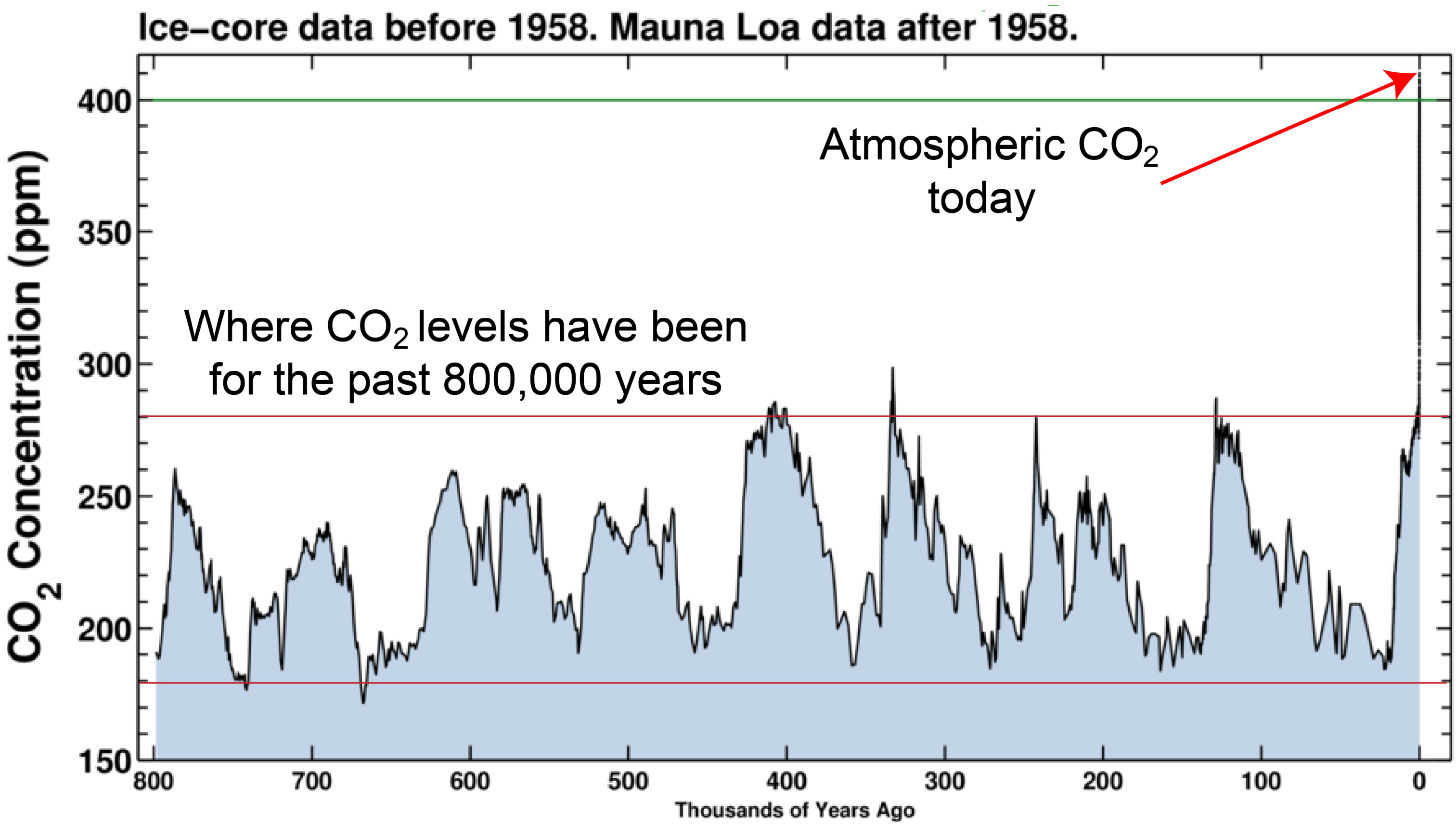
Ocean Acidification: a quick refresher

Ocean water absorbs CO_2 from the atmosphere

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

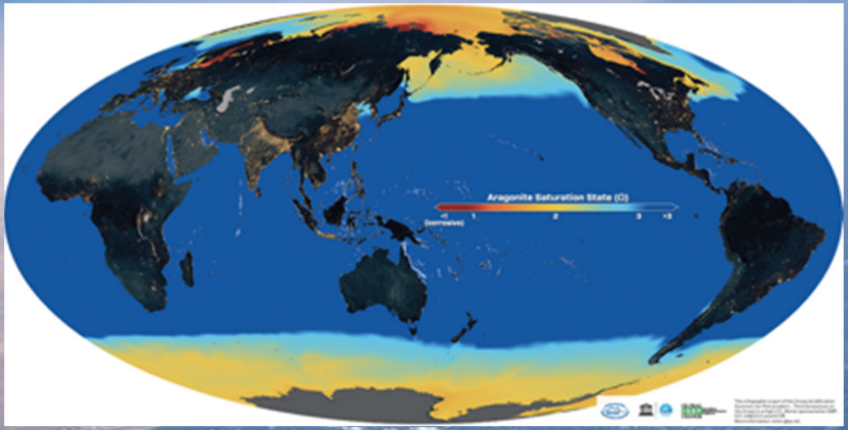


Atmospheric carbon dioxide in context

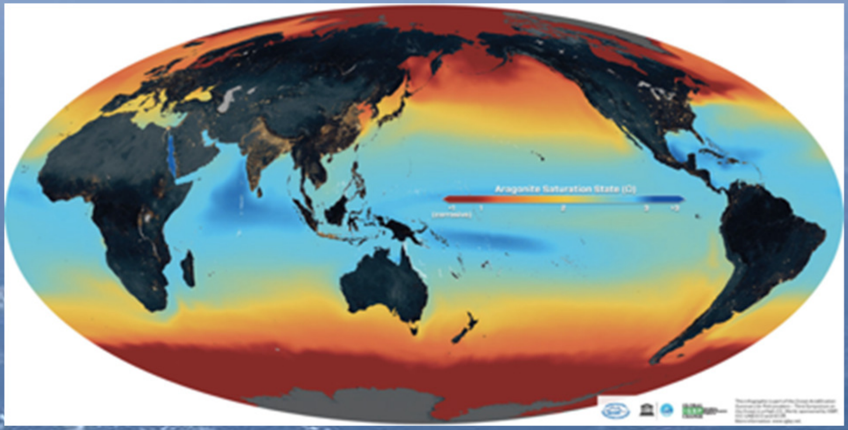


Ice–core data before 1958. Mauna Loa data after 1958.

Alaska waters are more susceptible

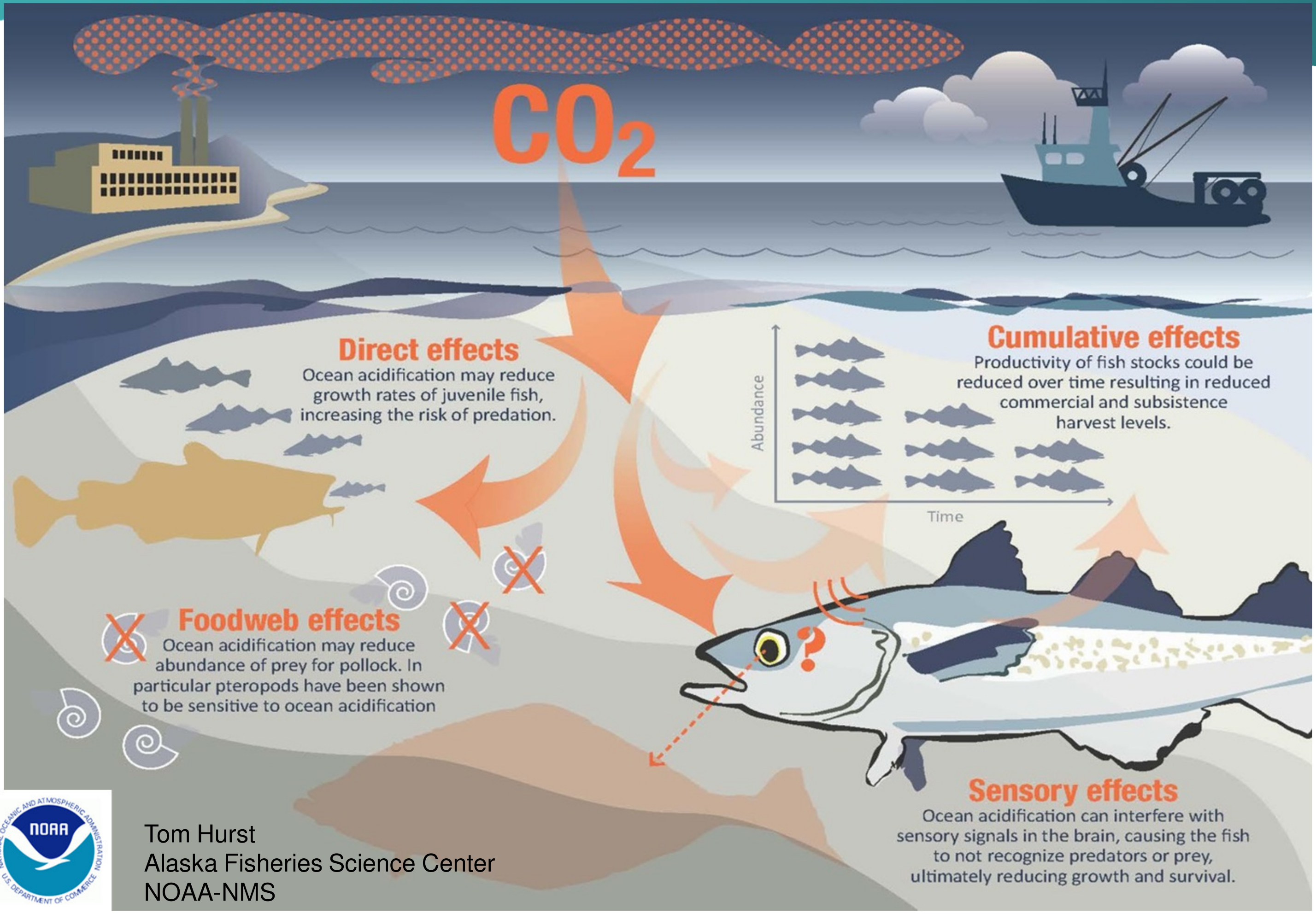


Pre-industrial



2100

Ocean acidification affects fish



Direct effects
Ocean acidification may reduce growth rates of juvenile fish, increasing the risk of predation.

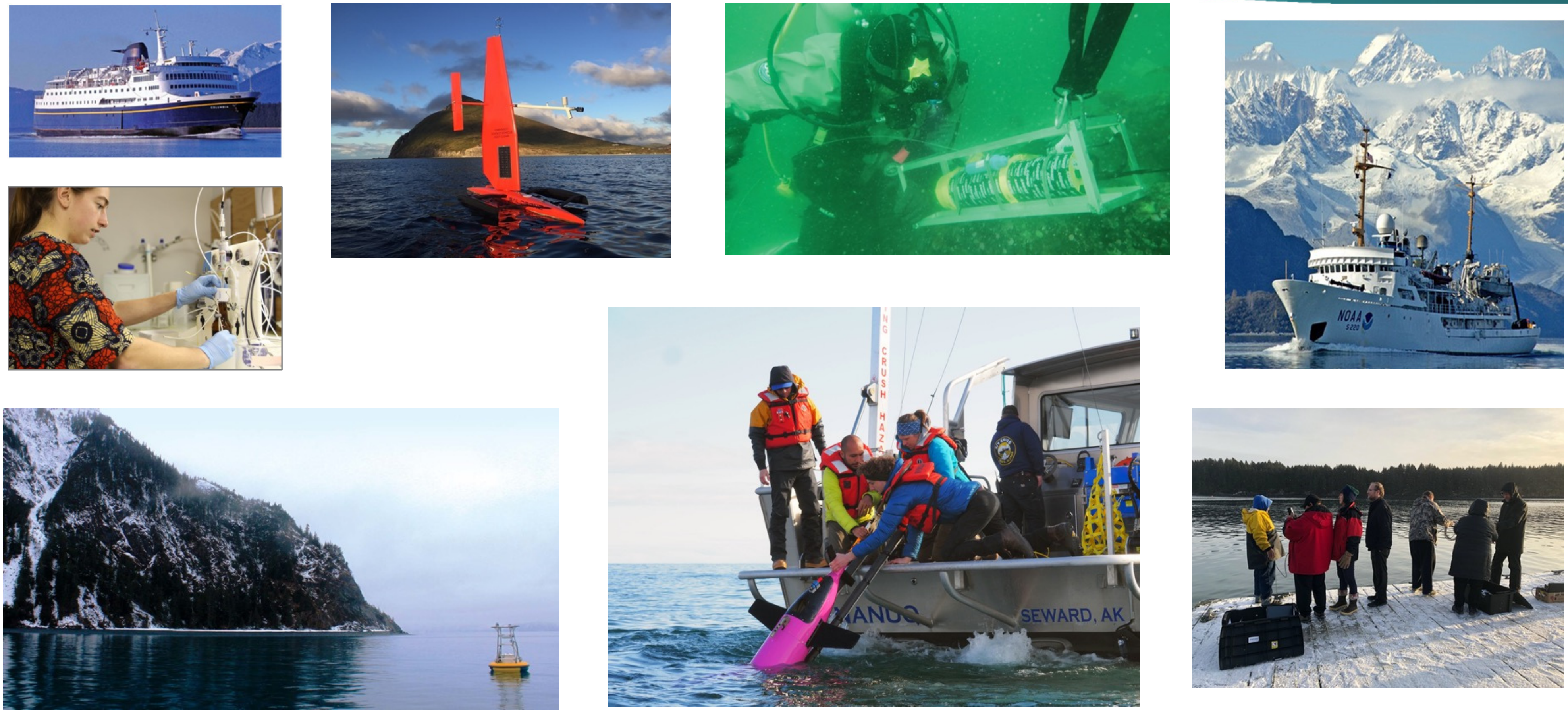
Cumulative effects
Productivity of fish stocks could be reduced over time resulting in reduced commercial and subsistence harvest levels.

Foodweb effects
Ocean acidification may reduce abundance of prey for pollock. In particular pteropods have been shown to be sensitive to ocean acidification

Sensory effects
Ocean acidification can interfere with sensory signals in the brain, causing the fish to not recognize predators or prey, ultimately reducing growth and survival.

Tom Hurst
Alaska Fisheries Science Center
NOAA-NMS

Monitoring: a multi-faceted approach



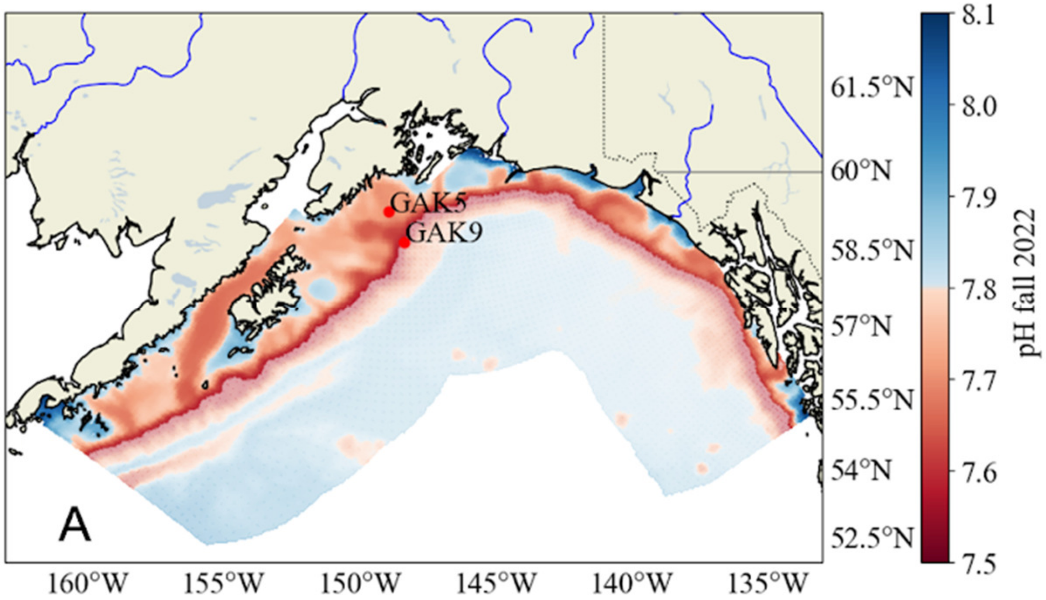
What are we learning?

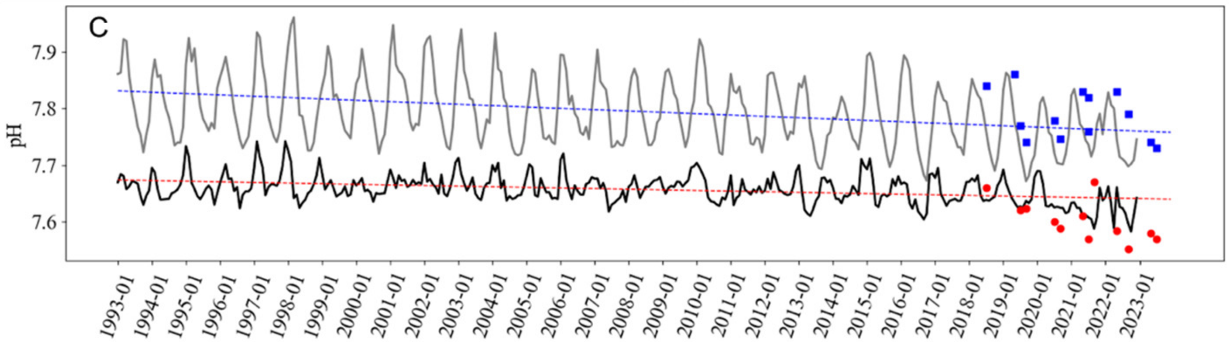
- Corrosive water is occurring now
- Conditions are not uniform
- Seasonal fluxes are large and predictable
- Fall/winter tend to have more acidic conditions
- Glacial melt/freshwater outflow and upwelling are exacerbating factors
- Despite natural variability, we can track a long term change.
- Ocean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





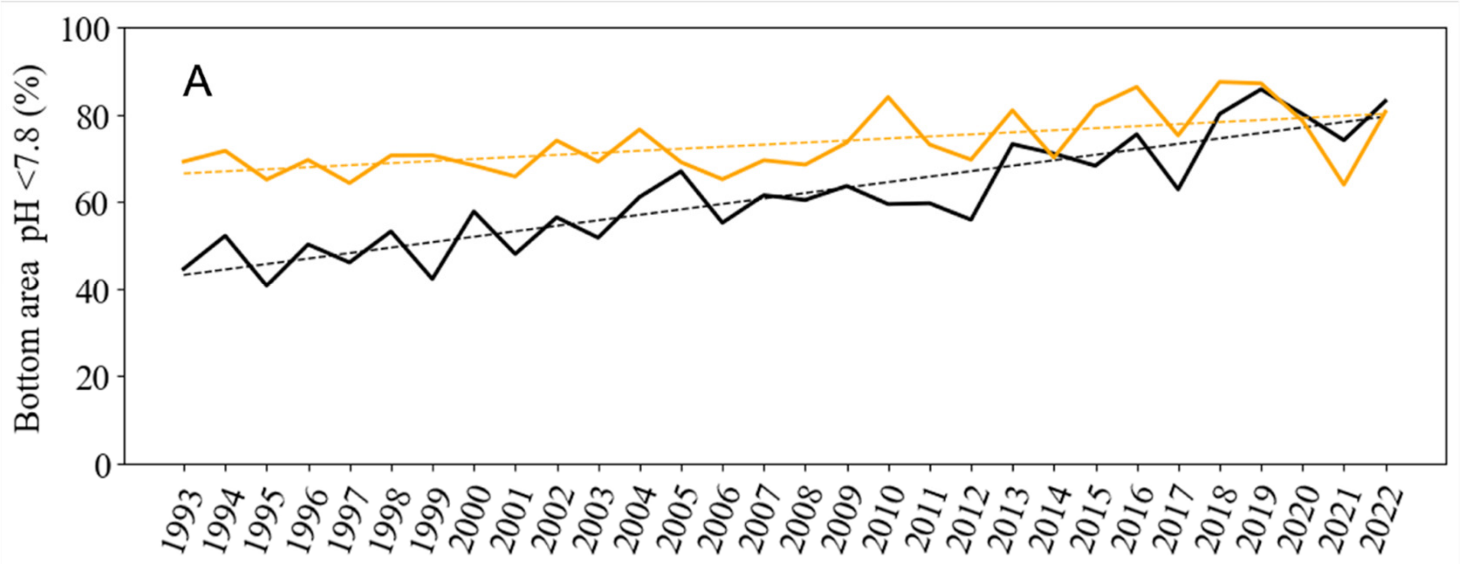
Figures from Claudine Hauri (UAF) submitted for 2023 Ecosystem Status report

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

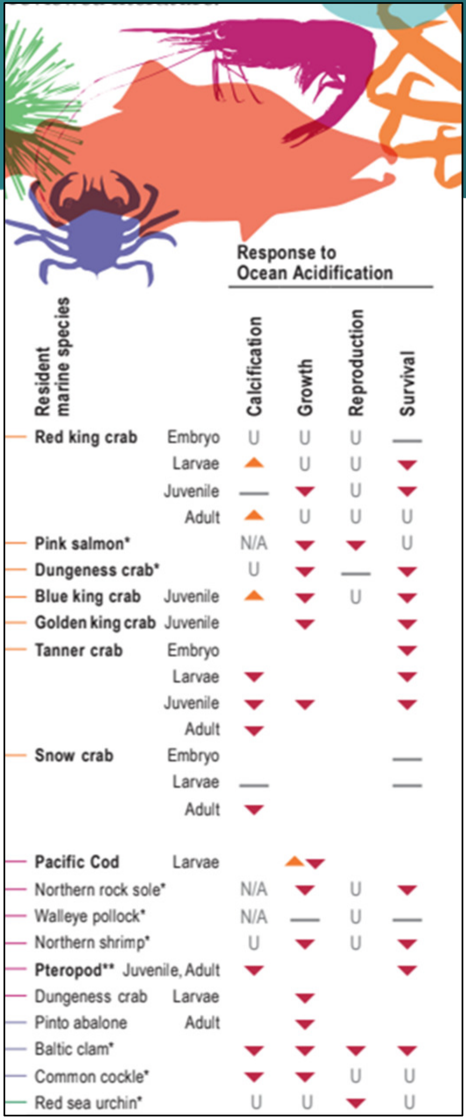
Yellow line = eastern shelf

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



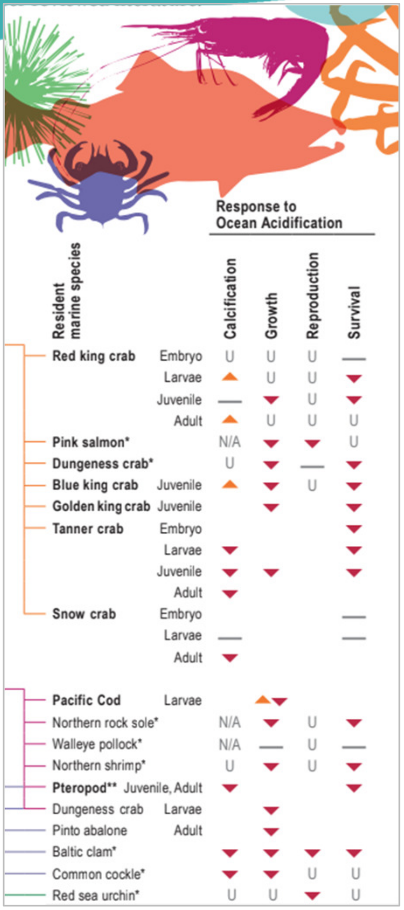
		Response to Ocean Acidification			
Resident marine species		**Calcification**	**Growth**	**Reproduction**	**Survival**
Red king crab	Embryo	U	U	U	—
	Larvae	▲	U	U	▼
	Juvenile	—	▼	U	▼
	Adult	▲	U	U	U
Pink salmon*		N/A	▼	▼	U
Dungeness crab*		U	▼	—	▼
Blue king crab	Juvenile	▲	▼	U	▼
Golden king crab	Juvenile		▼		▼
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.aoos.org/

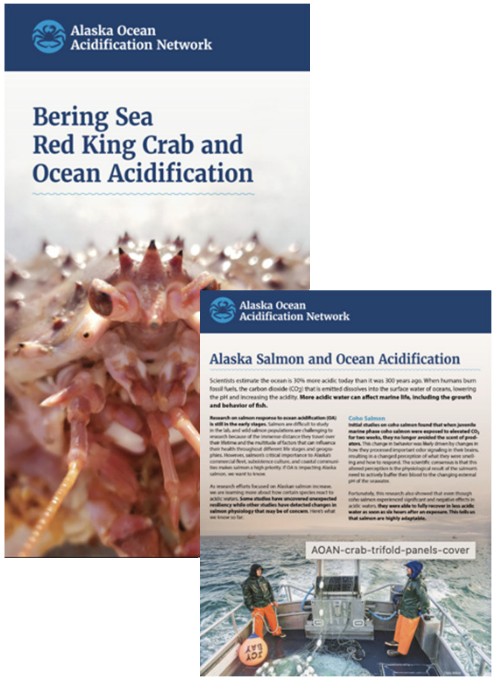
- Engage with communities to expand understanding
- Identify information needs and monitoring priorities
- Share best practices and data
- Explore adaptation and mitigation

Addressing ocean acidification is an active discussion



Resident marine species		Response to Ocean Acidification			
		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

Species response synthesis



Alaska Ocean Acidification Network

Bering Sea Red King Crab and Ocean Acidification

Alaska Ocean Acidification Network

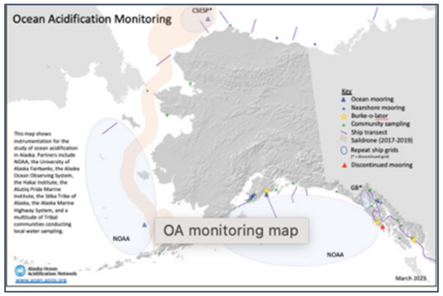
Alaska Salmon and Ocean Acidification

Scientists estimate the ocean is 30% more acidic today than it was 300 years ago. When humans burn fossil fuels, the carbon dioxide (CO_2) that is emitted dissolves into the surface water of oceans, lowering the pH and increasing the acidity. **More acidic water can affect marine life, including the growth and behavior of fish.**

Coho Salmon

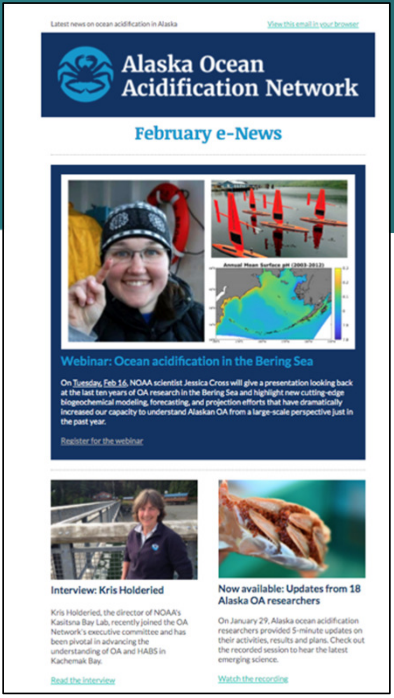
Brochures on species

Presentations and Discussion Series



This map shows instrumentation for the study of ocean acidification in Alaska. Partners include NOAA, the University of Alaska Fairbanks, the Alaska Ocean Observing System, the Hakai Institute, the Alutiiq Pride Marine Institute, the Sitka Tribe of Alaska, the Alaska Marine Highway System, and a multitude of Tribal communities conducting local water sampling.

Instrument map



Latest news on ocean acidification in Alaska

View this email in your browser

Alaska Ocean Acidification Network

February e-News

Webinar: Ocean acidification in the Bering Sea

On Tuesday, Feb 16, NOAA scientist Jessica Cross will give a presentation looking back at the last ten years of OA research in the Bering Sea and highlight new cutting-edge biogeochemical modeling, forecasting, and projection efforts that have dramatically increased our capacity to understand Alaskan OA from a large-scale perspective just in the past year.

Register for the webinar

Interview: Kris Holderied

Kris Holderied, the director of NOAA's Kasitsna Bay Lab, recently joined the OA Network's executive committee and has been pivotal in advancing the understanding of OA and HABS in Kachemak Bay.

Read the interview

Now available: Updates from 18 Alaska OA researchers

On January 29, Alaska ocean acidification researchers provided 5-minute updates on their activities, results and plans. Check out the recorded session to hear the latest emerging science.

Watch the recording

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

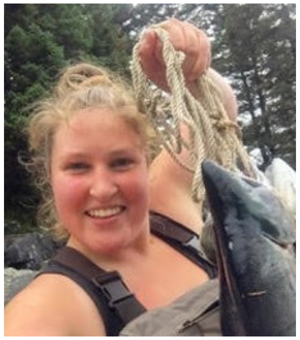
- Lab study on pink salmon response (higher acidity, reduced food)
- Biometric analysis (60 years of salmon and oceanographic data)
- Commercial fishermen engagement (interviews and survey)
- Bio-economic modeling

Funding source: NOAA's Ocean Acidification Program

OAP
NOAA 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

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

Marina Alcantar[1], Shelby Bacus[1], Dr. Peter Westley[1], Dr. Amanda Kelley[1]

[1]College of Fisheries and Ocean Sciences,

University of Alaska Fairbanks

Rasmuson Fisheries Research Center

Pink Salmon Response to OA

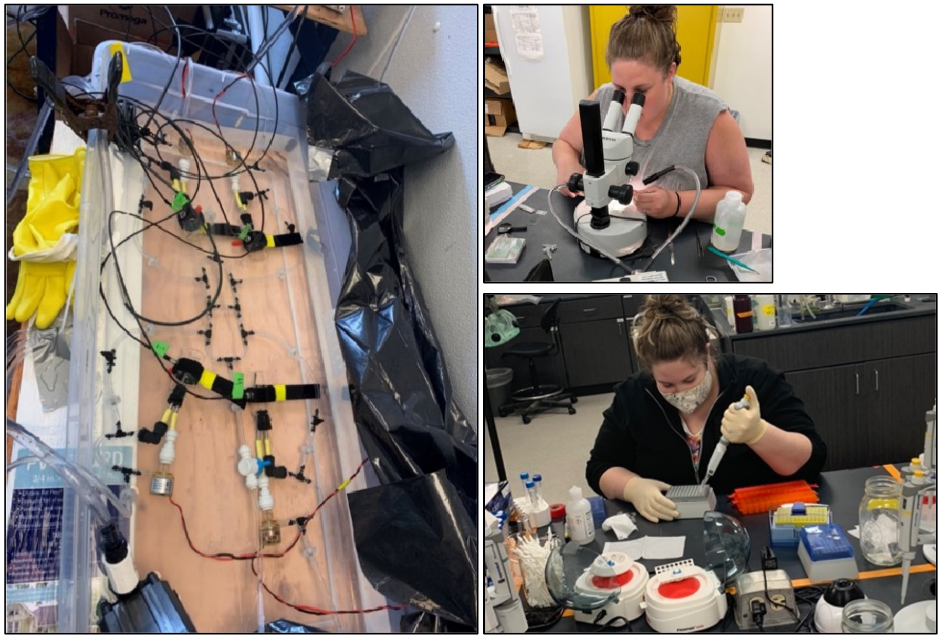
Ou et al. (2015)	Frommel et al. (2020)
Hatchery fish	Wild caught
Embryo → juvenile	Juvenile (67-87 mm fork length)
Freshwater acidification and OA	Exposed to natural corrosive regime ~1000 µatm pCO_2
450, 1000, 2000 µatm pCO_2	850-2000 µatm pCO_2
OA effects on growth, olfactory responses and anti-predator behavior	**No OA effect on mortality, condition factor (Fulton's K), plasma [Cl^-] or CTmax**

Both studies characterize response after 2-week seawater exposure

Full Factorial: OA and Food Reduction

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

The Complete Picture



Whole organism

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

Tissue

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

Biomineralogy

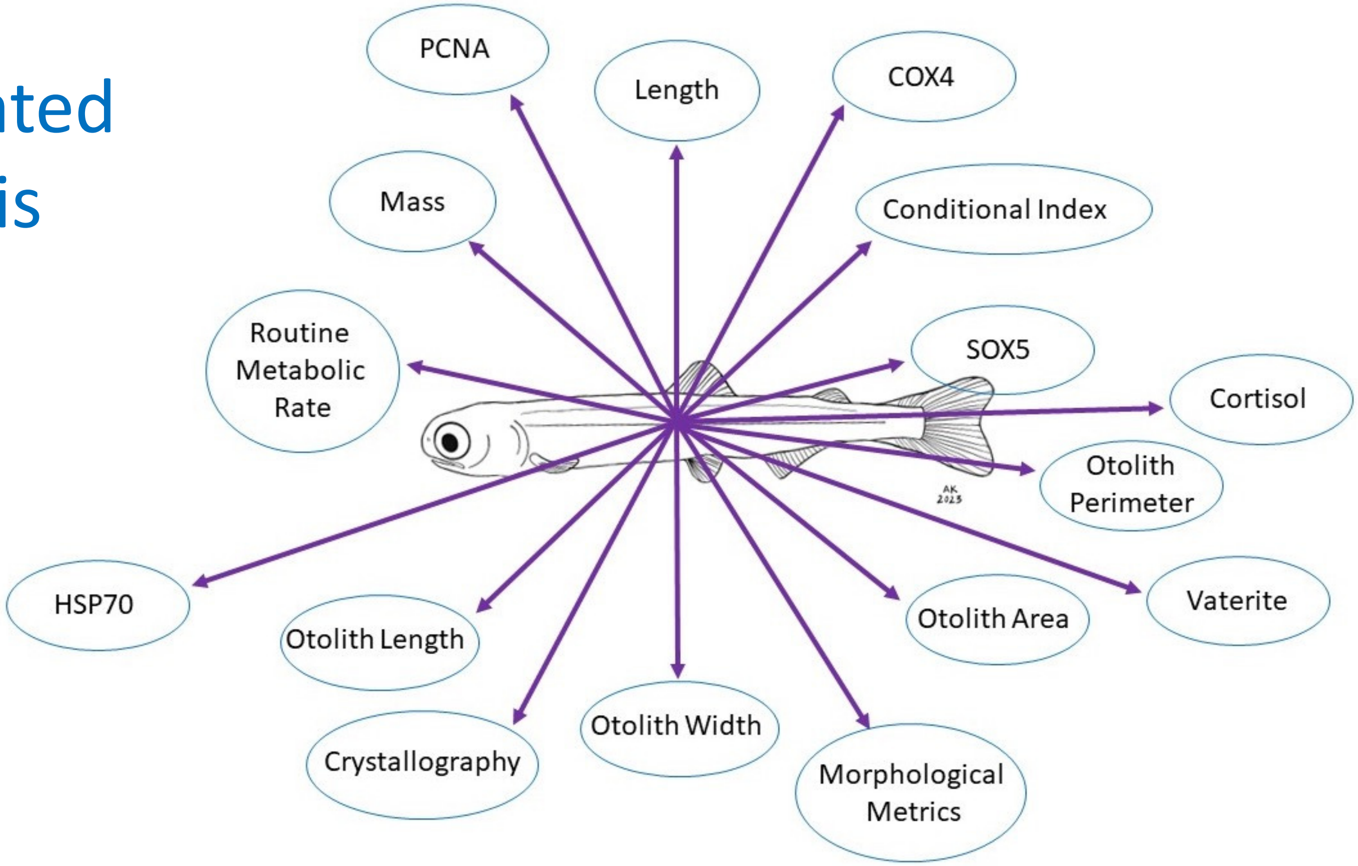
- Otolith growth
- **Mineralogy- aragonite vs. vaterite**

Cellular

- Gene expression
- HSP70, SOX5, COX4, PCNA

The Complete Picture

Integrated Analysis



PCNA

Length

COX4

Mass

Conditional Index

Routine Metabolic Rate

SOX5

Cortisol

Otolith Perimeter

HSP70

Otolith Length

Otolith Area

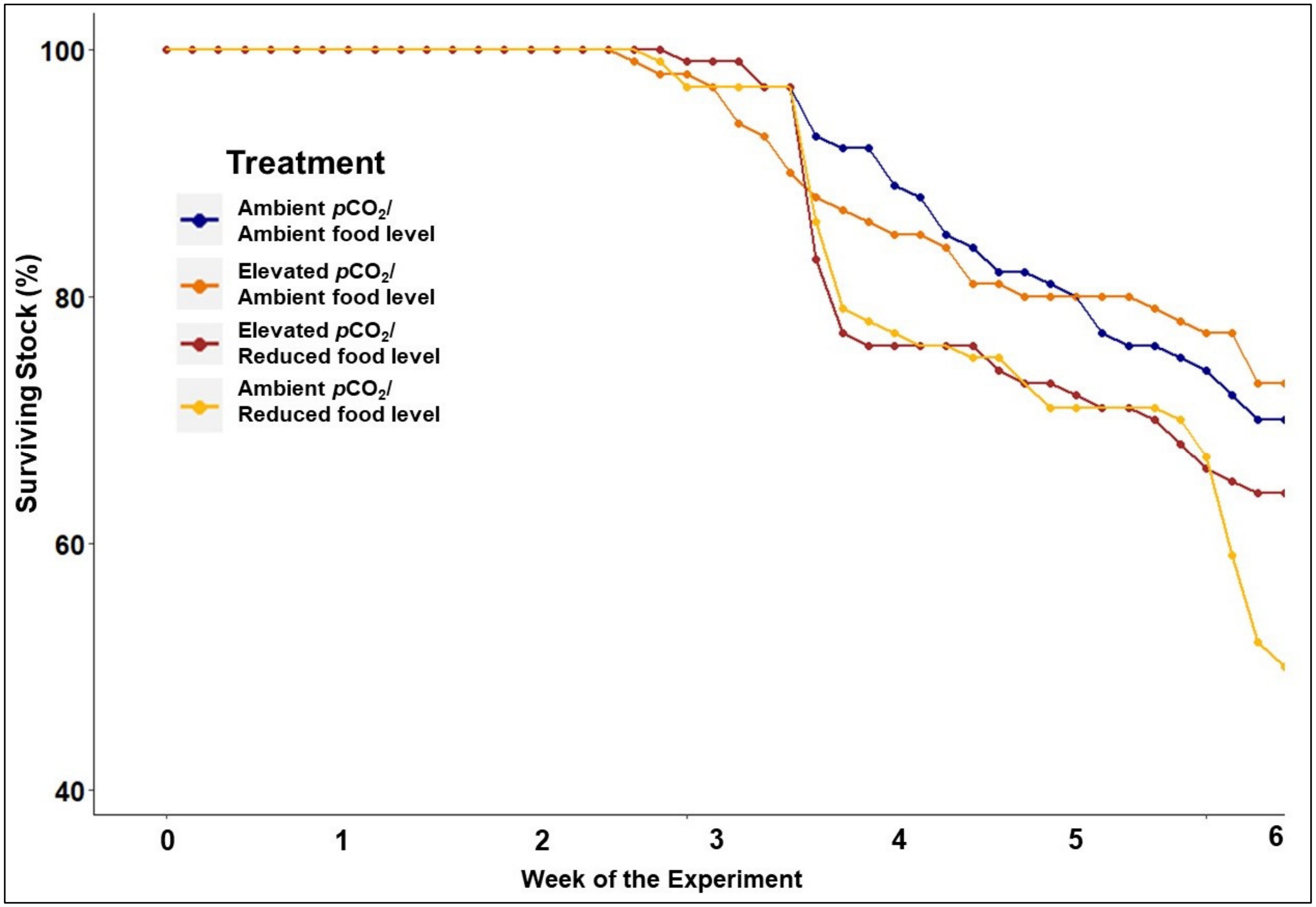
Vaterite

Crystallography

Otolith Width

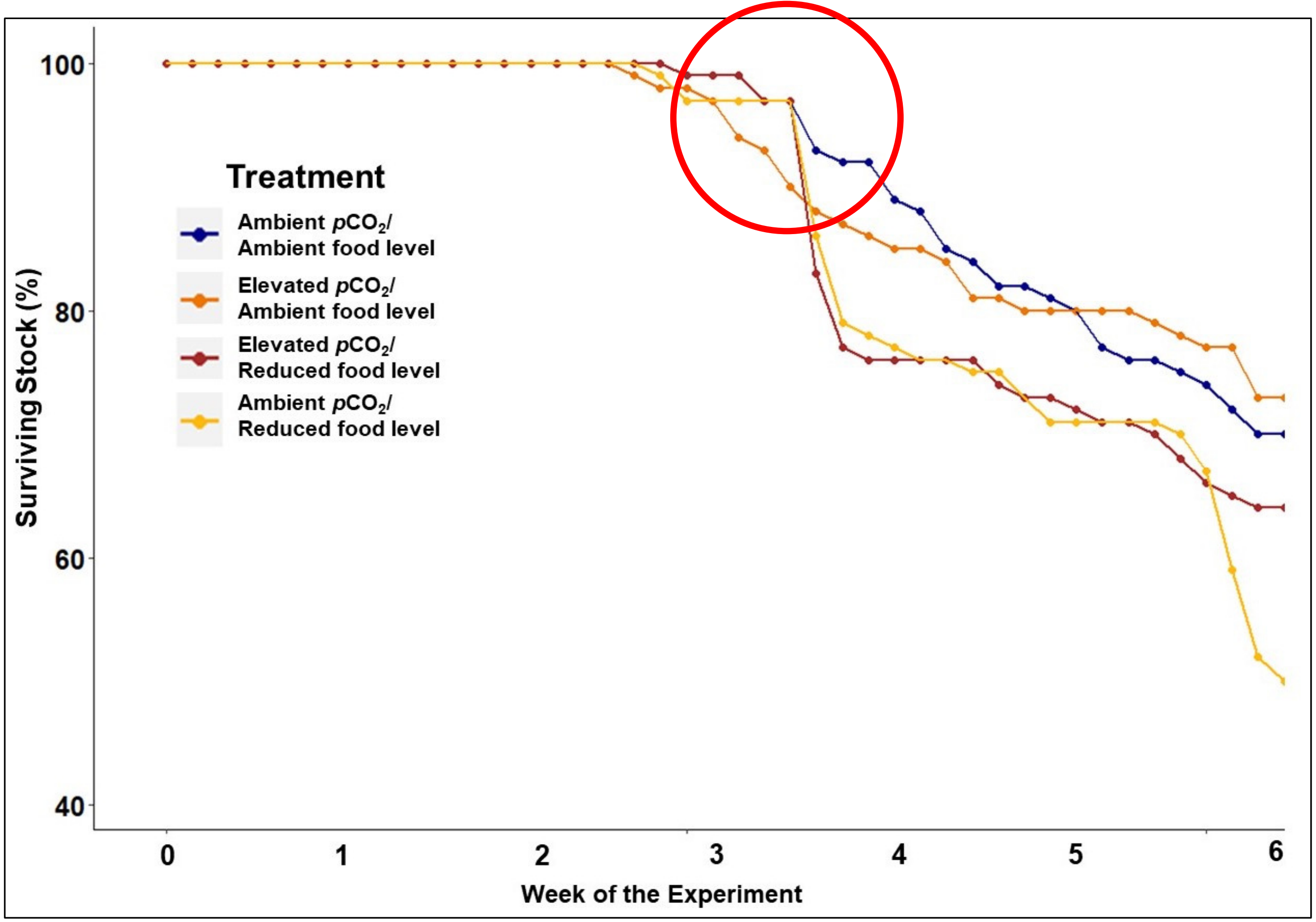
Morphological Metrics

Mortality

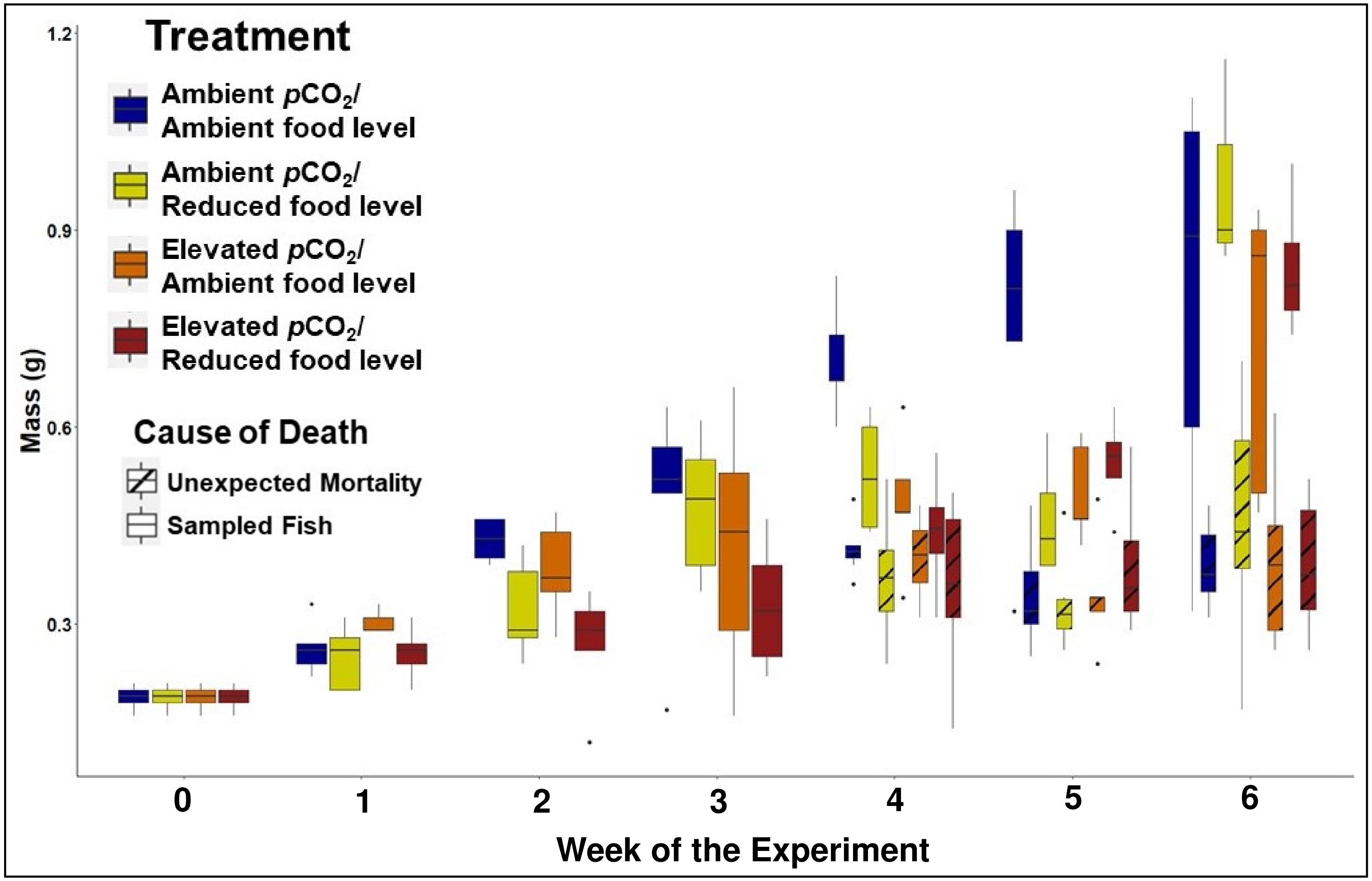

Treatment
Ambient pCO_2/ Ambient food level
Elevated pCO_2/ Ambient food level
Elevated pCO_2/ Reduced food level
Ambient pCO_2/ Reduced food level
Surviving Stock (%)
100
80
60
40
0
1
2
3
4
5
6
Week of the Experiment

Mortality

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

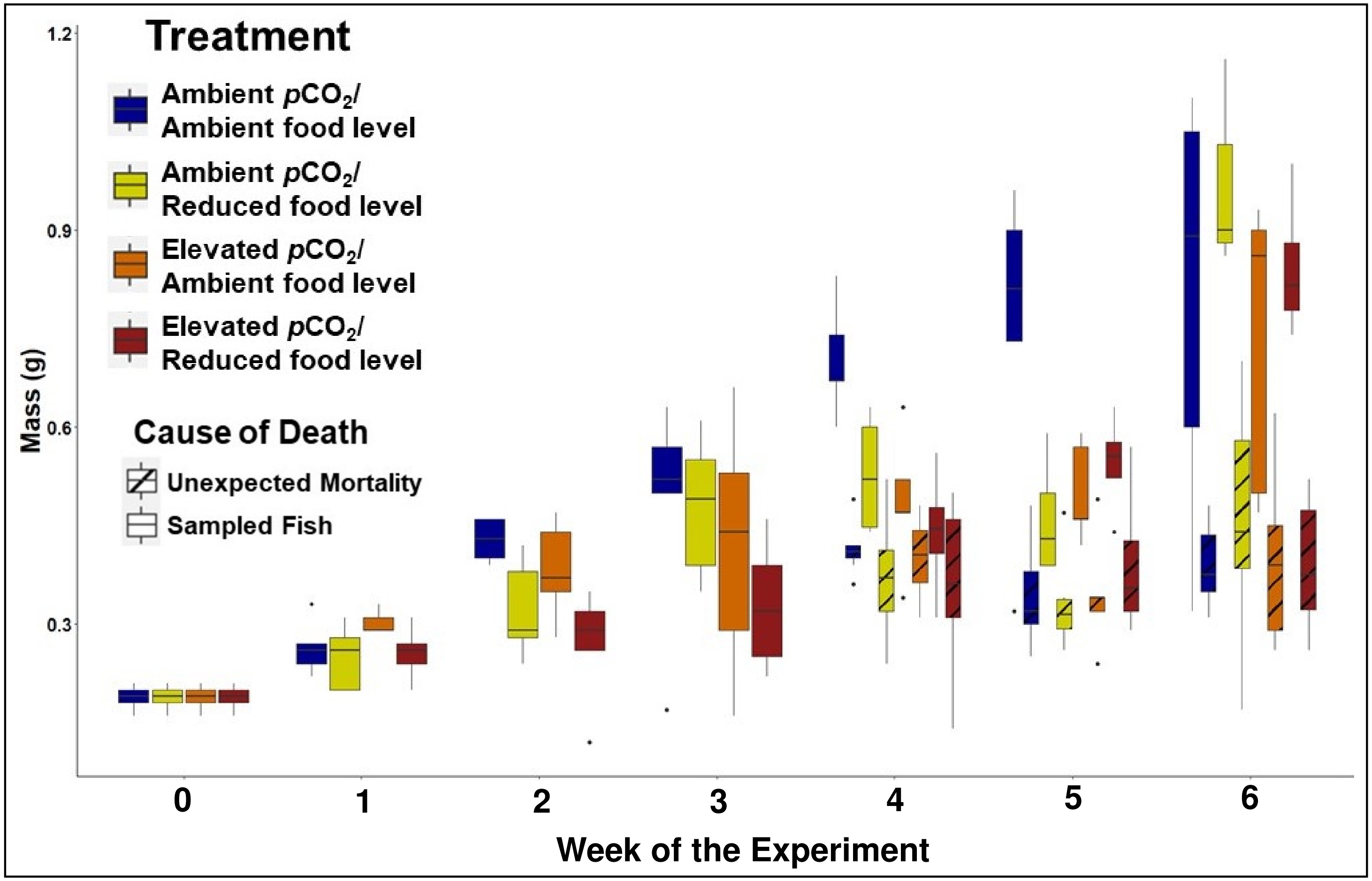


Fish Mass


Treatment
Ambient pCO₂/ Ambient food level
Ambient pCO₂/ Reduced food level
Elevated pCO₂/ Ambient food level
Elevated pCO₂/ Reduced food level
Cause of Death
Unexpected Mortality
Sampled Fish
Mass (g)
1.2
0.9
0.6
0.3
0
1
2
3
4
5
6
Week of the Experiment

Fish Mass

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

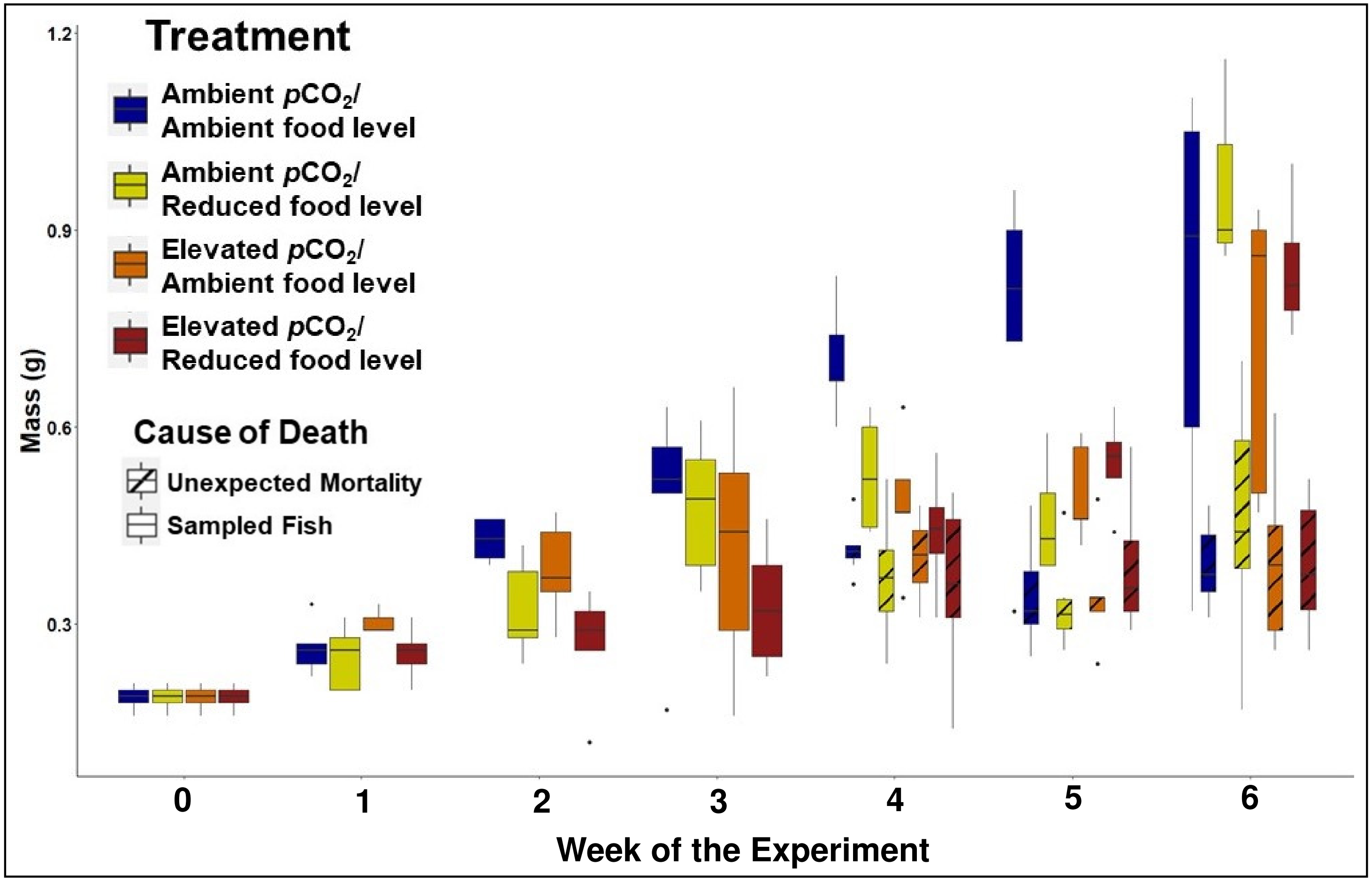


Results → Whole Organism

Fish Mass

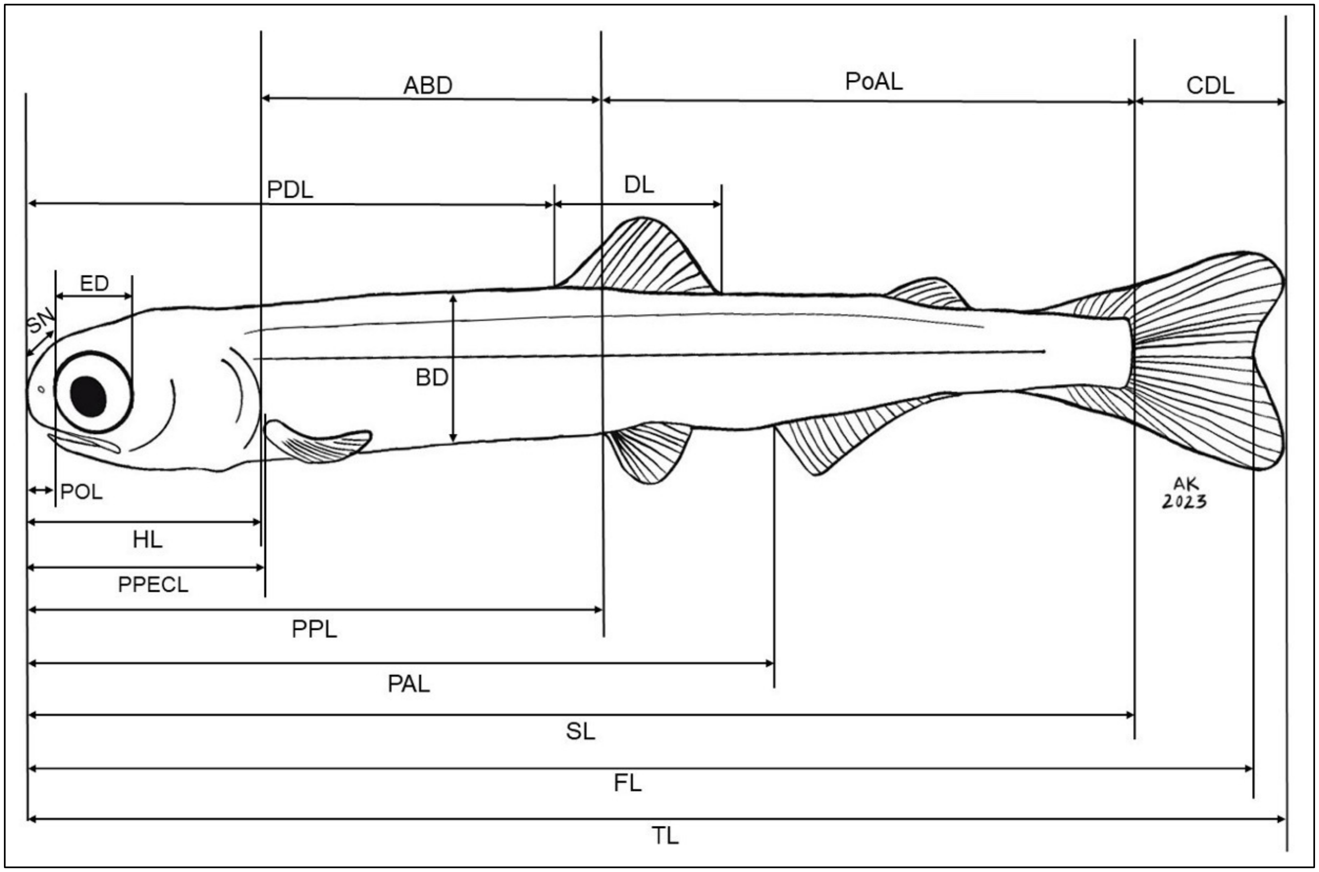
* *p*CO_2 exposure and food availability had a significant effect on overall mass

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

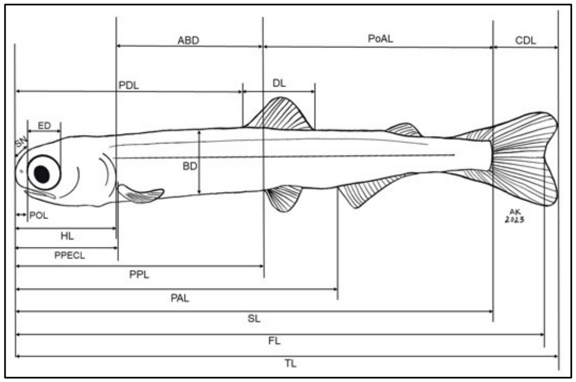


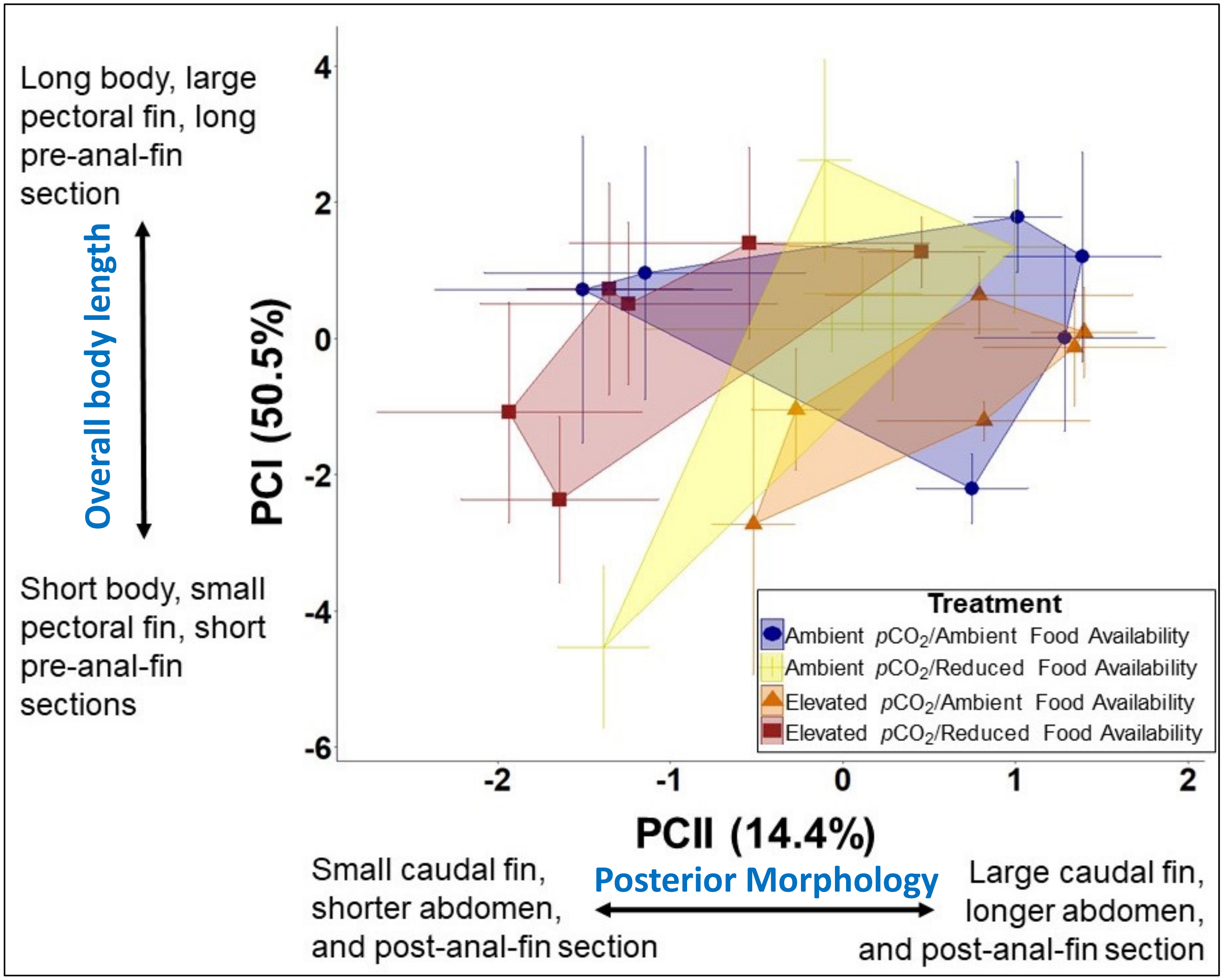
Morphology

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

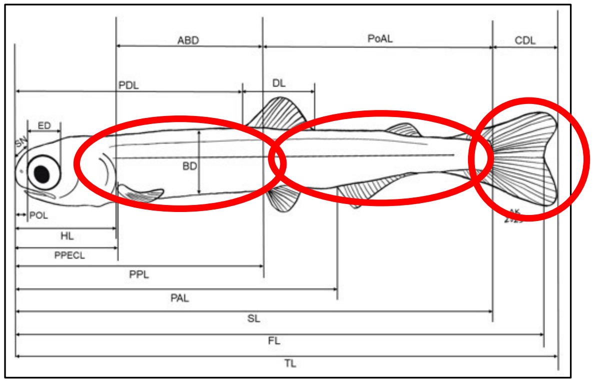


Morphology

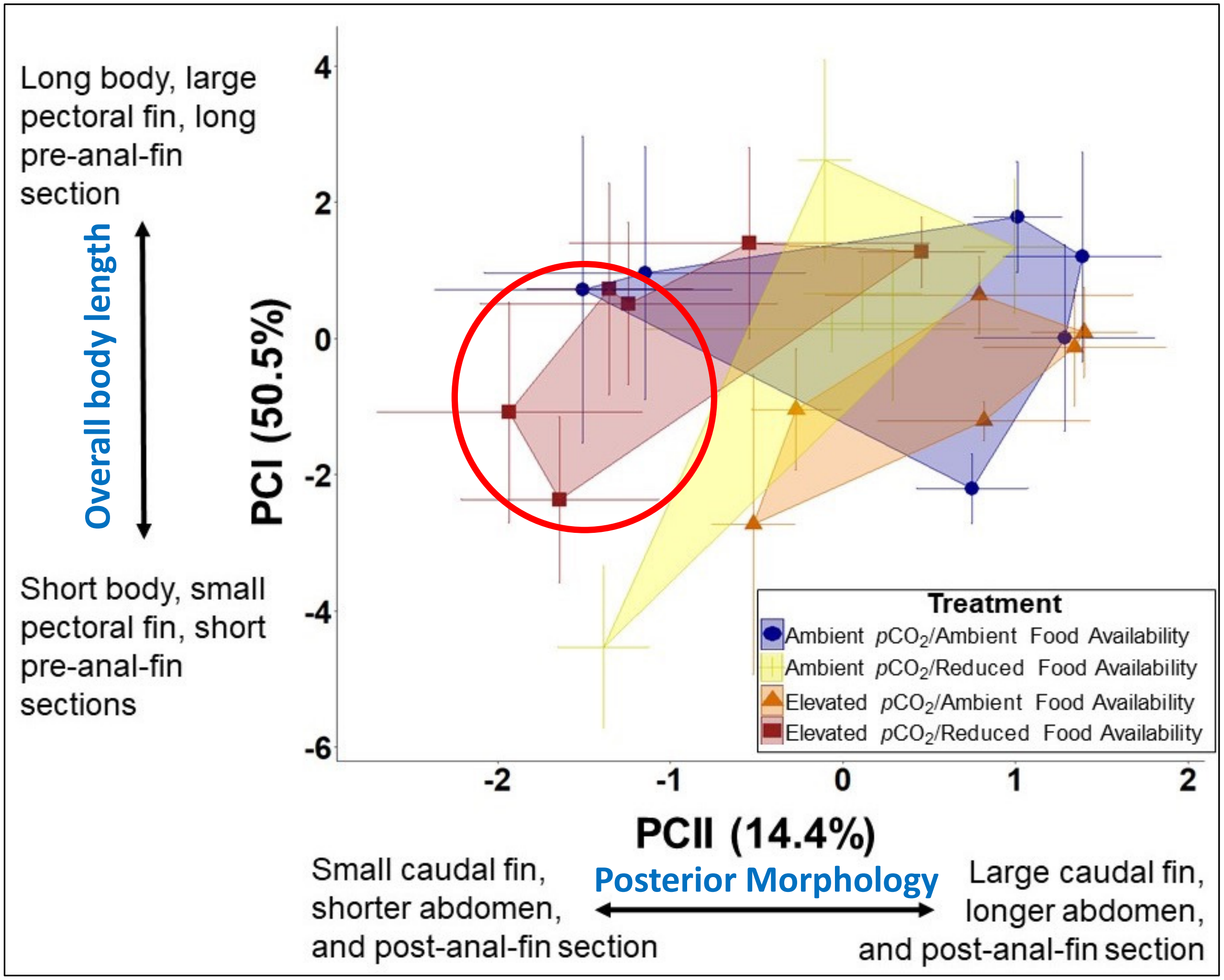

ABD
PoAL
CDL
PDL
DL
ED
SN
BD
POL
HL
PPECL
PPL
PAL
SL
FL
TL
AK 2023


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%)
4
2
0
-2
-4
-6
-2
-1
0
1
2
PCII (14.4%)
Treatment
Ambient pCO2/Ambient Food Availability
Ambient pCO2/Reduced Food Availability
Elevated pCO2/Ambient Food Availability
Elevated pCO2/Reduced Food Availability
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 pCO_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

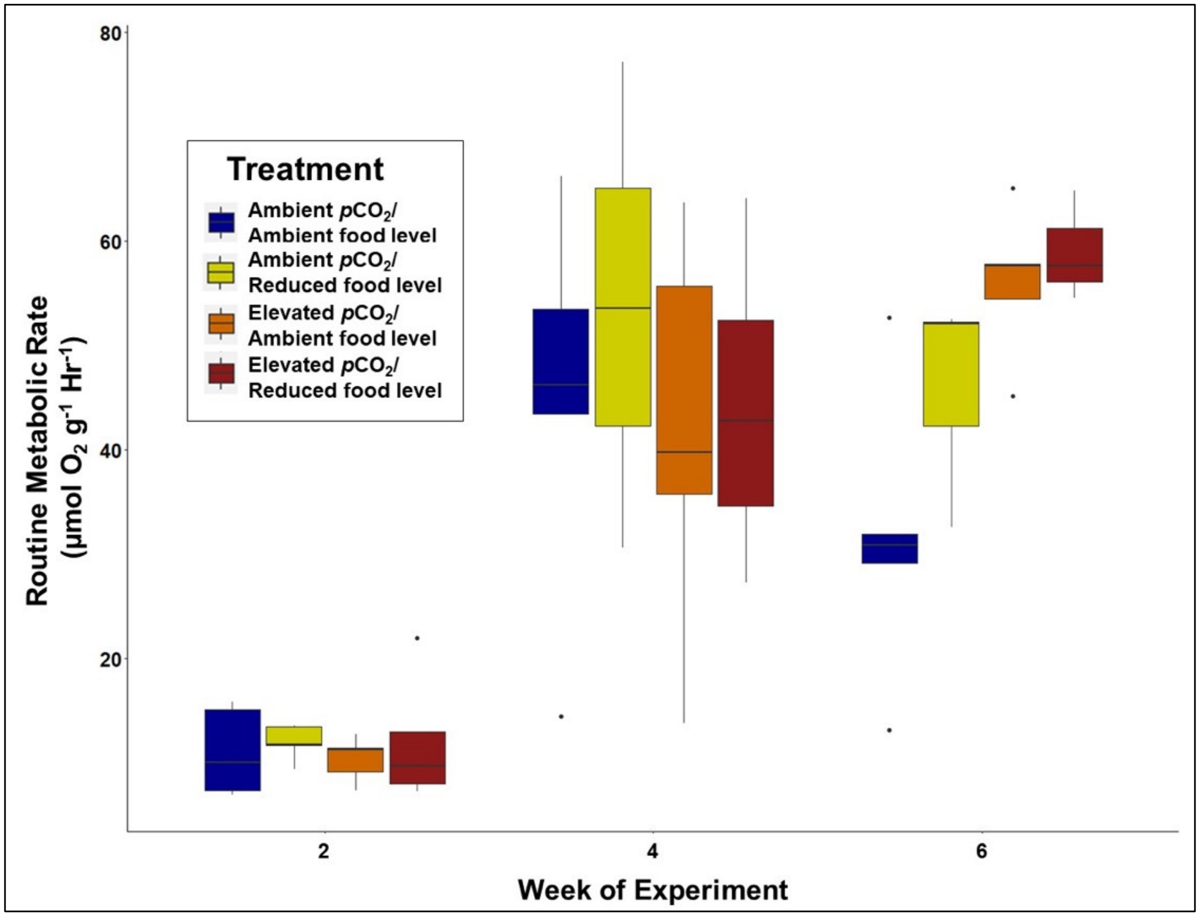
Small caudal fin, shorter abdomen, and post-anal-fin section

Posterior Morphology

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

Results → Whole Organism

Routine Metabolic Rate (RMR)



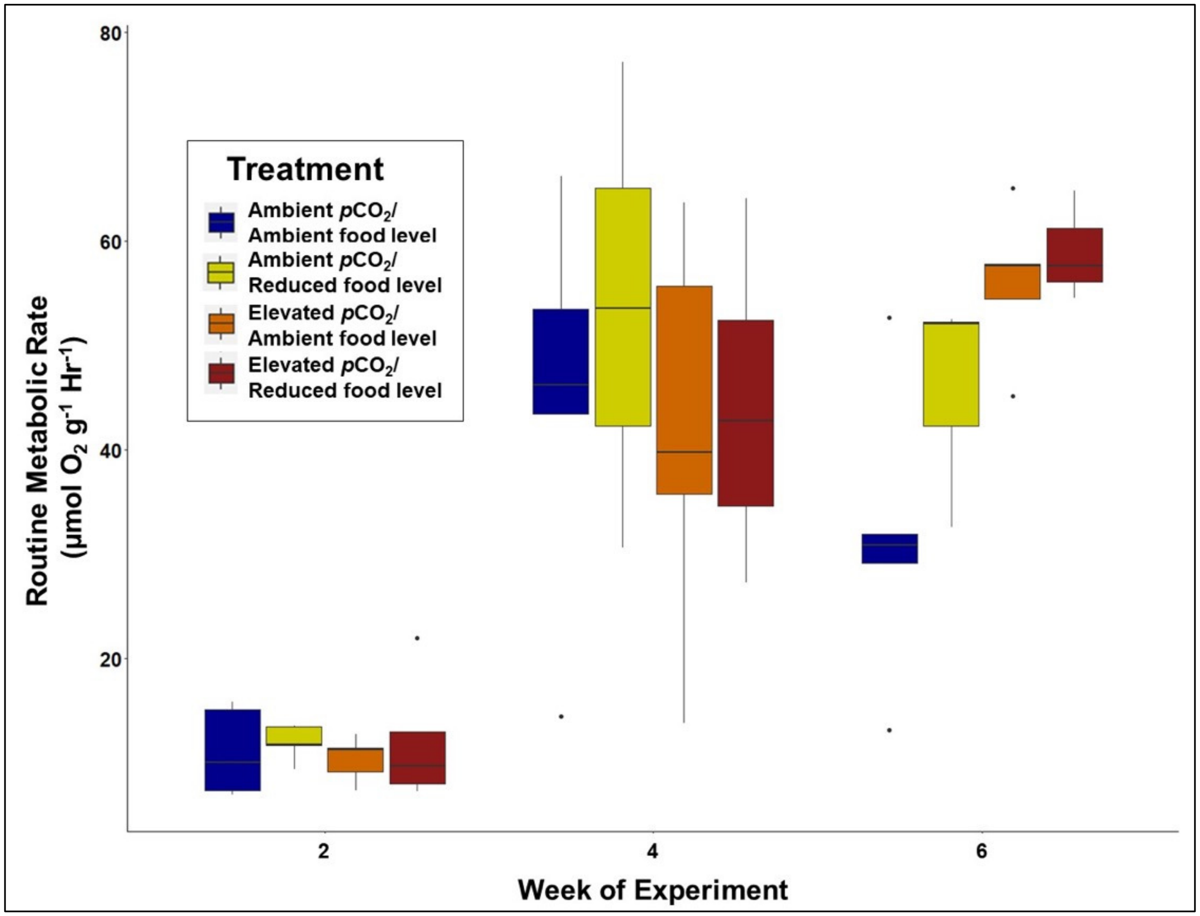
Results → Whole Organism

Routine Metabolic Rate (RMR)

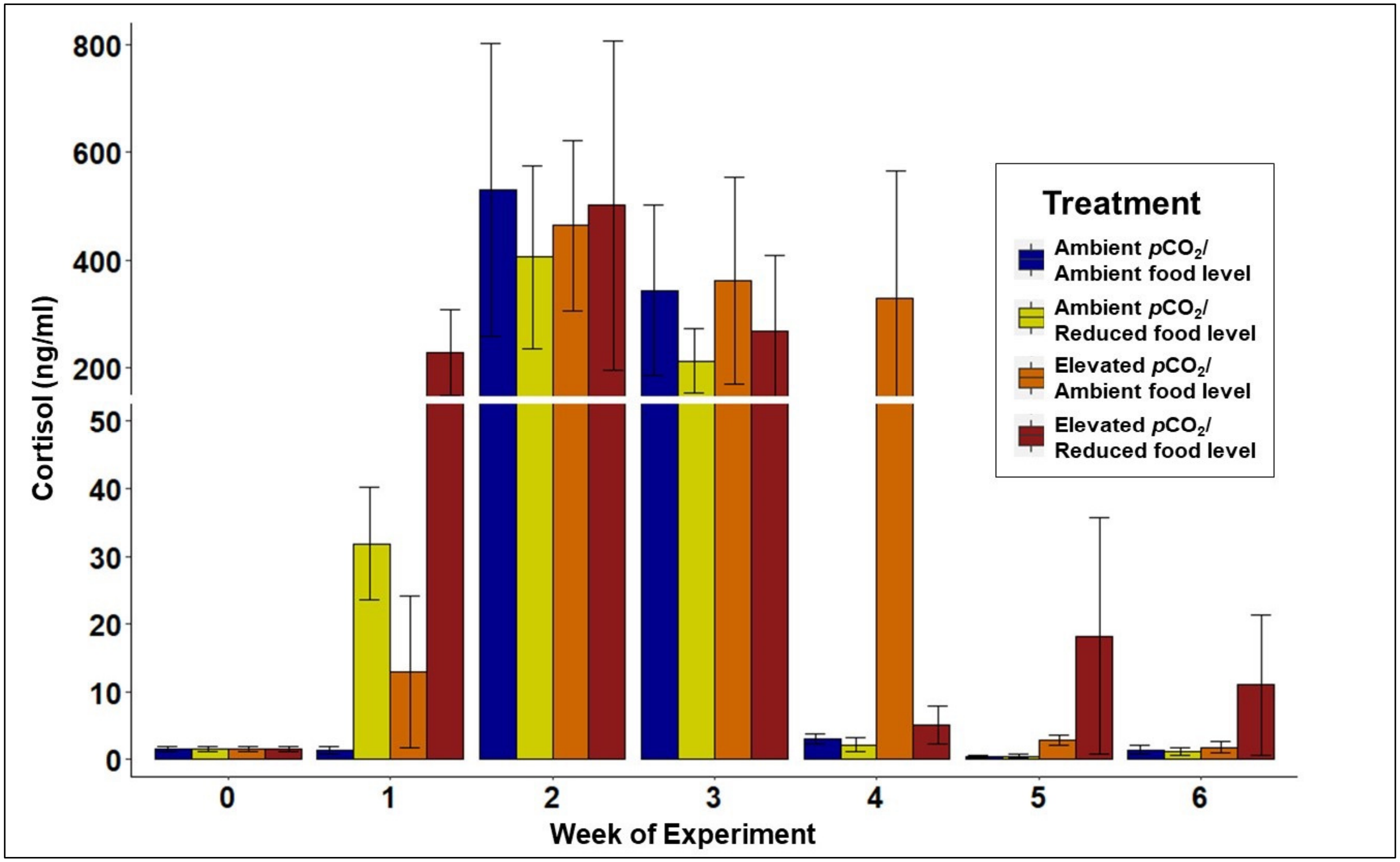
***Significant effect of *p*CO_2 exposure on RMR**

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

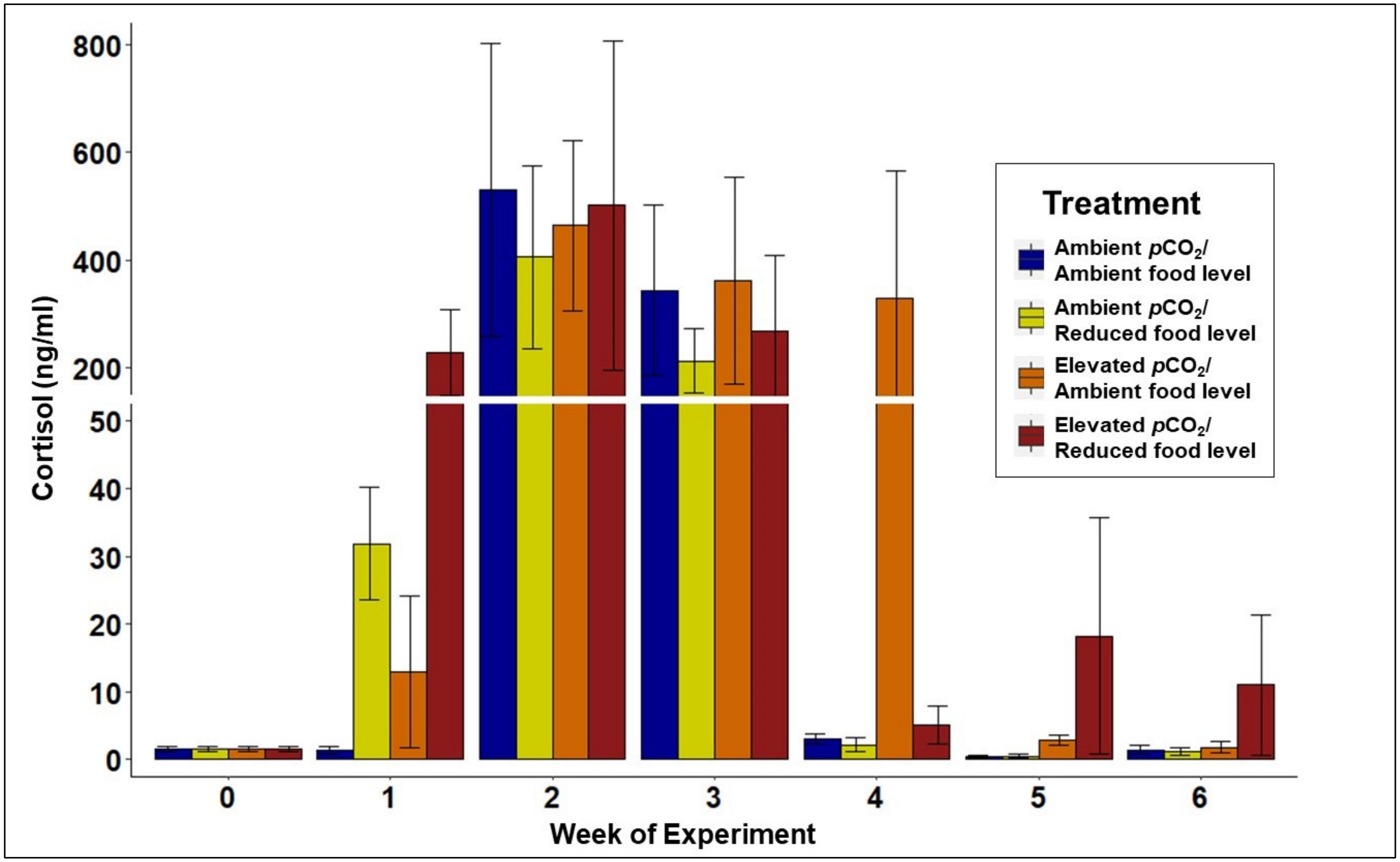
***Significant effect of time on RMR**



Endocrine Response



Endocrine Response

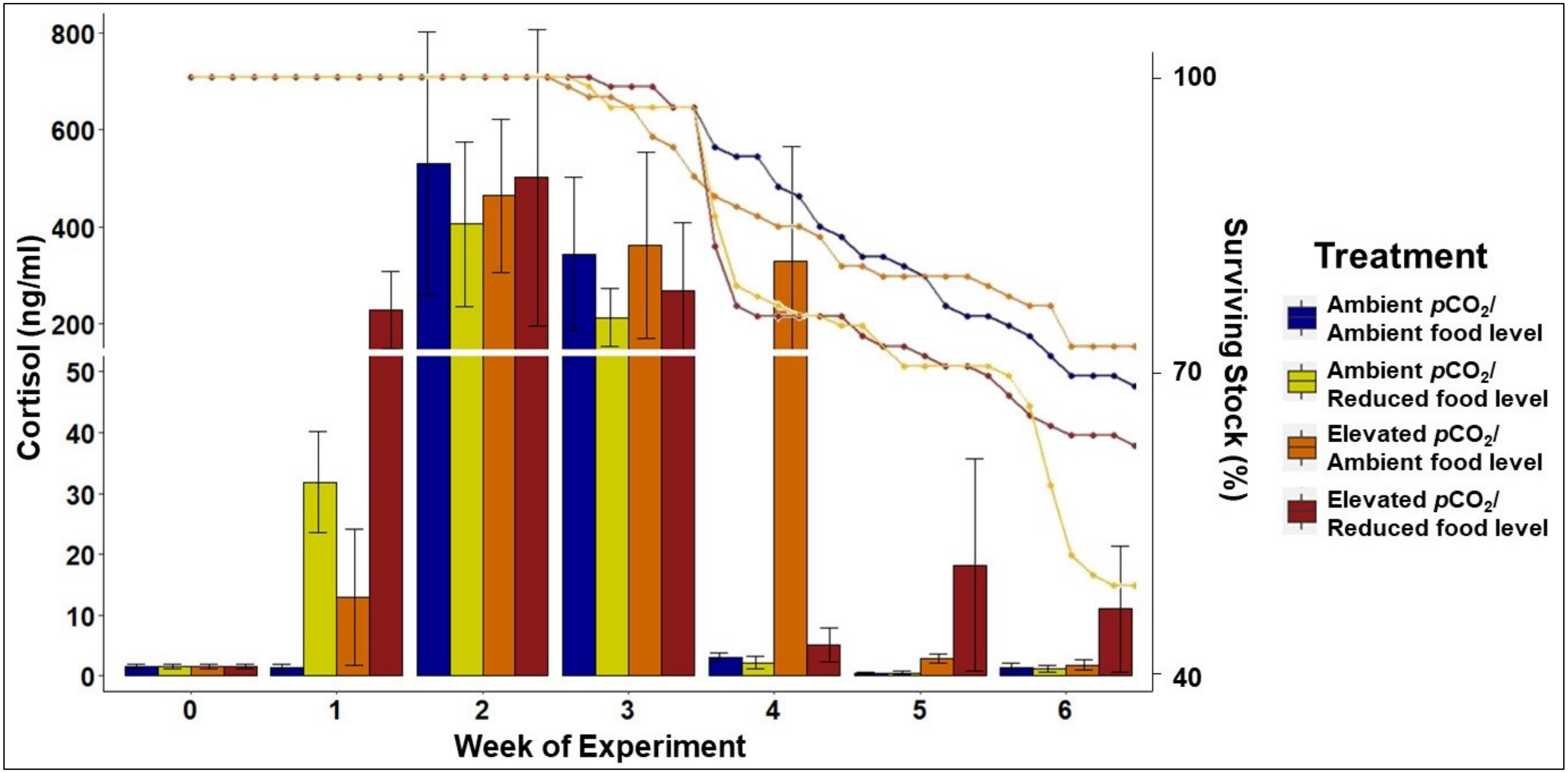


***Significant effect of $p\text{CO}_2$ exposure on cortisol expression**

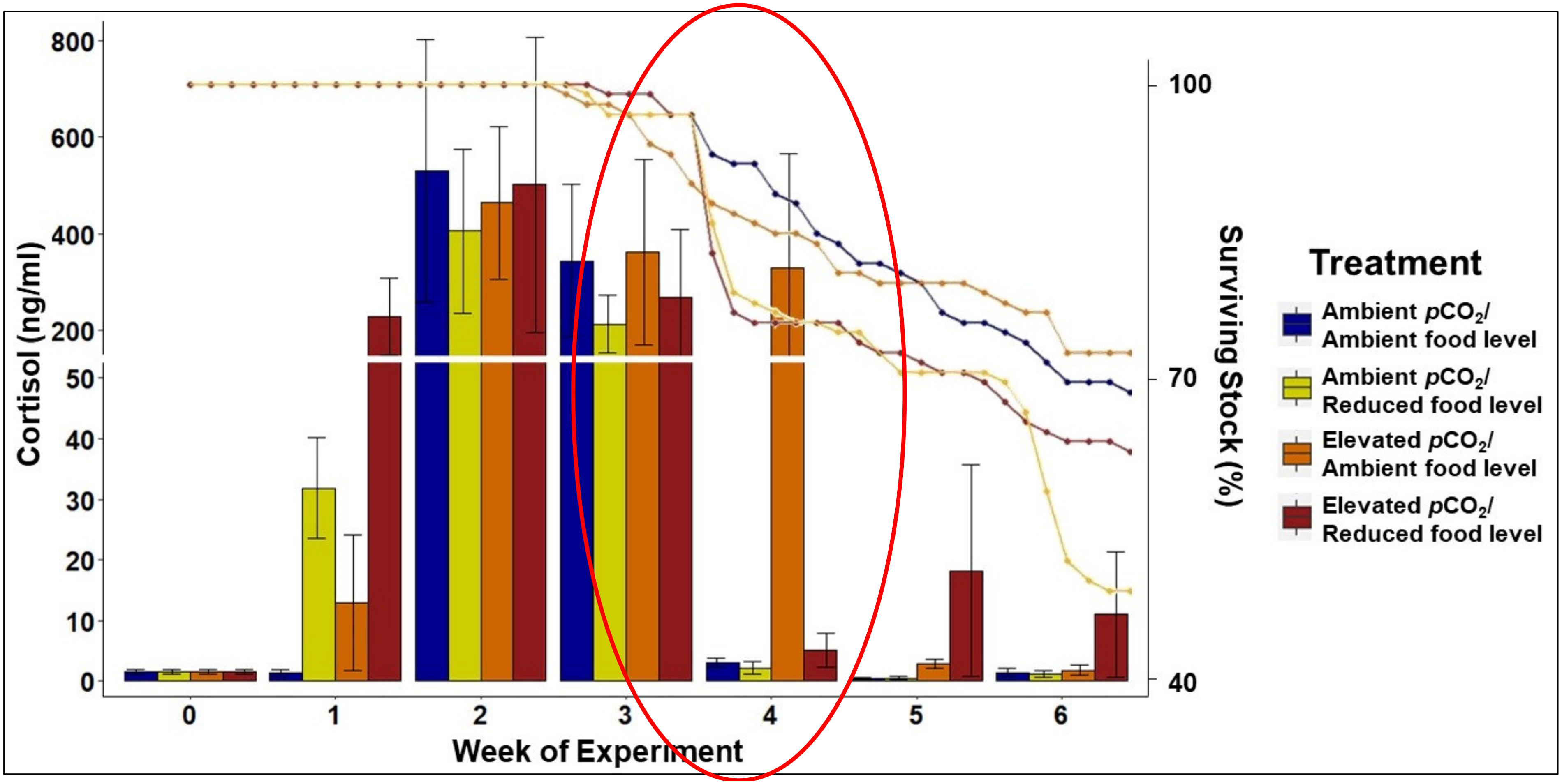
***Significant effect of time on cortisol expression**

Results → Endocrine Response

Endocrine Response & Mortality

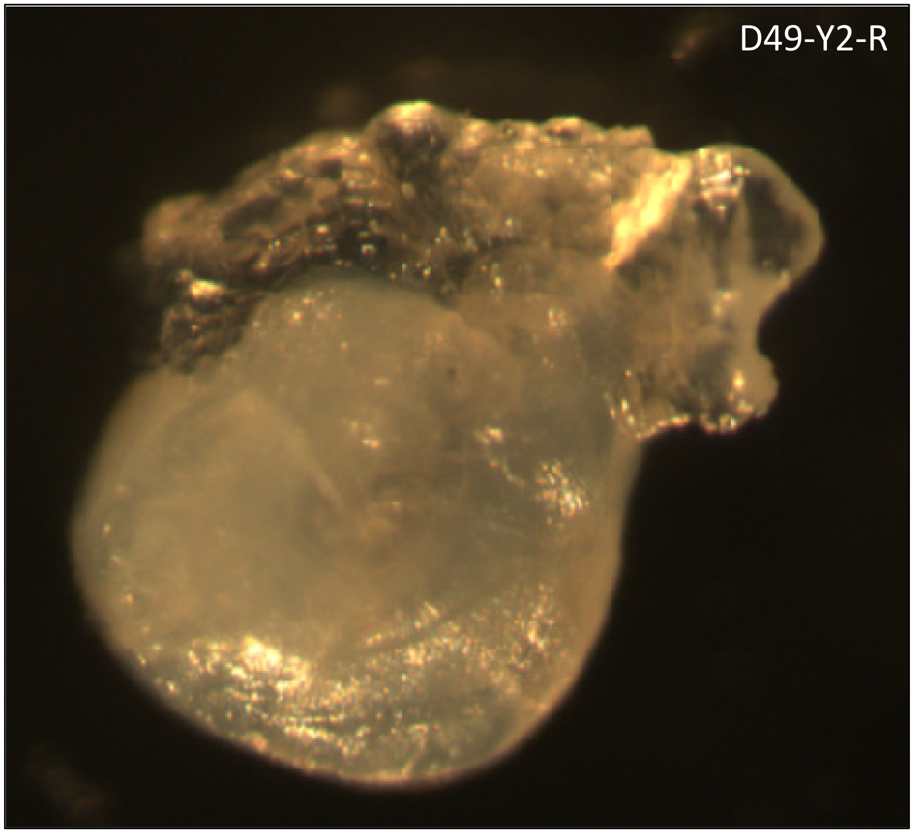


Endocrine Response & Mortality

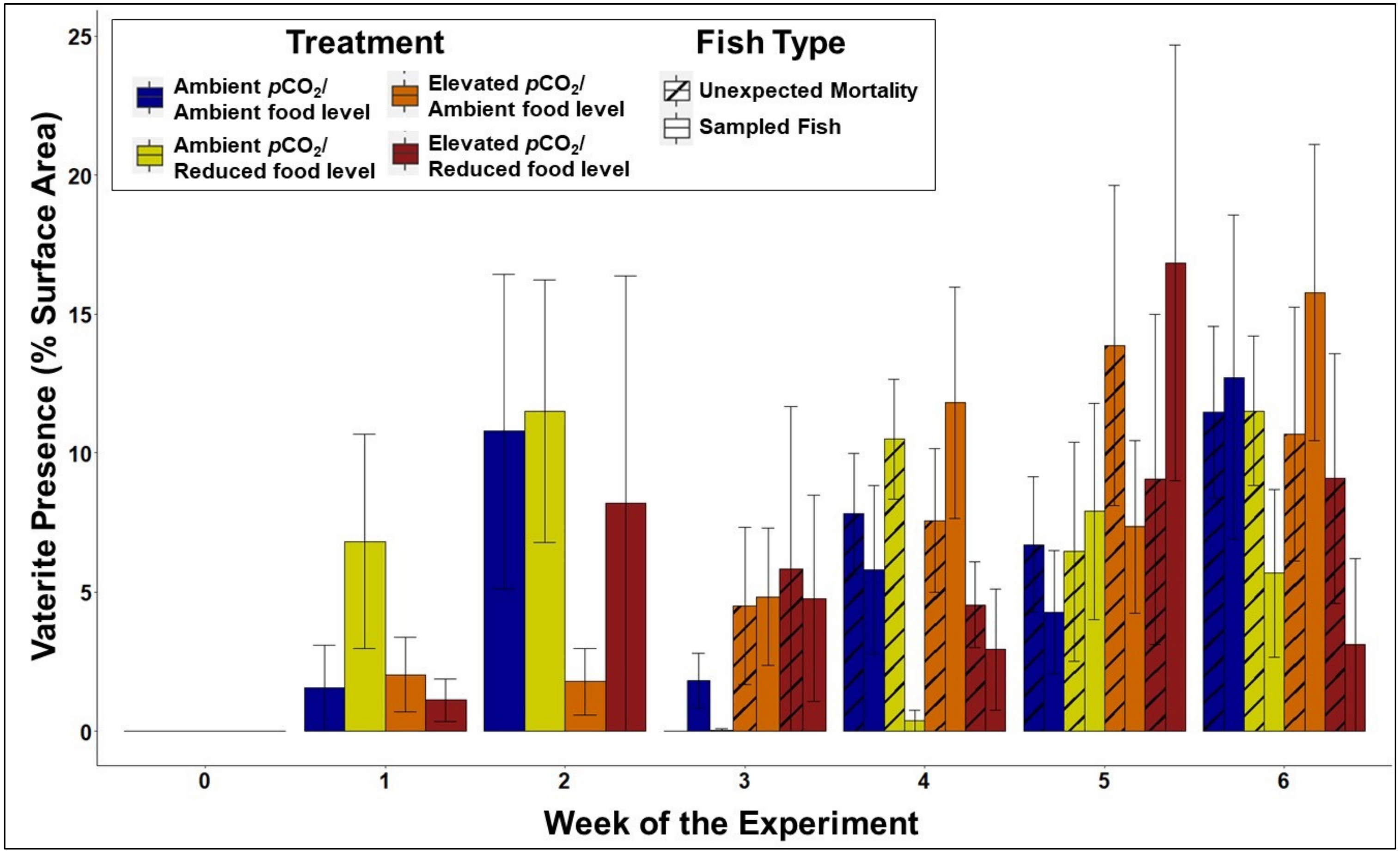


Biomineralogy- Vaterite vs. Aragonite

- 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)



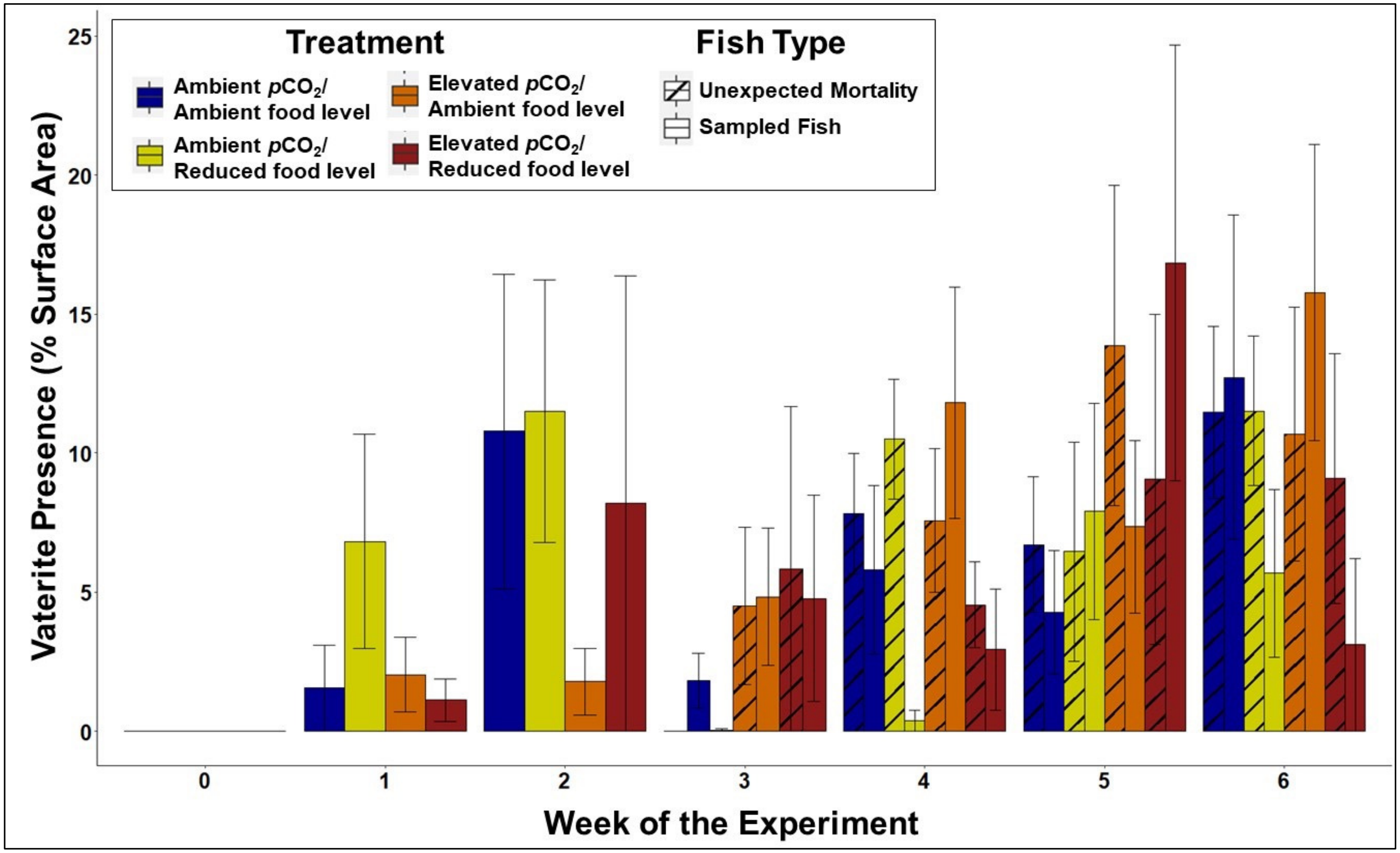
Vaterite Presence



Vaterite Presence

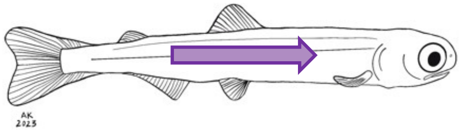
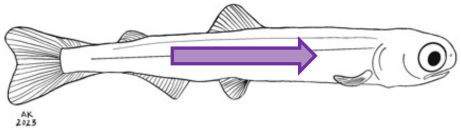
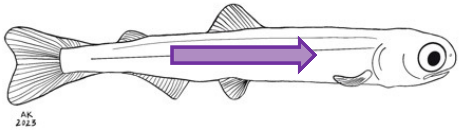
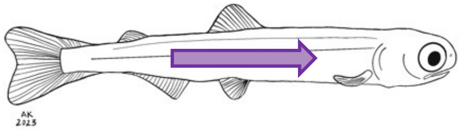
***<u>NO</u> significant effect of pCO_2 exposure or food availability**

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



Summary

What does it all mean?

Our results		**What it means for pinks**
Reduced Mass		Smaller pink salmon in the future
Smaller posterior body sections		Reduced predation escape success, velocity
Increased routine metabolic rate		Increased demand for food
Elevated cortisol expression		Cardiac malformation, reduced cardiac output

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Project video

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The Meridian Institute
NOAA Fisheries
The University of Wyoming
The University of Alaska Anchorage

OAP
NOAA OCEAN ACIDIFICATION PROGRAM

FIRE & ICE

Alaska EPSCoR

ALUTIIQ PRIDE MARINE INSTITUTE

Rasmuson Fisheries Research Center

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Bio-economic Modeling

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

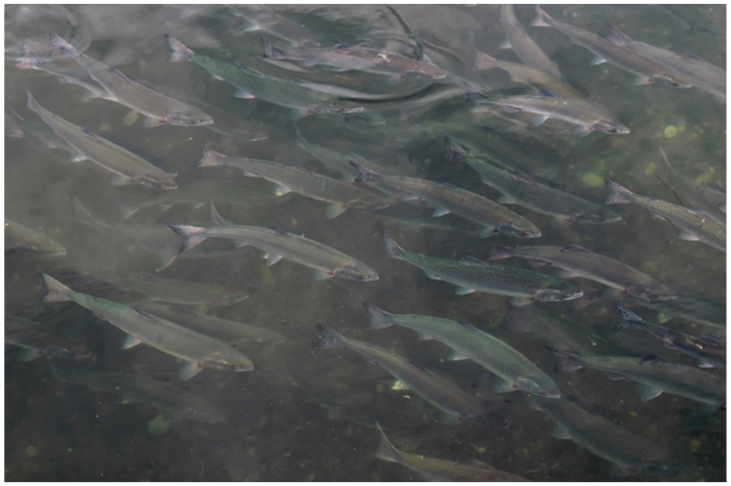
Motivation

- 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 CO_2 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 <u>wild</u> pink salmon productivity more than the other variables studied.**

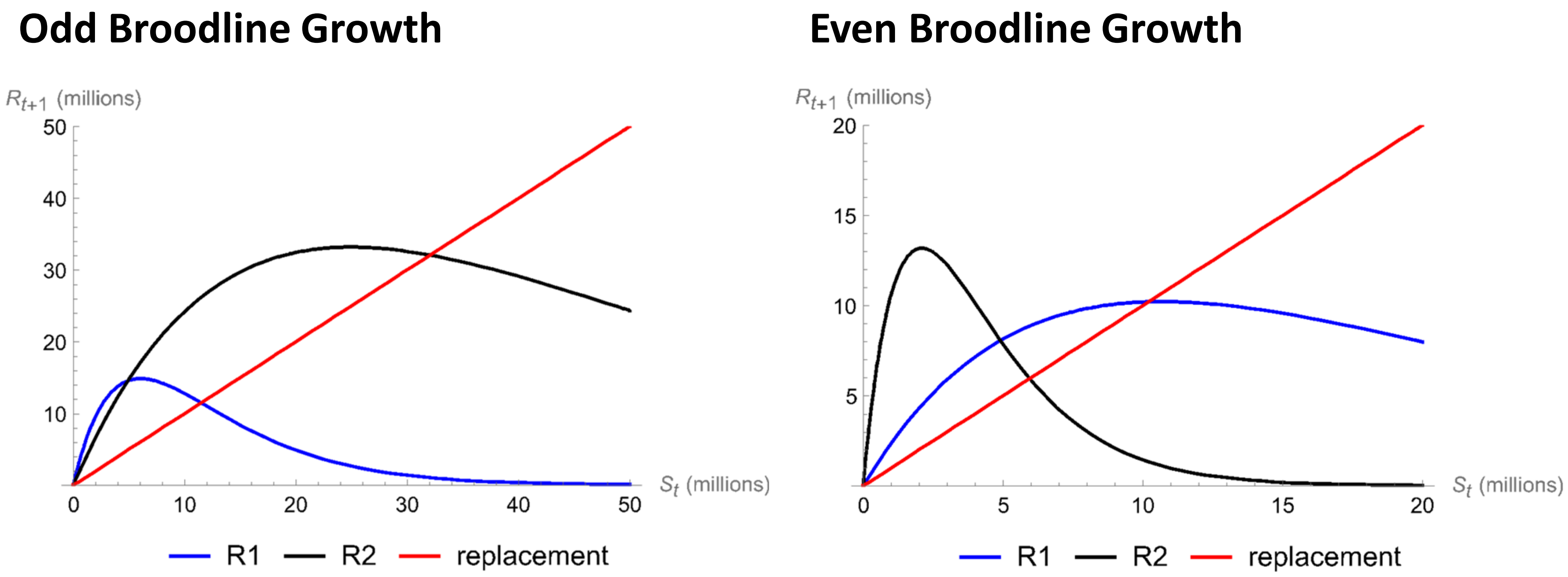
Fishermen Engagement Data

- 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

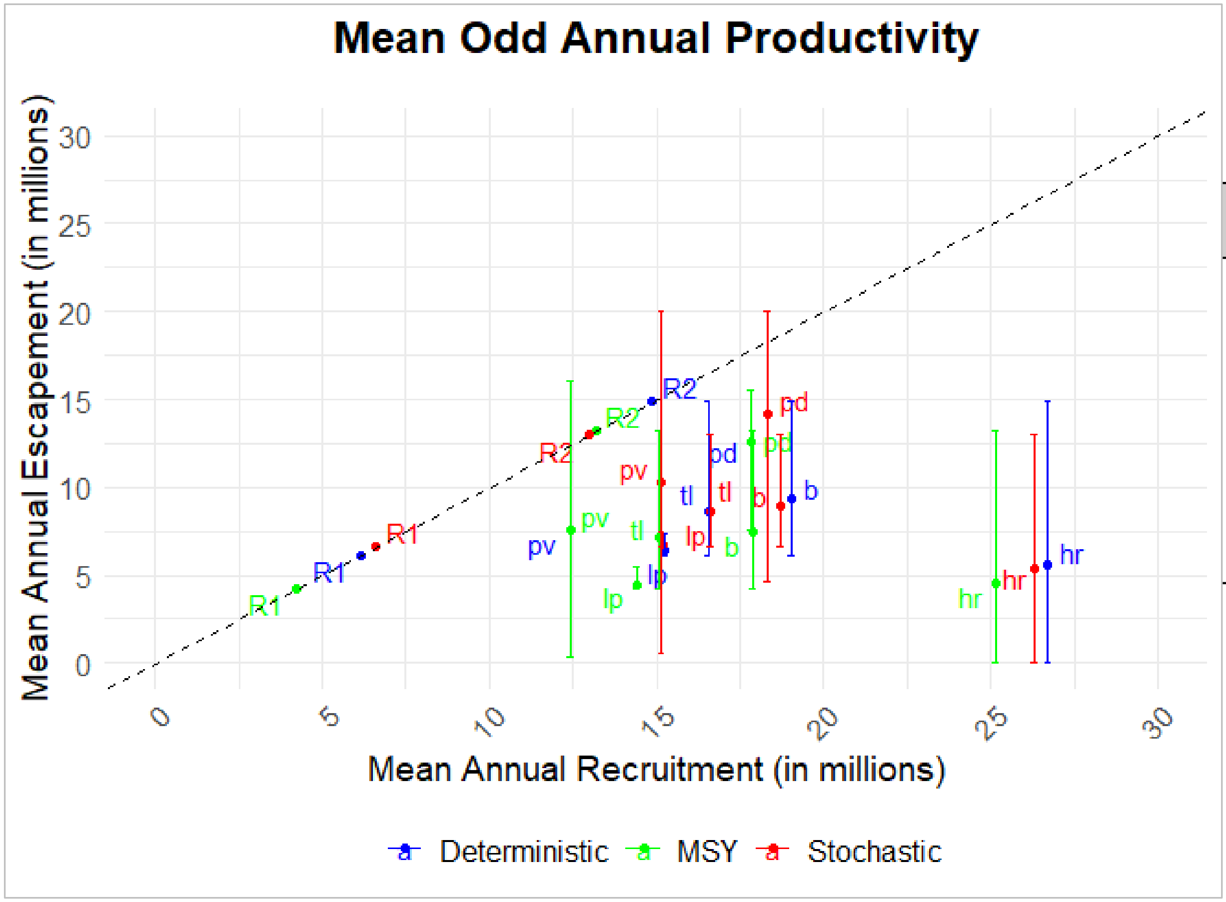
- Maximum Sustainable (ecological) Yield: ignore economic parameters
    - Maximizing natural productivity to protect the resource itself
- Deterministic: ignore the potential for regime shifts
    - Balance the return from the fishery with the next best alternative investment
- Stochastic: determine 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

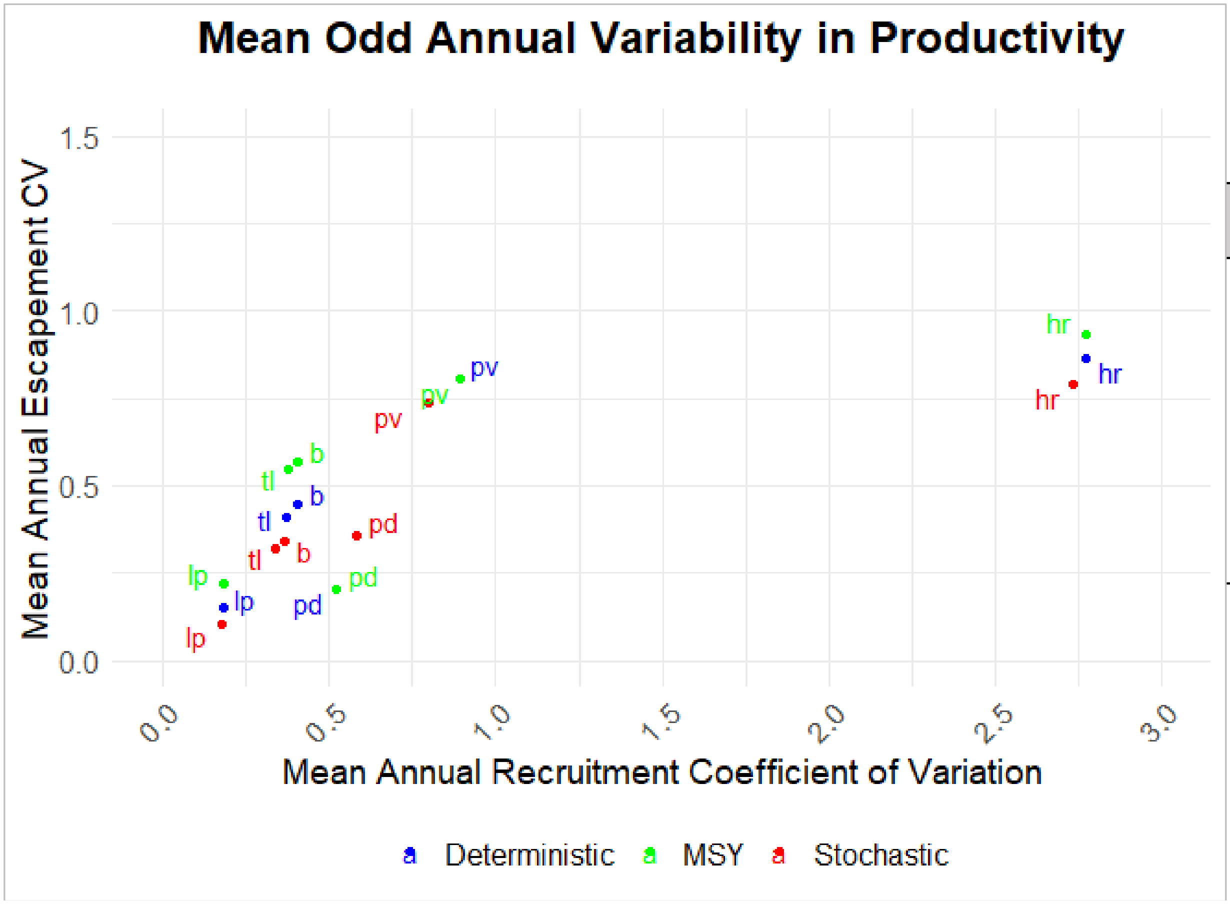
	Escapement in millions of fish			
Brood line Year	Odd		Even	
Regime	R1	R2	R1	R2
MSY Rule	4.228	13.222	4.448	1.807
Deterministic Rule	6.143	14.848	6.179	2.598
Stochastic Rule	6.595	12.971	5.637	2.741

Average escapement varies less with stochastic rules



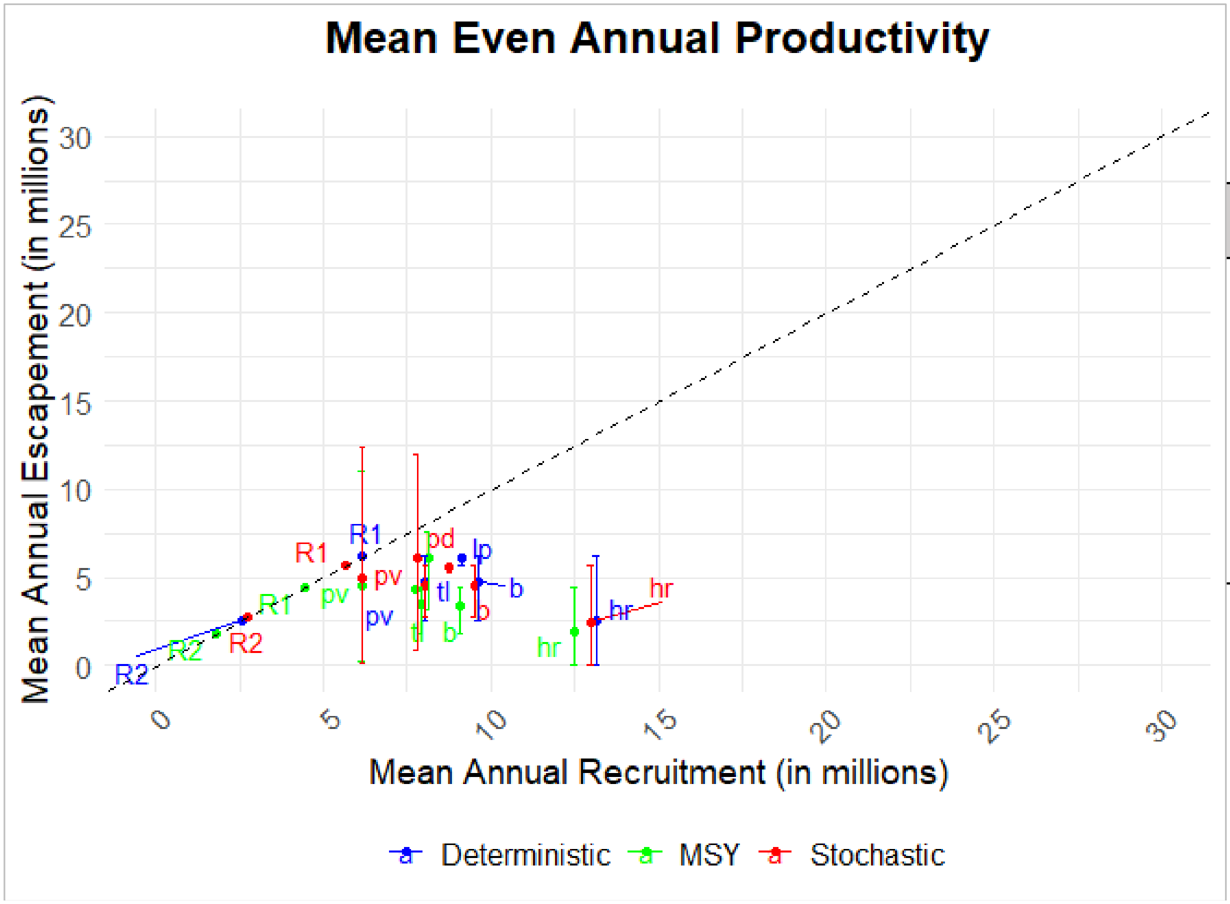
Scenario	Notation
Baseline	b
High recruitment variation	hr
Low probability of transition (R1->R2)	lp
Time lagged management response	tl
Price decline	pd
Price variation	pv

High recruitment scenario is an important outlier



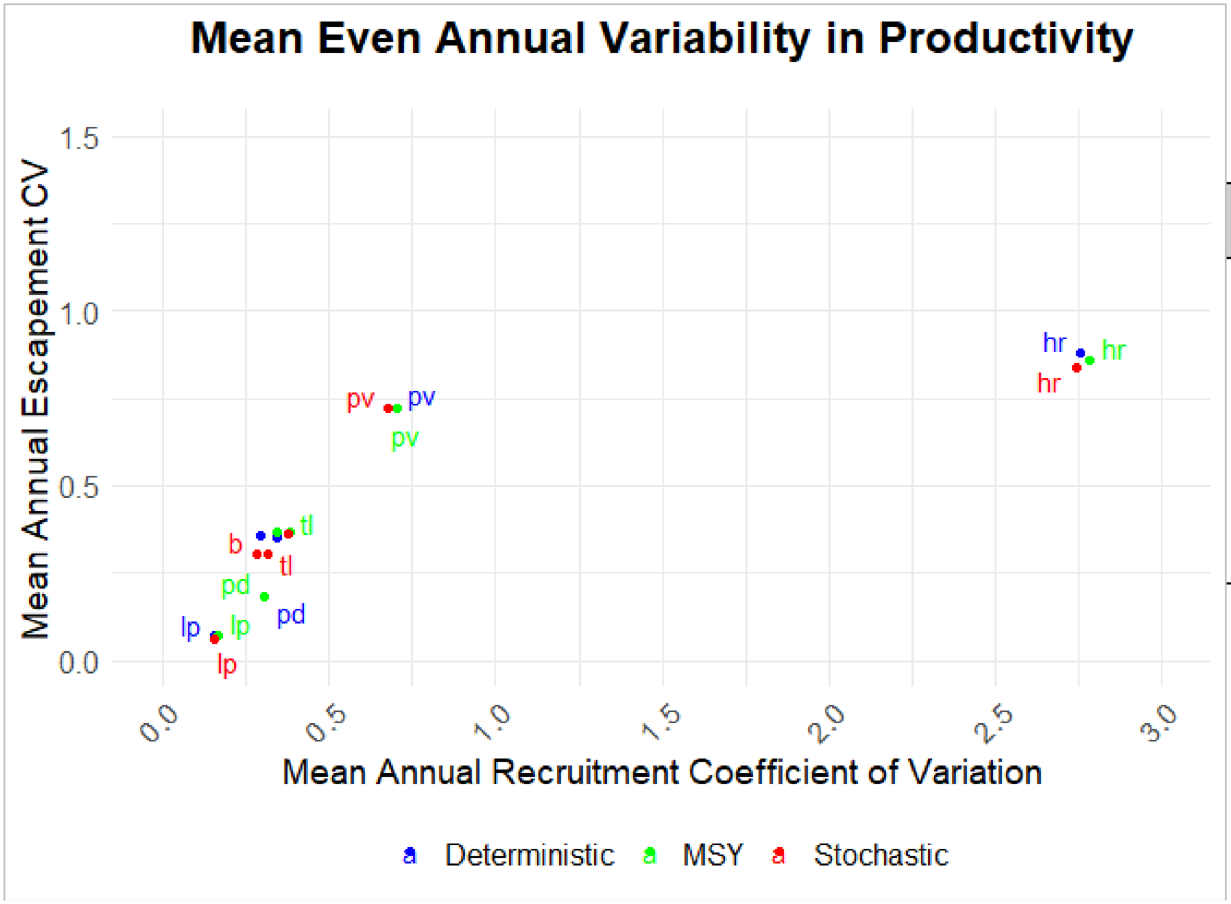
Scenario	Notation
Baseline	b
High recruitment variation	hr
Low probability of transition (R1->R2)	lp
Time lagged management response	tl
Price decline	pd
Price variation	pv

Responsive management regimes reduce escapement variability



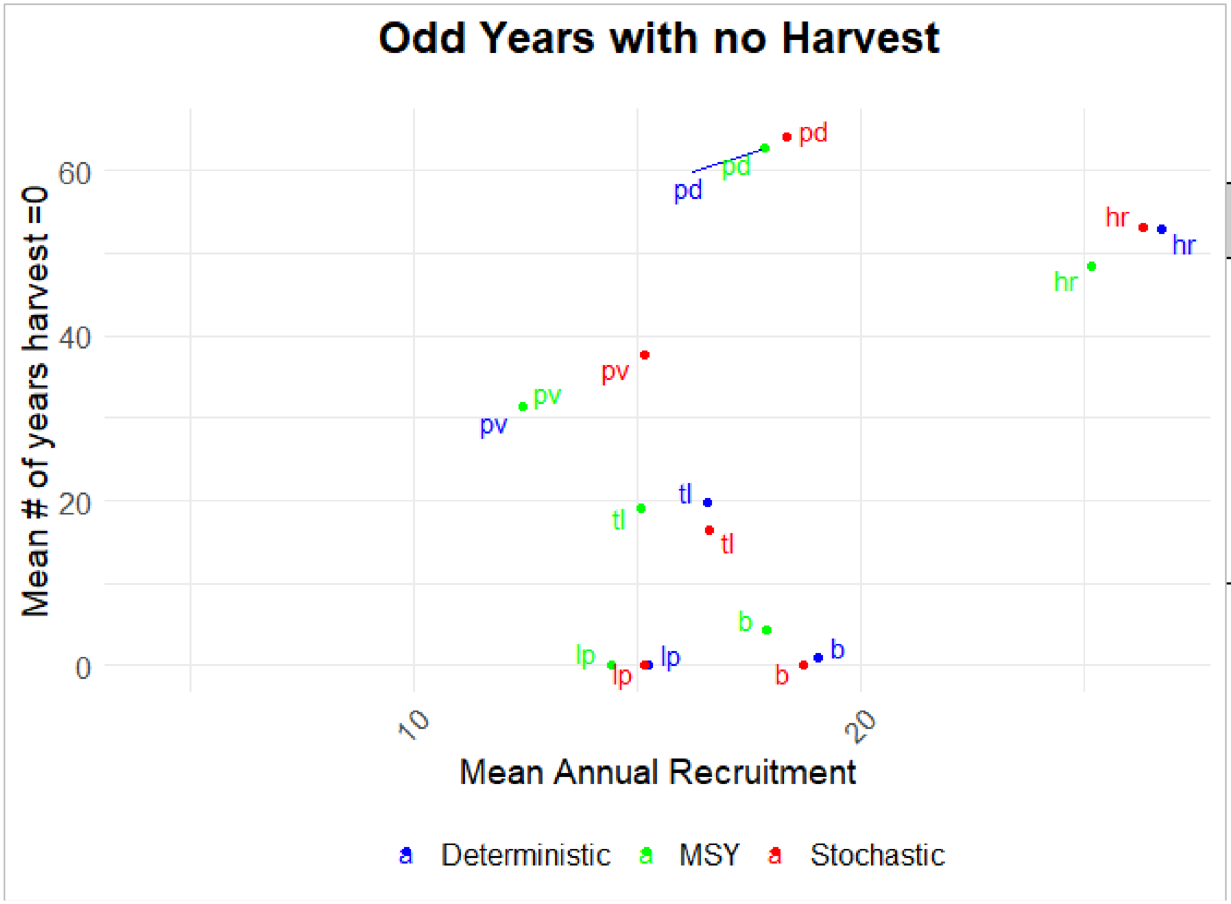
Scenario	Notation
Baseline	b
High recruitment variation	hr
Low probability of transition (R1->R2)	lp
Time lagged management response	tl
Price decline	pd
Price variation	pv

High recruitment variation makes a big difference



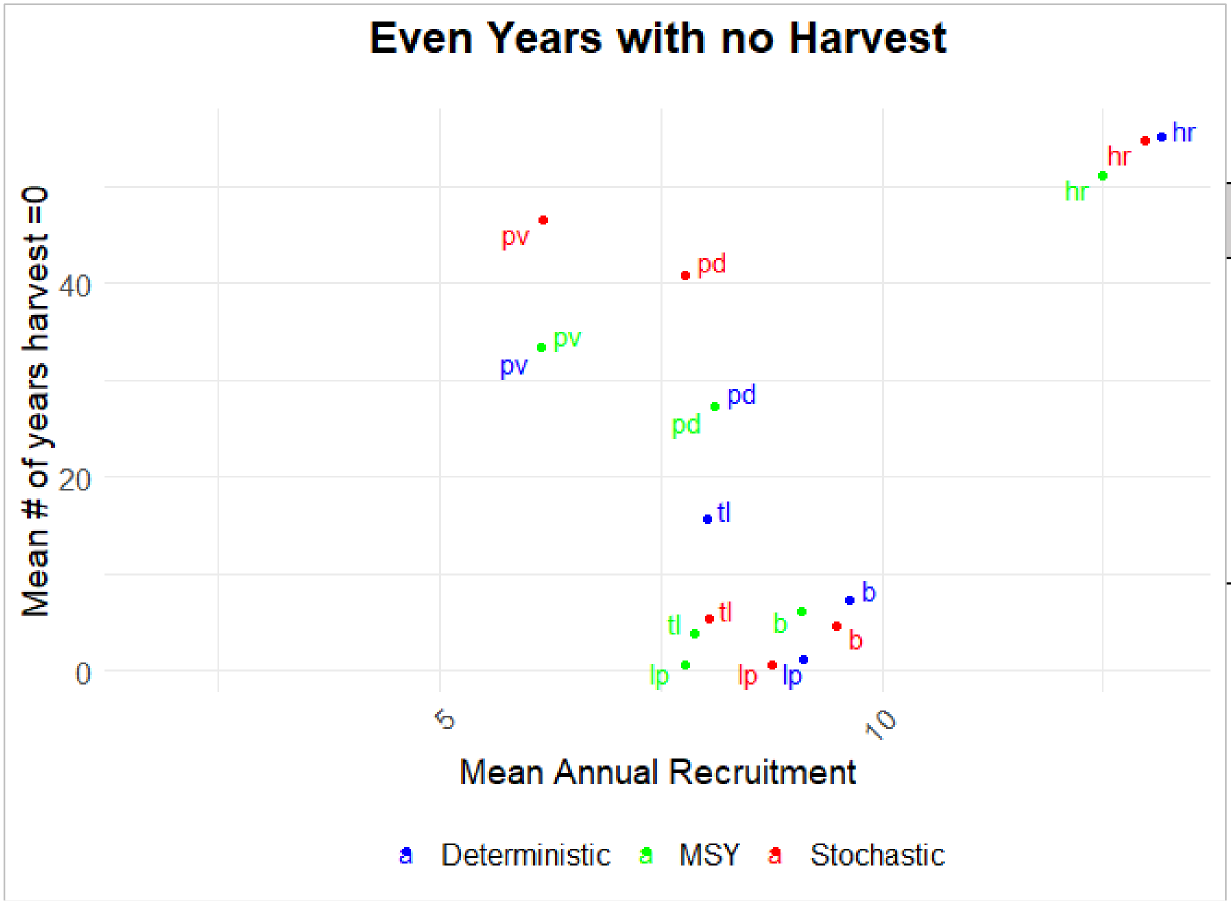
Scenario	Notation
Baseline	b
High recruitment variation	hr
Low probability of transition (R1->R2)	lp
Time lagged management response	tl
Price decline	pd
Price variation	pv

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



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

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!

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Thanks from the Tipping Points team

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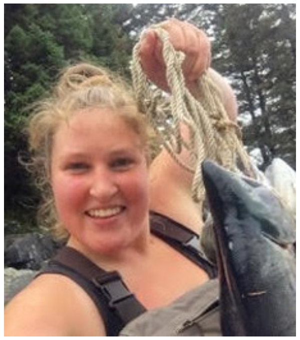

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