# Climate attribution time series to support decision-making by fisheries stakeholders

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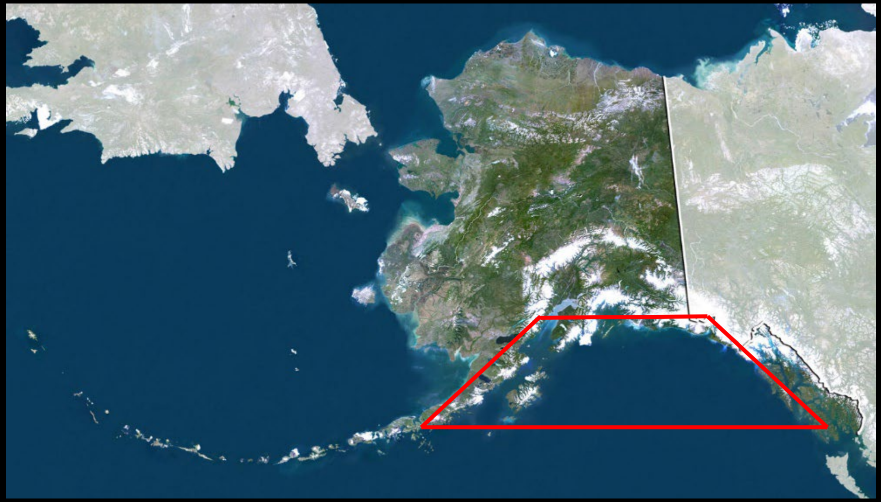
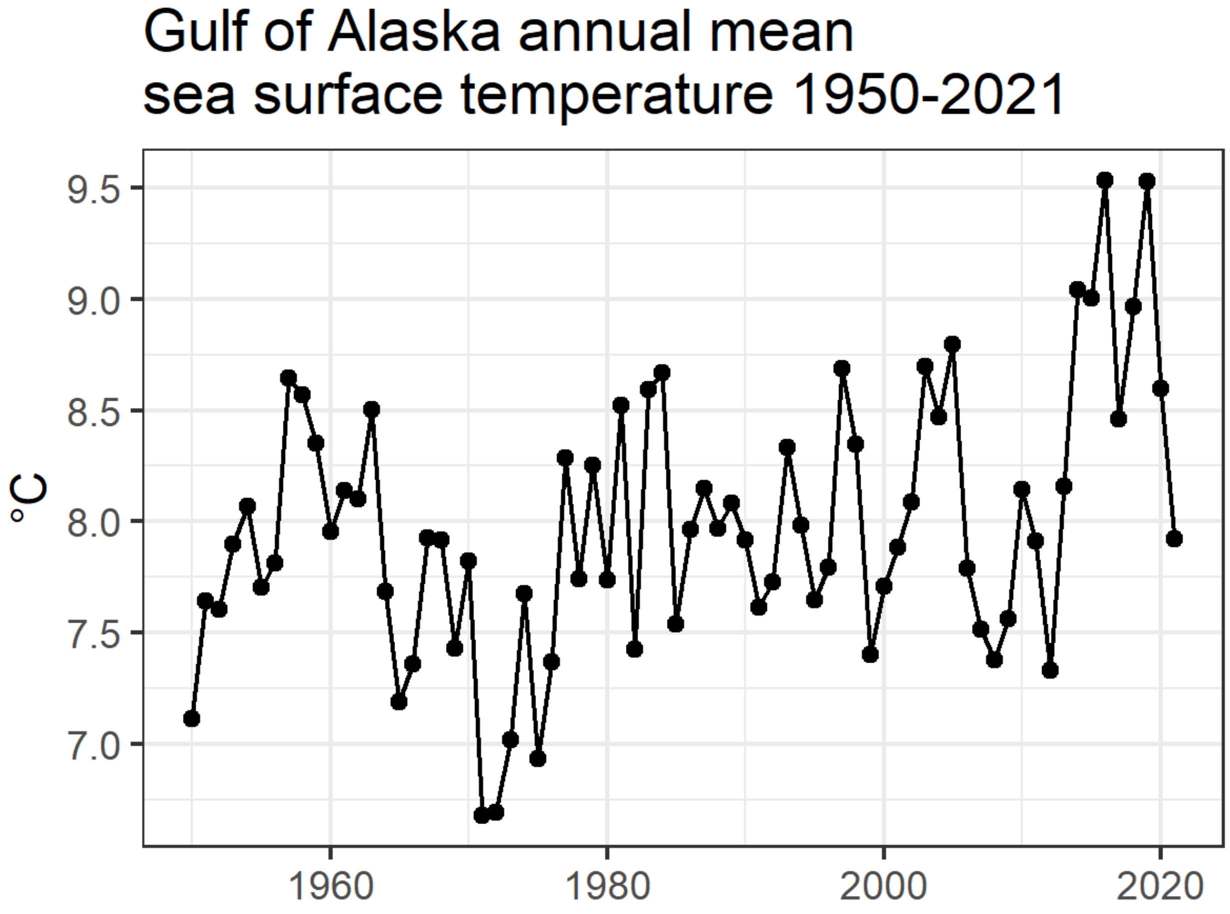
# Gulf of Alaska sockeye salmon runs as a marine ecosystem service

- ~$69 M USD commercial fishery
- Employs thousands of people
- Community-based local fishery
- Food security
- Cultural identity



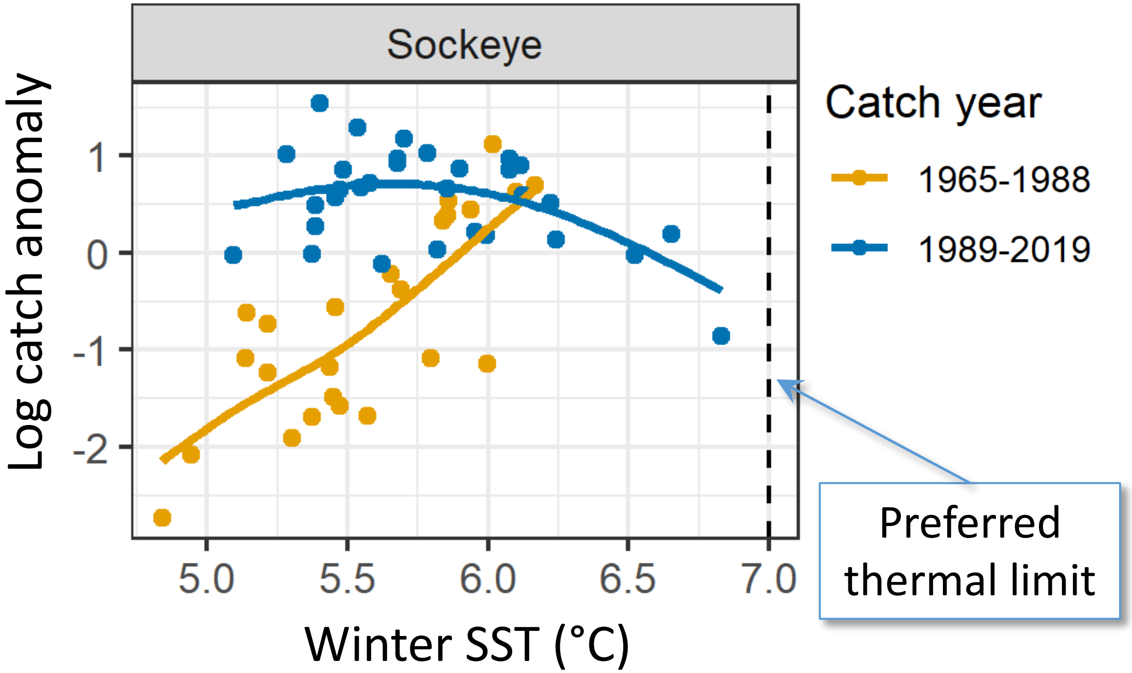
“Are we crazy to be putting everything we have into this fishery?”



# Climate effects on Gulf of Alaska sockeye

- *Positive* SST-production relationships *before* late 1980s
- *Neutral* SST-production relationships *after* late 1980s
- Possibly *negative* SST-production relationships *since* 2014

Commercial catch and winter SST, 1965-2019




## Ecological questions

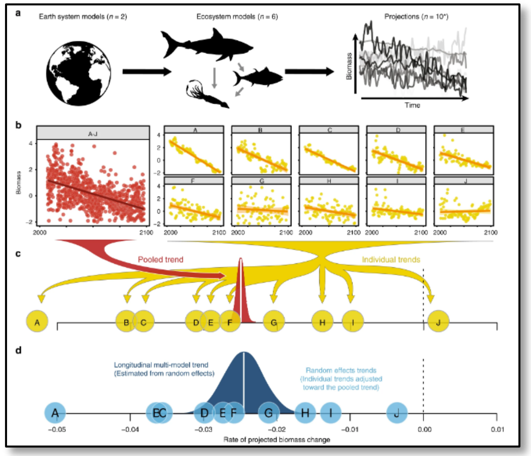
- Can we elucidate the relevant mechanisms?
- Can we develop ecosystem models capable of out-of-sample prediction?

## Stakeholder questions

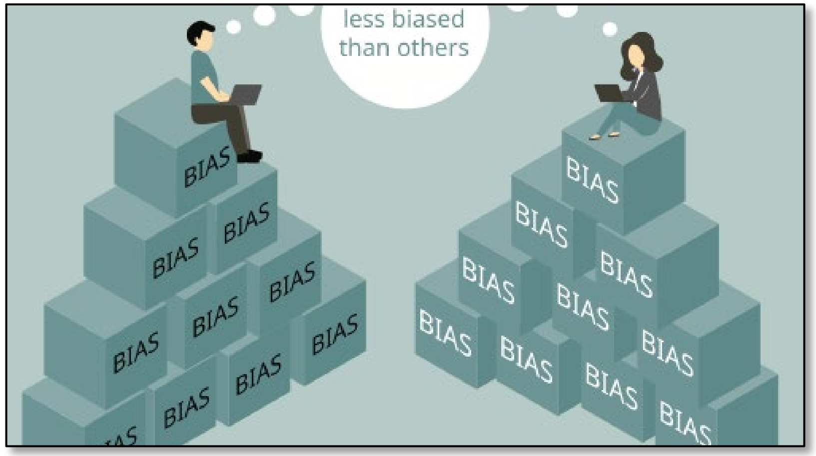
- How can we minimize bad outcomes of climate change and take advantage of any beneficial outcomes? (adaptation)
- What should we do this year / this decade?

Litzow et al. 2020, Geophysical Research Letters

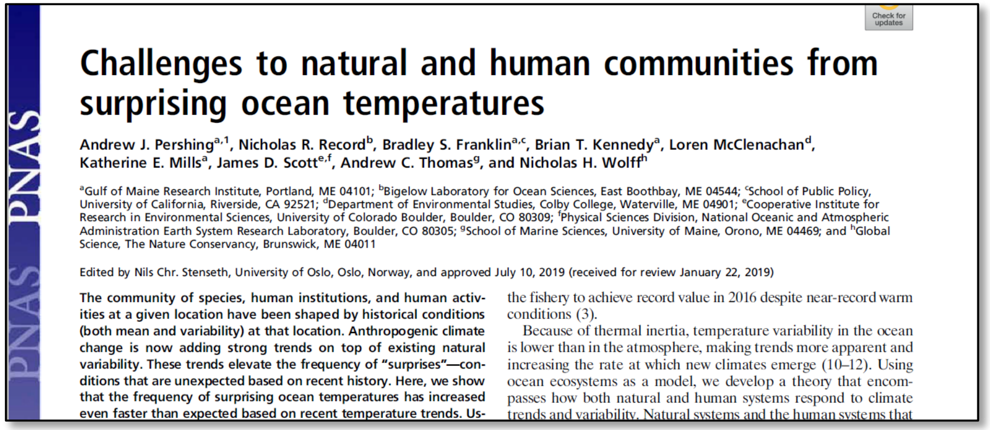
# Cognitive barriers to adaptation decision-making




Complexity of scientific advice




Inability to attribute change



PNAS

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## Challenges to natural and human communities from surprising ocean temperatures


Andrew J. Pershing[a,1], Nicholas R. Record[b], Bradley S. Franklin[a,c], Brian T. Kennedy[a], Loren McClenachan[d], Katherine E. Mills[a], James D. Scott[e,f], Andrew C. Thomas[g], and Nicholas H. Wolff[h]

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Edited by Nils Chr. Stenseth, University of Oslo, Oslo, Norway, and approved July 10, 2019 (received for review January 22, 2019)



The community of species, human institutions, and human activities at a given location have been shaped by historical conditions (both mean and variability) at that location. Anthropogenic climate change is now adding strong trends on top of existing natural variability. These trends elevate the frequency of "surprises"—conditions that are unexpected based on recent history. Here, we show that the frequency of surprising ocean temperatures has increased even faster than expected based on recent temperature trends. Us-


the fishery to achieve record value in 2016 despite near-record warm conditions (3).

Because of thermal inertia, temperature variability in the ocean is lower than in the atmosphere, making trends more apparent and increasing the rate at which new climates emerge (10–12). Using ocean ecosystems as a model, we develop a theory that encompasses how both natural and human systems respond to climate trends and variability. Natural systems and the human systems that

Using history as a guide for future risk

Pershing et al. 2019 Proceedings of the National Academy of Sciences of the United States

# Goal: create scientific advice for decision-making

Climate studies that:

- *Include attribution*
- *Are simple but empirically rigorous*
- *Are matched to adaptation timescales*
- *Support forward-looking perspective*

# Extreme event attribution

## 8. THE HIGH LATITUDE MARINE HEAT WAVE OF 2016 AND ITS IMPACTS ON ALASKA

John E. Walsh, Richard L. Thoman, Uma S. Bhatt, Peter A. Bieniek, Brian Brettschneider, Michael Brubaker, Seth Danielson, Rick Lader, Florence Fetterer, Kris Holderied, Katrin Iken, Andy Mahoney, Molly McCammon, and James Partain

*The 2016 Alaska marine heat wave was unprecedented in terms of sea surface temperatures and ocean heat content, and CMIP5 data suggest human-induced climate change has greatly increased the risk of such anomalies.*

chapter 10

## THE RECORD LOW BERING SEA ICE EXTENT IN 2018: CONTEXT, IMPACTS, AND AN ASSESSMENT OF THE ROLE OF ANTHROPOGENIC CLIMATE CHANGE

Richard L. Thoman Jr., Uma S. Bhatt, Peter A. Bieniek, Brian R. Brettschneider, Michael Brubaker, Seth L. Danielson, Zachary Labe, Rick Lader, Walter N. Meier, Gay Sheffield, and John E. Walsh

Record low Bering Sea sea ice in 2018 had profound regional impacts. According to climate models, human-caused warming was an overwhelmingly likely contributor, and such low levels will likely be typical by the 2040s.

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journal homepage: www.elsevier.com/locate/pocean

## Evaluating ecosystem change as Gulf of Alaska temperature exceeds the limits of preindustrial variability

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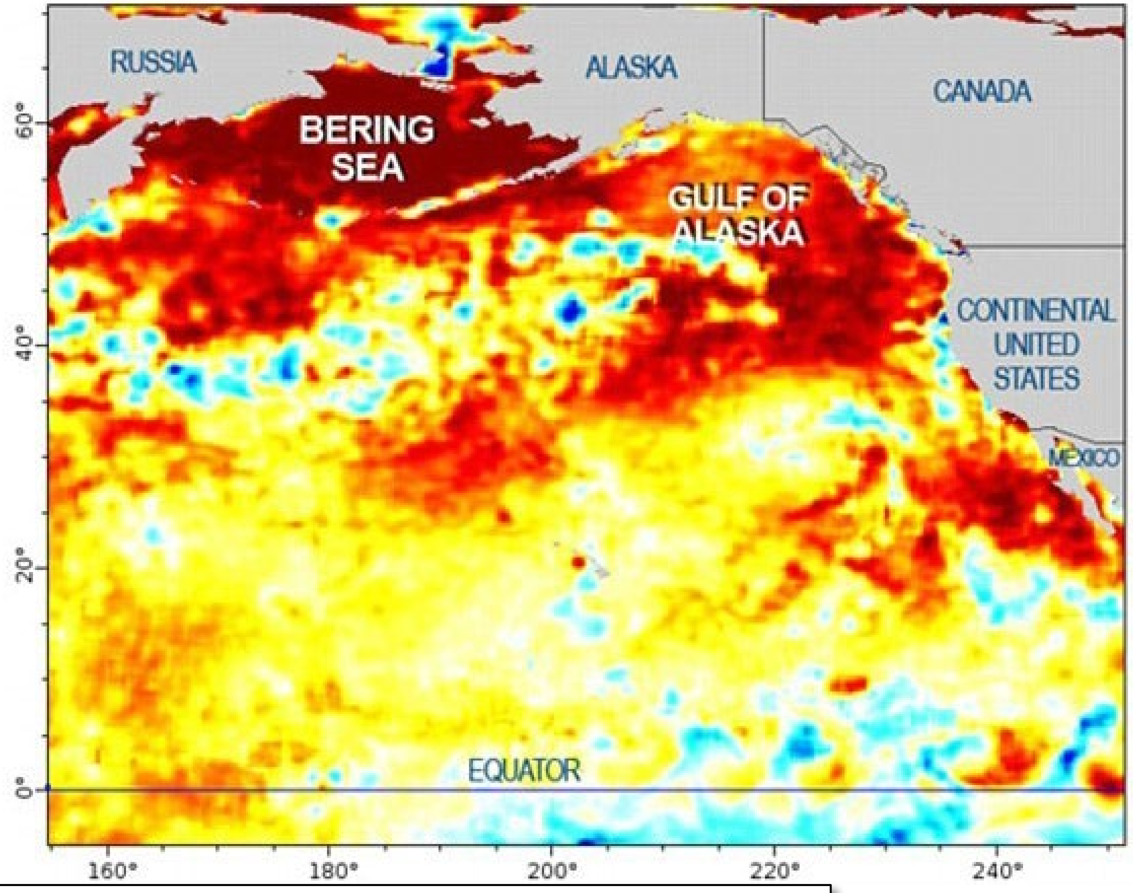



RESEARCH

OCEAN TEMPERATURE

## High-impact marine heatwaves attributable to human-induced global warming

Charlotte Laufkötter[1,2]*, Jakob Zscheischler[1,2], Thomas L. Frölicher[1,2]

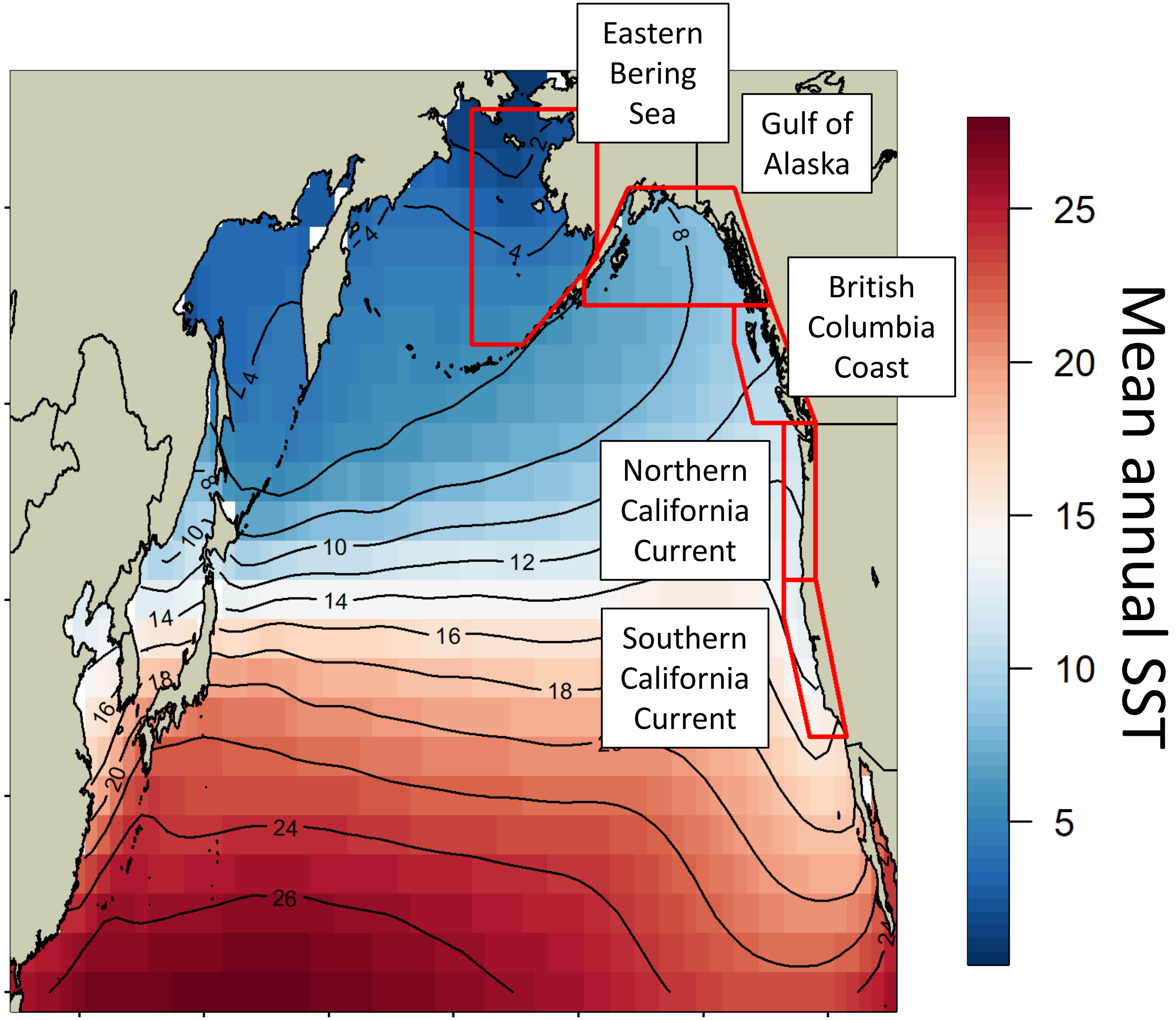
Marine heatwaves (MHWs)—periods of extremely high ocean temperatures in specific regions—have occurred in all of Earth's ocean basins over the past two decades, with severe negative impacts on marine organisms and ecosystems. However, for most individual MHWs, it is unclear to what extent they have been altered by human-induced climate change. We show that the occurrence probabilities of the duration, intensity, and cumulative intensity of most documented, large, and impactful MHWs have increased more than 20-fold as a result of anthropogenic climate change. MHWs that occurred only once every hundreds to thousands of years in the preindustrial climate are projected to become decadal to centennial events under 1.5°C warming conditions and annual to decadal events under 3°C warming conditions. Thus, ambitious climate targets are indispensable to reduce the risks of substantial MHW impacts.

that equals or exceeds the duration, intensity, and cumulative intensity of the observed MHW in preindustrial and present-day model simulations. These probabilities are denoted by $P^{duration}_{present-day}$, $P^{intensity}_{present-day}$, $P^{cumulativeintensity}_{present-day}$, $P^{duration}_{preindustrial}$, $P^{intensity}_{preindustrial}$, and $P^{cumulativeintensity}_{preindustrial}$, respectively.

Here, we explicitly take changes in the frequency of heatwaves as well as changes in the duration, intensity, or cumulative intensity of heatwaves into account (see materials and methods). Our approach builds on the work of Stott *et al.* (28) and Oliver *et al.* (6) but with several modifications. In contrast to most previous attribution studies, we specifically calculate the occurrence probabilities of heatwaves as opposed to the probabilities of ex-

# Methods

1. Build time series of attribution statistics to measure change in human influence on North Pacific SST
2. Use attribution statistics as covariates in statistical models to evaluate ecosystem services during different levels of human influence
3. Use climate model hindcasts and projections to compare climate risk from backward-looking and forward-looking perspectives



# Fraction of Attributable Risk (FAR)

FAR: how much of the risk for an event is due to human activity?

$$\text{FAR} = 1 - \frac{\text{preindustrial probability}}{\text{current probability}}$$

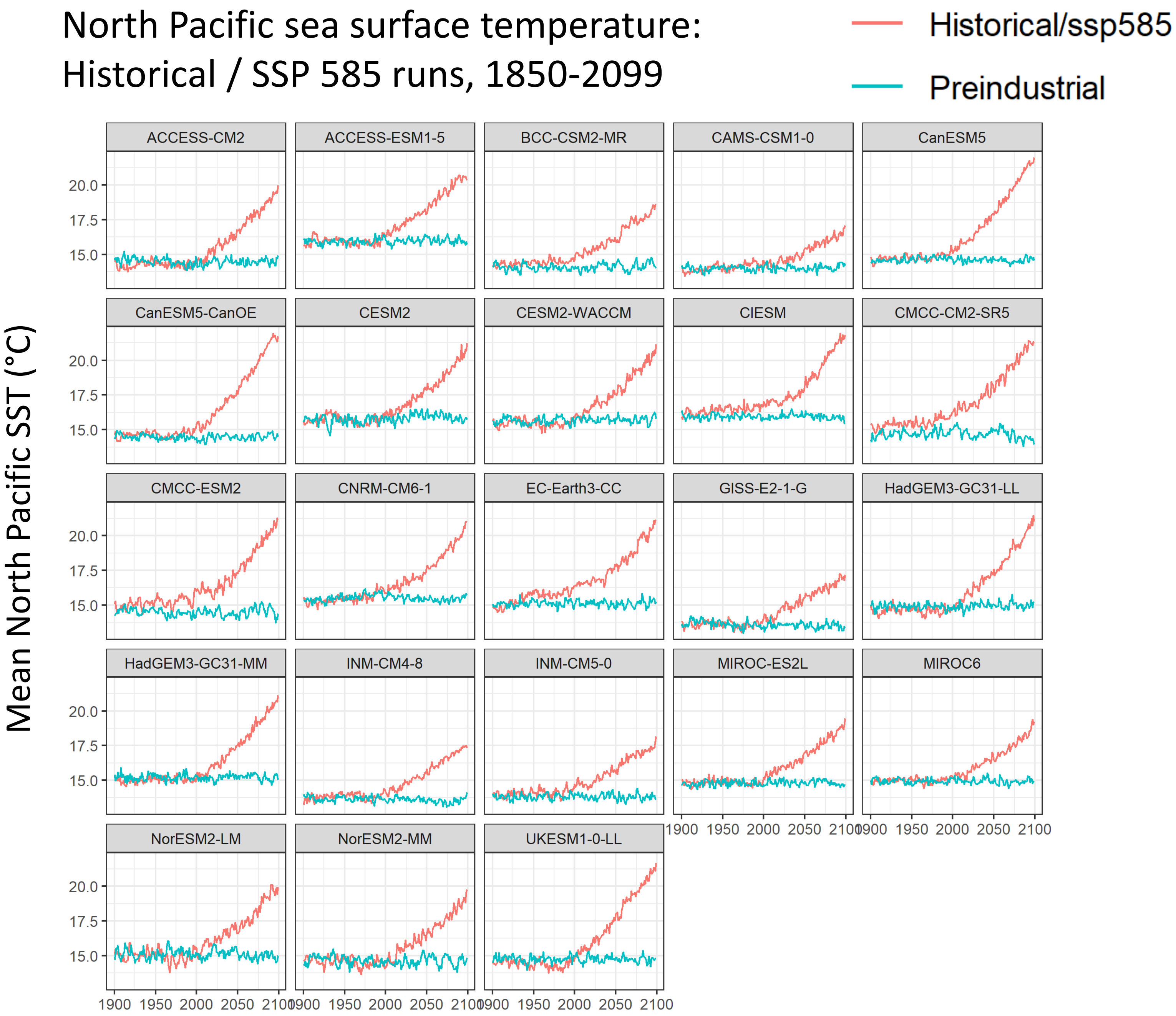
FAR = 0 → equally likely with / without human influence

FAR = 0.5 → twice as likely with human influence

FAR = 1 → only possible with human influence

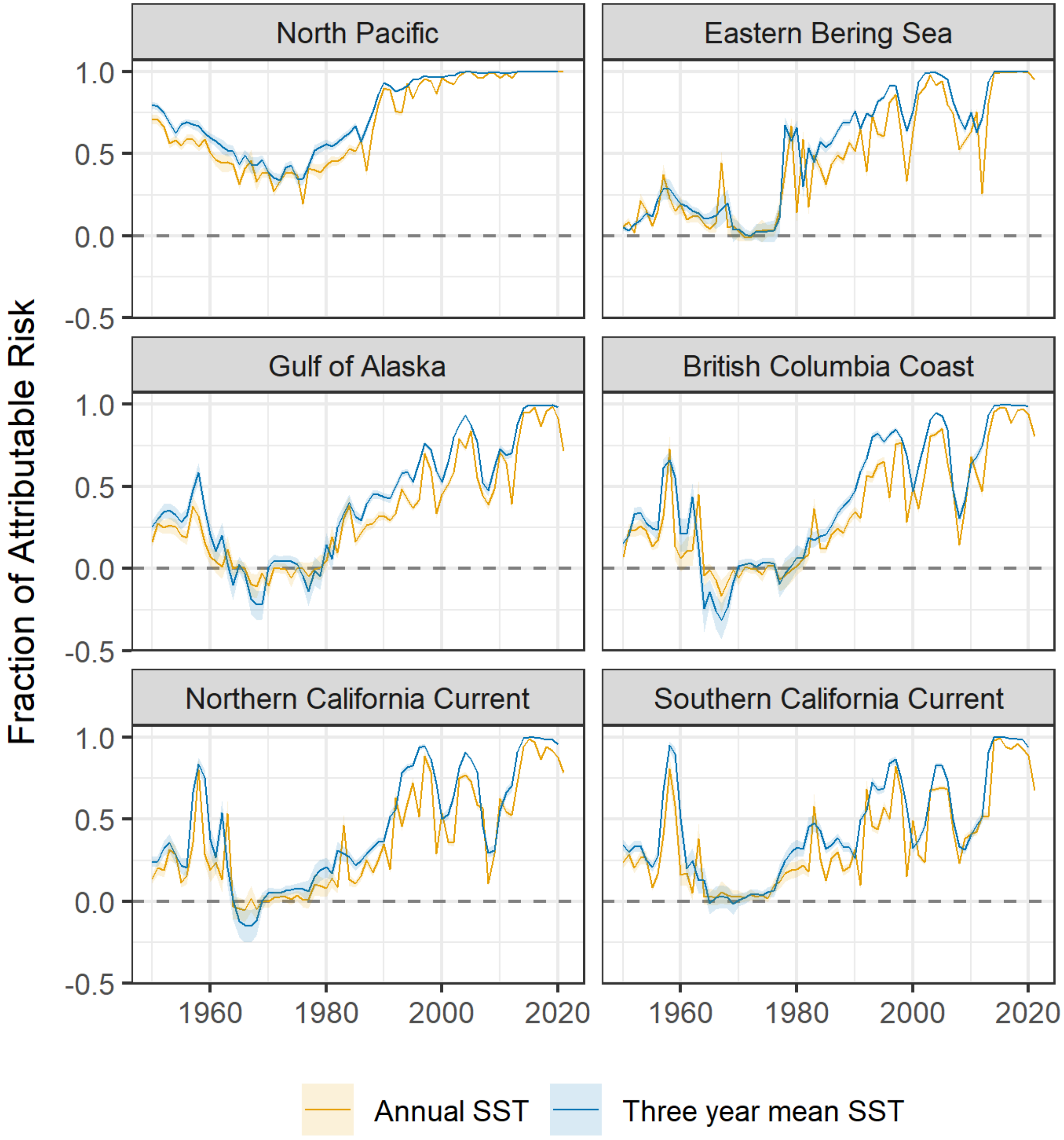
# FAR calculated from 23 CMIP6 models

- Weighted for bias, autocorrelation, low-frequency prediction (compared with observations)
- Corrected for differences in climate sensitivity and predicted warming rate (~~model democracy~~)
- Multi-model estimates constructed with Bayesian methods

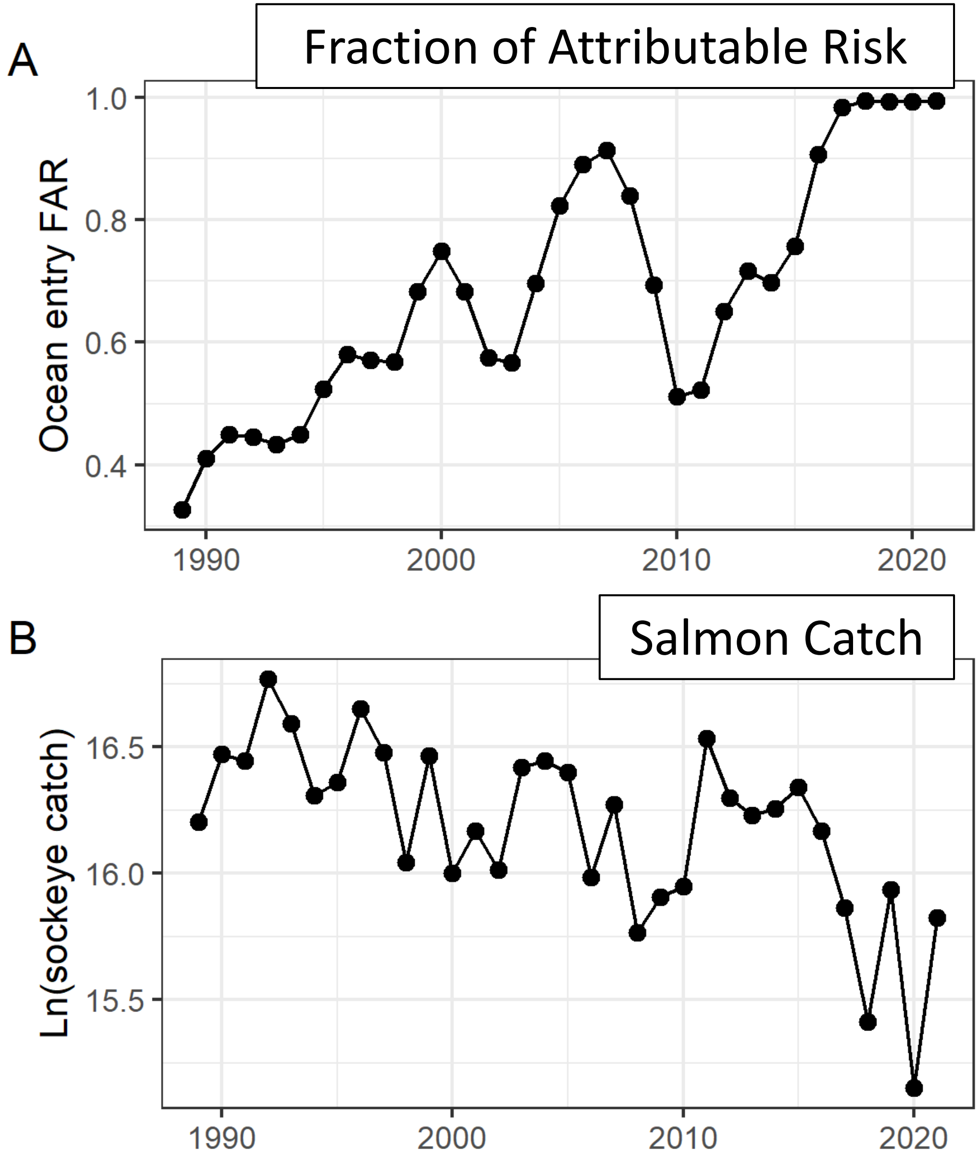


# Attribution time series show the trend in human influence on North Pacific SST

FAR for SST: posterior means with 95% credible intervals

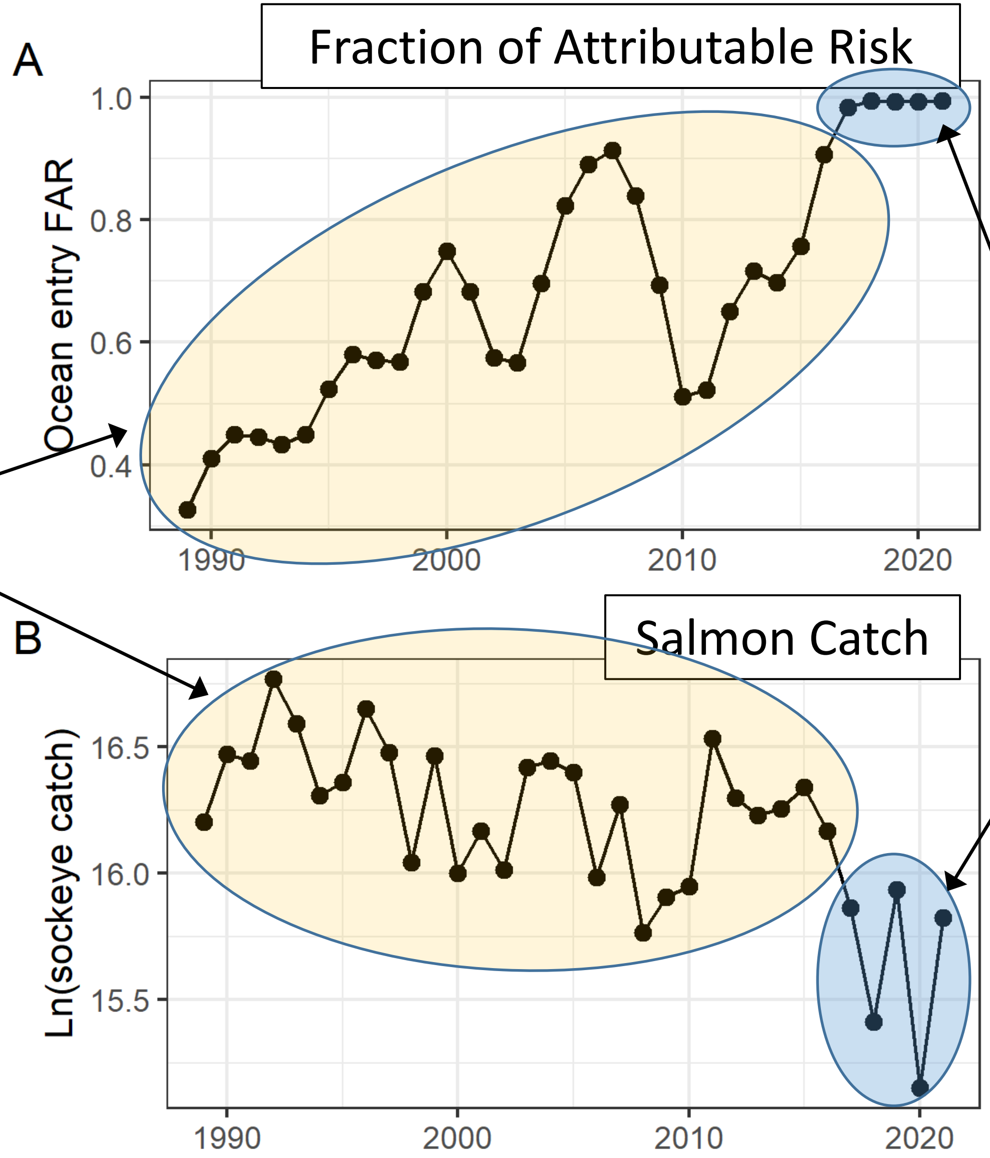


# How have anthropogenic extremes affected sockeye salmon to date?



# How have anthropogenic extremes affected sockeye salmon to date?

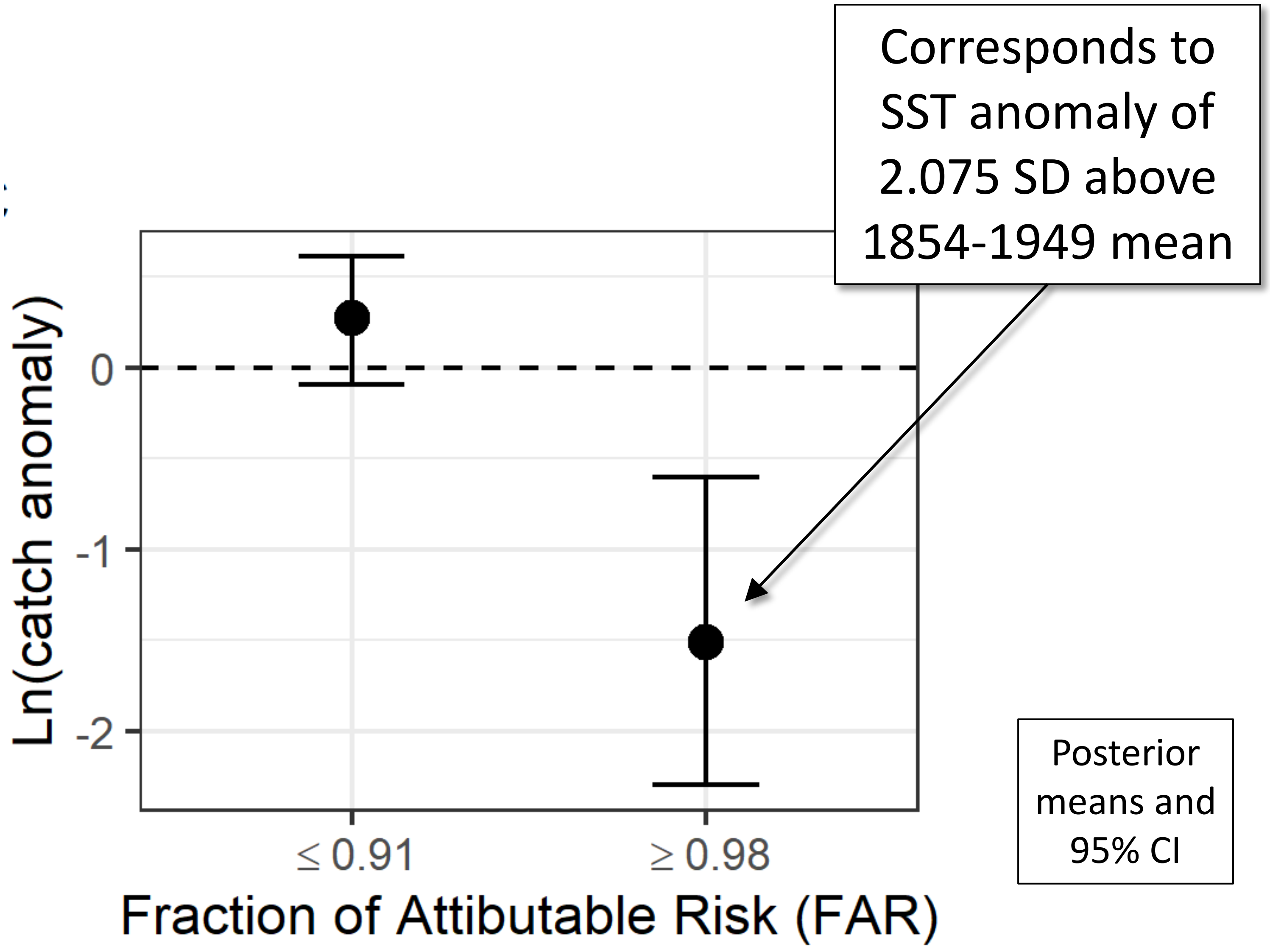
FAR < 0.91
Temperatures 1.5 – 11 times more likely due to human activities




FAR > 0.98
Temperatures 60 – 190 times more likely due to human activities

Predicted catches decline ~1.5 SD in log space when FAR > 0.98

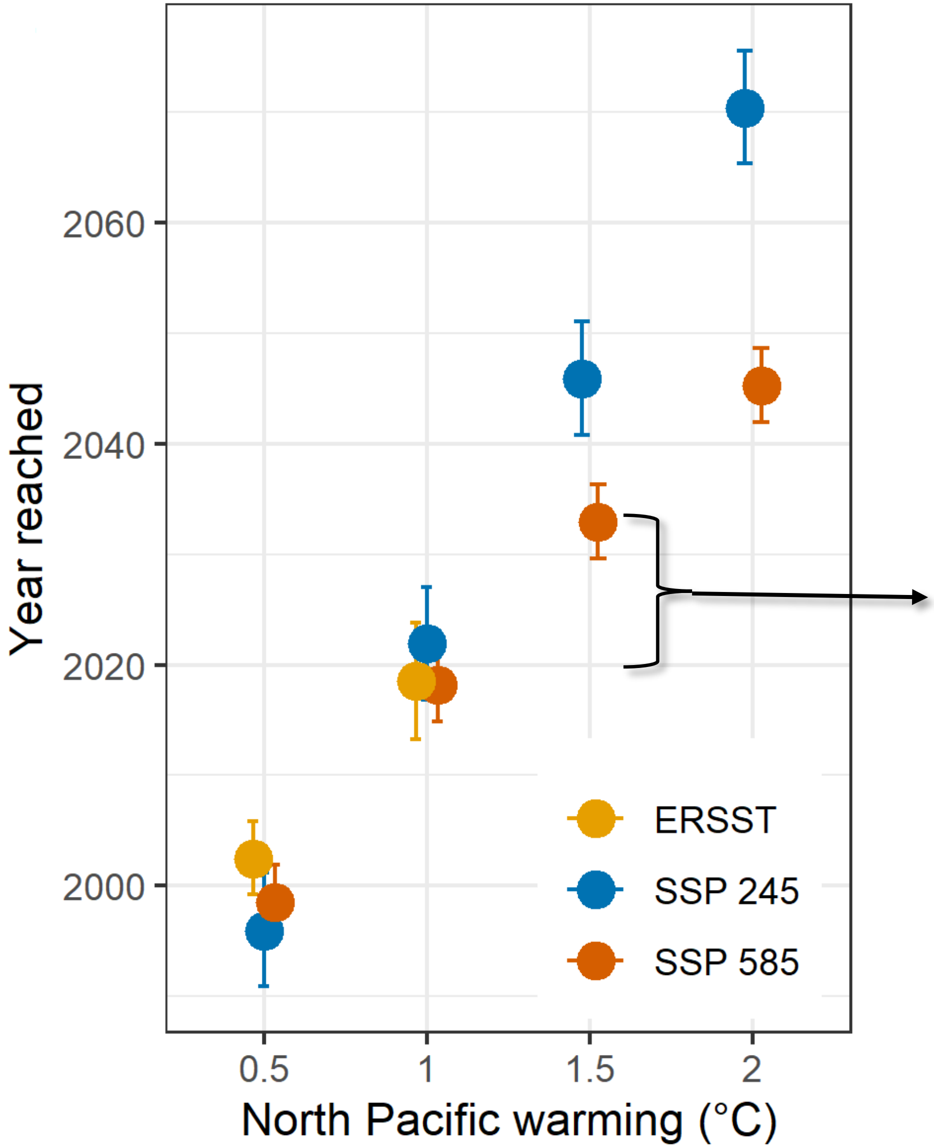
Adaptation question: How often should we expect anomalies this large?




Posterior means and 95% CI

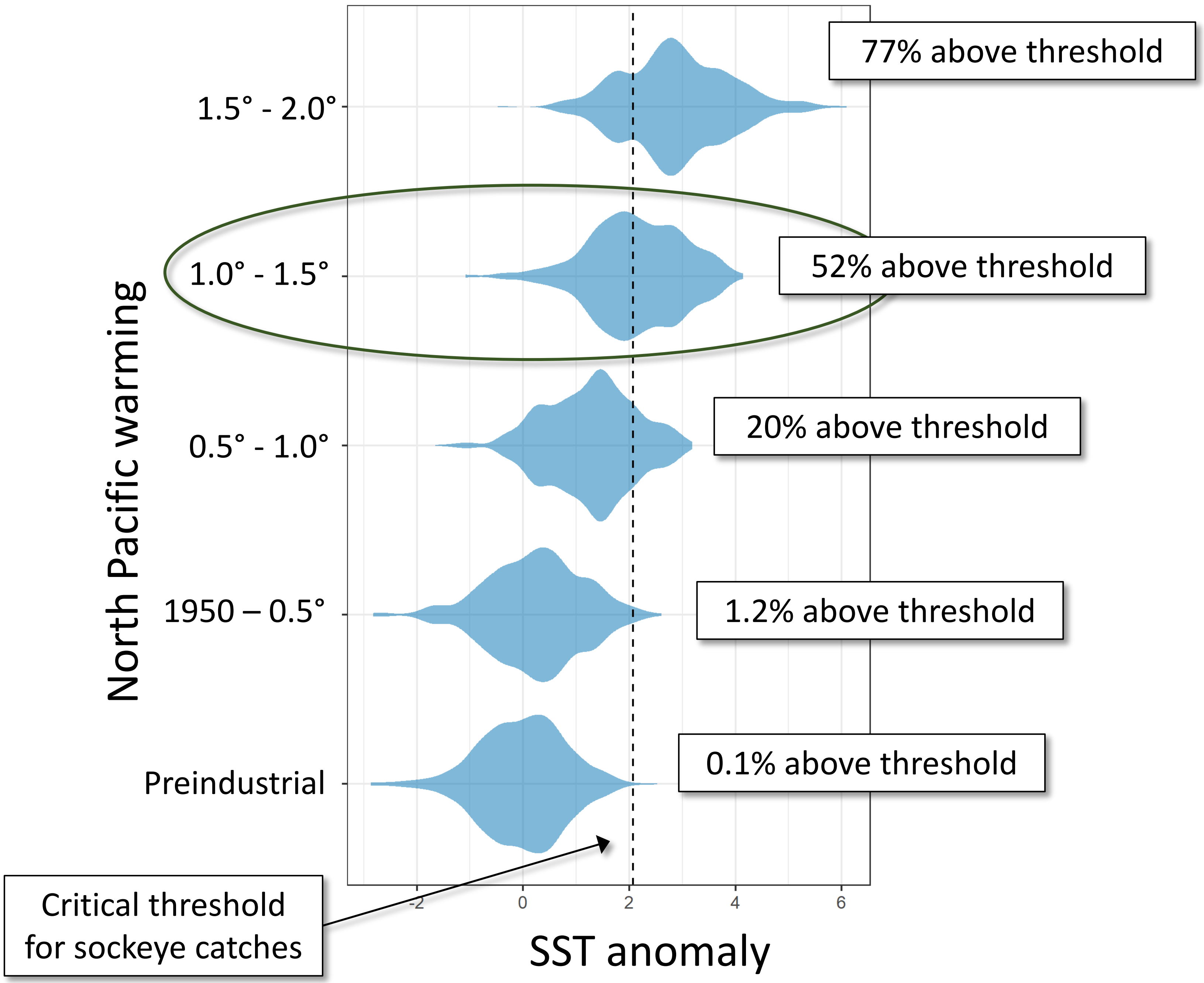
# Distinguishing backward-looking and forward-looking estimates of risk

North Pacific warming from preindustrial (1850-1949): observations (ERSST) and CMIP6 runs under two scenarios




North Pacific is currently between 1.0° and 1.5° warmer than preindustrial (very high confidence)

# Gulf of Alaska SST probability distributions at different levels of North Pacific warming

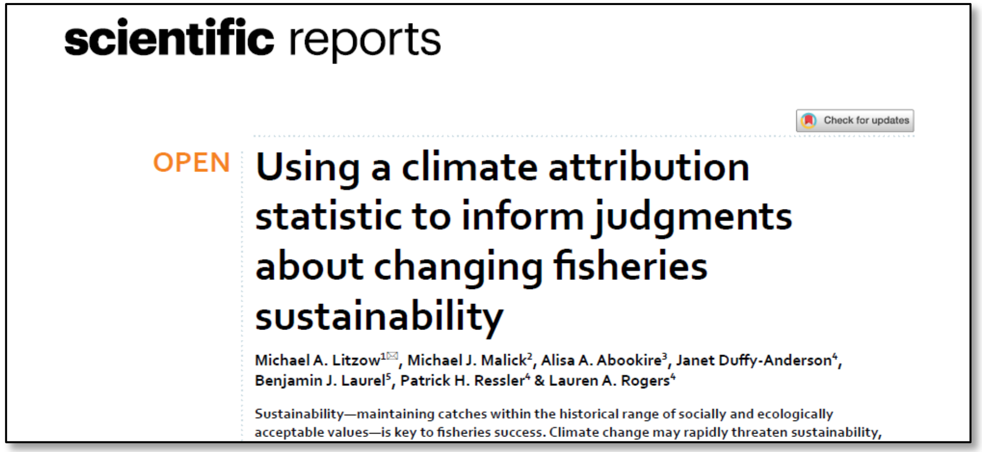


# Caveats

- Internal variability
- Regional-scale uncertainty in CMIP6
- Sensitivity to model weighting approach
- Assumes constant SST-salmon relationship going forward

# Other applications

Gulf of Alaska: Pacific cod and walleye pollock recruitment / sustainability


scientific reports

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OPEN

Using a climate attribution statistic to inform judgments about changing fisheries sustainability

Michael A. Litzow[1], Michael J. Malick[2], Alisa A. Abookire[3], Janet Duffy-Anderson[4], Benjamin J. Laurel[5], Patrick H. Ressler[4] & Lauren A. Rogers[4]

Sustainability—maintaining catches within the historical range of socially and ecologically acceptable values—is key to fisheries success. Climate change may rapidly threaten sustainability,

Litzow et al. (2020) Scientific Reports

Ongoing work: Bering Sea borealization and snow crab mortality