Climate informed decision support tools

ACLIM & CEFI

Kirstin Holsman
SSC Workshop
02-08-2023

ACLIM Team

Supporting climate resilience through climate-informed Ecosystem Based Management advice

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Cheryl Barnes
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Adam Hayes
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David Kimmel
Stan Kotwicki
Ben Laurel
Carey McGilliard
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Jennifer Bigman
Jessica Reynolds
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Cathleen Vestfals
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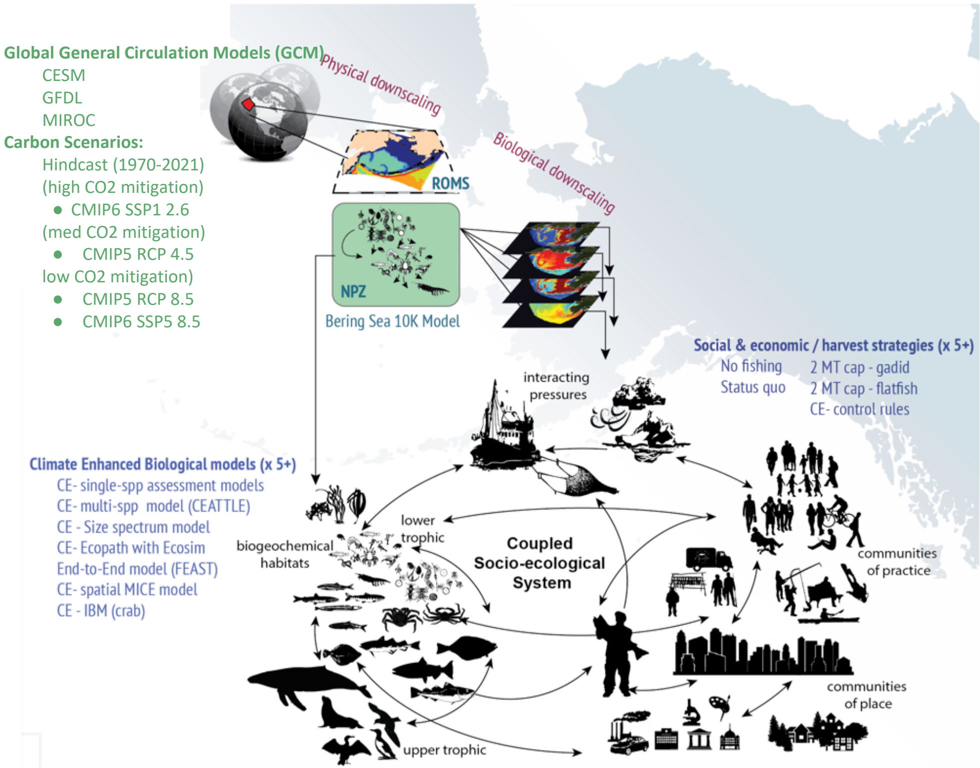
Charlie Stock
Mike Dalton
Jordon Watson
Franz Mueter
Thomas Hurst
James Thorson
Trond Kristiansen

www.fisheries.noaa.gov/alaska/ecosystems/alaska-climate-integrated-modeling-project

The Alaska Climate Integrated Modeling Project

Goal: To address climate information needs with best available science & tools



What to expect?

- Project physical and ecological conditions under levels of climate change (levels of global carbon mitigation)
- Characterize uncertainty

What can be done?

- Evaluate effectiveness of adaptation actions including those supported by fisheries management

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UNIVERSITY of WASHINGTON SAFS School of Aquatic and Fishery Sciences

IEA INTEGRATED ECOSYSTEM ASSESSMENT

ACLIM The Alaska Climate Integrated Modeling NOAA Alaska Fisheries Science Center

Hollowed et al. 2020. https://doi.org/10.3389/fmars.2019.00775

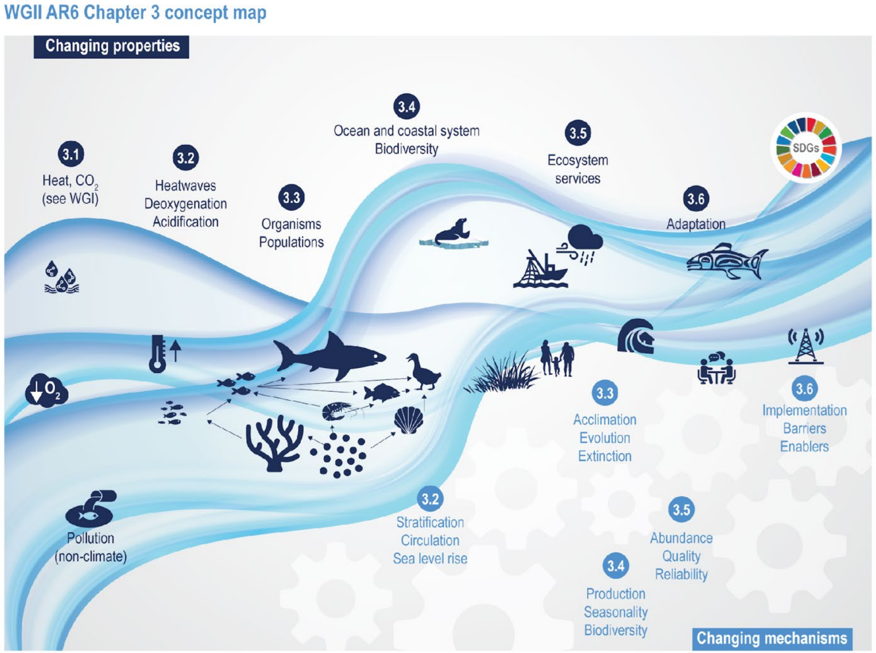
www.fisheries.noaa.gov/alaska/ecosystems/alaska-climate-integrated-modeling-project

Today's Talk

1. Brief introduction to climate planning, risk, adaptation, and CO_2 mitigation
2. Linking to day 1: projected changes to NEBS conditions and carrying capacity
3. Actionable advice
   a. Climate informed control rules (ACLIM2 spring sprint)
   b. Climate informed spatial and scenario planning
4. Next steps, CEFI and ACLIM3

Example Climate Change Impacts & Risks

- Shifting distributions & altered access
- Shifts in trophic pathways & size spectra
- Phenological mismatches & changes in productivity
- Reductions in fishery & subsistence resources
- Future risk to food & nutritional security
- Geopolitical, survey, stock boundary challenges
- Increased interactions between protected species & fisheries (e.g., pot fisheries)
- Compound multiple climate impacts (MHW, HABs, and low DO) & non-climate pressures (e.g., pollution, shipping)
- Increasing fishery emergencies & economic losses
- Reduced confidence in management
- Supply chain disruption (e.g., ports)
- Changes in safety & security
- Changes in markets & demand (interactions with agriculture)



www.ipcc.ch/report/sixth-assessment-report-working-group-ii


Adaptation is underway but remains largely reactive, uncoordinated, and uneven across regions, communities, and sectors.

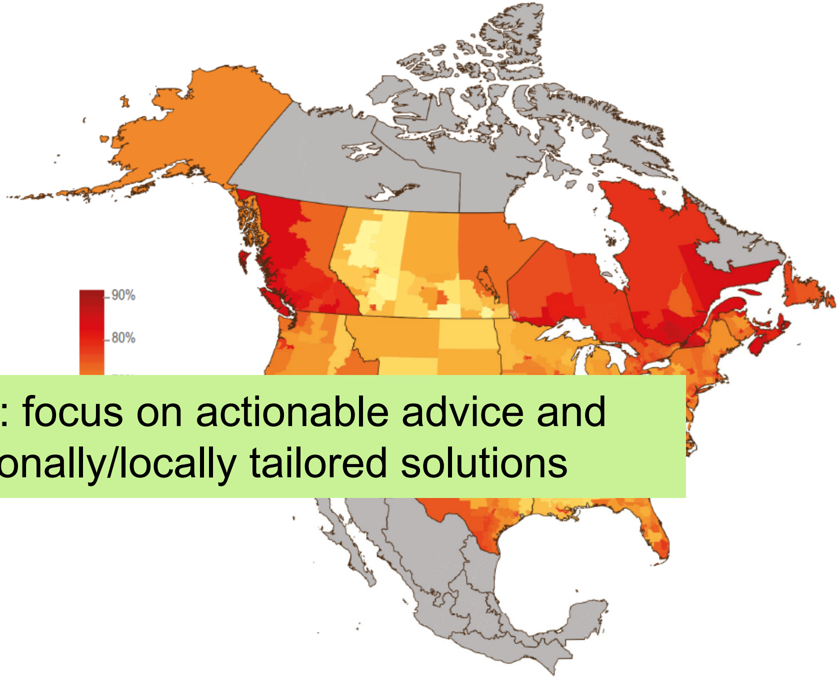
14.3.4 Factors Influencing Perceptions of Climate-Change Risks and Adaptation Action

“**Communicating** to educate or enhance knowledge on climate-change science or consensus can, but **does not necessarily lead individuals to revise their beliefs**”

“**Psychological distancing**–the perception that the greatest impacts occur sometime in the distant future and to people and places far away–**can lead to discounting of risk and the need for adaptation**”

“**Communication focused extensively on risks and dangers** of climate change can produce fear or dread, lessen agency and **create fatalism that hinders action**”

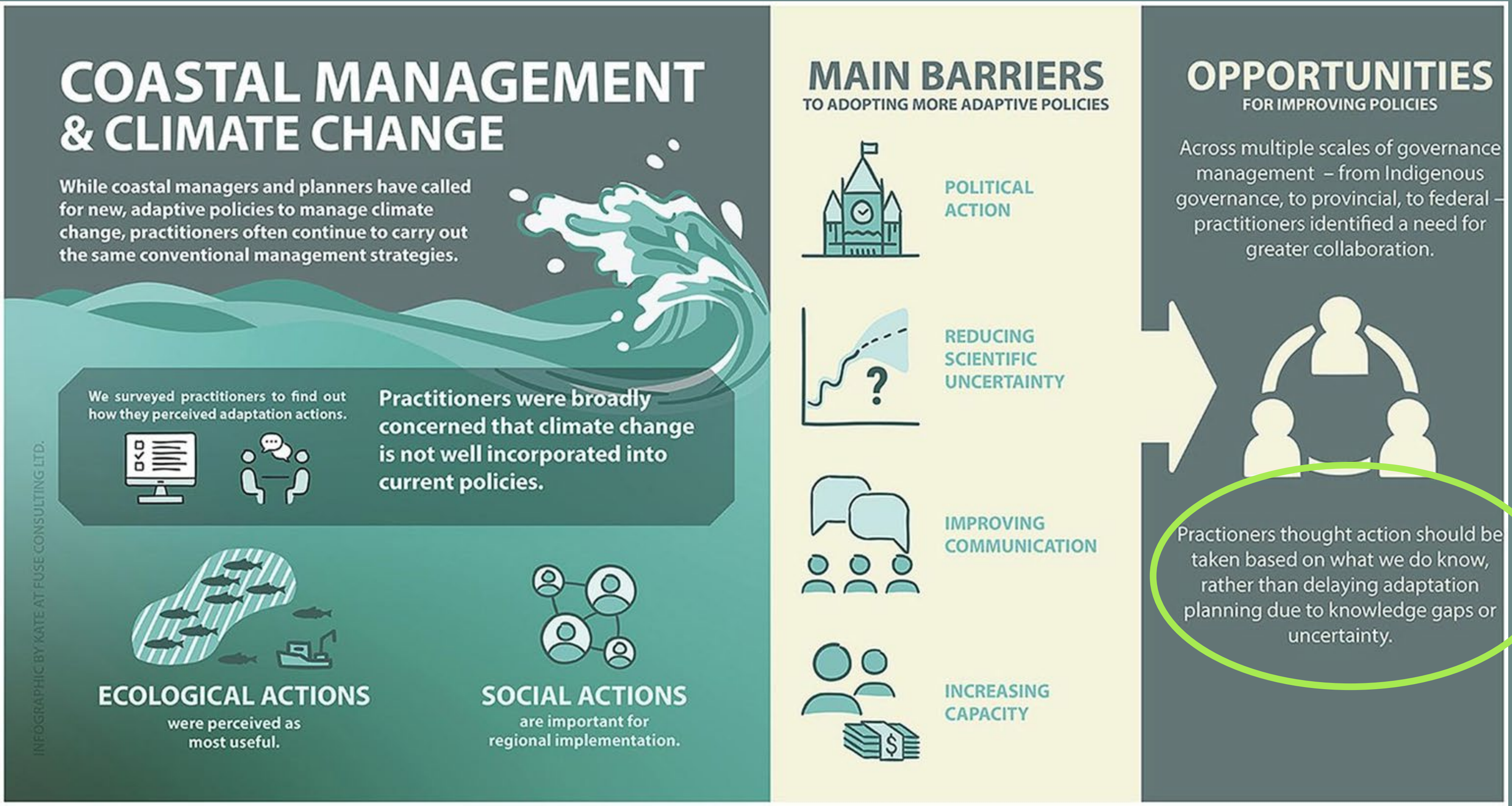
Estimated percent (%) of adults who think earth is getting warmer



Key: focus on actionable advice and regionally/locally tailored solutions

Figure 14.3 | Regional distribution of public perception that ‘the Earth is getting warmer’ as a surrogate for public acceptance that climate change is happening (percent of population). Scale is the Canadian federal electoral district or riding level and US congressional district. The three northern territories and Labrador, in Canada, did not meet population thresholds for modelling. The figure updates Mildenberger et al. (2016) and is based on equivalent public surveys in both countries: Canadian ‘Earth is getting warmer’ and US ‘global warming is happening’ undertaken in 2019. Equivalent surveys and modelling for Mexico are not available at the time of writing.

www.ipcc.ch/report/sixth-assessment-report-working-group-ii



Whitney and Ban, 2019 www.sciencedirect.com/science/article/abs/pii/S0964569119300390

Overall, the latest studies on the net economic implications of decarbonisation – which also account for avoided climate damages – **point to overall benefit from the transition.**

-*Prof Valentina Bosetti*

If people are provided with opportunities to make choices supported by policies, infrastructure and technologies, there is an untapped mitigation potential to **bring down global emissions by between 40 and 70% by 2050** compared to a baseline scenario.

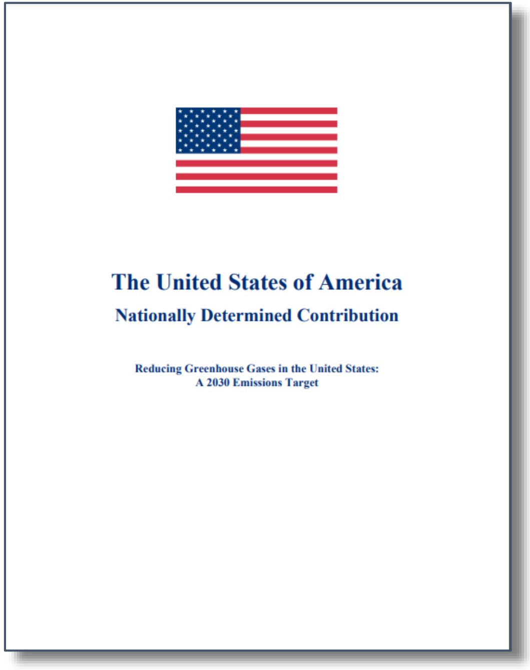
-*Prof Joyashree Roy*

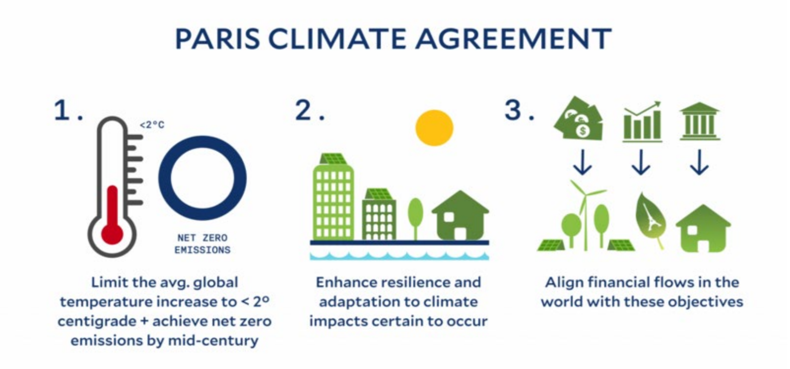
The evidence is clear: there are now mitigation options available in all sectors that could together **halve global greenhouse gas emissions by 2030.**

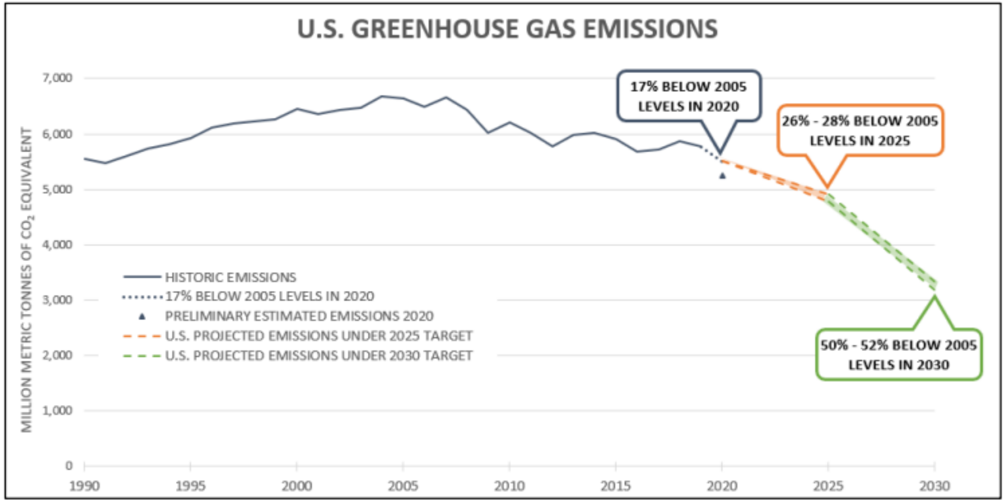
-*Dr Céline Guivarch*

Nationally Determined Contributions (NDCs)

https://unfccc.int/ndc-information/nationally-determined-contributions-ndcs



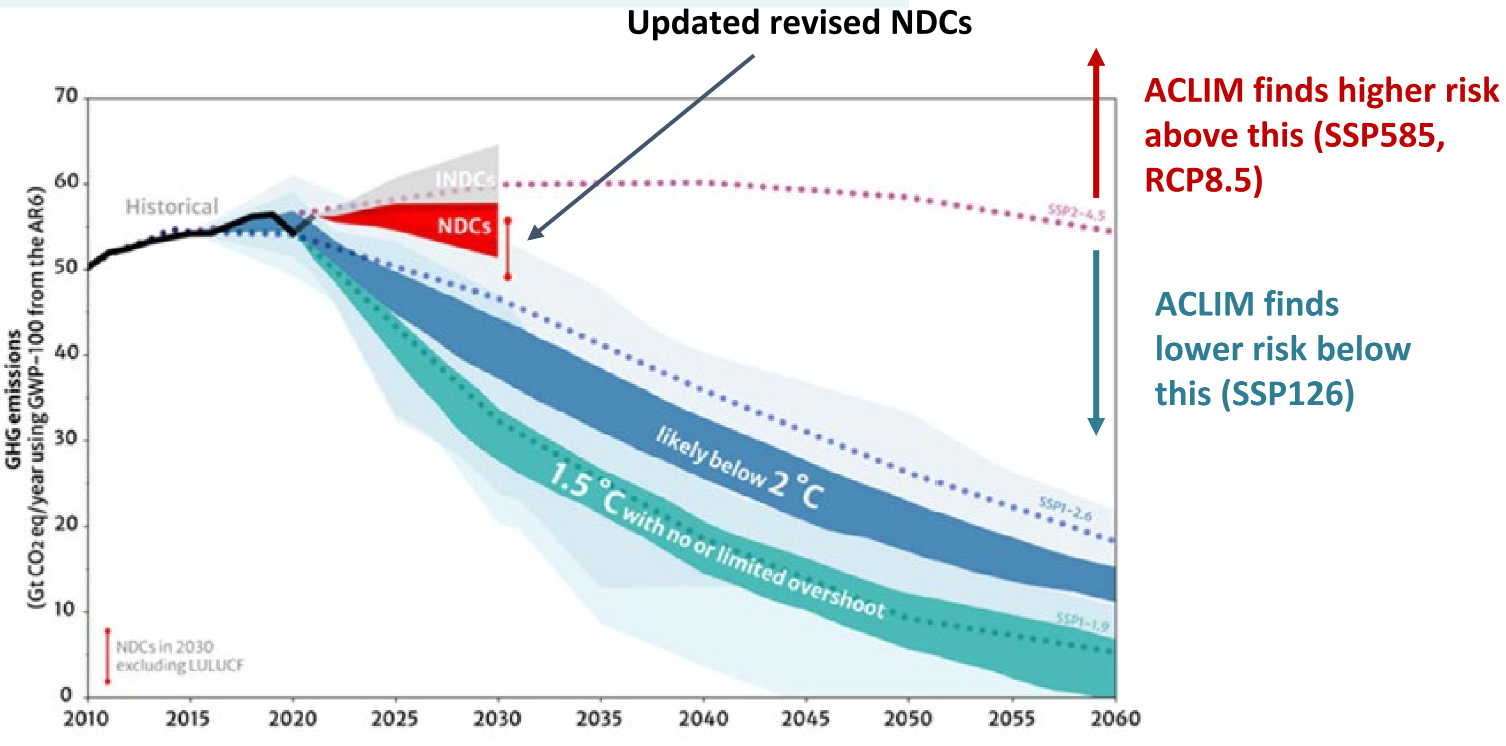




United States Historic Emissions and Projected Emissions Under 2030 Target

Graphic: https://sustainability.yale.edu/explainers/yale-experts-explain-paris-climate-agreement

UNFCC 2022 NDC Synthesis report



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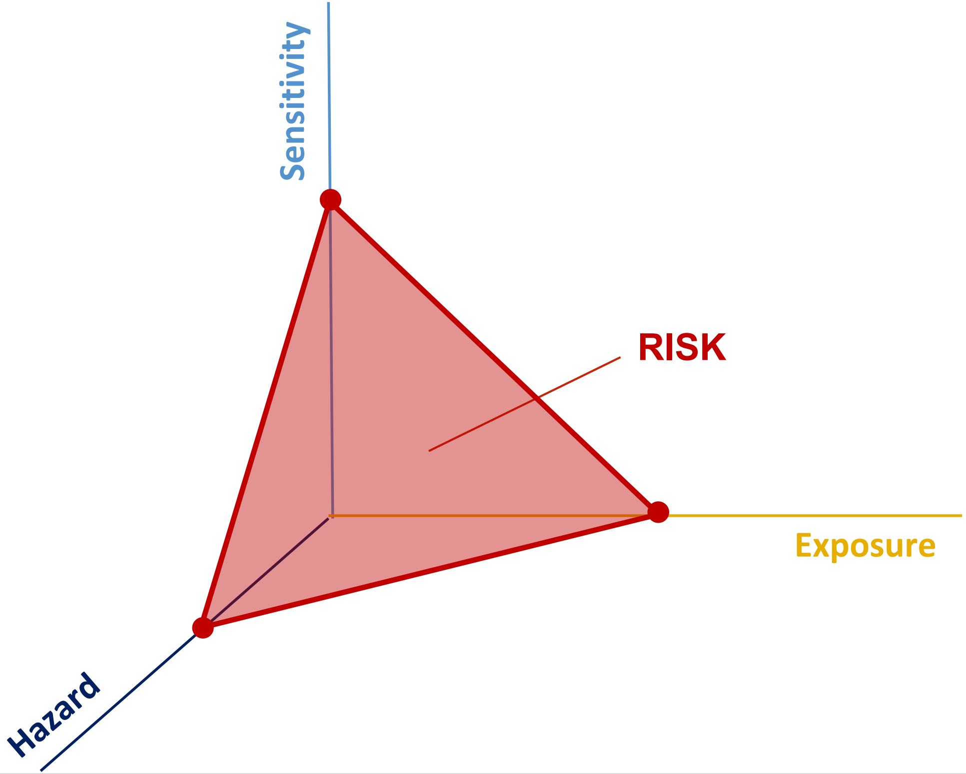
Climate Change Risk



- **Risk: potential for adverse consequences** for human or ecological systems, recognizing the diversity of values and objectives associated with such systems
- **Risk can arise from potential impacts of climate change as well as human responses** to climate change.
- **Residual risk** = remaining risk after adaptation
- **Maladaptation = Actions that may lead to increased risk of adverse climate-related outcomes,** including via increased GHG emissions, increased vulnerability to climate change, or diminished welfare, now or in the future

Modified from: www.ipcc.ch/report/sixth-assessment-report-working-group-ii

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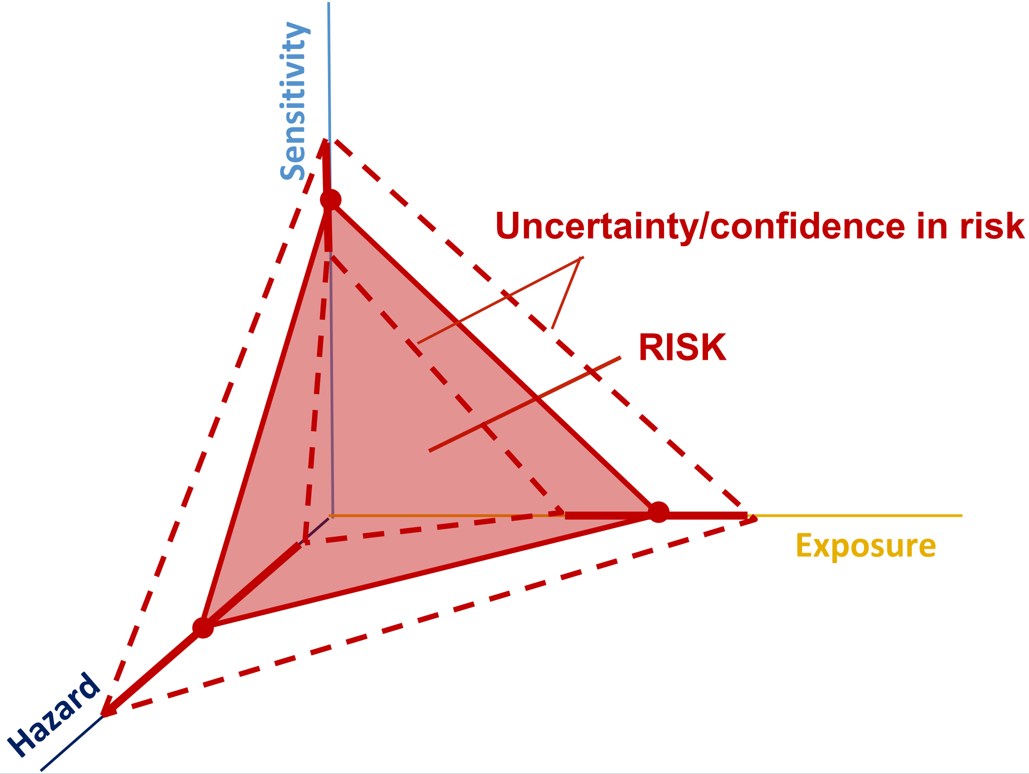

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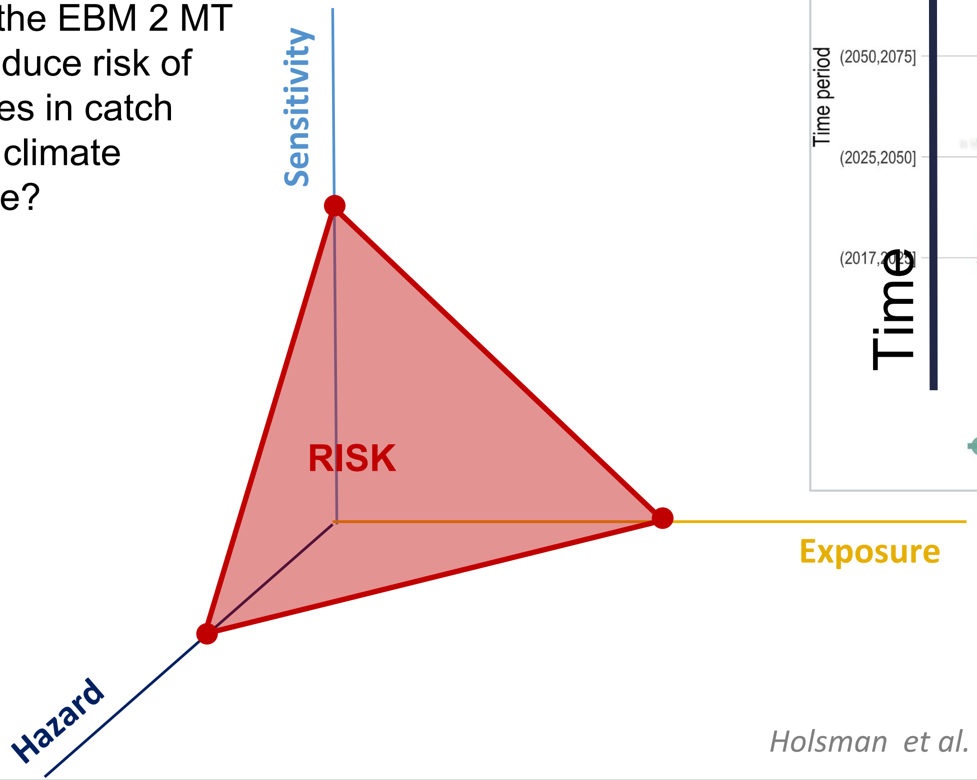
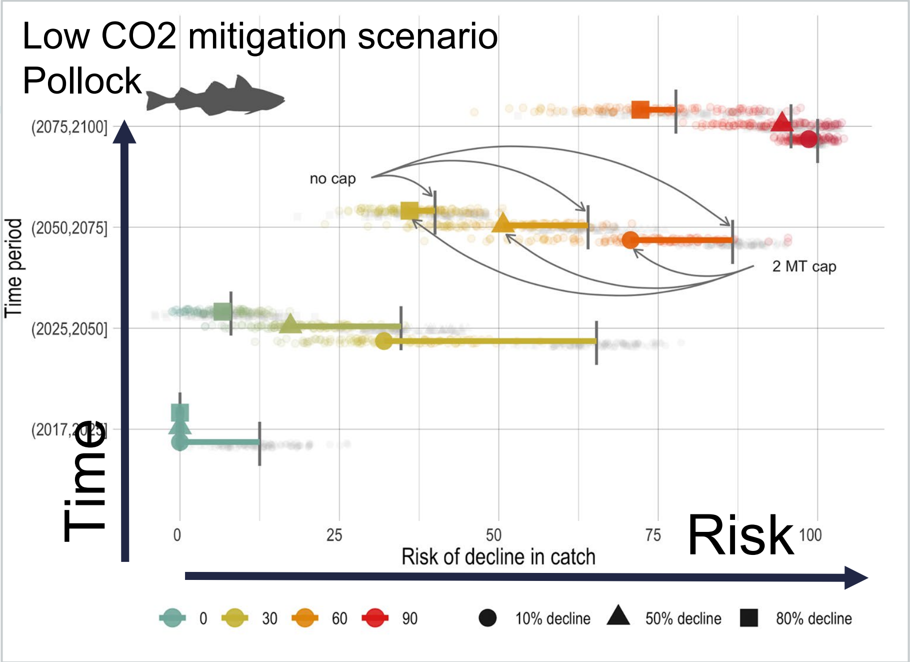
Climate Change Risk

Does the EBM 2 MT cap reduce risk of declines in catch under climate change?





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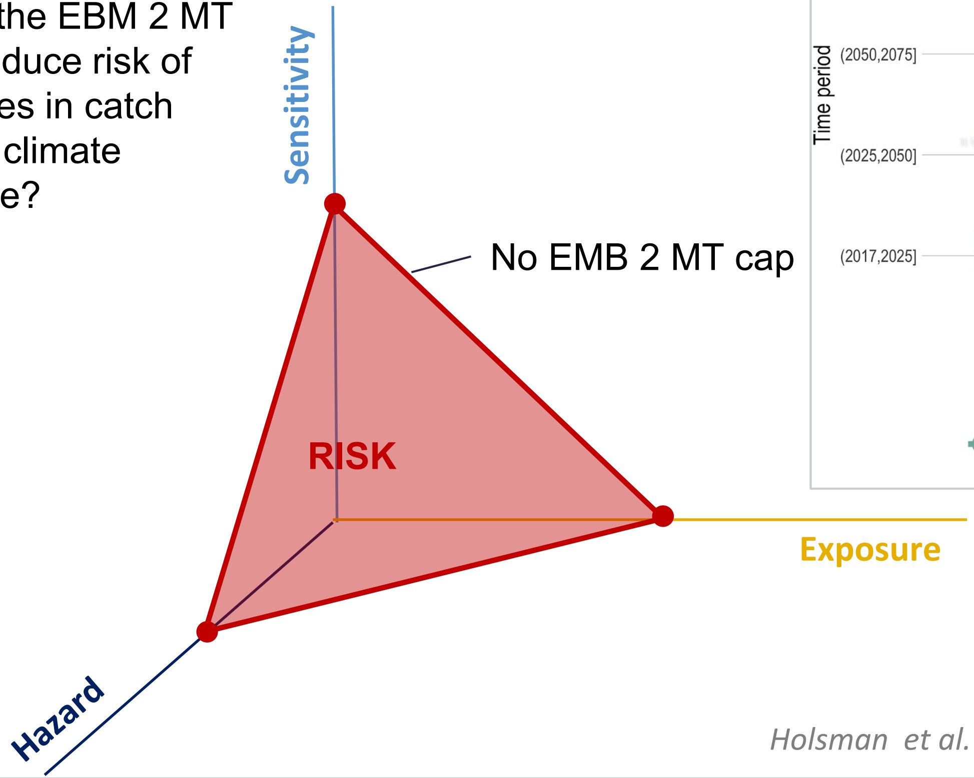

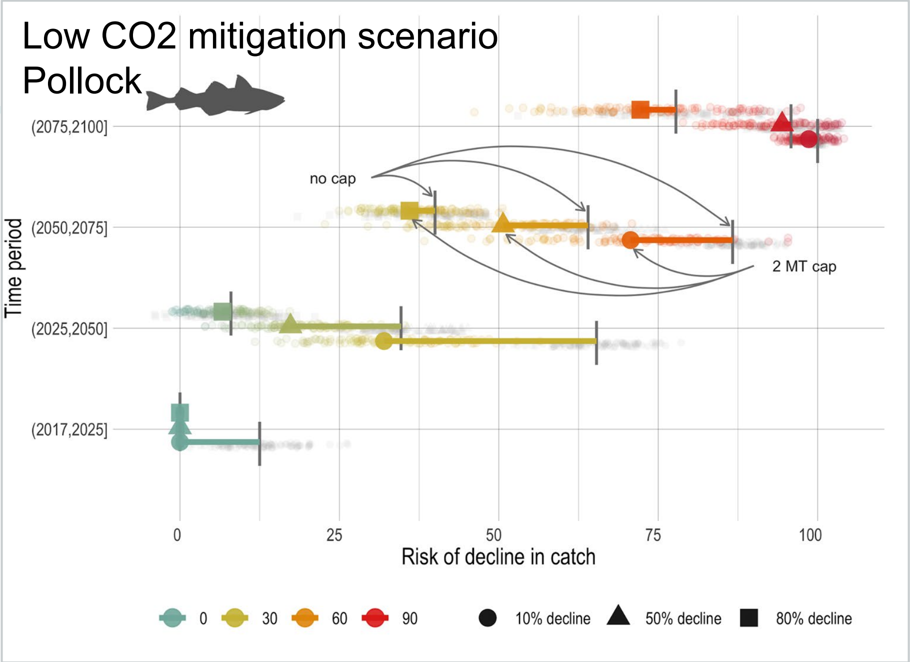

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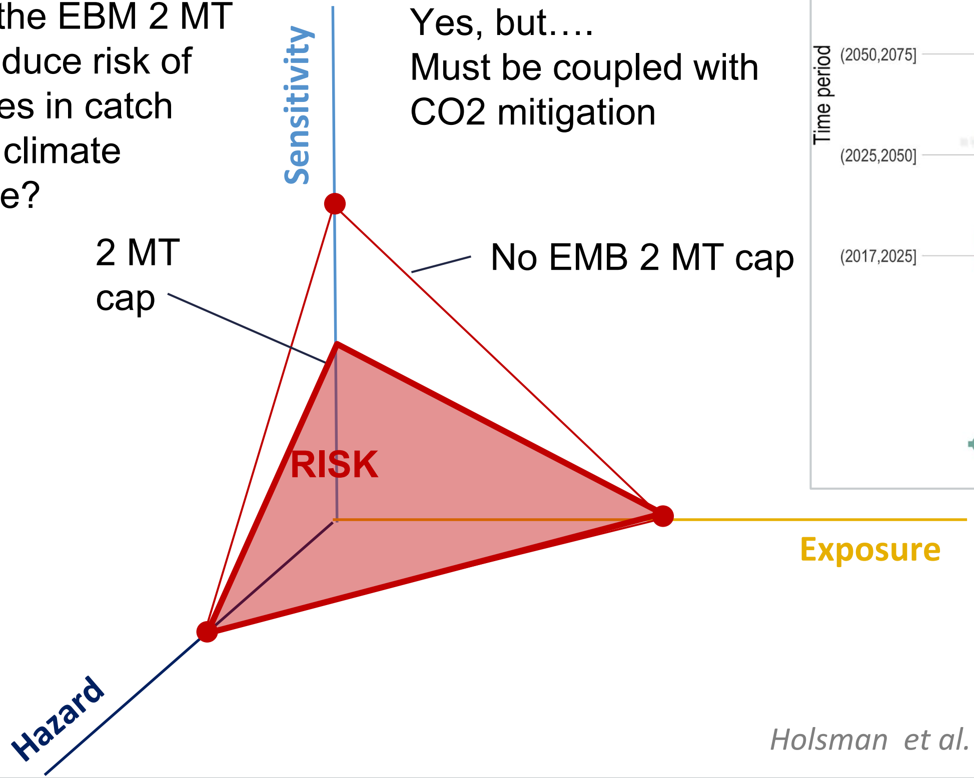
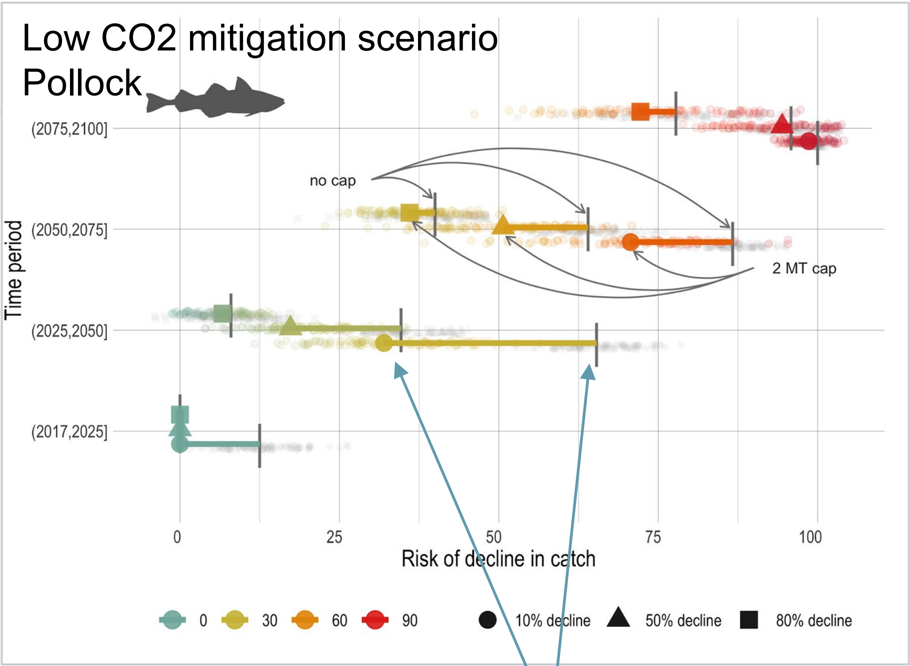
Must be coupled with CO_2 mitigation





Risk is lower for EBFM

Holsman et al. (2020). https://doi.org/10.1038/s41467-020-18300-3

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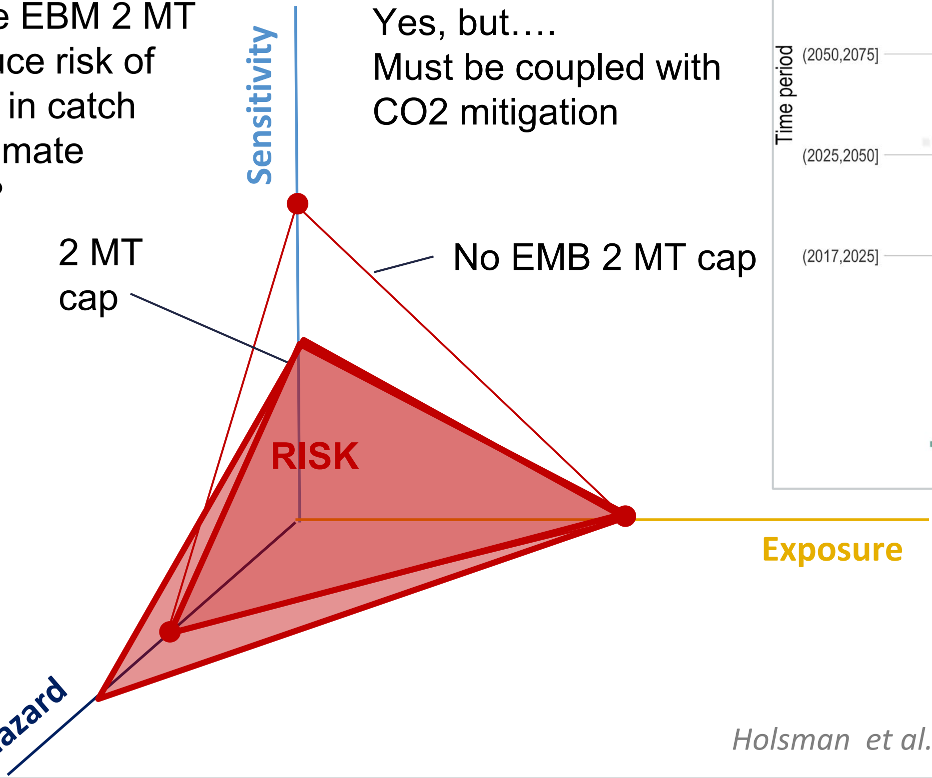

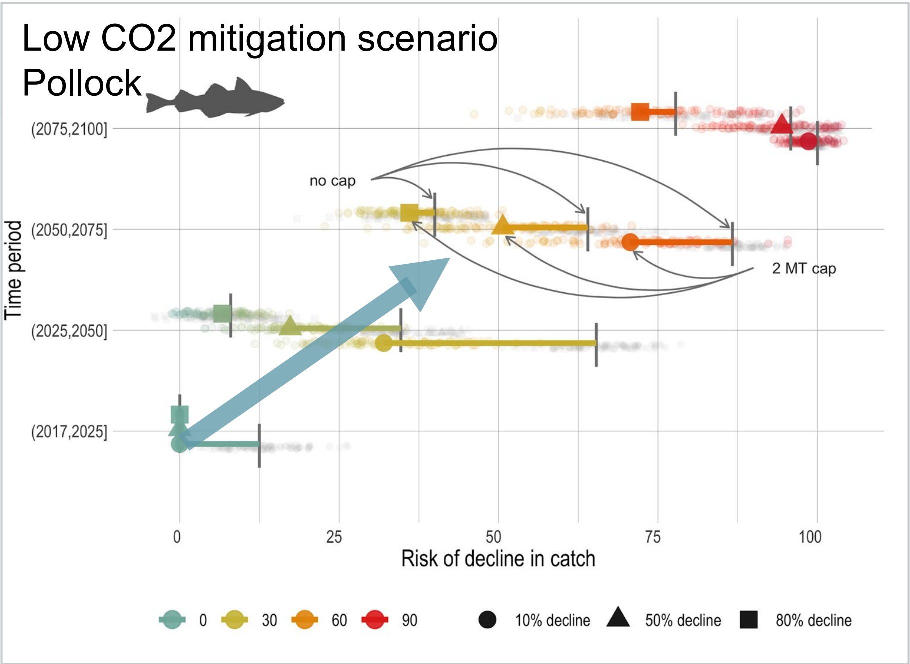

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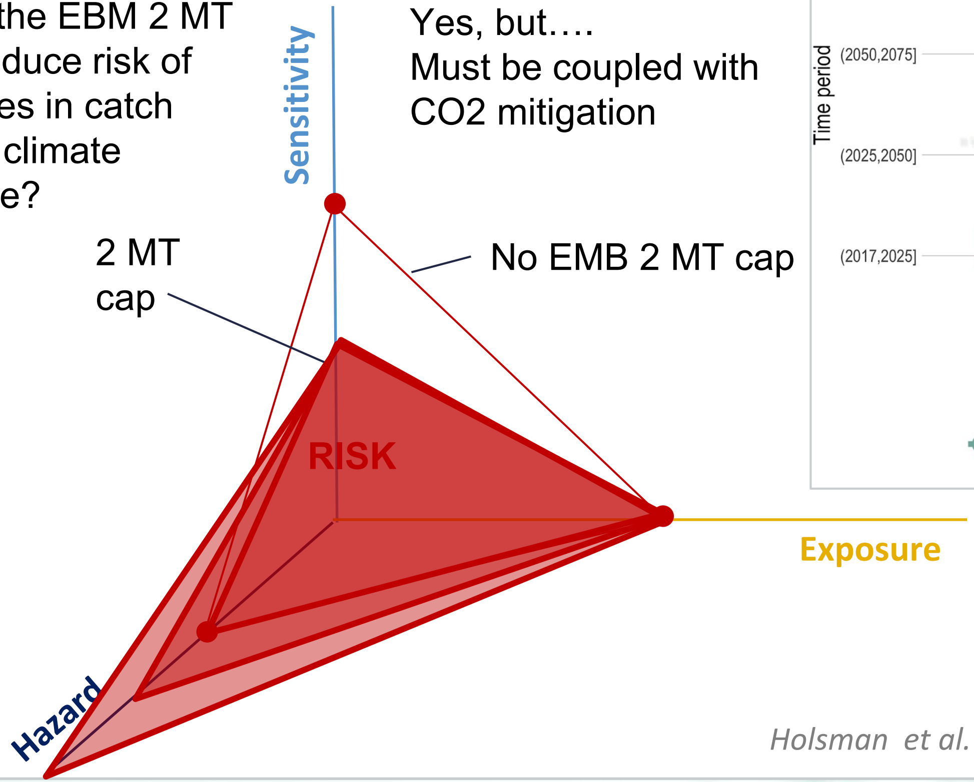

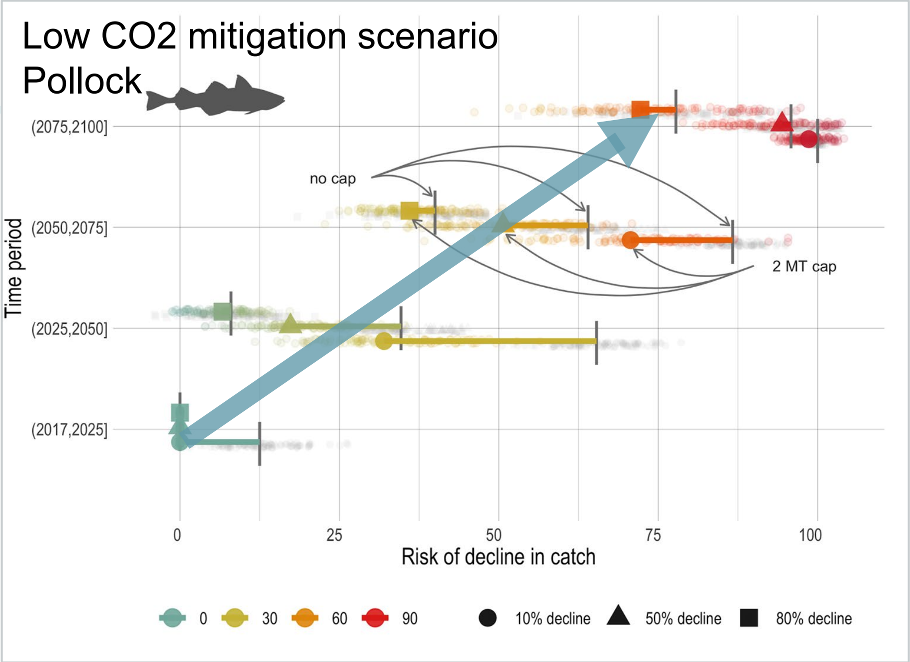

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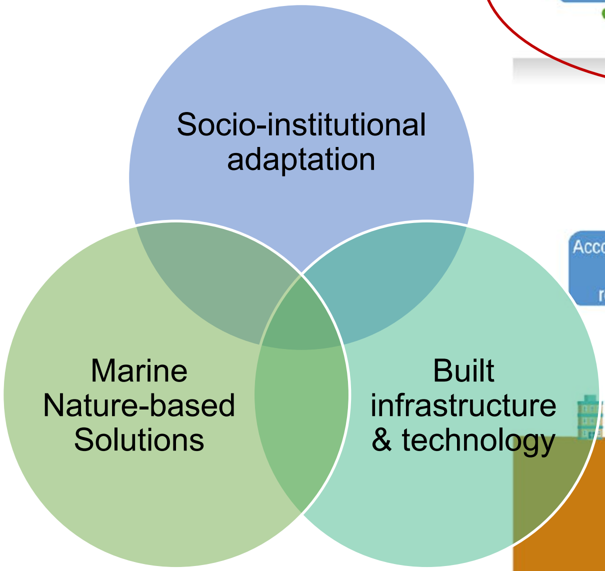
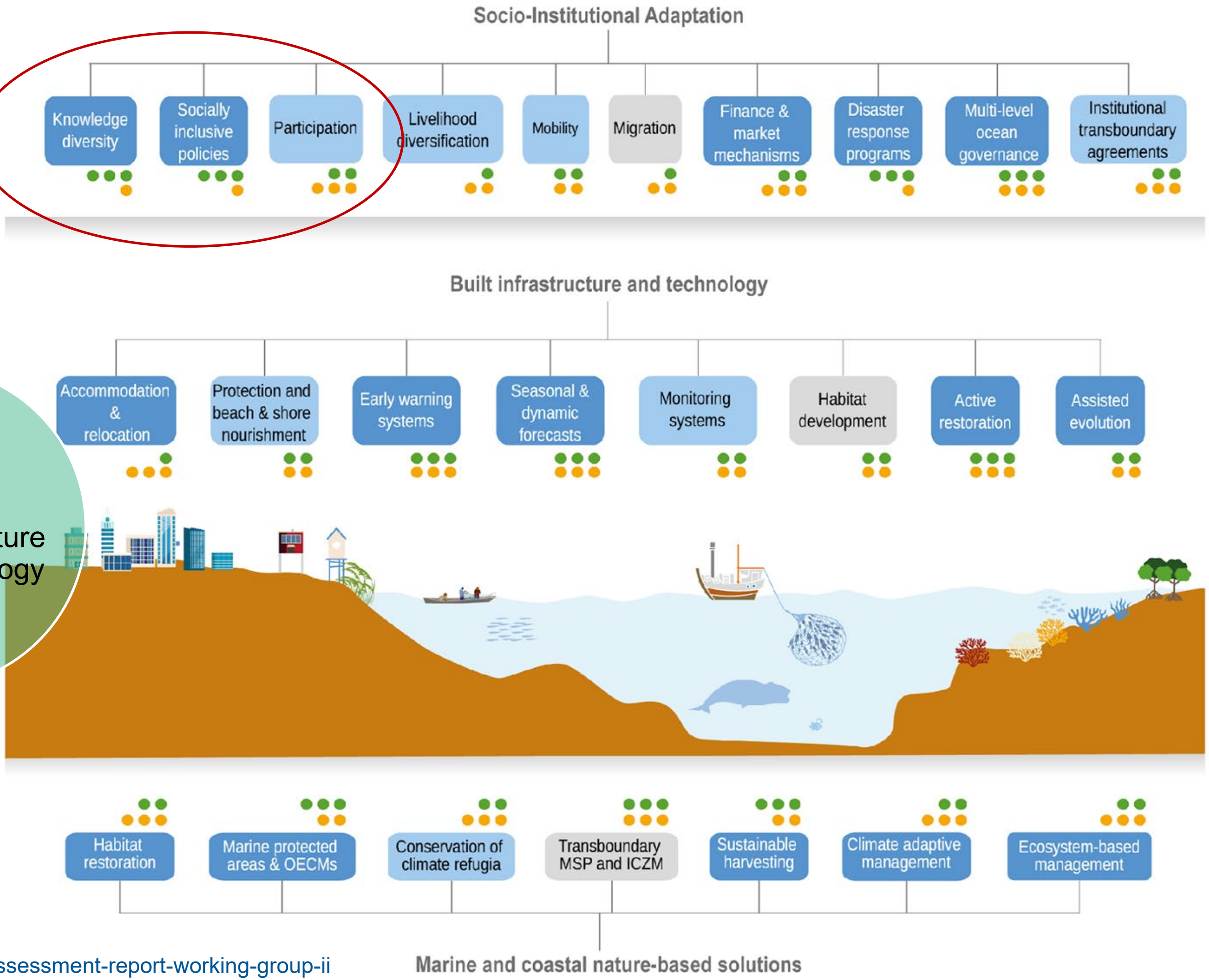
Adaptation





Chp3: www.ipcc.ch/report/sixth-assessment-report-working-group-ii

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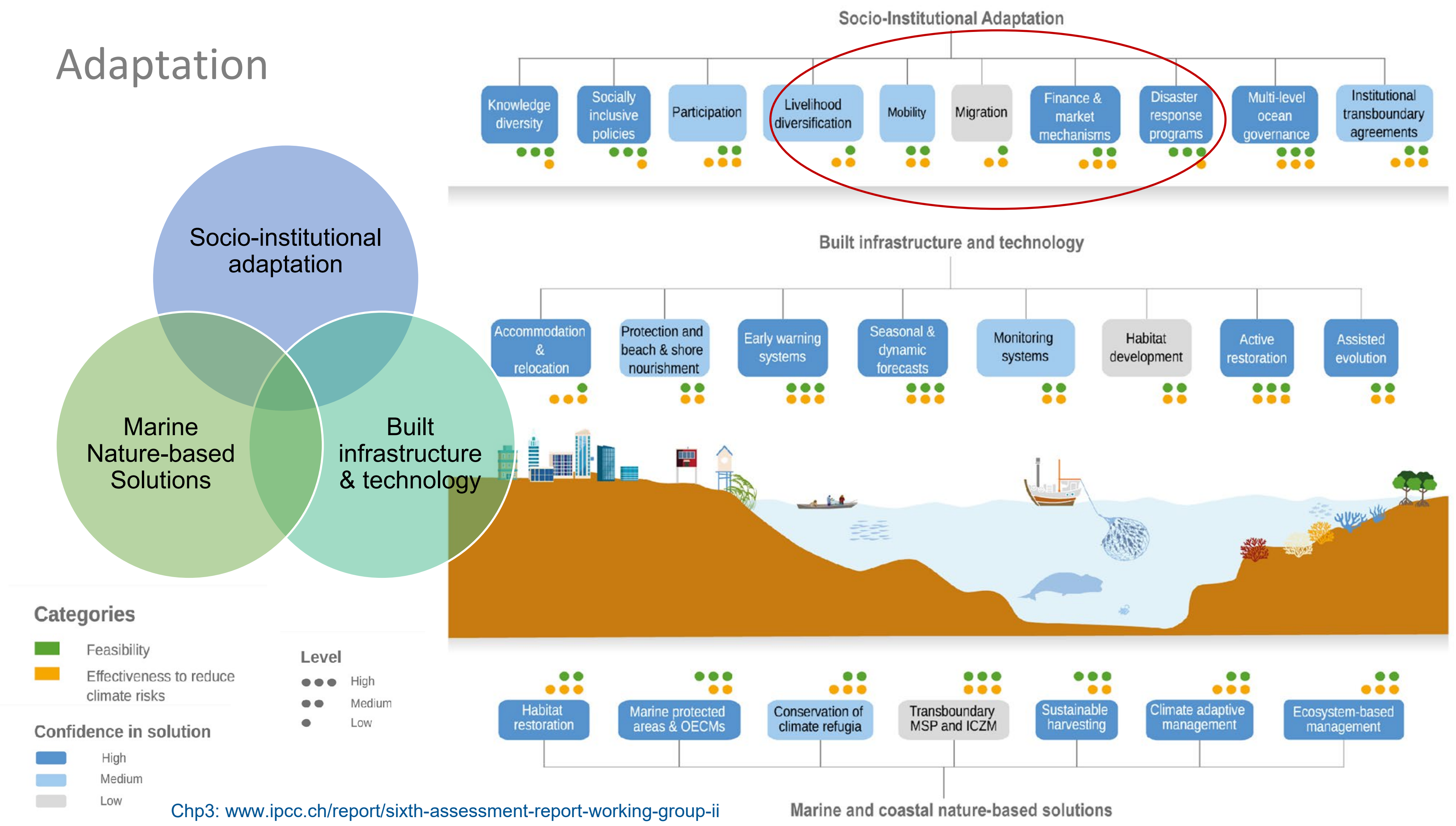

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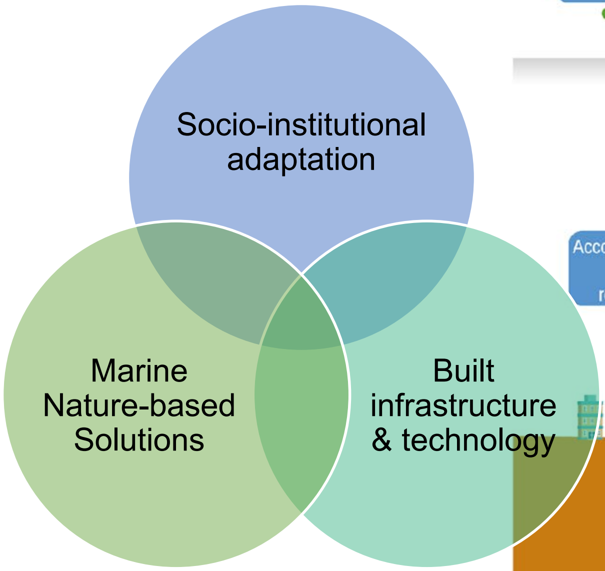

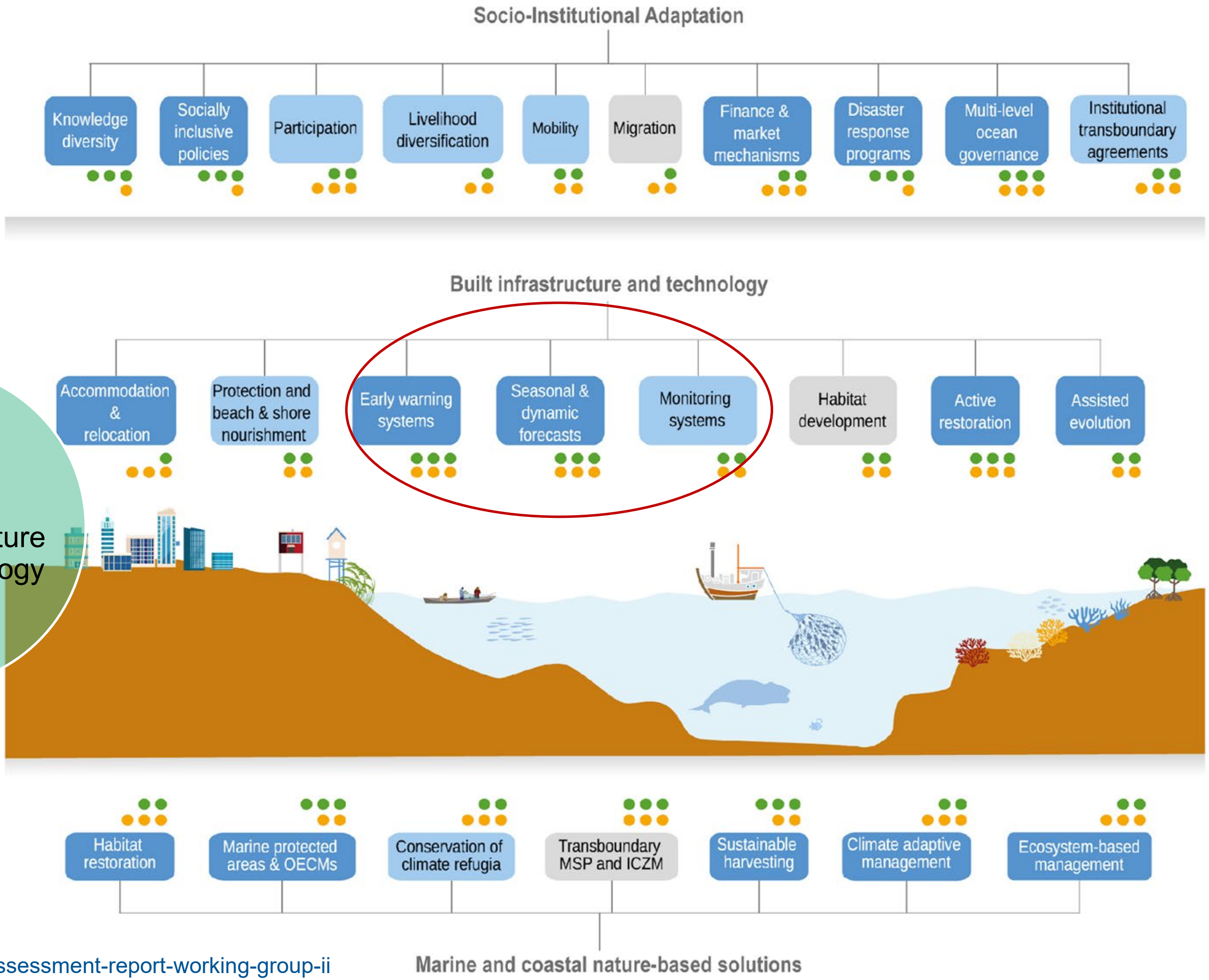

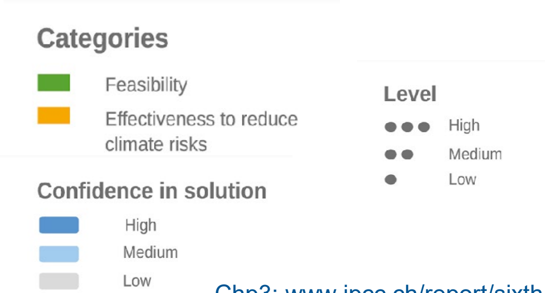

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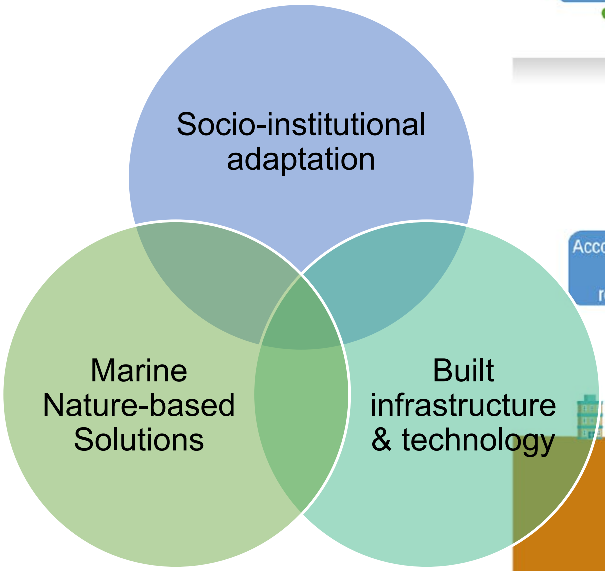

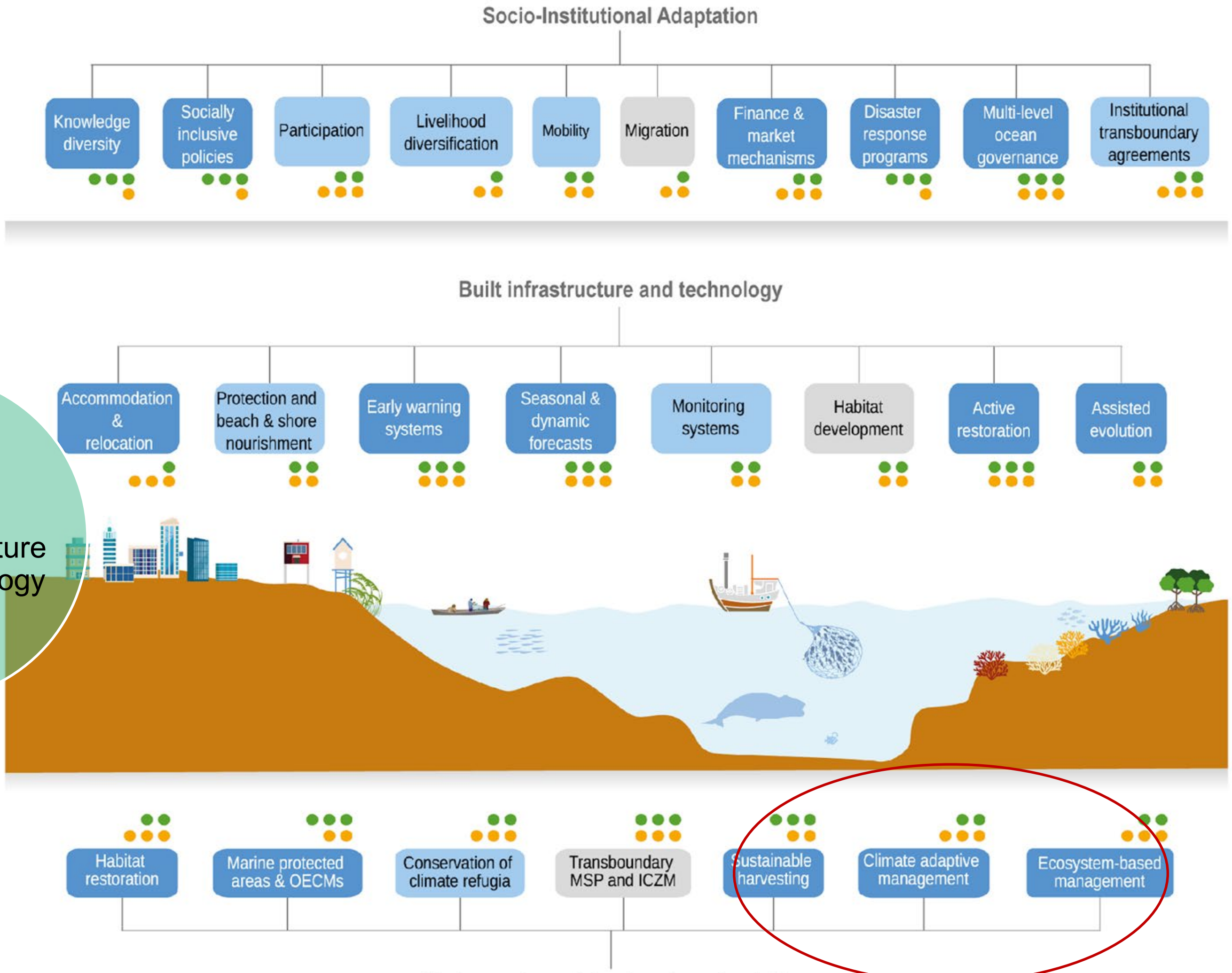

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Key elements of climate ready advice

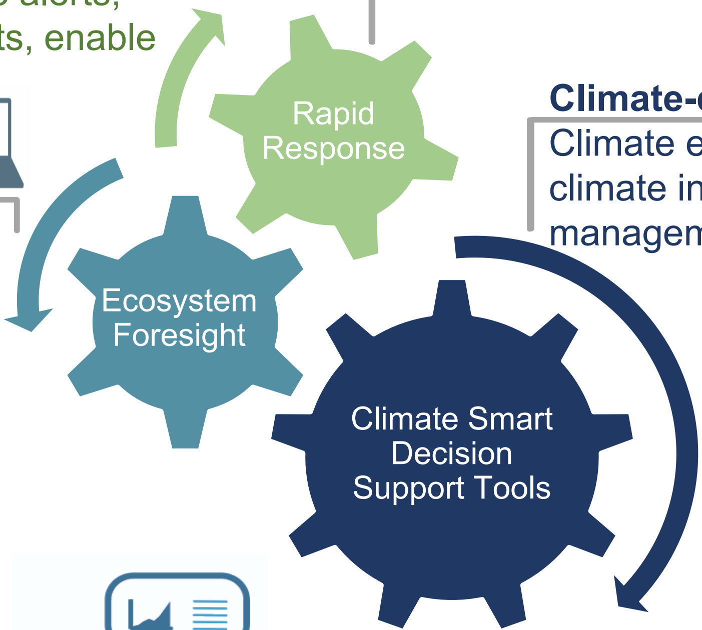
Holsman et al. in prep

Rapid response
Plan & predict, near-real time alerts, emergency aid, triage impacts, enable individual adaptation

e.g., Emergency relief

Ecosystem foresight

Social-ecological system forecasts & projections, tipping points & early warnings



Climate-driven decision support tools
Climate enhanced stock assessments, climate informed advice & tools, dynamic management

e.g., Risk assessment & probability of increase or decrease

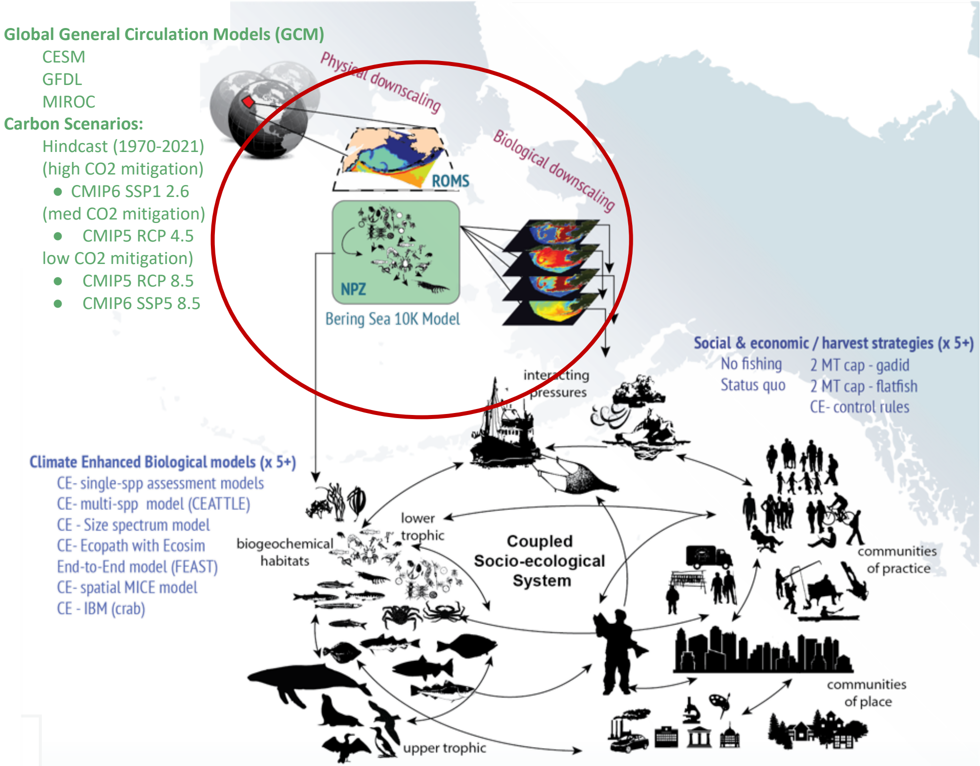
Coordinated science & advice

Inter- & intra-agency coordination, national strategies aligned with regional priorities, efficient information sharing, reduced redundancy

Effective monitoring & research
Improved research & climate-ready survey design, increased speed of response

The Alaska Climate Integrated Modeling Project

Goal: To address climate information needs with best available science & tools



What to expect?

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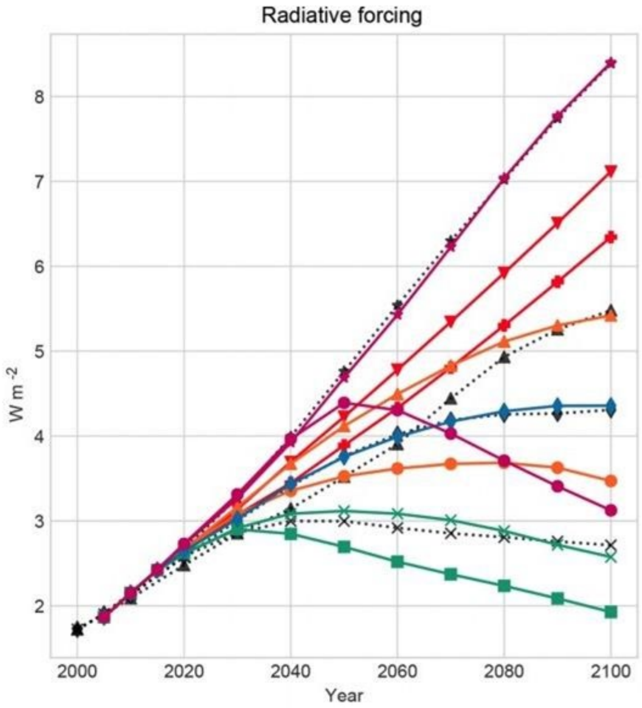
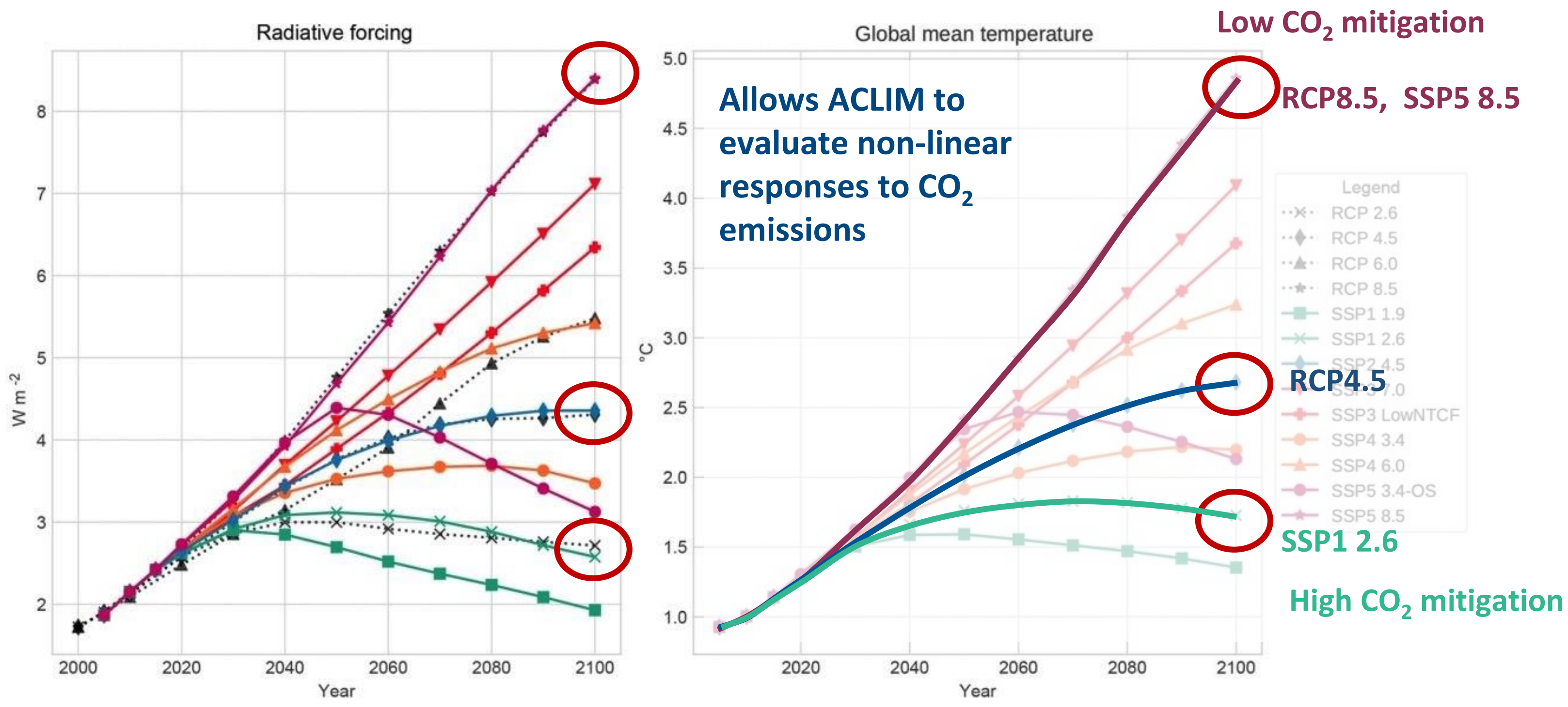
Carbon Emission Scenarios



"**plausible descriptions** of how the future may evolve with respect to a range of variables…they are not meant to be policy prescriptive, (i.e. **no likelihood or preference is attached** to any of the individual scenarios of the set)"

van Vuuren et al. 2011

Gidden et al. (2019). Global emissions pathways under different socioeconomic scenarios for use in CMIP6: a dataset of harmonized emissions trajectories through the end of the century. Geosci. Model Dev., 12, 1443–1475, 2019 https://doi.org/10.5194/gmd-12-1443-2019



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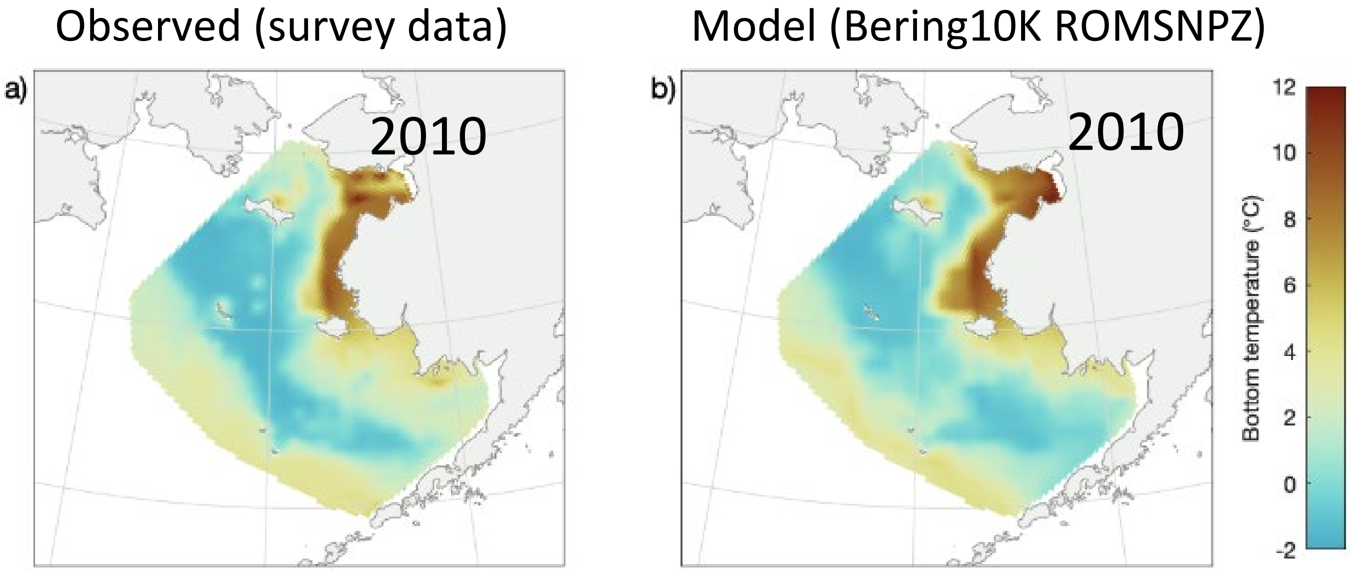
High-res model reproduces the Bering Sea environment



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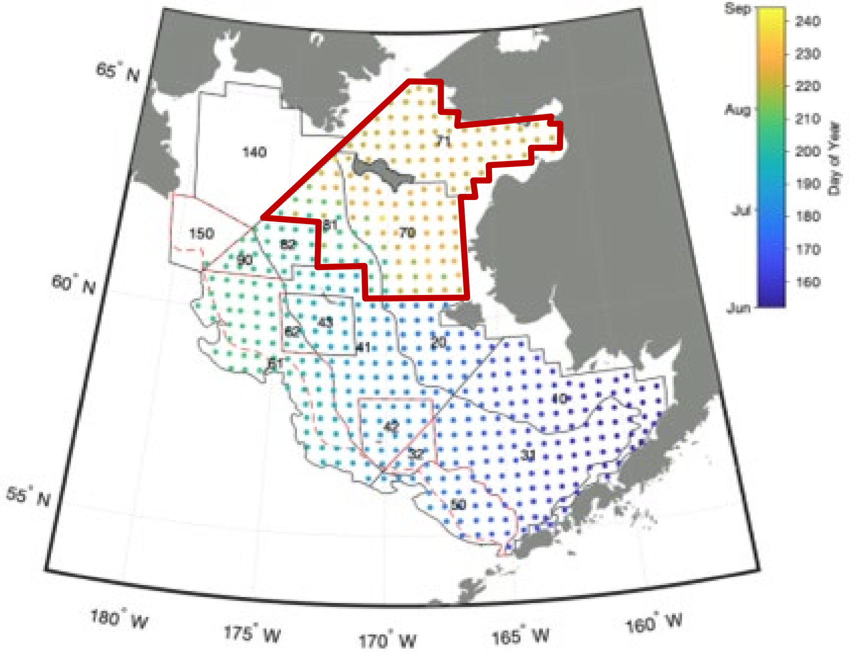

NEBS strata = 70, 71, 81

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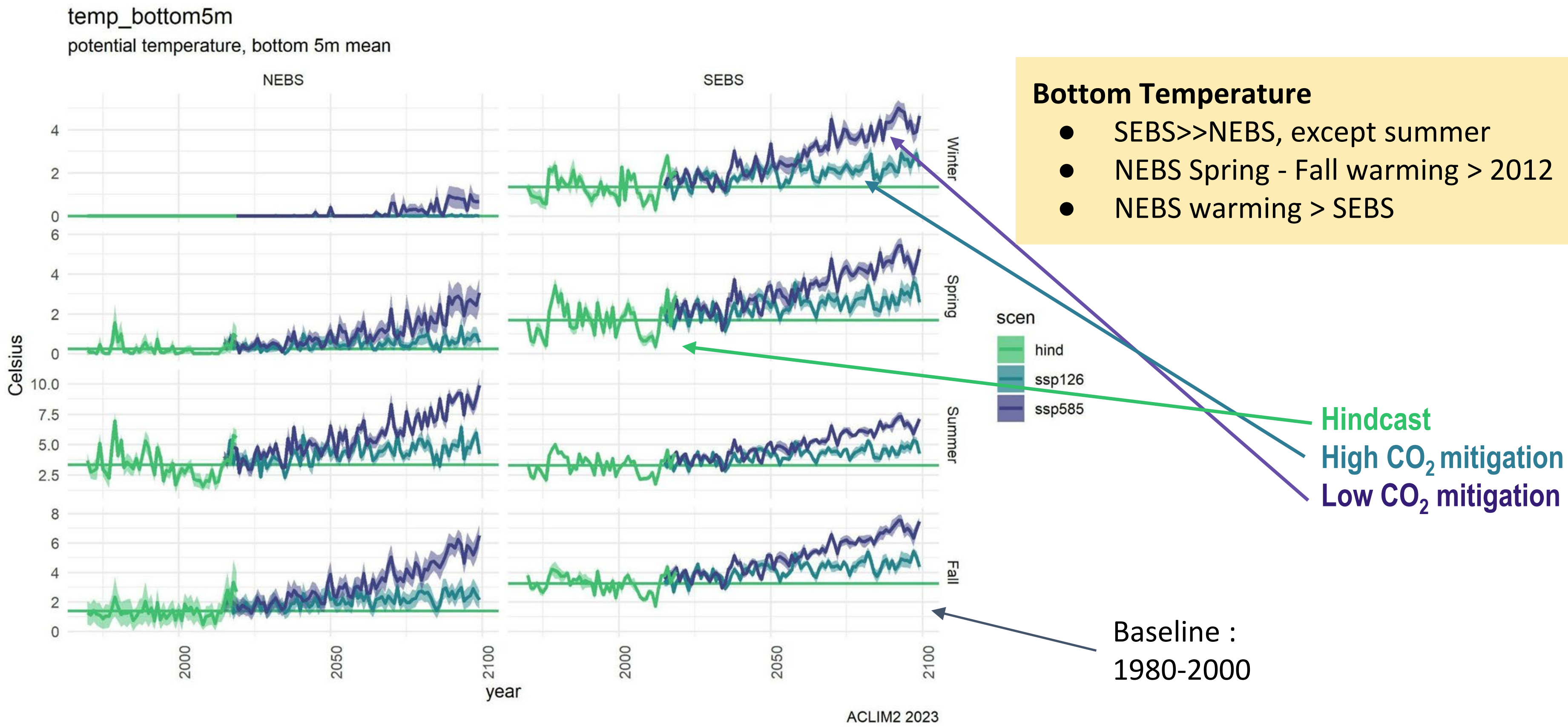

Bottom Temperature

- SEBS>>NEBS, except summer
- NEBS Spring - Fall warming > 2012
- NEBS warming > SEBS

Model: Bering10K vK20P19 ROMSNPZ

Pilcher et al. 2019 https://www.frontiersin.org/articles/10.3389/fmars.2018.00508/full
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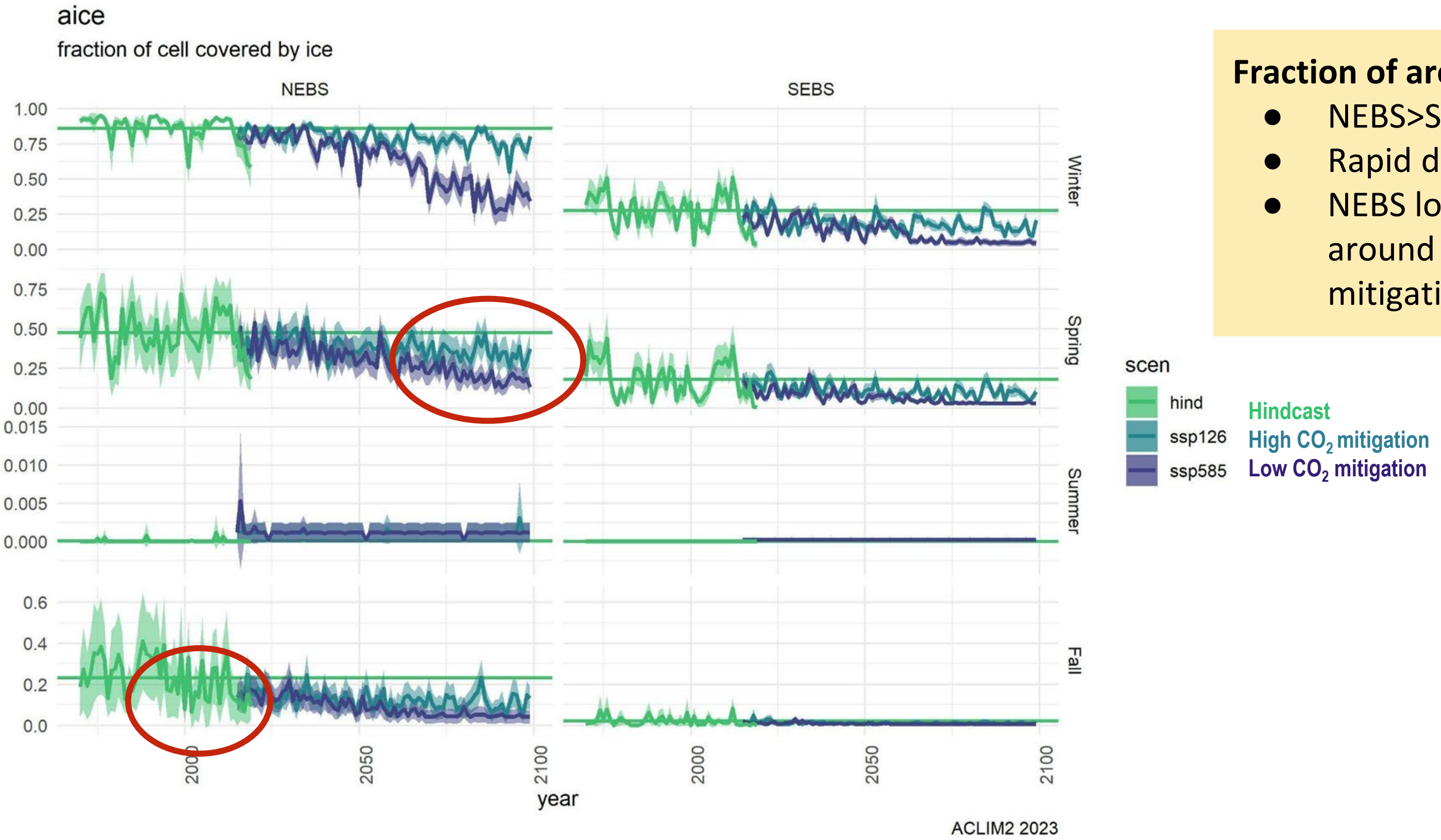
Cheng, et al. (2021) https://www.sciencedirect.com/science/article/pii/S0967064521000515



Fraction of area with ice

- NEBS>SEBS
- Rapid declines > 2010
- NEBS looks like current EBS around 2070 under low CO2 mitigation

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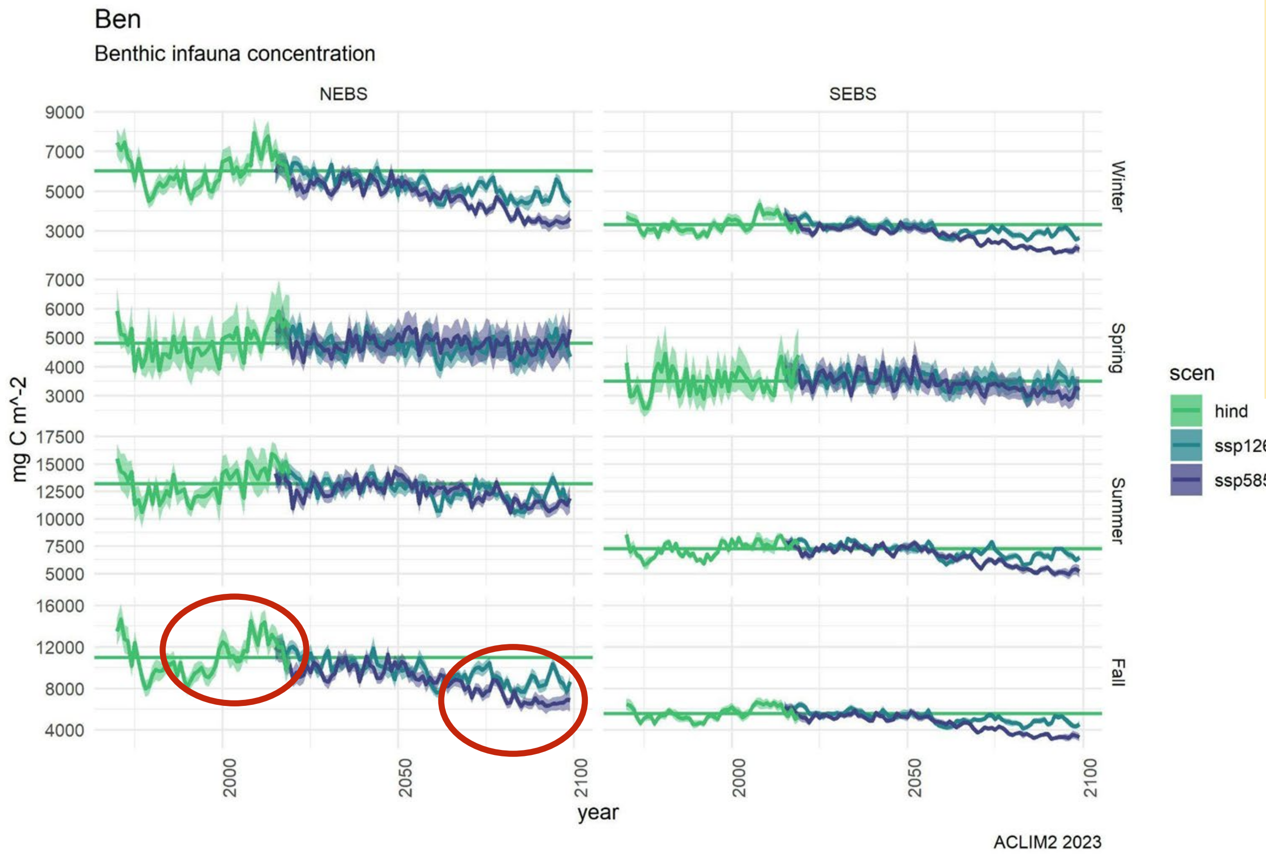

Benthos

- Higher in NEBS>SEBS
- "Switching" between pelagic (warm) and benthic (cold)
- Projected declines in benthos with warming, except in spring
- **NOTE: validation is on-going**

Hindcast
High CO_2 mitigation
Low CO_2 mitigation

Model: Bering10K vK20P19 ROMSNPZ

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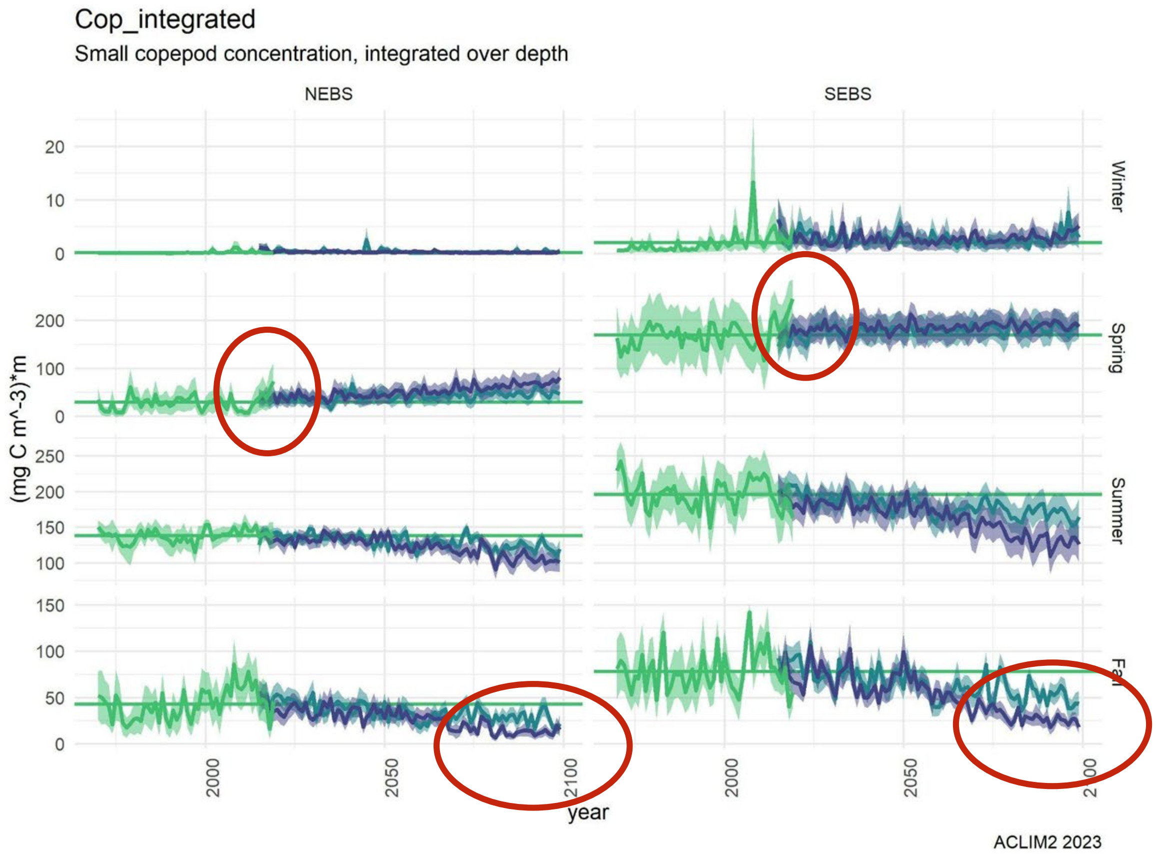

Small copepods

- SEBS > NEBS
- Increases in spring
- Declines in summer & fall

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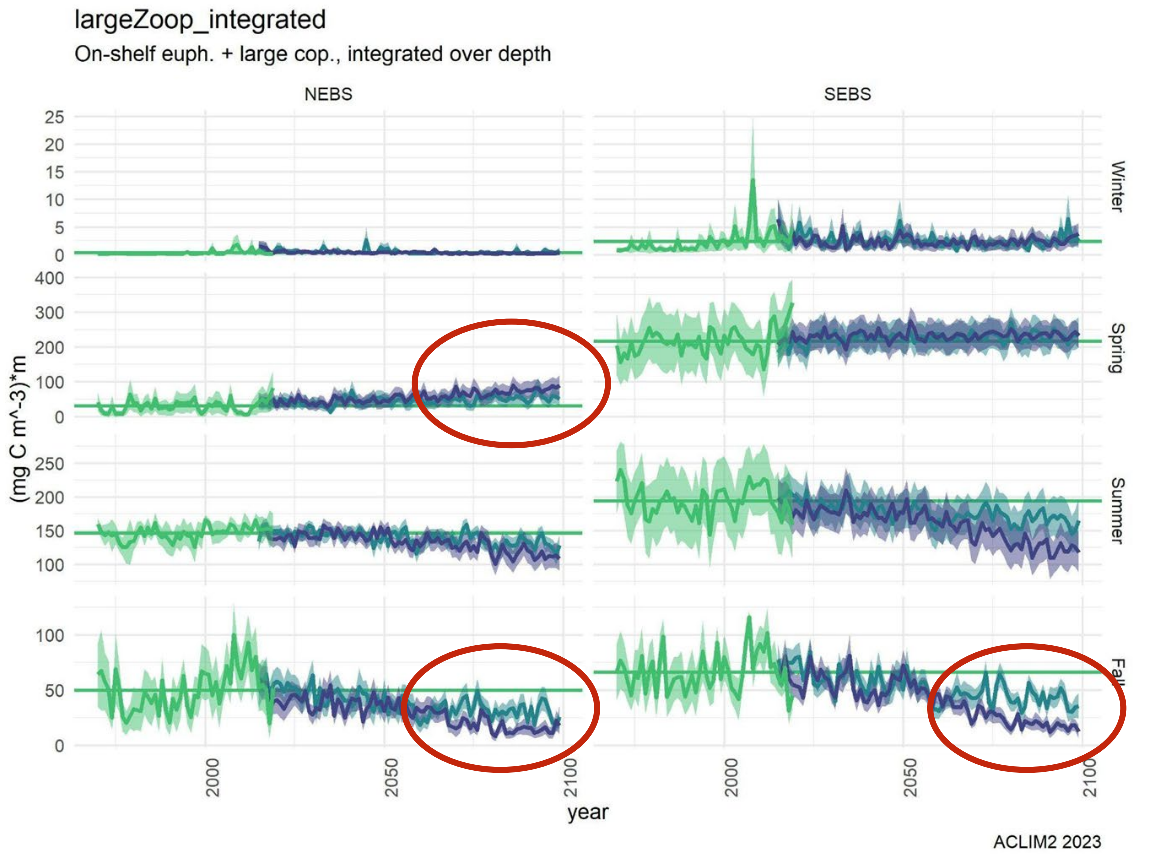


Hindcast
High CO_2 mitigation
Low CO_2 mitigation

Large Zoop ("SEBS type")

- Increases in spring >2015
- Fall decreases >2010
- SEBS declines > 2015
- NEBS declines > 2050

Reduction in carrying capacity for the NEBS?

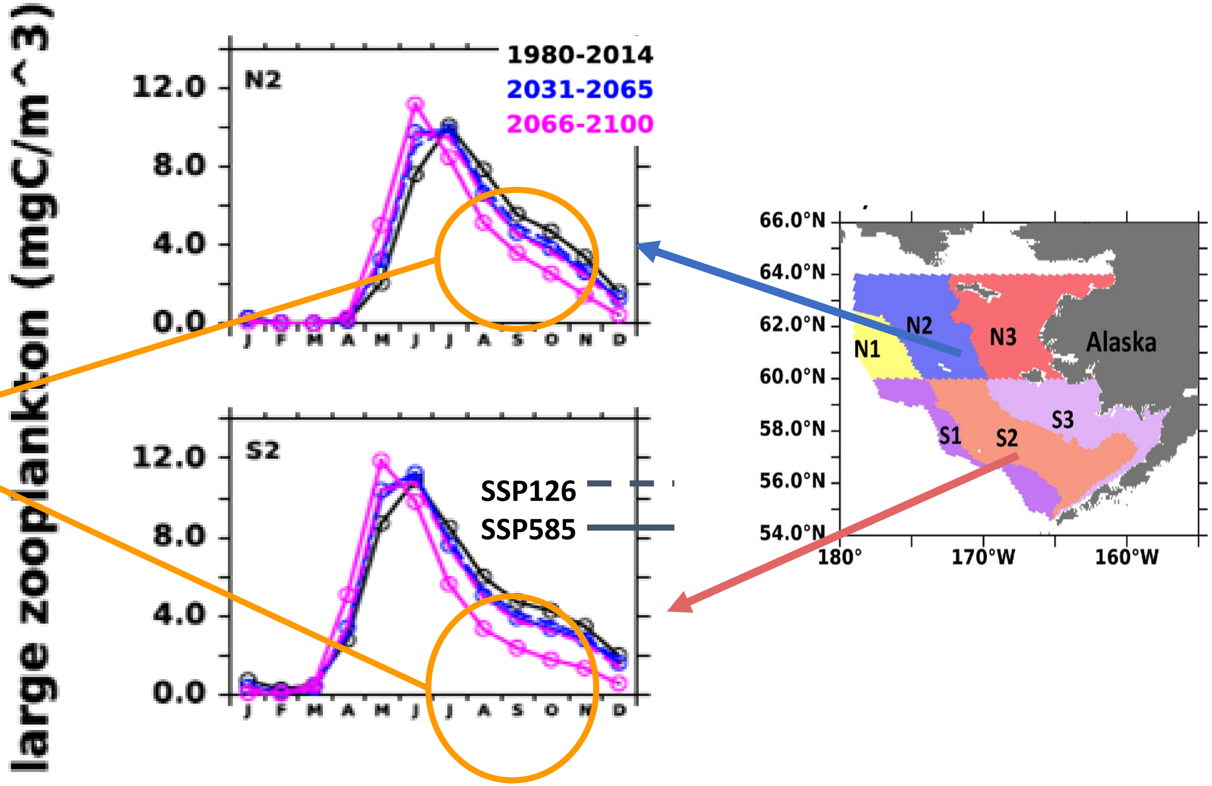
Model: Bering10K vK20P19 ROMSNPZ

Pilcher et al. 2019 https://www.frontiersin.org/articles/10.3389/fmars.2018.00508/full
Kearney et al. (2020 https://gmd.copernicus.org/articles/13/597/2020/) & Kearney K. (2021). NMFS-AFSC-415, 40 p. link.
Hermann et al. (2021) https://doi.org/10.1016/j.dsr2.2021.104974
Cheng, et al. (2021) https://www.sciencedirect.com/science/article/pii/S0967064521000515

Change in the timing (phenology) of prey resources

Cheng, et al. (2021) https://www.sciencedirect.com/science/article/pii/S0967064521000515

Declines projected during critical bottlenecks for fish overwinter survival



Recap of ROMSNPZ model projections

Bottom Temp:

- SEBS>NEBS, except summer
- SEBS Winter warming > 2012
- NEBS Fall warming > 2012
- NEBS warming > SEBS

Ice Area:

- NEBS>SEBS
- Rapid declines > 2010
- NEBS looks like 2019 SEBS around 2070 under low CO_2 mitigation

Dissolved Oxygen:

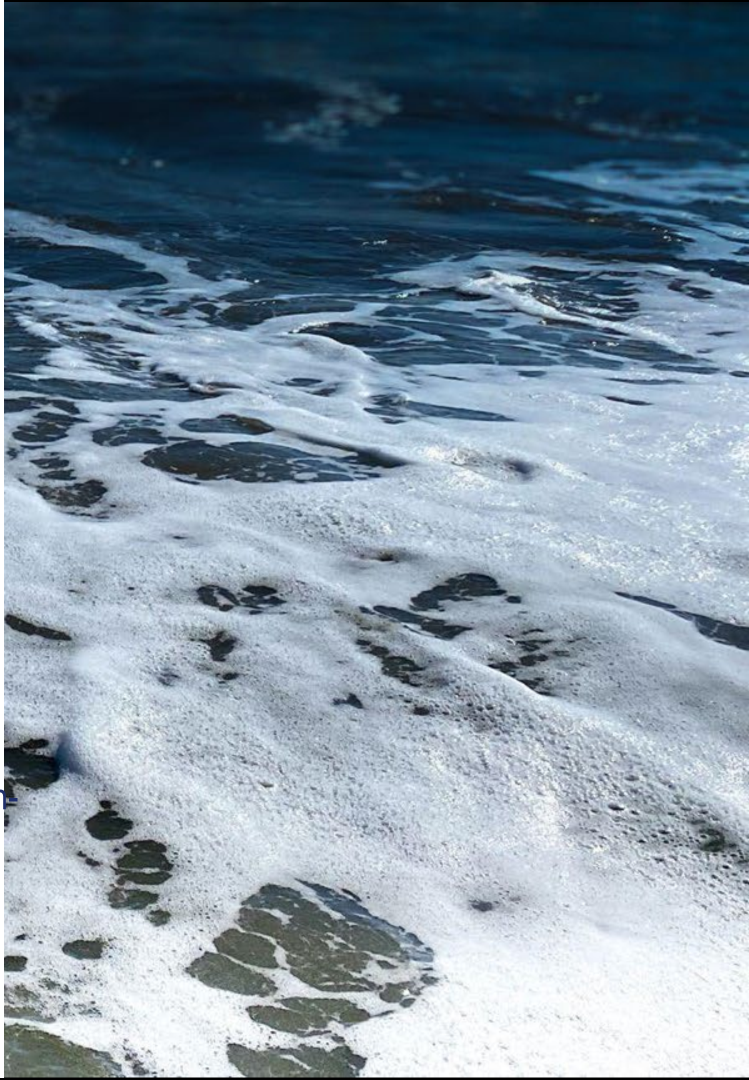
- SEBS some declines >2010
- O2 stays well above hypoxia

Ph (Ocean acidification)

- Declines in all areas > 2000
- NEBS declines 2010
- Significant declines under low mitigation projected but skill validation is on-going

Zooplankton:

- SEBS > NEBS
- Small increases in spring, shift earlier peaks
- Large declines in summer & fall under low CO_2 mitigation

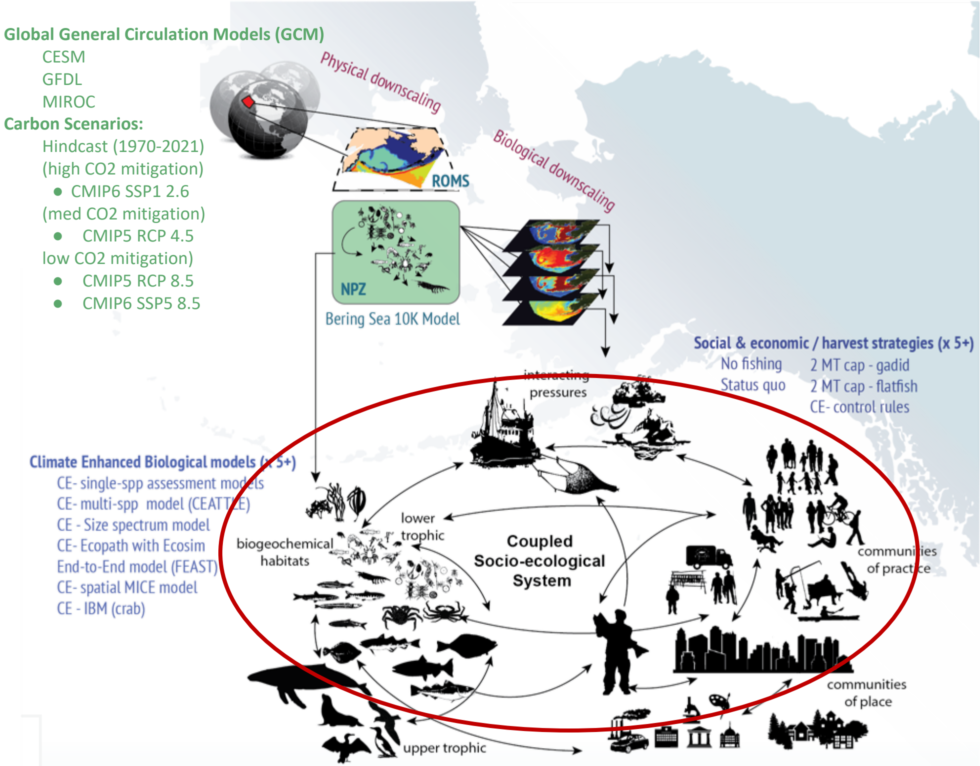


Today's Talk

1. Brief introduction to climate planning, risk, adaptation, and CO_2 mitigation
2. Linking to day 1: projected changes to NEBS conditions and carrying capacity
3. Actionable advice
   a. Climate informed control rules (ACLIM2 spring sprint)
   b. Climate informed spatial and scenario planning
4. Next steps, CEFI and ACLIM3

The Alaska Climate Integrated Modeling Project

Goal: To address climate information needs with best available science & tools



What to expect?

- Project physical and ecological conditions under levels of climate change (levels of global carbon mitigation)
- Characterize uncertainty

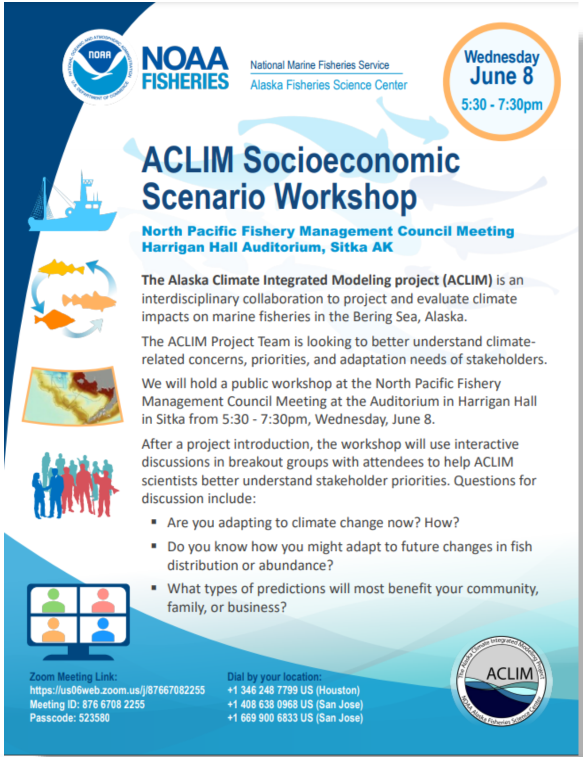
What can be done?

Evaluate effectiveness of adaptation actions including those supported by fisheries management

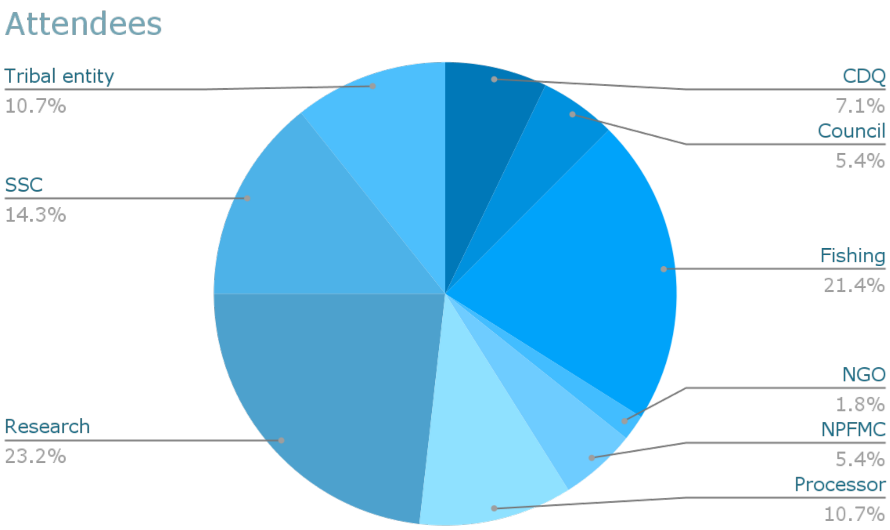
www.fisheries.noaa.gov/alaska/ecosystems/alaska-climate-integrated-modeling-project

Hollowed et al. 2020. https://doi.org/10.3389/fmars.2019.00775

ACLIM Scenarios workshop



8 Remote
48 In Person



Hollowed et al. in prep

Research topics

- Climate informed or climate naive targets?
- Climate informed or climate naive models for ABC?
- Eval performance of Climate Enhanced HCRs
- Eval. potential emergency responses
- Eval effect of climate driven distributions on pop-dynamics,catch, & bycatch
- Eval skill of ecosystem forecasts to “foresight”
- Consider inclusive evaluation metrics
- Consider lags in markets to climate shocks

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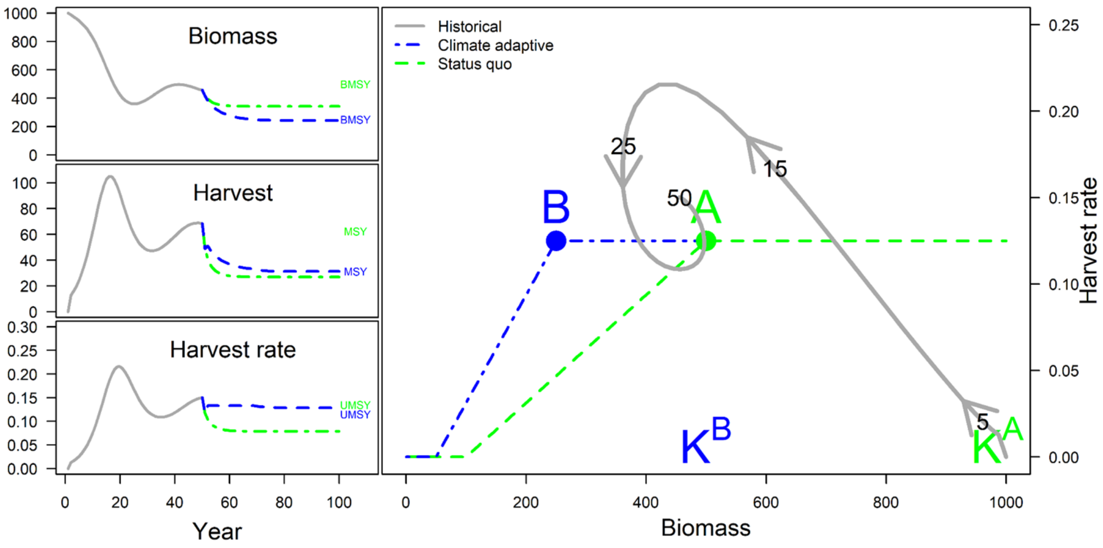
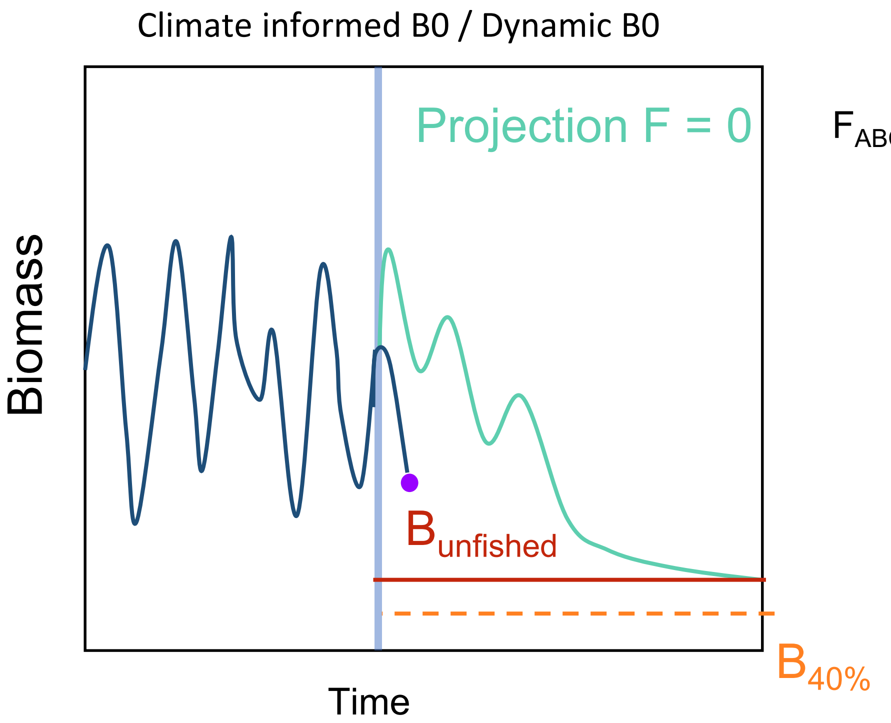
Adapting reference points to reflect changes in productivity

- MSA directs reference points to reflect current and probable future environmental conditions
- Changing reference points for stocks undergoing climate-related productivity shifts can result in counter-intuitive management actions:
    - Declining stocks could be fished harder
    - Flourishing stocks could be fished more conservatively



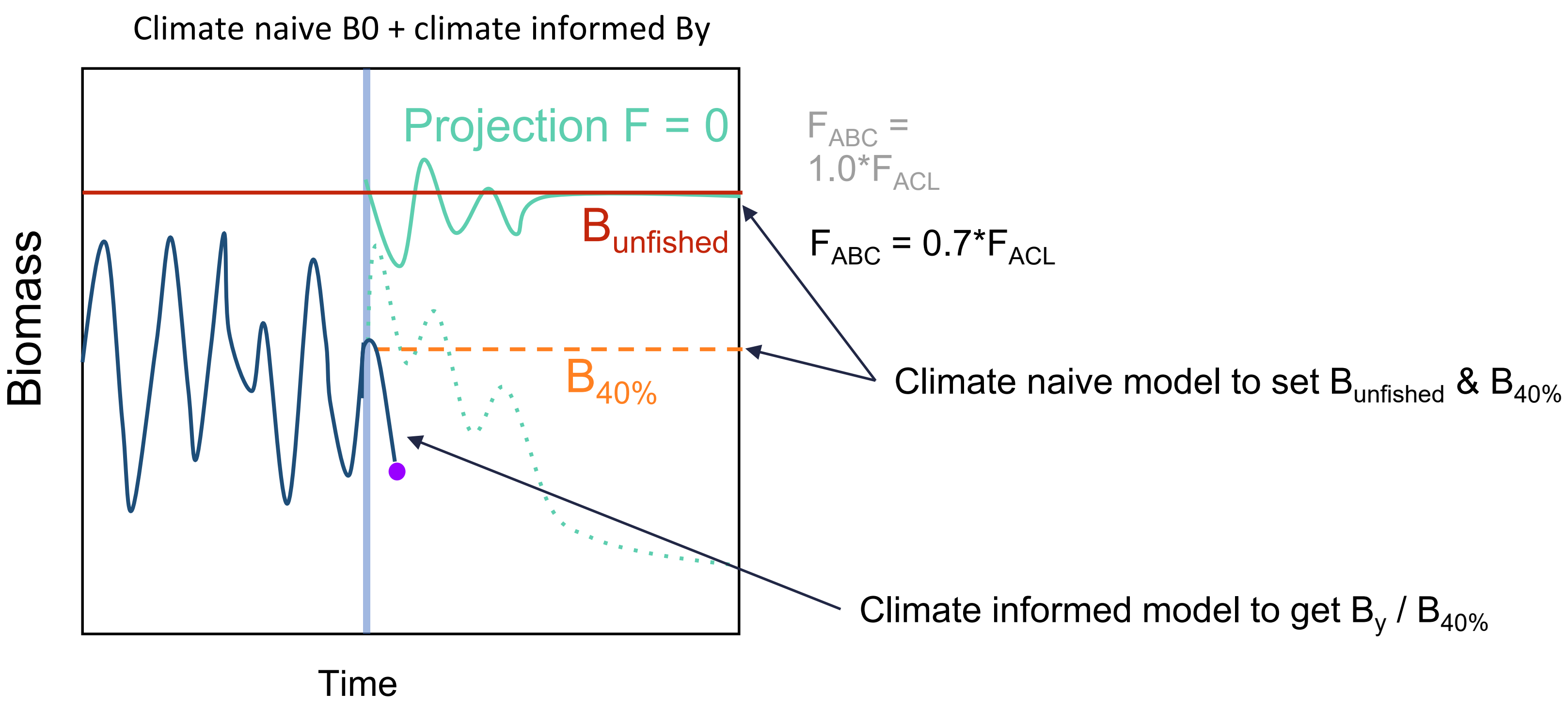
Szuwalski et al. in press, Unintended consequences of climate-adaptive fisheries management targets. Fish and Fisheries.

First: Set Target / reference points



$F_{ABC} = 1.0*F_{ACL}$

“hybrid” climate- naive & climate informed approach



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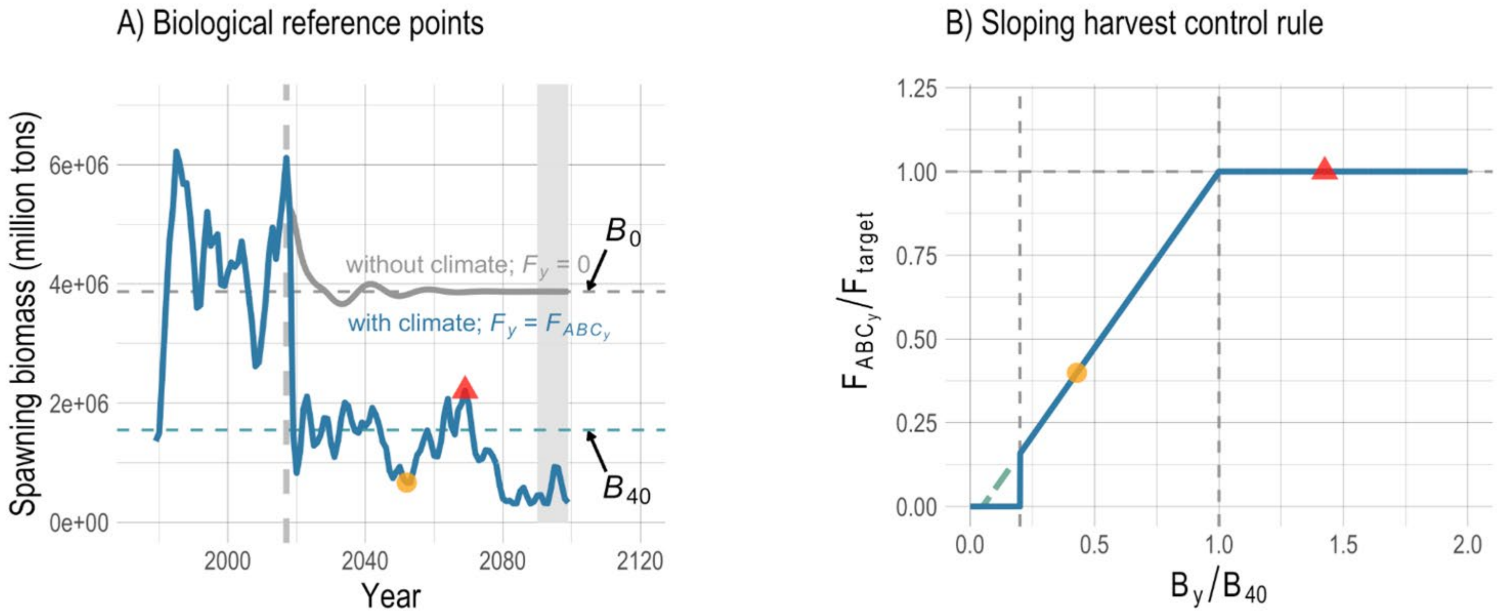
Solution?

Set B40 using climate naive models (or historical $B_{unfished}$), eval. current B:B40 using climate informed models



Holsman, K.K., Haynie, A.C., Hollowed, A.B. et al. Ecosystem-based fisheries management forestalls climate-driven collapse. Nat Commun 11, 4579 (2020). https://doi.org/10.1038/s41467-020-18300-3

Multispecies assessment

2022 Climate-enhanced multi-species Stock Assessment for walleye pollock, Pacific cod, and arrowtooth flounder in the South Eastern Bering Sea

Kirstin K. Holsman, Jim Ianelli, Kerim Aydin, Grant Adams, Kelly Kearney, Kalei Shotwell, Grant Thompson, and Ingrid Spies

kirstin.holsman@noaa.gov *November 2022*
Alaska Fisheries Science Center, National Marine Fisheries Service, NOAA,
7600 Sand Point Way N.E., Seattle, Washington 98115

Summary of assessment results for 2022:

Biomass

- At 6.8 million tons, the 2022 SEBS pollock spawning biomass from the multispecies model is above the long-term (1979-2015) average of 4.9 million tons and represents a 31% change from 2021 and 35% change from 2020 spawning biomass levels. Similarly, the downward trend in total biomass observed in the past few years has continued through 2022, with recent declines placing the total 2022 biomass (23 million t) above the 1979-2015 average of 15.4 million tons. However it is important to note that because there was no Alaska Fisheries Science Center summer bottom trawl survey in 2020, estimates of, and differences relative to the 2020 biomass should be interpreted cautiously.
- The 2022 SEBS Pacific cod female spawning biomass has declined -10% since 2021 and -26% since 2020. 2022 estimates are approximately -17% below the 1979-2015 average. Total biomass in the SEBS has declined -45% since 2016, and at approximately 758 thousand tons, is 26% below the long-term 1979-2015 average of 1 million tons. These patterns are driven in part by continued low survey indices in 2021 and warm bottom temperatures that have induced northward redistribution of the P. cod stock (Spies et al. 2020, Stevenson et al. 2019). This assessment does not include Northern Bering Sea survey data collected in 2017, 2018, and 2019.
- Arrowtooth total and spawning biomass estimates are 48% and 65% greater than the long-term 1979-2015 average (respectively), and trends suggest relatively stable biomass since 2012.
- The multispecies model estimates of a 31% and -10% change in spawning biomass (SSB) between 2021 and 2022 for pollock and Pacific cod (respectively) agree with CEATTLE single species model patterns of decline (25% and -10%, respectively). Both models predict an increase (slightly) in spawning biomass for arrowtooth flounder relative to 2021.

Recruitment

- While pollock age 1 recruitment estimates for this year are 35% above the 1979-2015 average, estimated recruitment has decreased (slightly) in 2022 relative to 2021(note that the most recent estimates have the highest uncertainty).

Probability of near-term (+ 1-2 yr) biomass decline or increase:

- Relative to 2022 levels, the model projects SSB of pollock will increase in 2023 (projected based on 2022 catch) followed by an increase in SSB in 2024 (projected with F_{ABC}). For Pacific cod the model projects a decline in SSB in both 2023 and 2024.
- Ensemble projections using climate-enhanced recruitment models and projected future warming scenarios (including high carbon mitigation (ssp126), low carbon mitigation (ssp585), as well as persistence scenarios and assuming 2022 catch for 2023 and F_{ABC} for 2024) estimate a 95% chance that pollock ... of 2022 SSB

Use climate informed model to characterize risk in +1 & +2 years

...ojections esti- ...f 2022 SSB in

...ojections esti- mate a 95% chance that arrowtooth SSB will be between 92 and 130% of 2022 SSB in 2023 and will be between 87 and 117% of 2022 SSB levels in 2024.

Probability of long-term (2032, 2050, 2080) biomass decline or increase under high mitigation (low warming) scenarios:

Note that projections assume no adaptation by the species, fishery, or fishery management.

- Ensemble projections using climate-enhanced recruitment models and projected future warming sce- ...will be between ...71-75% of 2022

Use climate informed model to characterize risk in 10 + years with low warming

...rojections esti- ...etween 69-74%

- Ensemble projections using climate-enhanced recruitment models based on long-term projections estimate a 95% chance that arrowtooth SSB will be between 76-100% of 2022 SSB in 2032, between 81-92% of 2022 SSB levels in 2050, and between 76-90% of 2022 SSB levels in 2080.

Probability of long-term (2032, 2050, 2080) biomass decline or increase under low carbon mitigation scenarios (high warming):

Note that projections assume no adaptation by the species, fishery, or fishery management.

...e warming sce- ...will be between ...between 48 and

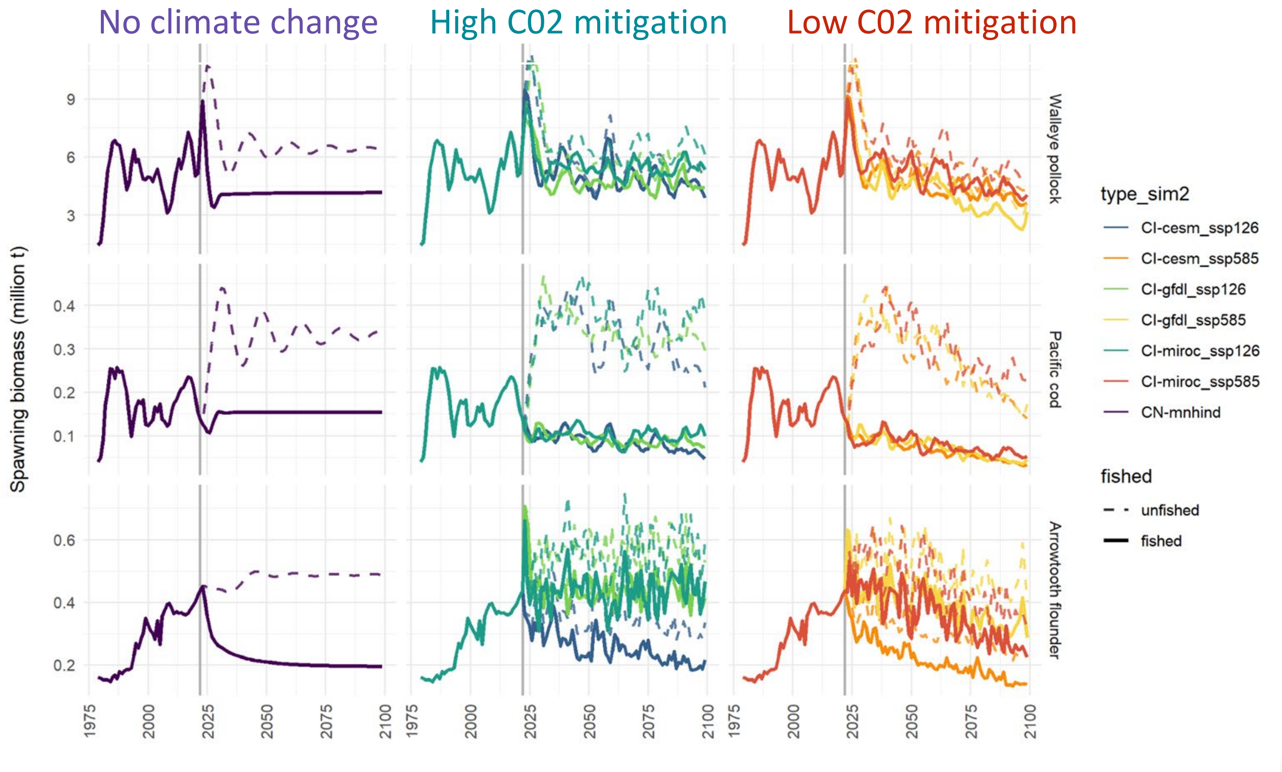
Use climate informed model to characterize risk in 10 + years with high warming

...rojections esti- mate a 95% chance that Pacific cod SSB will be between 55 and 90% of 2022 SSB in 2032, between 61 and 75% of 2022 SSB levels in 2050, and between 36 and 48% of 2022 SSB levels in 2080.

The Alaska Climate Integrated Modeling Project — ACLIM — NOAA Alaska Fisheries Science Center

https://apps-afsc.fisheries.noaa.gov/Plan_Team/2022/EBSmultispp.pdf

CE-MSM (CEATTLE model Holsman)



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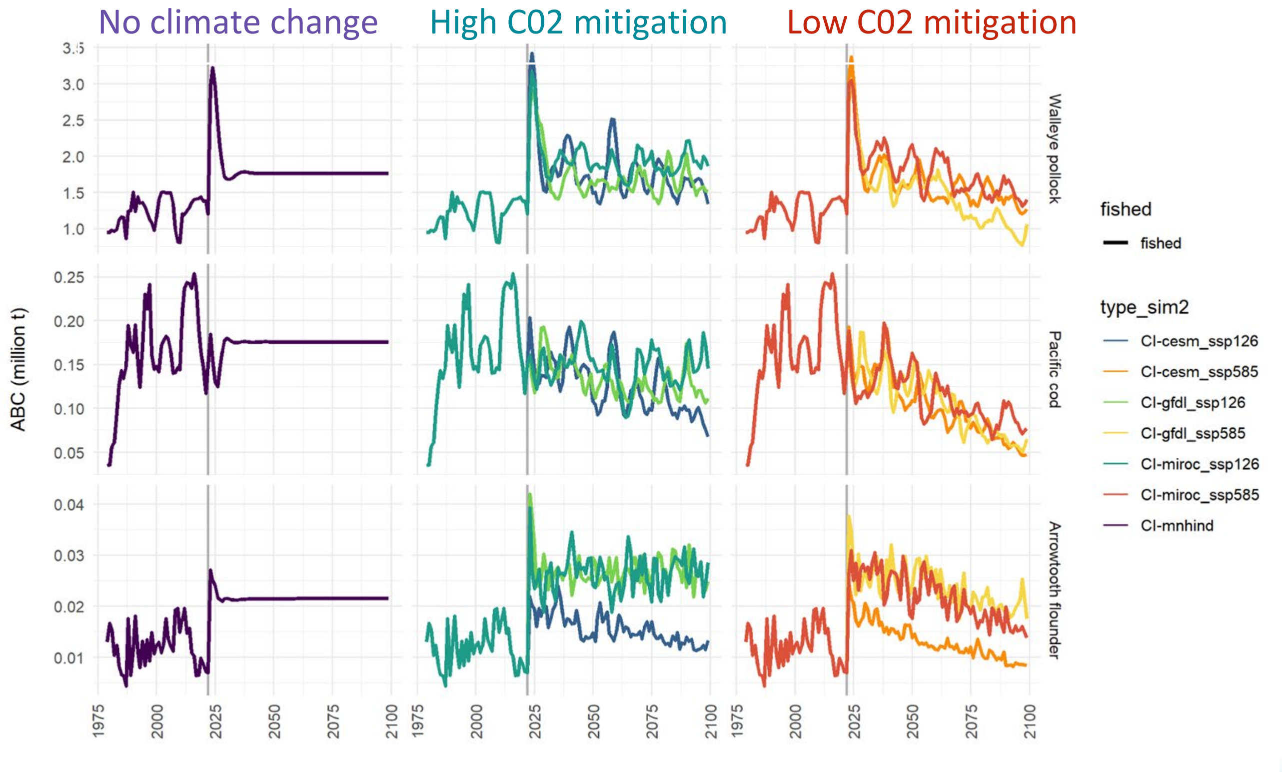

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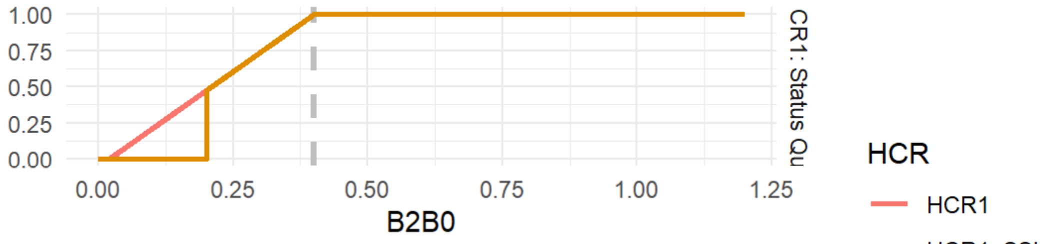
CE-HCR evaluations

HCR1

- Set $B_{F=0}$ based on 2015
- F_{target} is F rate to get to 40% $B_{F=0}$
- F_{adj} from sloping HCR where
  - alpha = 0.05
  - F →0 at B20% for SSL prey

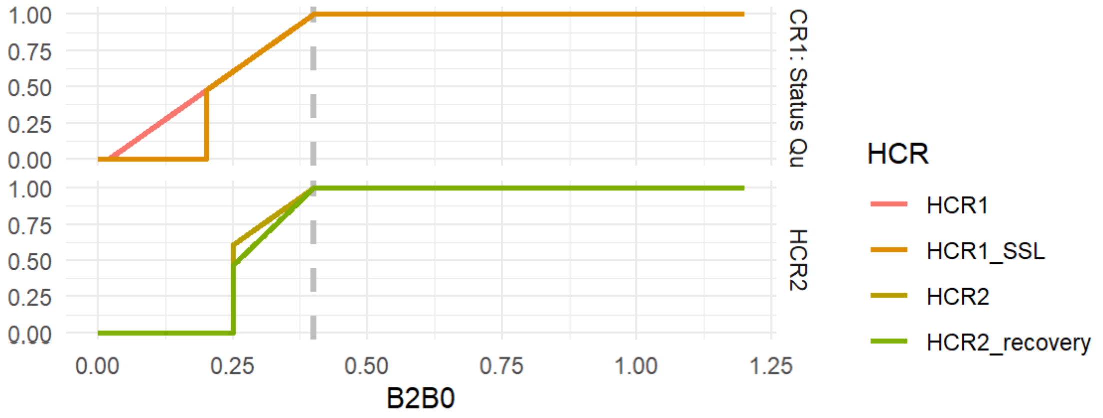


$$F_{ABC} = F_{target} * F_{adj}$$

CE-HCR evaluations

HCR2

- Set $B_{F=0}$ based on 2015
- F_{target} is F rate to get to 40% $B_{F=0}$
- F_{adj} from sloping HCR where
  - alpha = 0.05
  - *Opt b: alpha recovery =0.3*
  - F →0 at B25%

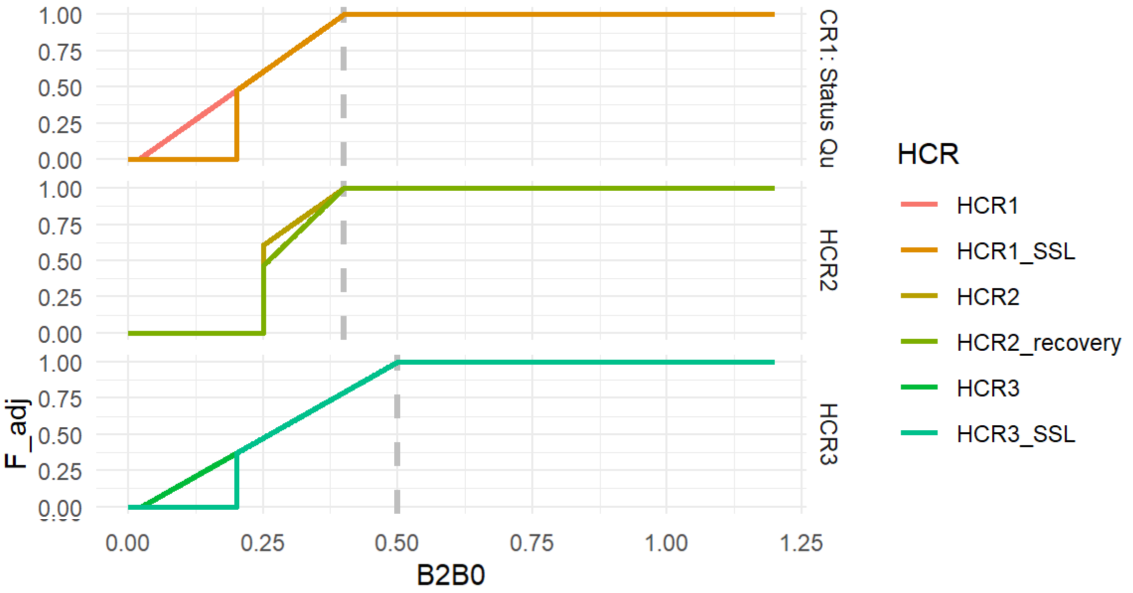


Simulate effective closure at B25% and lag following shock in order to estimate emergency relief financing needs

CE-HCR evaluations

HCR3

- Set $B_{F=0}$ based on 2015
- F_{target} is F rate to get to 50% $B_{F=0}$
- F_{adj} from sloping HCR where
  - alpha = 0.05
  - F →0 at B20% for SSL prey

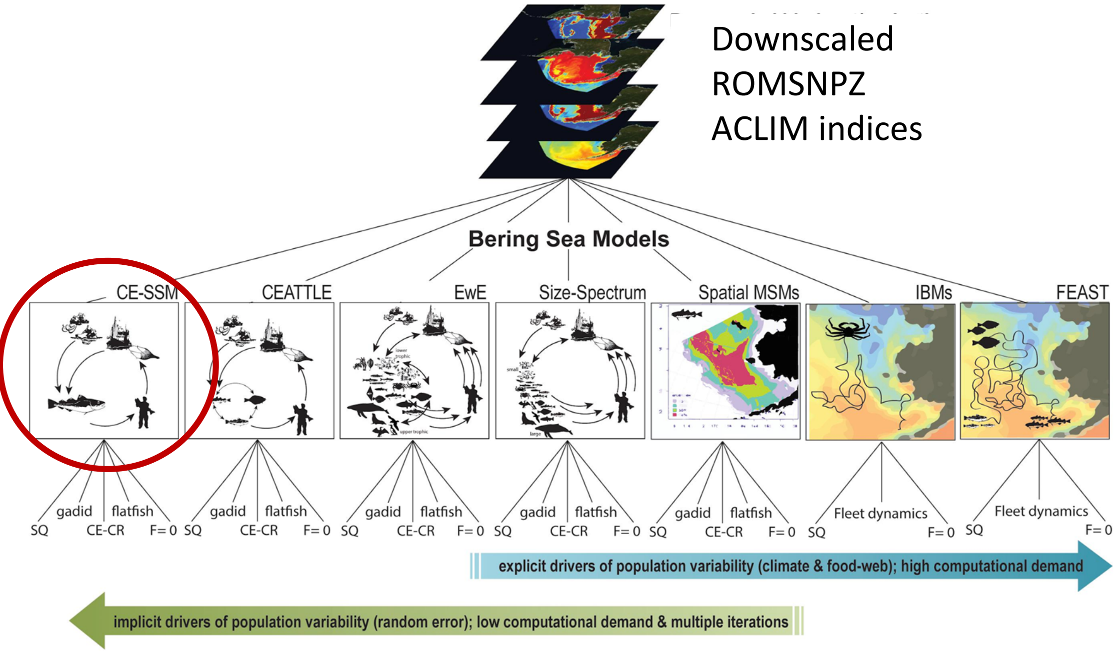


Long-term resilience via larger B "target"?

Examples

Draft results from ACLIM2
Spring modeling sprint

Integrated Climate Management Strategy Evaluations



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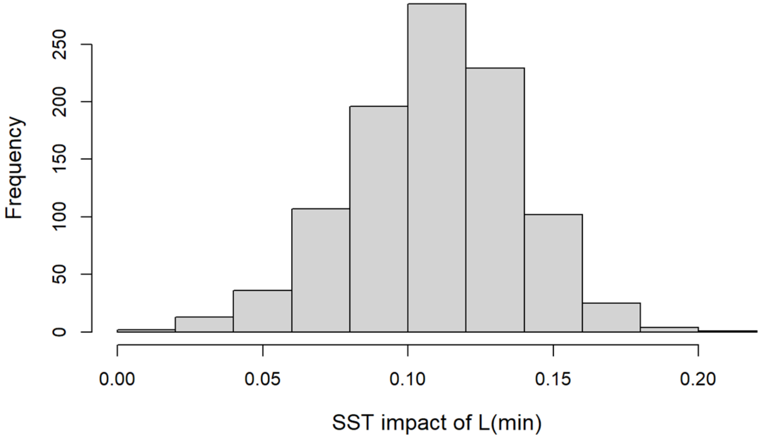
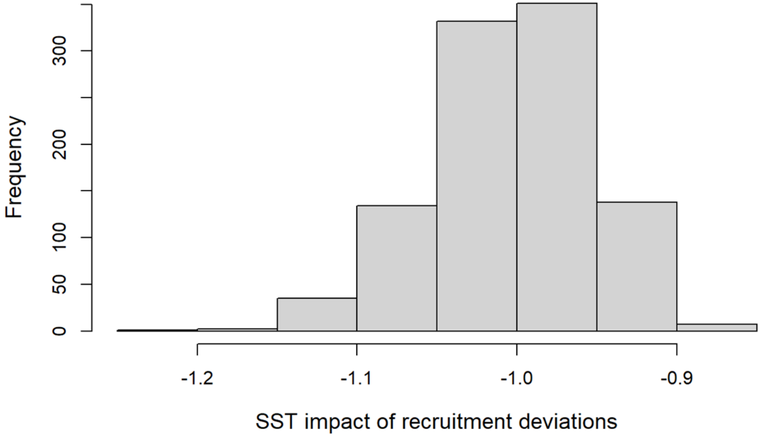
Hollowed et al. 2020. https://doi.org/10.3389/fmars.2019.00775

Pacific cod in the eastern Bering Sea

An extended single-species assessment

- Based on model 19-12 (one of four models in the 2022 assessment).
- **Length-at-age 1** and **recruitment** deviations are related to **sea surface temperature**.
- For today results will be based on MLEs but Bayesian analysis suggests fairly strong environmental effects.



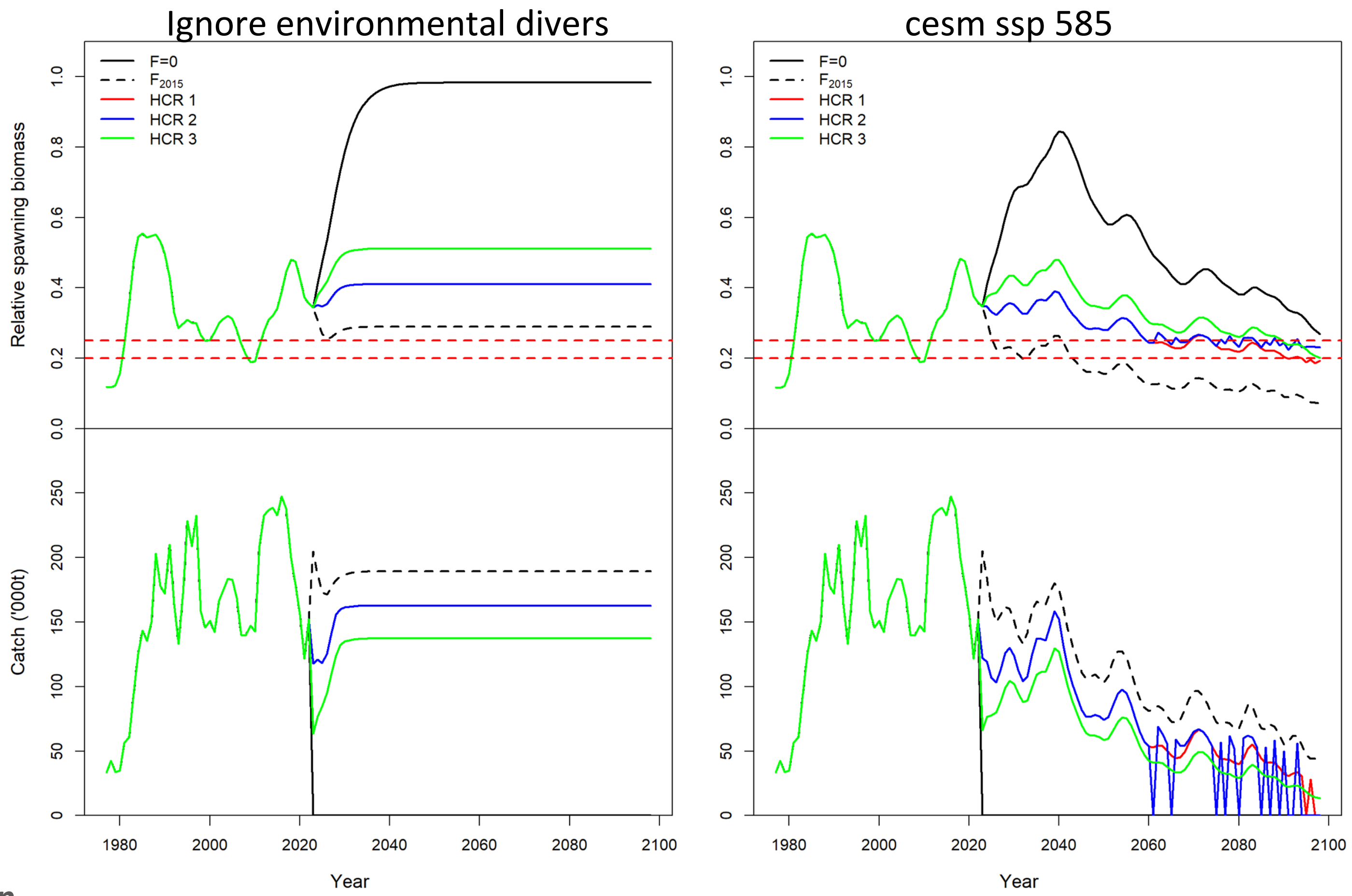


Punt et al. in prep.
Draft results, please do not copy or distribute without permission of the author

3 climate models
2 emission scenarios

ABCs constrained by ATTACH model

Based on a “special” version of Stock Synthesis.



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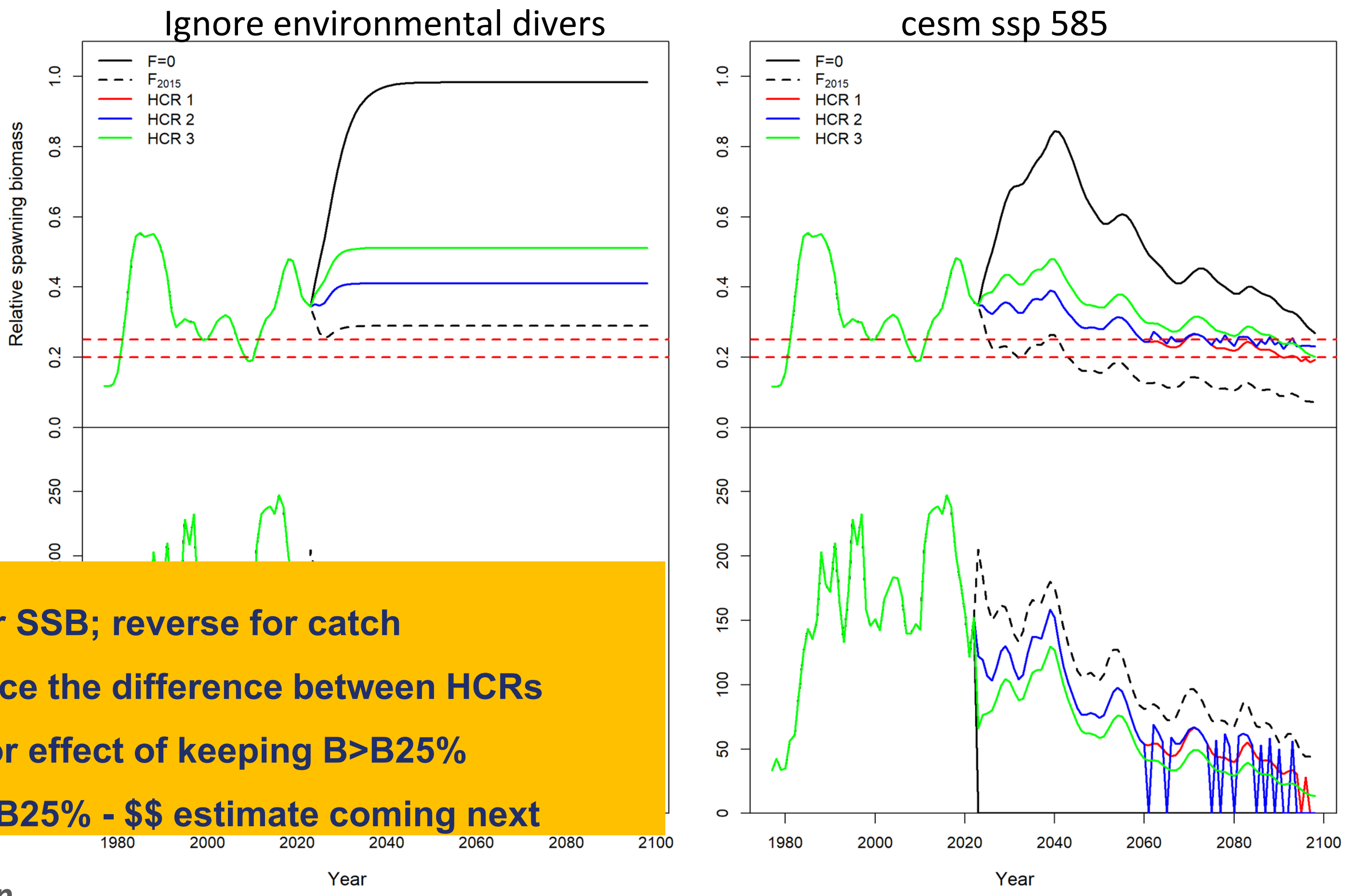

HCR 3 > HCR1&2 for SSB; reverse for catch

Climate effects reduce the difference between HCRs

HCR2 only has minor effect of keeping B>B25%

Non-minor costs of B25% - $$ estimate coming next

ACLIM
The Alaska Climate Integrated Modeling Project
NOAA Alaska Fisheries Science Center

Punt et al. in prep.

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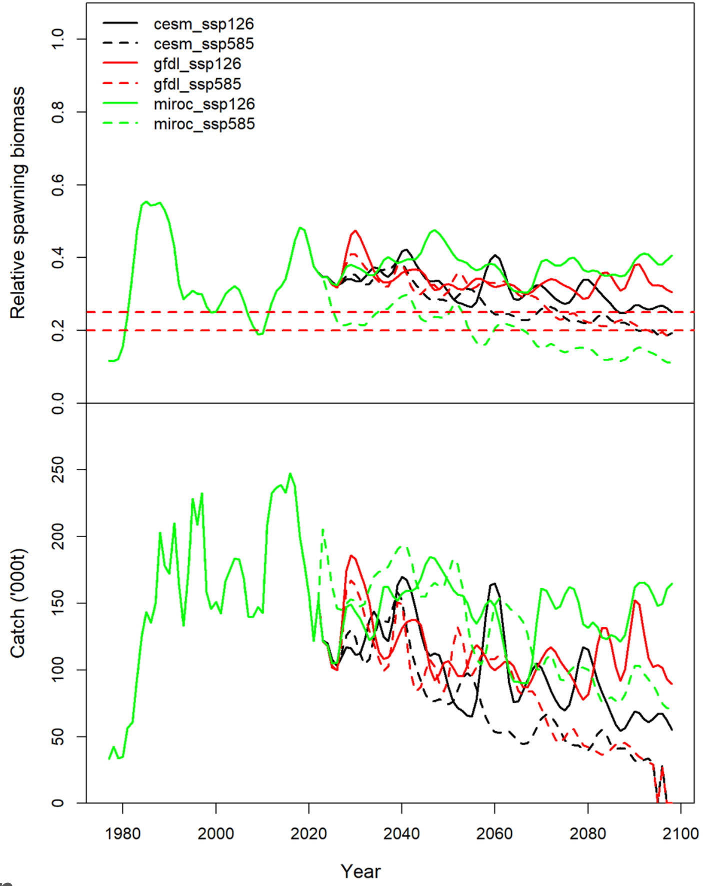
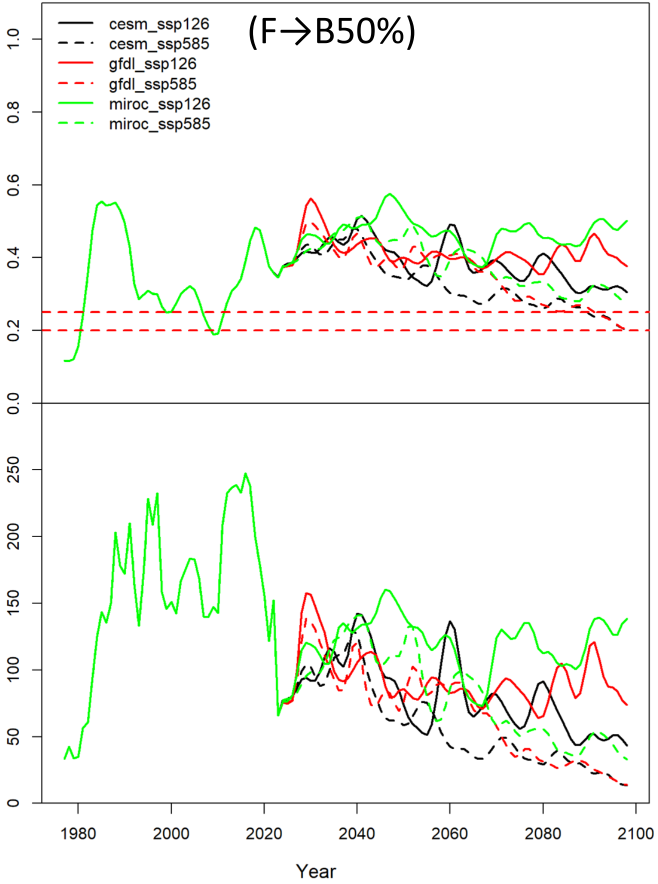
The future

- Bayesian samples
- Multiple models
- MEY control rules
- Cross catch checks

HCR 1 (status-quo)



HCR 3 (F→B50%)



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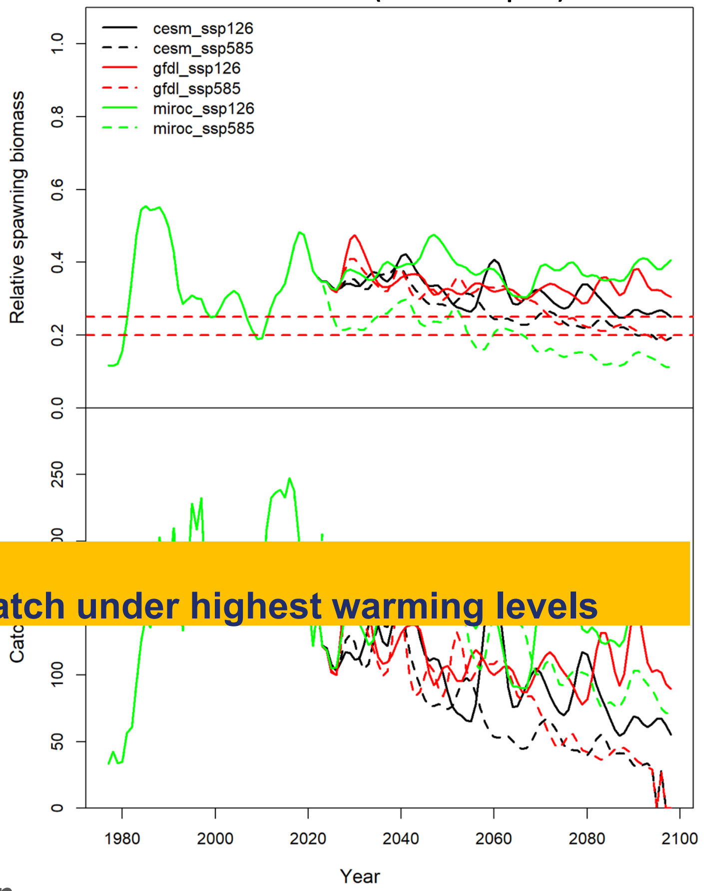
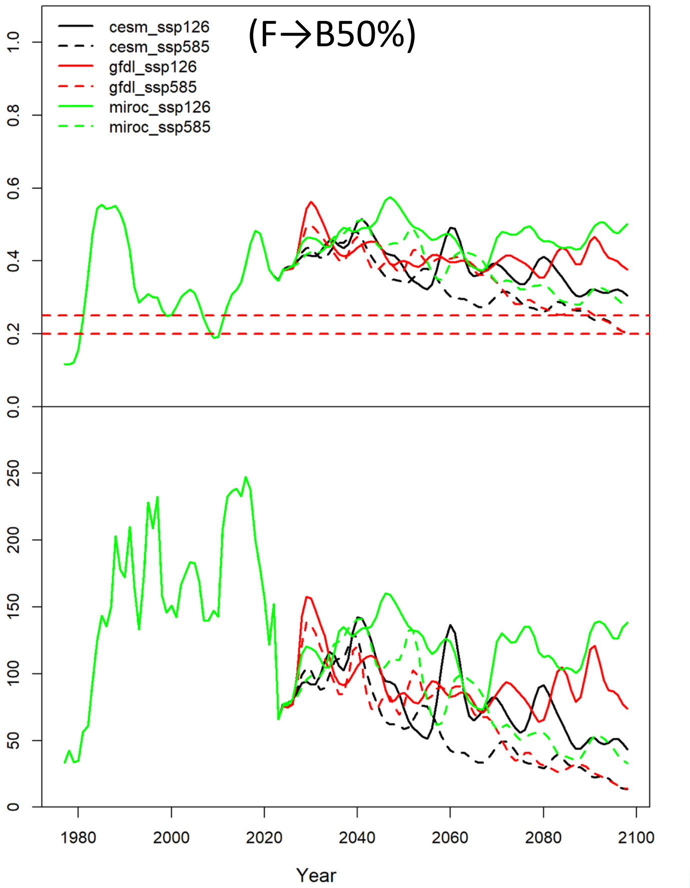


HCR 3

(F→B50%)



HCR 3 > HCR1 for catch under highest warming levels

Punt et al. in prep.

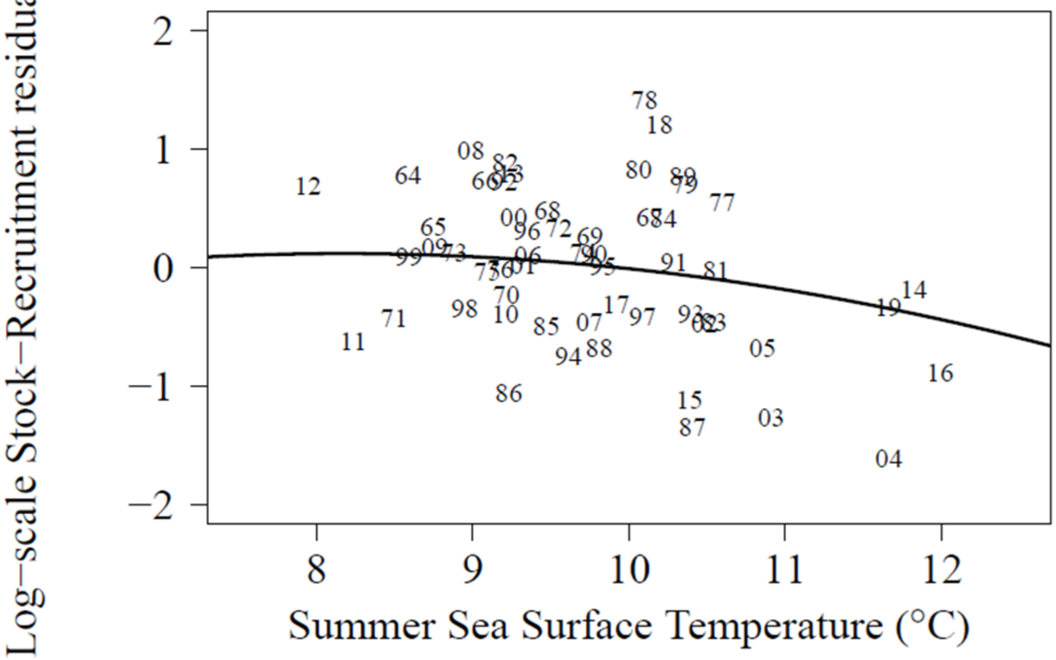
Draft results, please do not copy or distribute without permission of the author

Effect of temperature on recruitment

Pollock

$$-2.41 + 0.62 * SST - 0.038 * SST^2$$

$$R_t = f(SSB_{t-a}) e^{\propto + x_1 SST_{t-a} + x_2 SST^2_{t-a}} e^{\varepsilon_t}$$



Spencer et al. in prep.

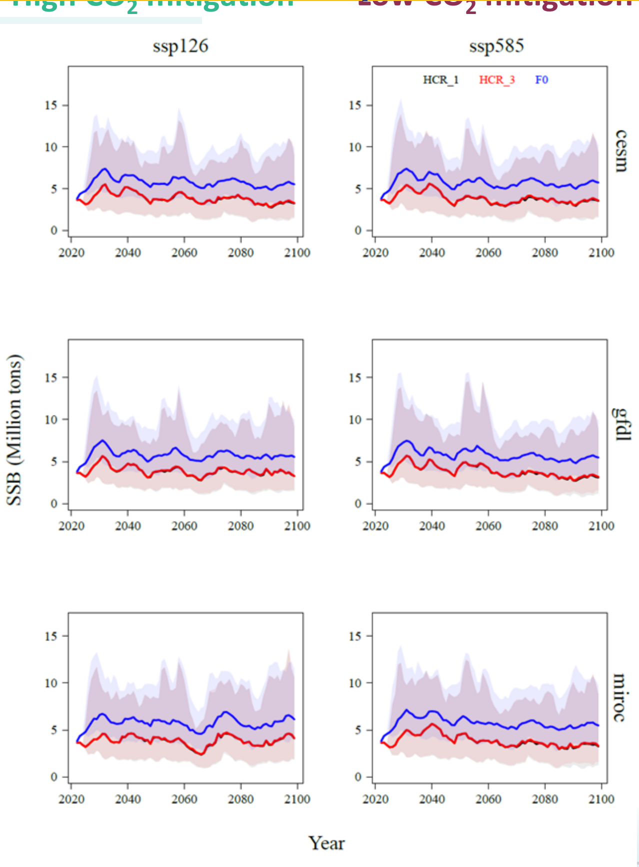
Draft results, please do not copy or distribute without permission of the author

Projections of SSB

Pollock : EBM 2 MT cap >> HCR levers

- Little differences between HCR 1 – 3 on the projected catch and biomass
- Future work will include
  - Model selection criteria (i.e., predictive ability of the stock-recruitment modeling alternatives)
  - Additional HCR formulations

Status quo
Bmin = B25%
B50%



Climate model 1

Climate model 2

Climate model 3

Ianelli et al. in prep,   Spencer et al. in prep.

Draft results, please do not copy or distribute without permission of the author

Projections of SSB

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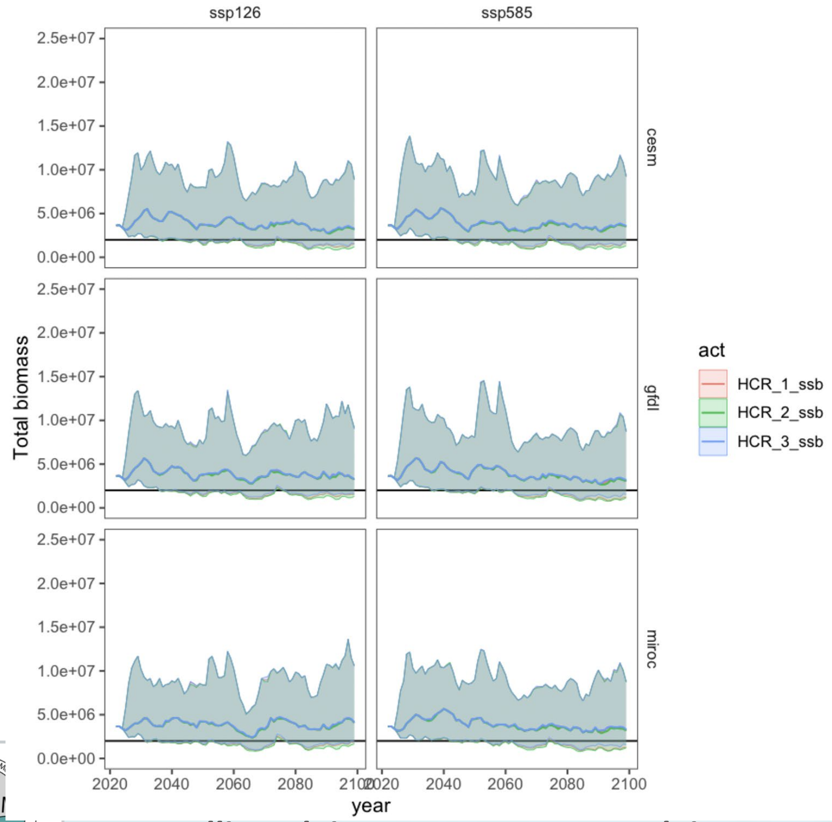

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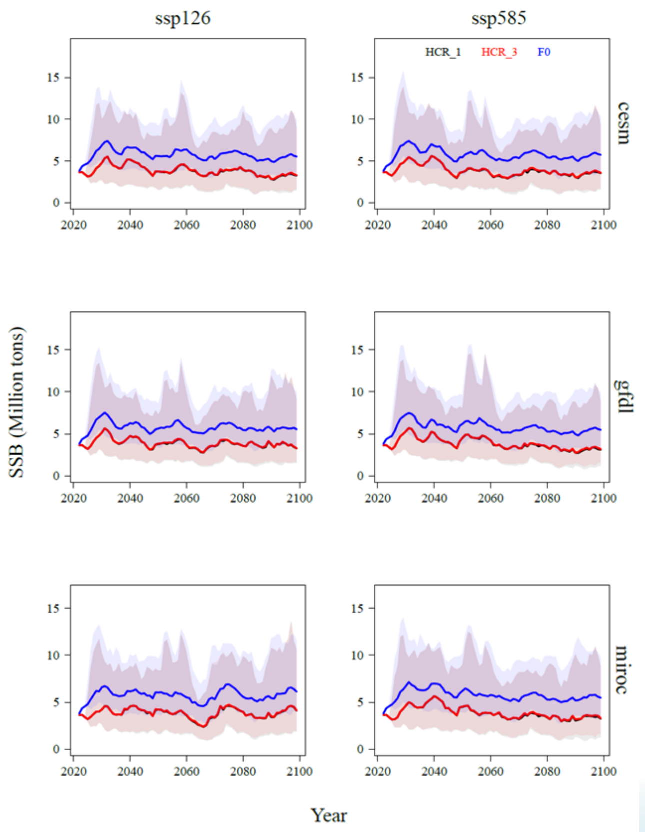

Climate model 1

Climate model 2

Climate model 3

Ianelli et al. in prep, Spencer et al. in prep.

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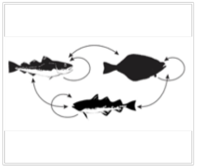
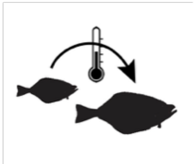
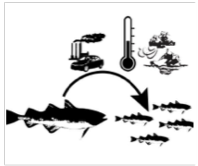
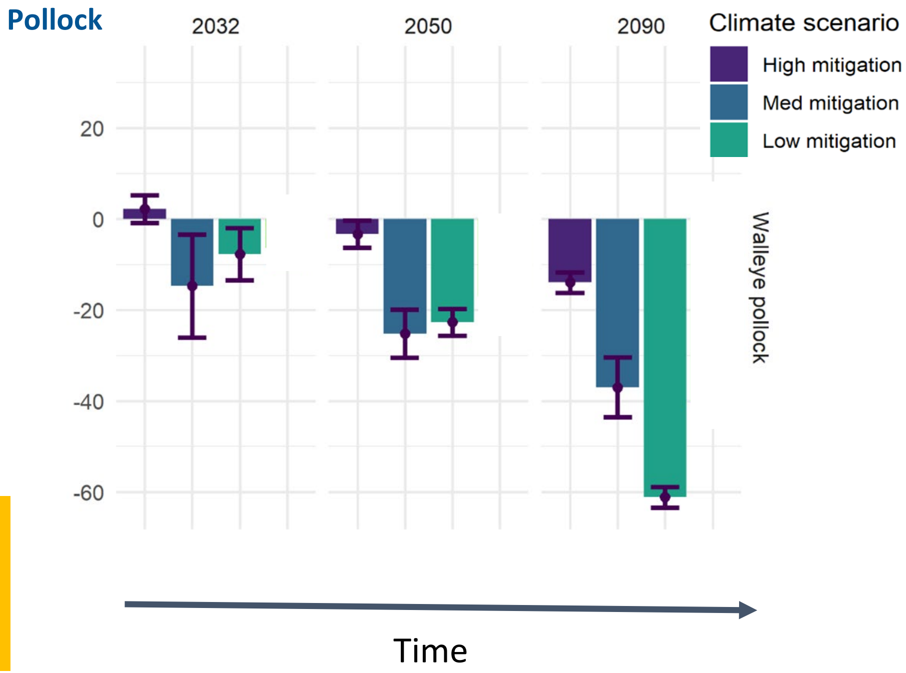
CEATTLE Model

Change in unfished SSB for pollock from "no climate change" simulation

Mortality	Weight @ Age	Rec	HCRs
			
• Empirical diets • Bioenergetics	• Empirical • VonB with Temp	• Climate-S/R • S/R • mean R	• Climate ABC • MMSY • MEY • SPR • Aggregate MSY

- **Pollock : Evidence of threshold effect**
- **Adding climate effects on mortality, growth and rec. results in different projections under CC**



Holsman et al. in prep.

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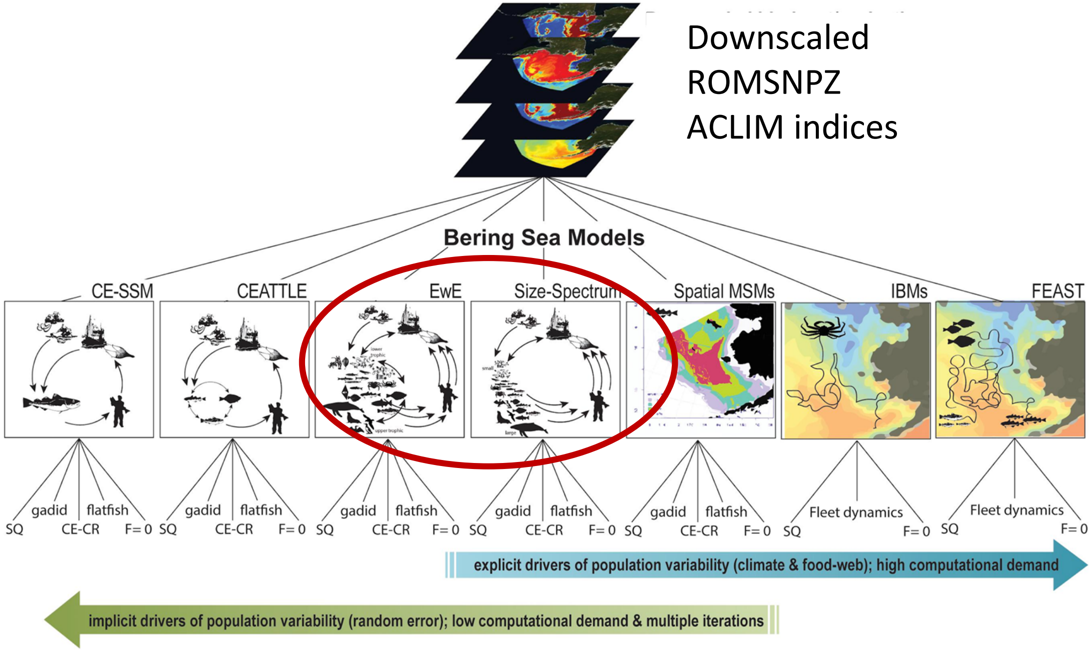
Integrated Climate Management Strategy Evaluations



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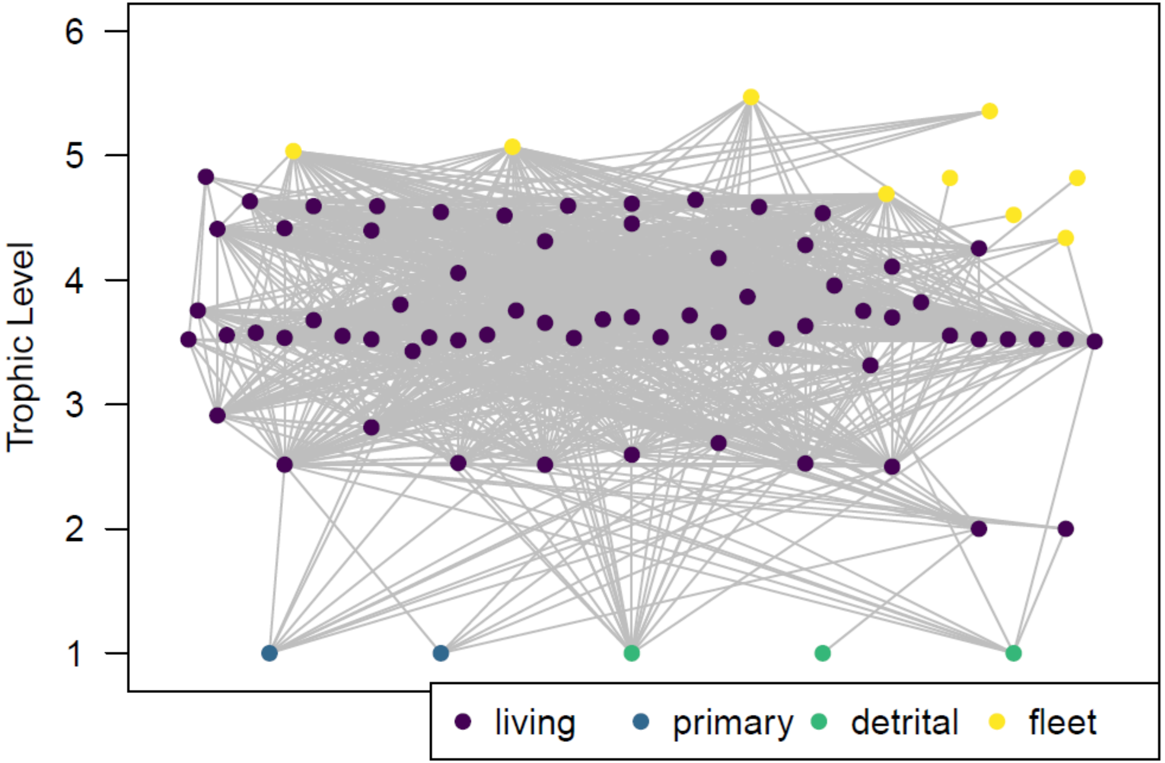
Hollowed et al. 2020. https://doi.org/10.3389/fmars.2019.00775

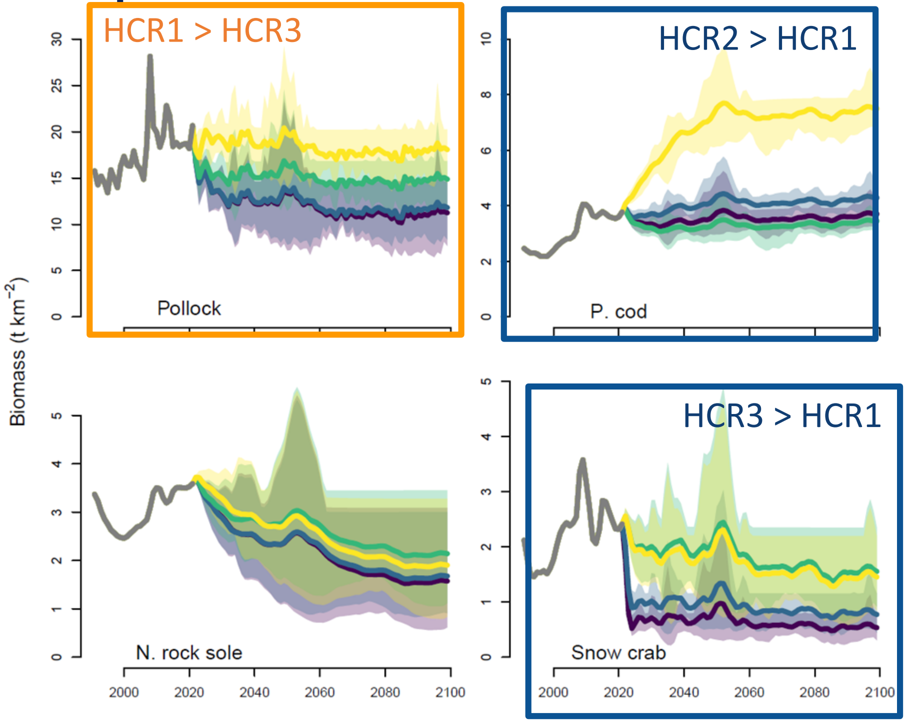
Rpath ecosystem model (A. Whitehouse)

- Whole food web
  - Ecopath with Ecosim algorithms as implemented in R
- 72 biological groups
- Including all 20 federally managed groundfish stocks
- 9 marine mammal groups
- 6 seabird groups
- 6 pelagic forage fish groups (incl. squids)
- ATTACH for harvest control rules under 2 MMT cap



Rpath: https://github.com/NOAA-EDAB/Rpath

Rpath



- HCR 1 Status quo
- HCR 3 B50%
- F static
- No fishing

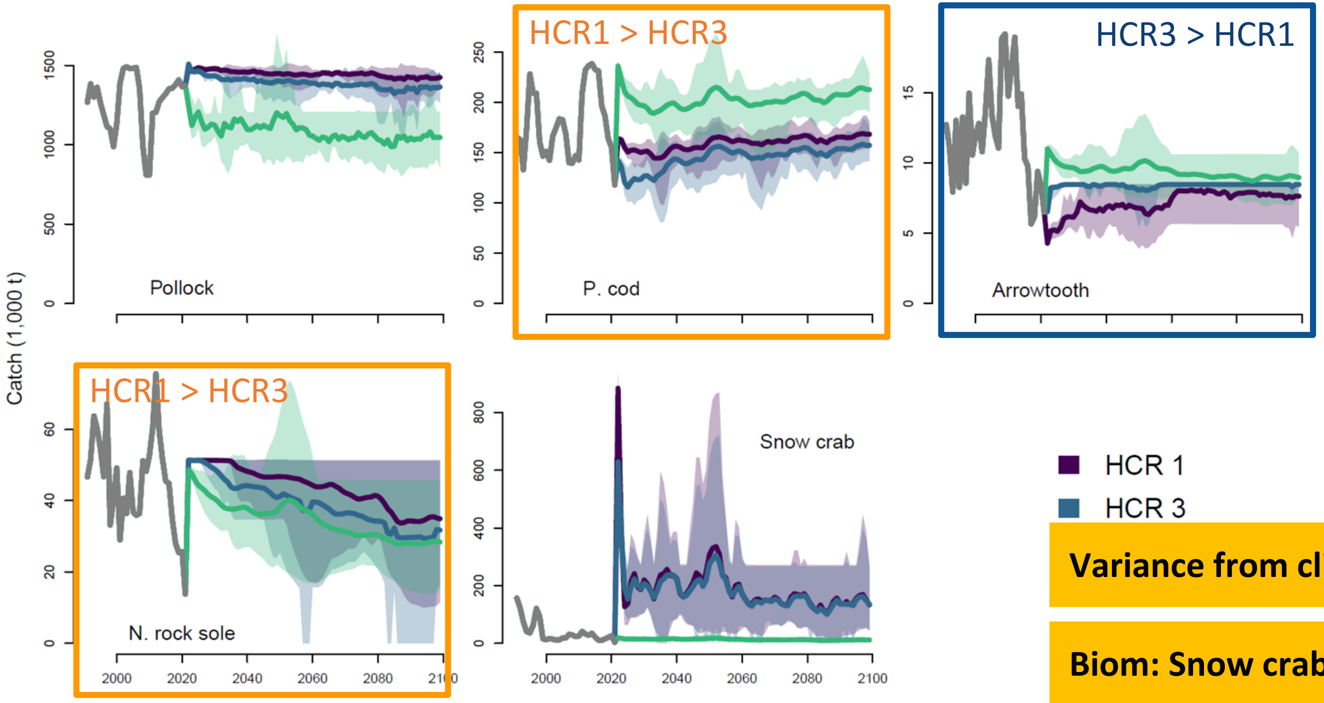
- Wide range of end of century outcomes across climate scenarios (3 ESMs x 2 SSPs and climate persistence)
- mean biomass projections for HCR 1 (status quo) and HCR 3 (B50) on similar trajectories

Variance from climate scenarios > HCRs

Biom: Snow crab and P cod HCR3 > HCR1 (slightly)

Whitehouse et al. in prep.
Draft results, please do not copy or distribute without permission of the author

Rpath



- Lower catch for pollock, P.cod and northern rock sole with HCR 3 (B50 target) vs. HCR 1 (status quo, B40 target).
- Northern rock sole biomass drops below HCR 3 limit threshold (B20) in GFDL SSP126 and SSP585 climate scenarios

Variance from climate scenarios > HCRs

Biom: Snow crab and Pcod HCR3 > HCR1 (slightly)

Catch: NRS and P.cod HCR1 > HCR2

- Ongoing work
  - Model fitting
  - Temperature-dependent bioenergetics for federally managed groundfish
  - Additional harvest control rules

Whitehouse et al. in prep.
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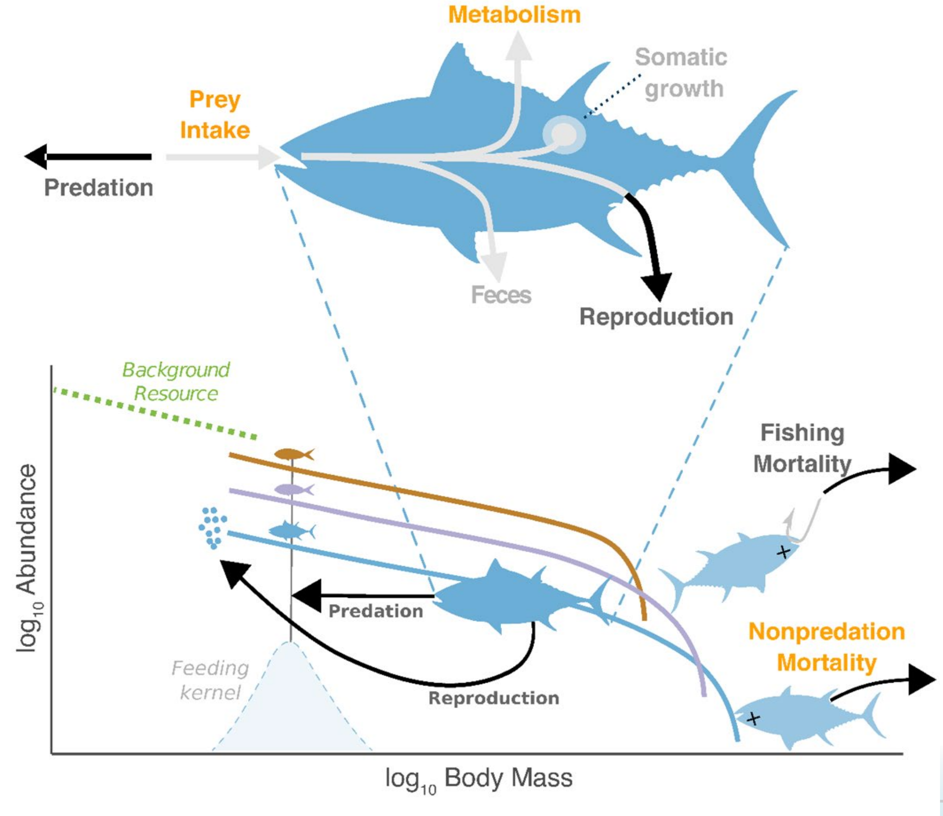
MIZER (J. Reum)

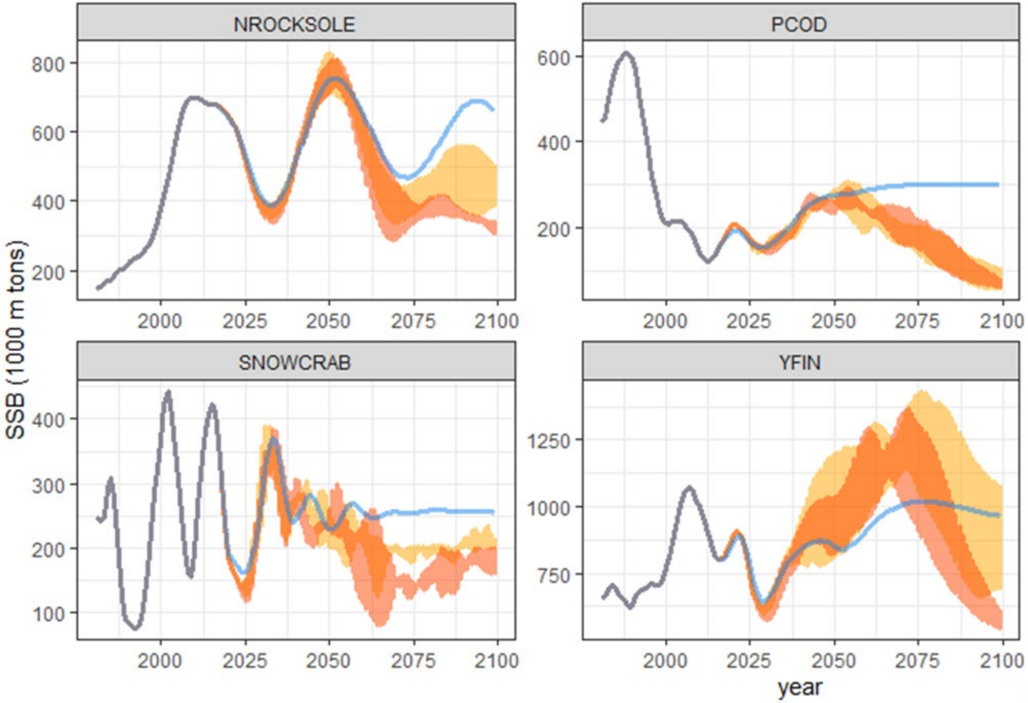
- Represents community and population size structure
- Predation and biological rates are size-dependent
- 8 fish species, 3 crab species
- 2 functional groups (sculpins & foragefish)
- ATTACH for harvest control rules under 2 MMT cap



EBS mizer: https://www.frontiersin.org/articles/10.3389/fmars.2020.00124/full

Size-spectrum food web model. *Status quo* HCRs

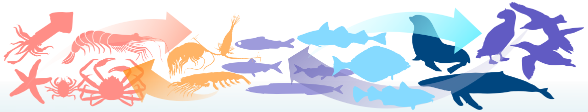
- **Adding climate effects on mortality, growth results in different projections under CC**
- **Evidence of goldilocks effect (non-linear response)**



ssp
ssp585 Low CO2 mitigation
static No climate change

- Climate forcings
  - Temperature effects
    - Metabolism
    - Consumption
    - Natural mortality
  - Pelagic and Benthic prey resources
  - Warmer futures support lower fish biomass

CE- MIZER



ACLIM

Reum et al. in prep.

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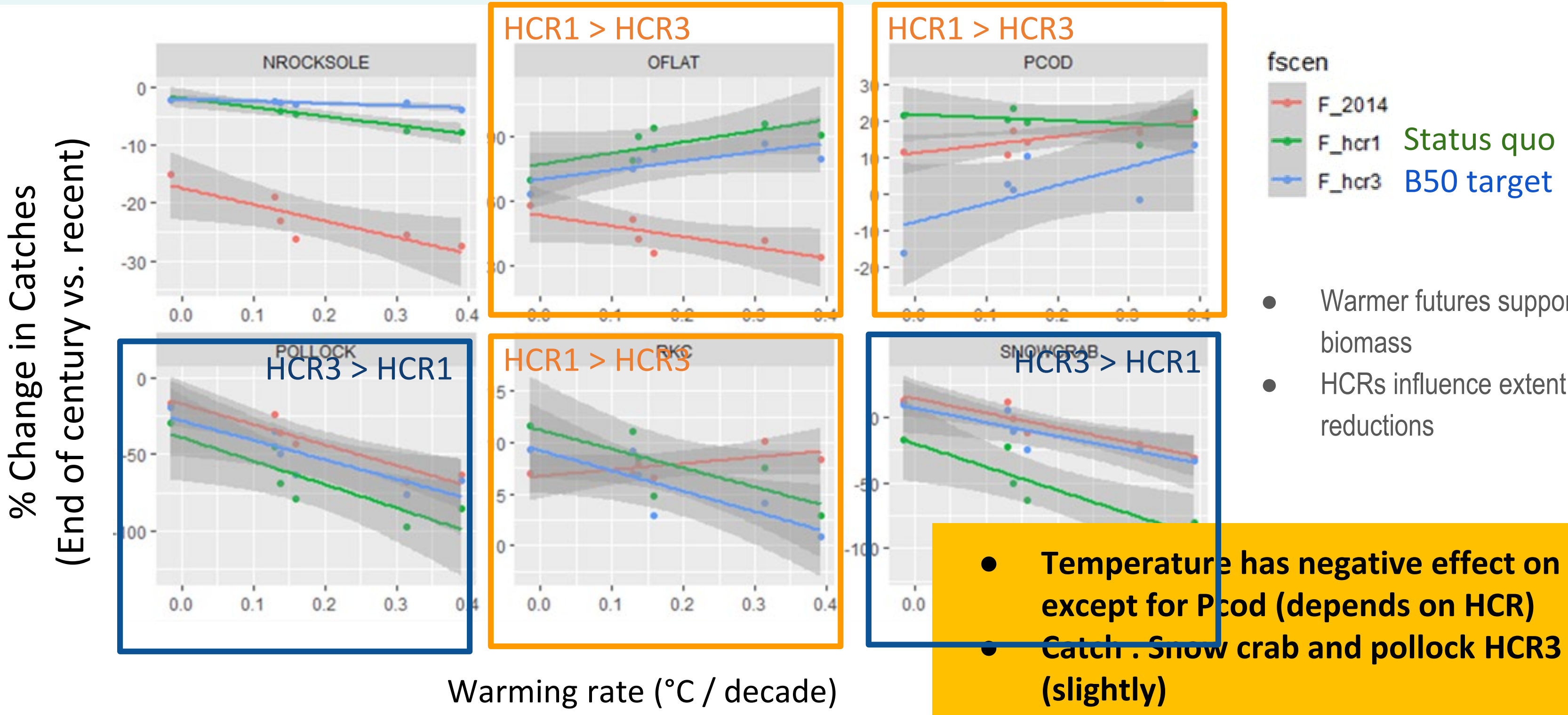
Size-spectrum food web model



- Warmer futures support lower fish biomass
- HCRs influence extent of catch reductions

- **Temperature has negative effect on catch, except for Pcod (depends on HCR)**
- **Catch : Snow crab and pollock HCR3 > HCR1 (slightly)**
- **Pcod HCR 1> HCR 3(similar to Rpath)**

Key Takeaways

- ➔ We have information needed to start planning & design
- ➔ Risk scales non-linearly with warming & are lower with CO_2 mitigation
- ➔ Declines in biomass and catch scale with warming
  - ◆ Some species exhibit “goldilocks” effect (non-linear)
- ➔ EBM measures like the 2 MT cap >> HCR “levers”
  - ◆ 2 MT cap has stronger effect than changing Btarget or Bcutoff
  - ◆ HCRs effects were stronger for species with complex coupling to climate
- ➔ Changing Bcutoff to B25% had little benefit to biomass, but non-minor loss to fisheries
- ➔ Climate effects reduce the difference between HCRs
- ➔ Projected declines in snow crab with high warming
  - ◆ For snow crab and pollock B50% might be > B40% (based on food web models)
  - ◆ Maybe for Pcod too under highest warming

New predictive tools can help fisheries prepare & plan

psl.noaa.gov/marine-heatwaves

Physical Sciences Laboratory

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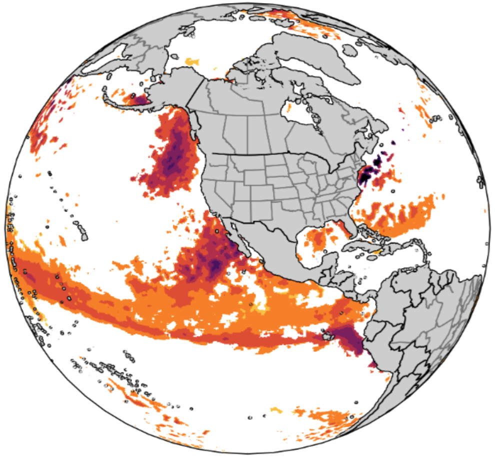
Overview

Marine heatwaves are periods of persistent anomalously warm ocean temperatures, which can have significant impacts on marine life as well as coastal communities and economies. Scientists at PSL are working to characterize marine heatwaves, understand how they form and dissipate, and predict them in advance. On this page, we will provide current ocean maps, forecasts of heatwaves, interactive tools for users to explore ocean heatwaves themselves, links to research results and to webpages at other institutions.



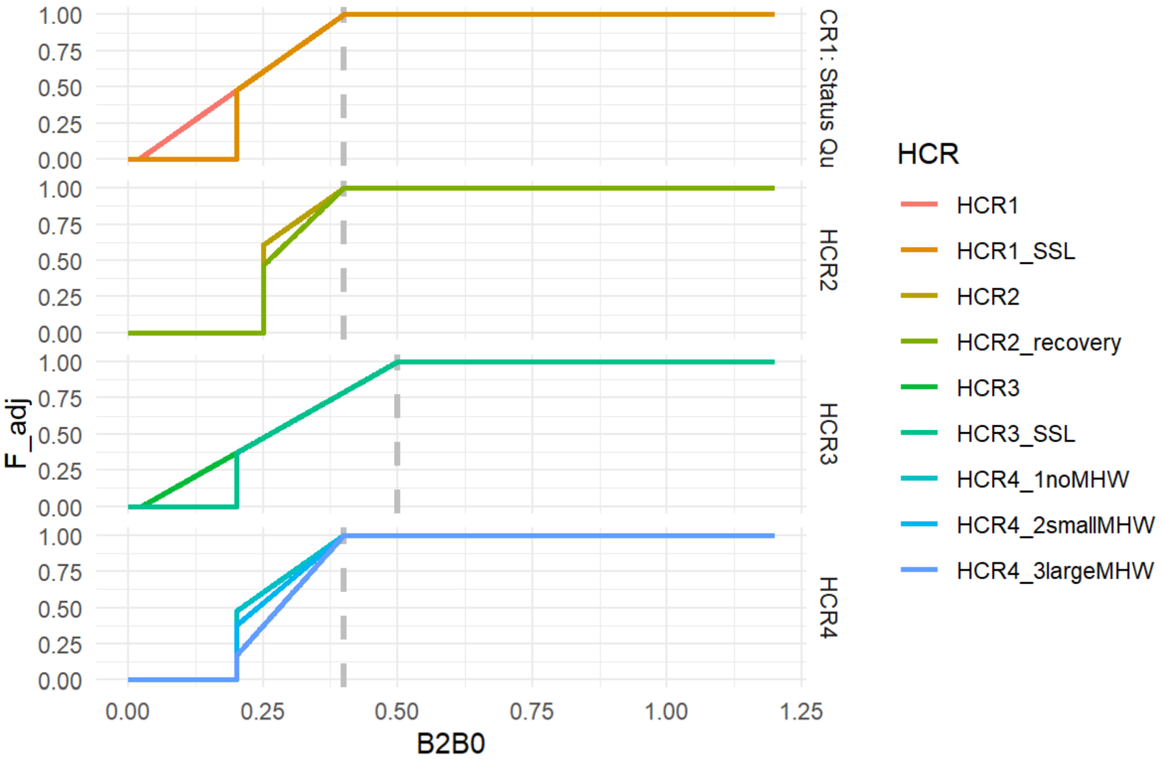
Can predict the probability of a marine heatwave 1-12 mo ahead of time

Jacox et al. 2022. www.nature.com/articles/s41586-022-04573-9

CE-HCR evaluations

HCR4

- Set $B_{F=0}$ based on 2015
- F_{target} is F rate to get to 40% $B_{F=0}$
- F_{adj} from sloping HCR where
  - alpha
    - no MHW = 0.05
    - Small MHW =0.2
    - Large MHw = 0.4
  - F →0 at B20%

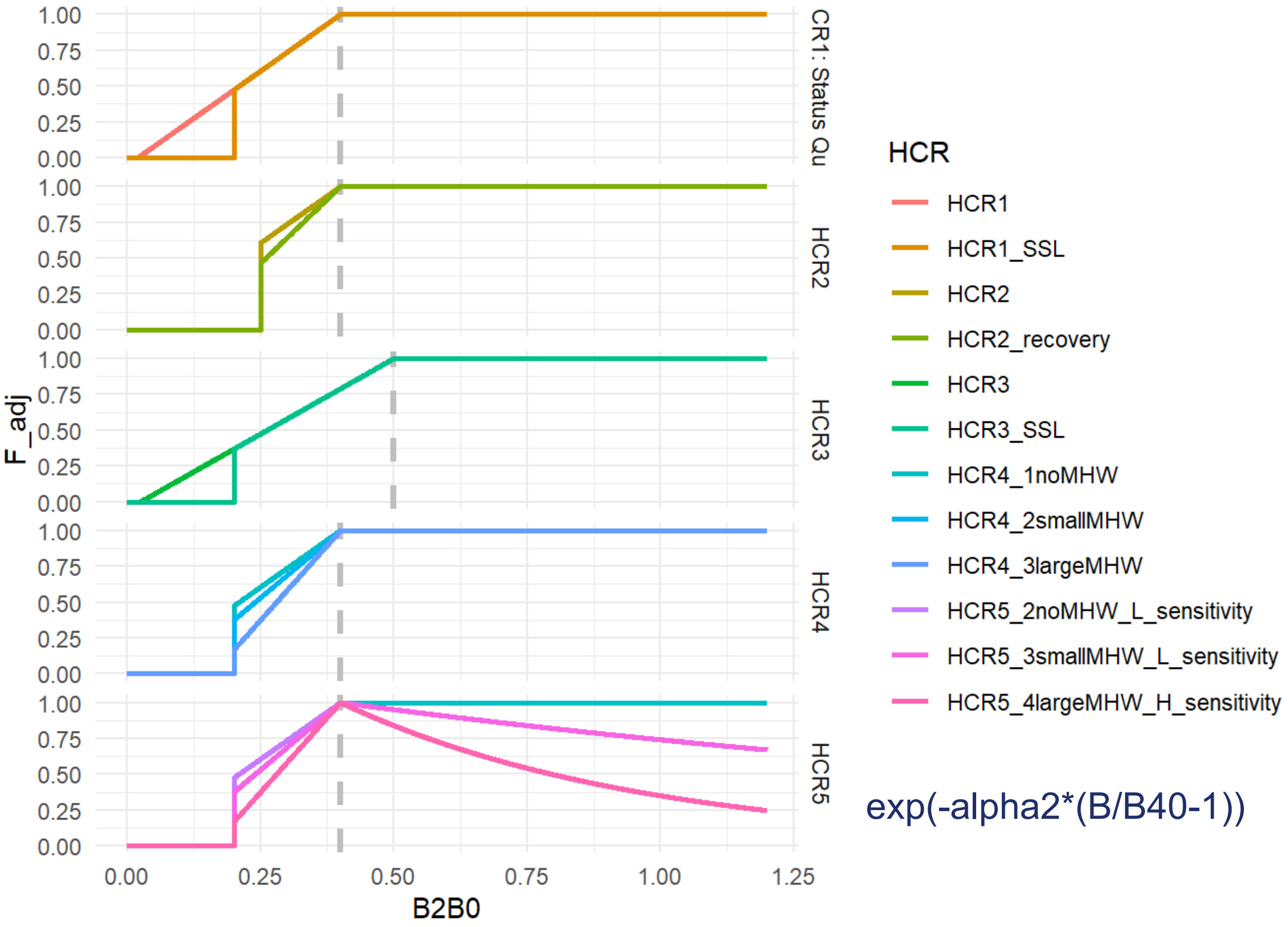


CE- HCR, scale back F in climate shocks

CE-HCR evaluations

HCR5

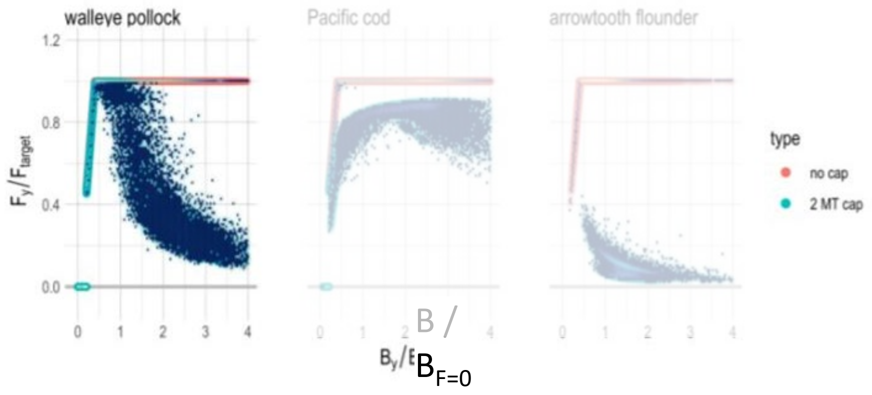
- Set $B_{F=0}$ based on 2015
- F_{target} is F rate to get to 40% $B_{F=0}$
- F_{adj} from sloping HCR where
  - alpha
    - no MHW = 0.05
    - Small MHW =0.2
    - Large MHw = 0.4
  - F →0 at B20%
  - Above 40% $B_{F=0}$ decrease exponentially
    - Alpha2 = 0.2
    - Alpha2 = 0.7



exp(-alpha2*(B/B40-1))

Build reserve for climate sensitive species

Apply effective pollock HCR cap-like effect



Supplementary Figure 3. Effective harvest rate F_y under the no cap and 2 MT cap

Holsman et al. 2020

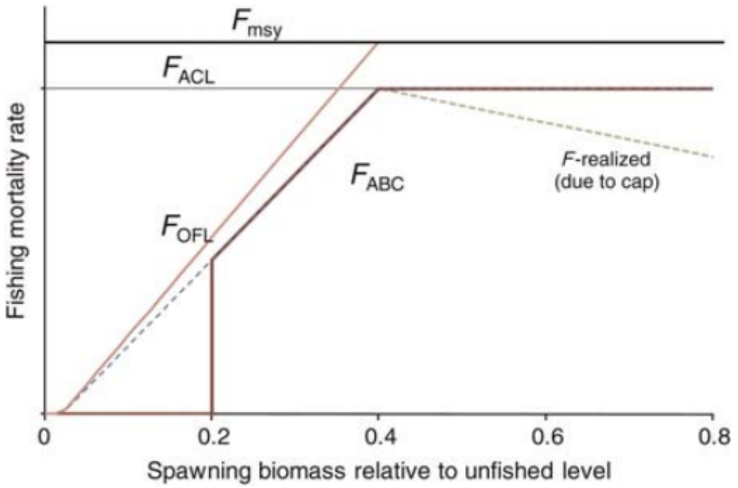


Figure 4. Schematic of harvest control rule currently affecting ABC or annual catch limit (ACL) for Alaska groundfish species like pollock (thick line). Note that this schematic indicates that B_{msy} is 40% of the unfished expected spawning biomass.

Ianelli et al. 2011

CE-HCR evaluations

HCR5

- Set $B_{F=0}$ based on 2015
- F_{target} is F rate to get to 40% $B_{F=0}$
- F_{adj} from sloping HCR where
  - alpha
    - no MHW = 0.05
    - Small MHW =0.2
    - Large MHw = 0.4
  - F →0 at B20%
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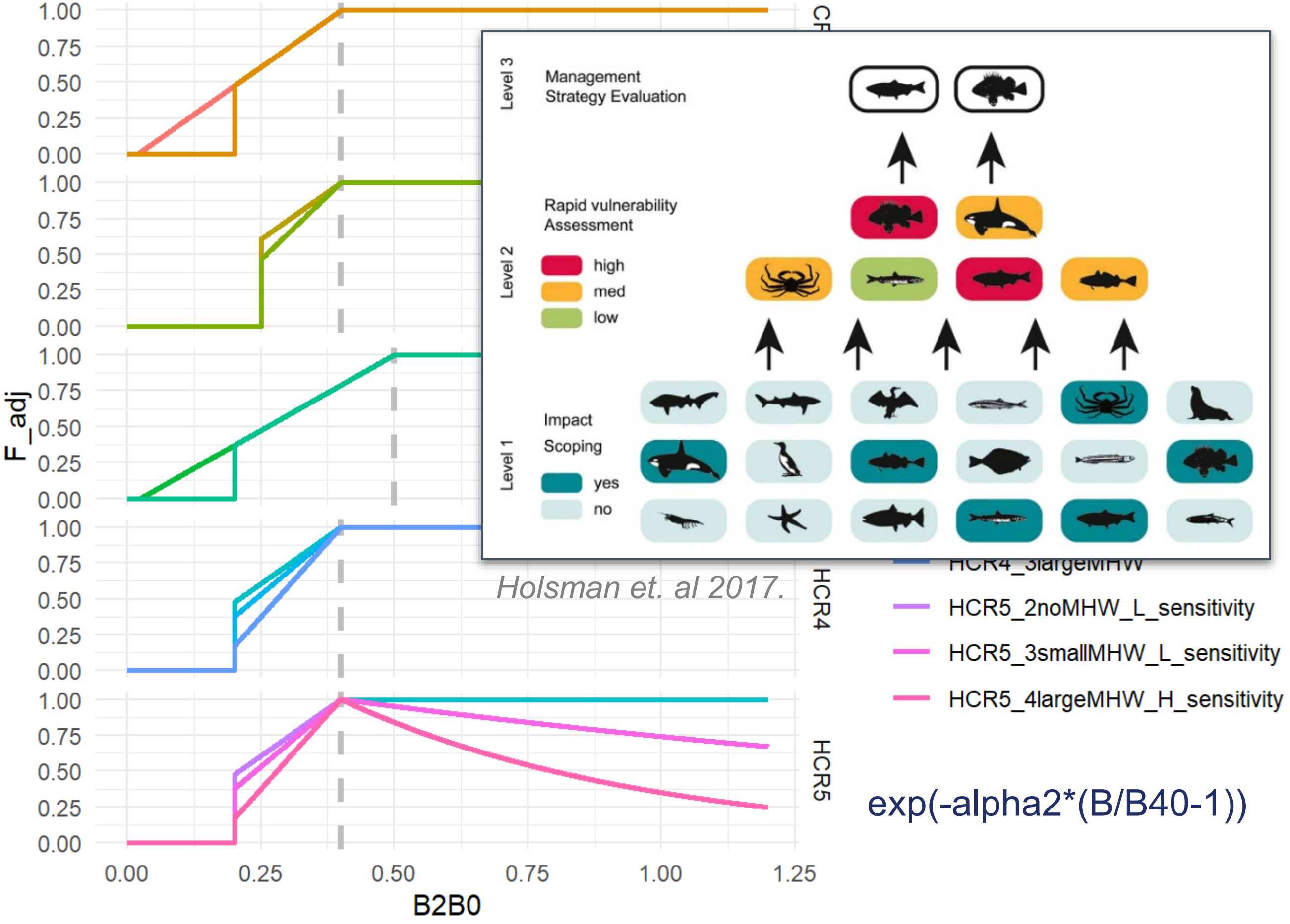
    - Alpha2 = 0.7



Build reserve for climate sensitive species

Additional results

Draft results from ACLIM2

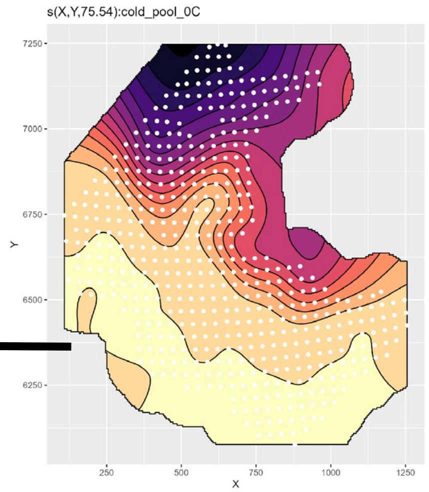
Species distribution models (Delta-Gamma GAMs)

Candidate model terms:

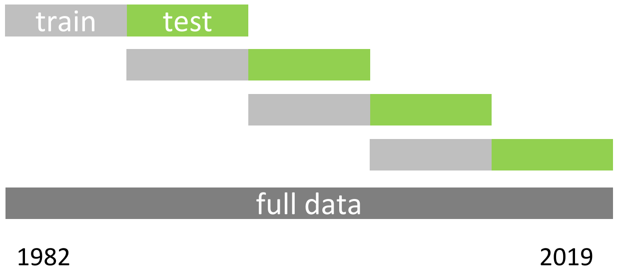
- Temperature (bottom 5m)
- Depth
- Oxygen (bottom 5m)
- Euphausiids (integrated)
- pH (bottom 5m)
- Cold pool (0C/2C – spatially varying)
- Total biomass (spatially varying)
- Principle components axes 1 & 2:

Ice area, salinity, alkalinity, Benthic infauna, boundary layer depth, Iron, NCaO, NH_4, Ice algae concentration, large & small plankton concentration, total inorganic carbon

~ 50% of variation explained



Environmental covariates selected via time-series cross validation, i.e. based on forward predictive skill

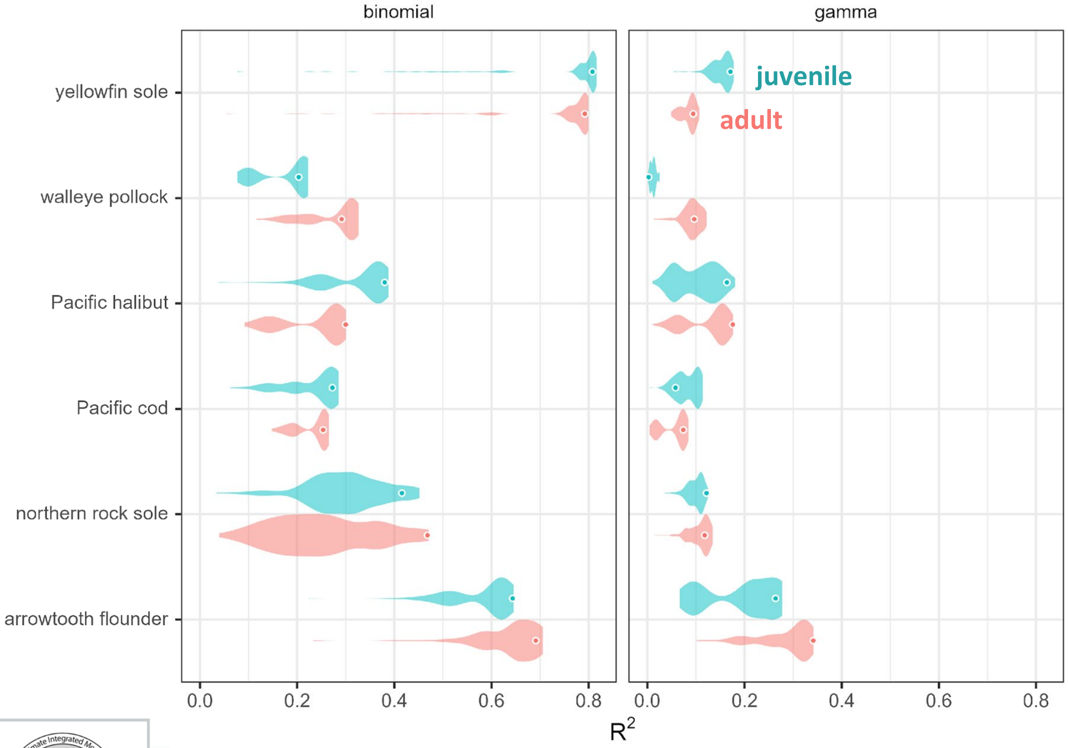


Preliminary models built for adults & juveniles:
walleye pollock, Pacific cod, Pacific halibut, arrowtooth flounder, yellowfin sole, & northern rock sole

Additional species planned:
Chinook salmon, red king crab, snow crab, capelin

Goodman et al. in prep.
Draft results, please do not copy or distribute without permission of the author

Species distribution models (Delta-Gamma GAMs)



- Bering-10K environmental covariates explain substantial variation in some species ranges, but relatively little in others
- Models can be used to project probably of encounter / presence-absence field, and/or relative biomass distribution
- Uncertainty in species distribution models can be propagated into estimates of area occupied, range centroids, and species overlap
- Overlap indices can potentially be incorporated in multispecies models for scenario testing

Goodman et al. in prep.

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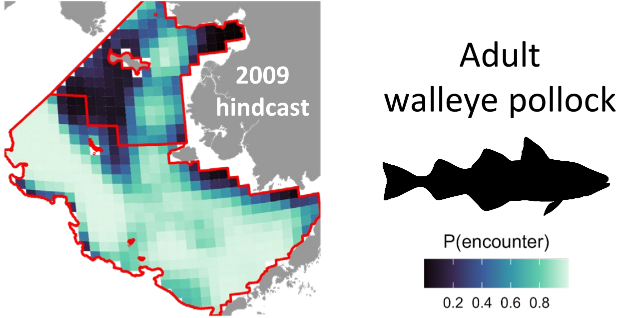
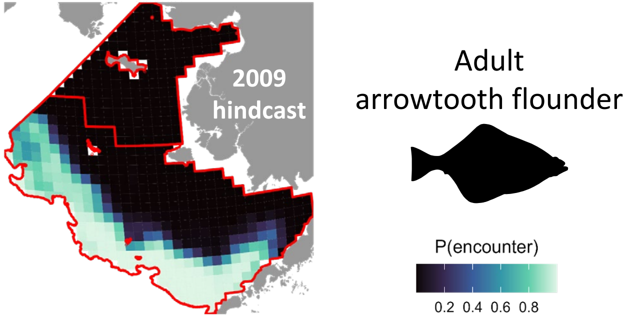
Species distribution models (Delta-Gamma GAMs)

Example preliminary probability of encounter estimates (CMIP6 MIROC)





Goodman et al. in prep.

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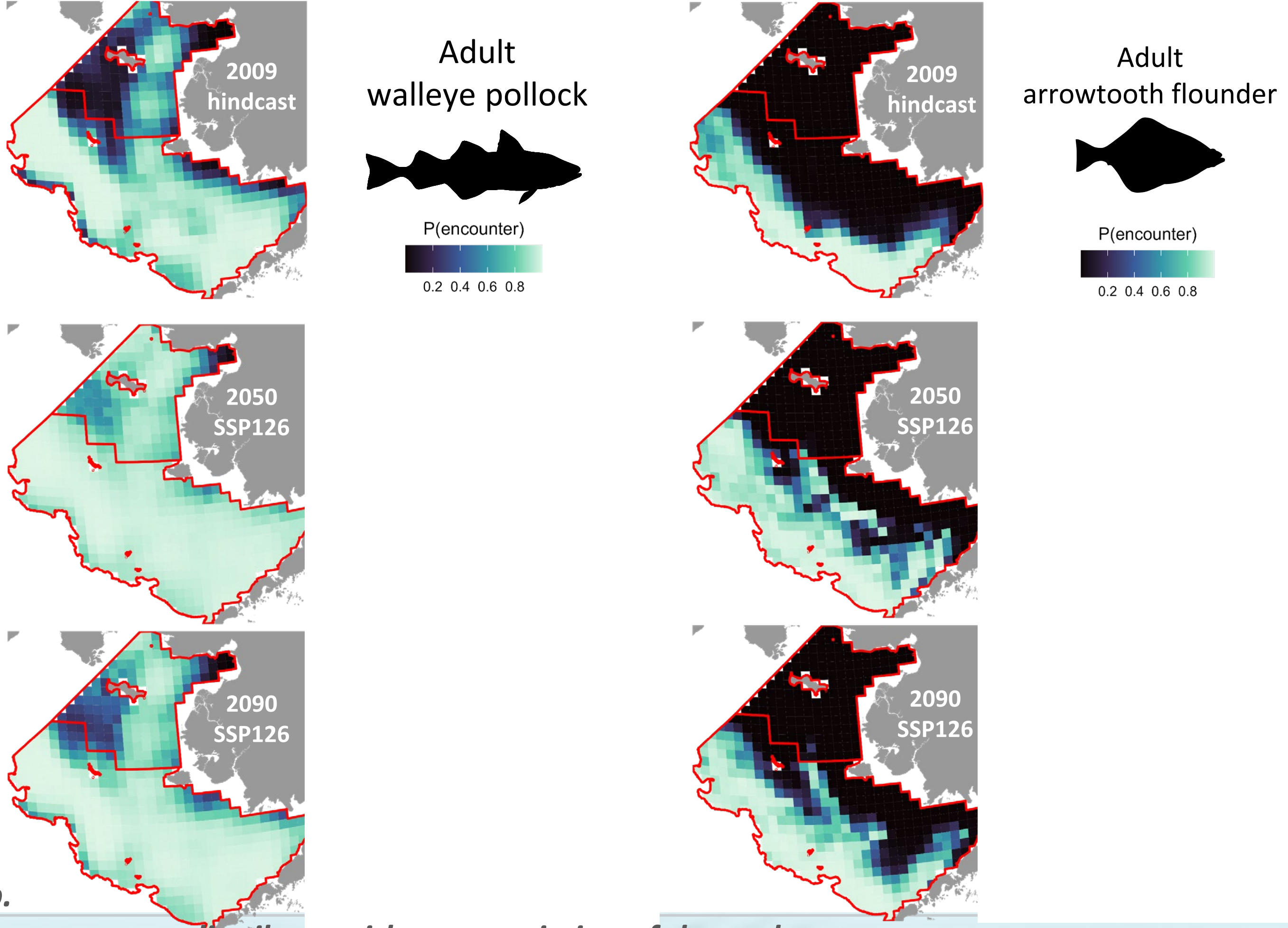
Species distribution models (Delta-Gamma GAMs)

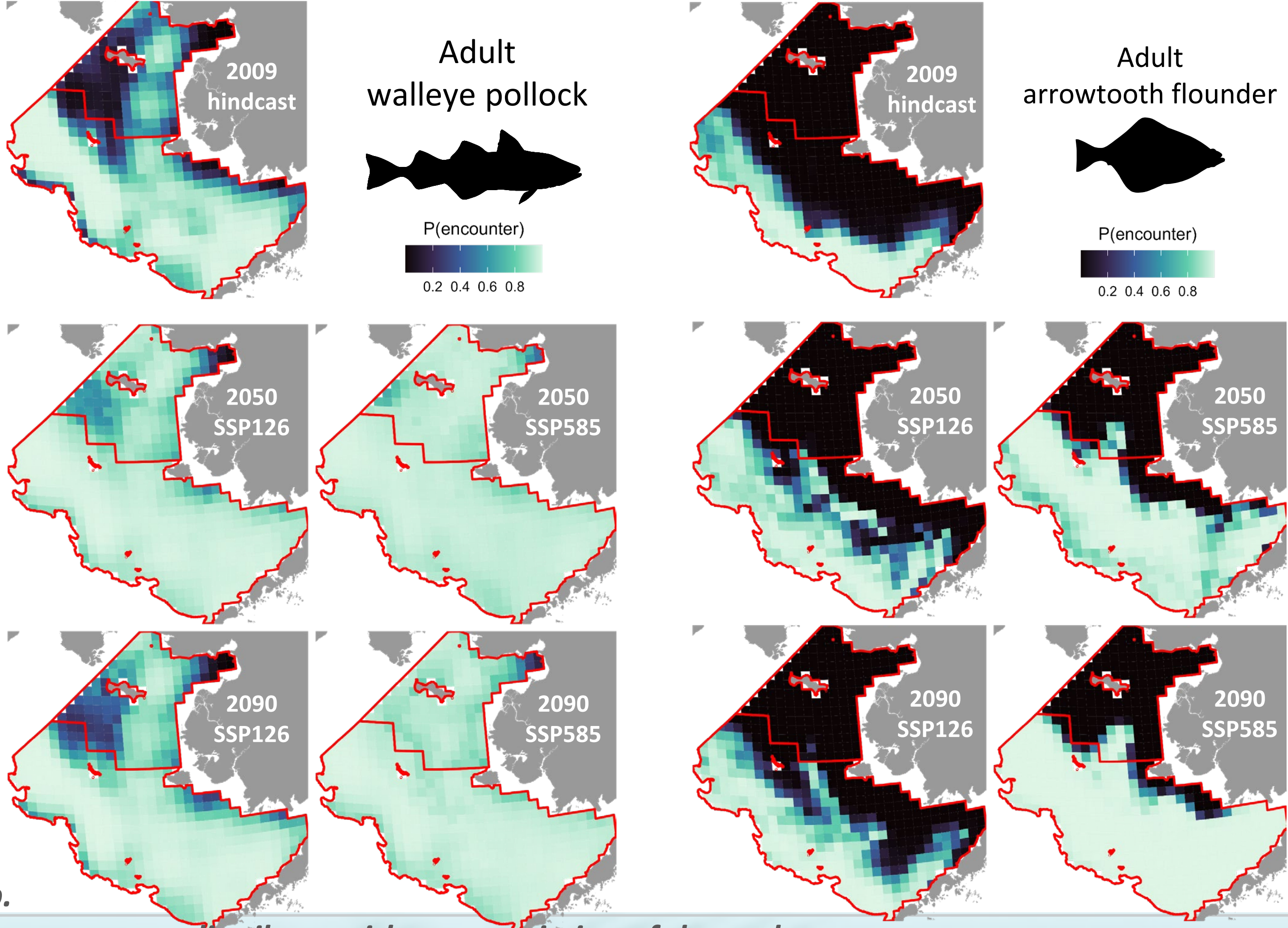
Example preliminary probability of encounter estimates (CMIP6 MIROC)



Goodman et al. in prep.

Species distribution models (Delta-Gamma GAMs)

Example preliminary probability of encounter estimates (CMIP6 MIROC)



Goodman et al. in prep.

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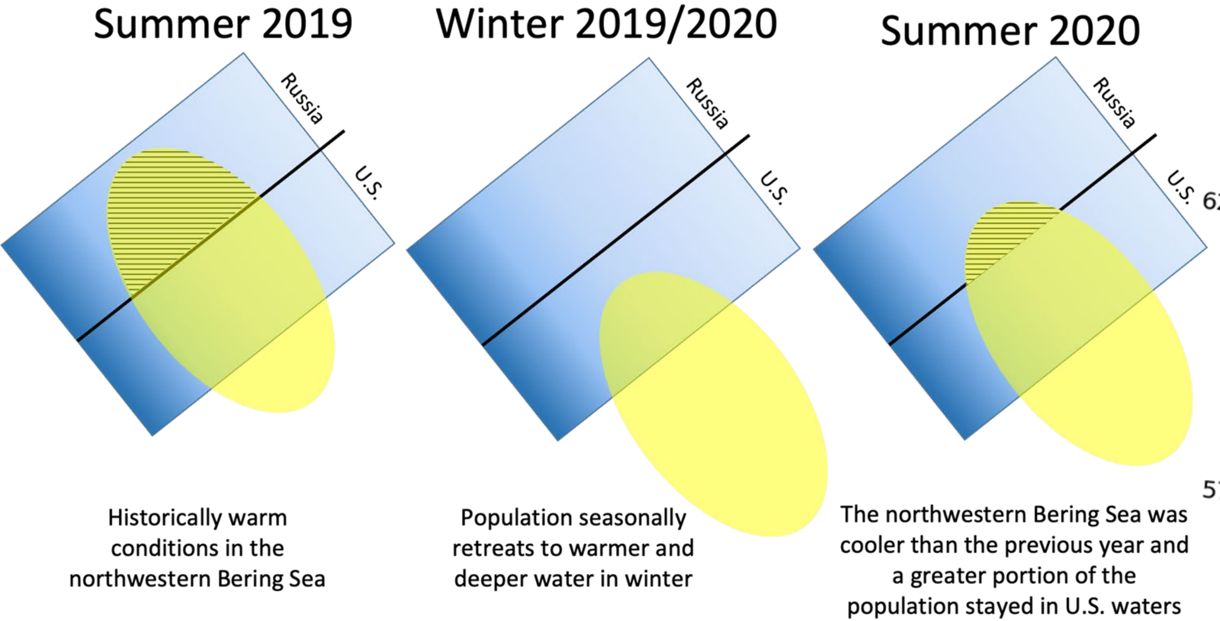
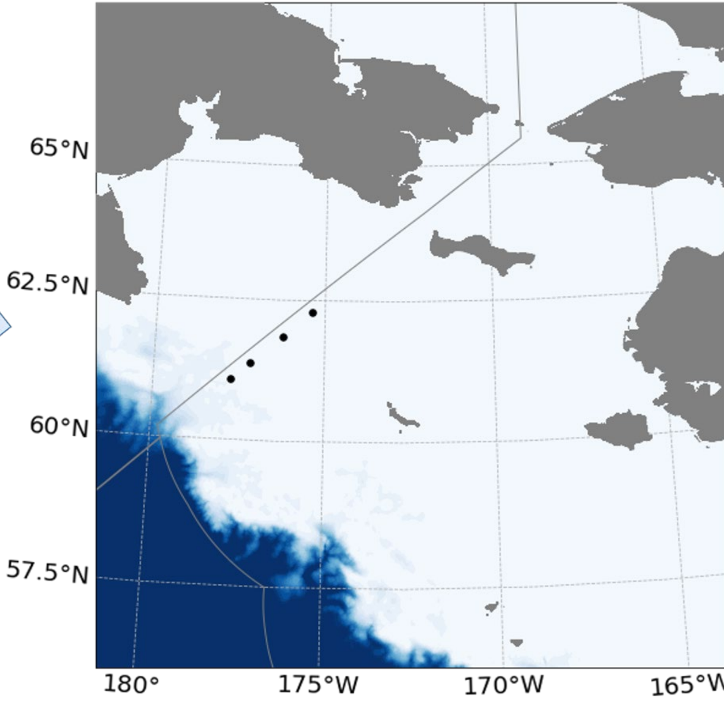
ROMS-US/RUS pollock work (R. Levine, De Robertis, Ianelli)





Levine, De Robertis, Ianelli

Levine et al. in prep.

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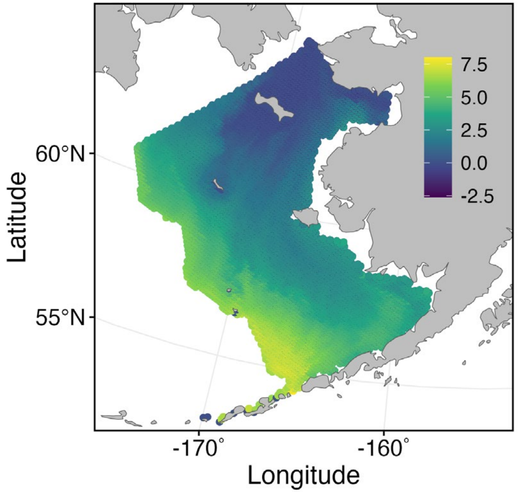
Size-at-age model (J. Bigman)

Coupling Bering10k ROMS temperature and oxygen hindcasts and projections with survey data to understand and predict how changes in size and growth with warming will affect size-at-age, reproductive output, and fisheries productivity

Bering10k ROMS bottom temperature

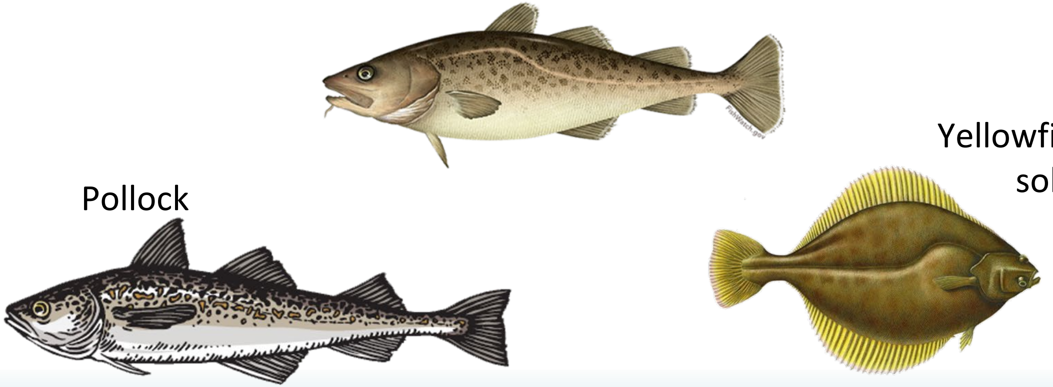


Survey data: age & weight

Pacific cod

Pollock

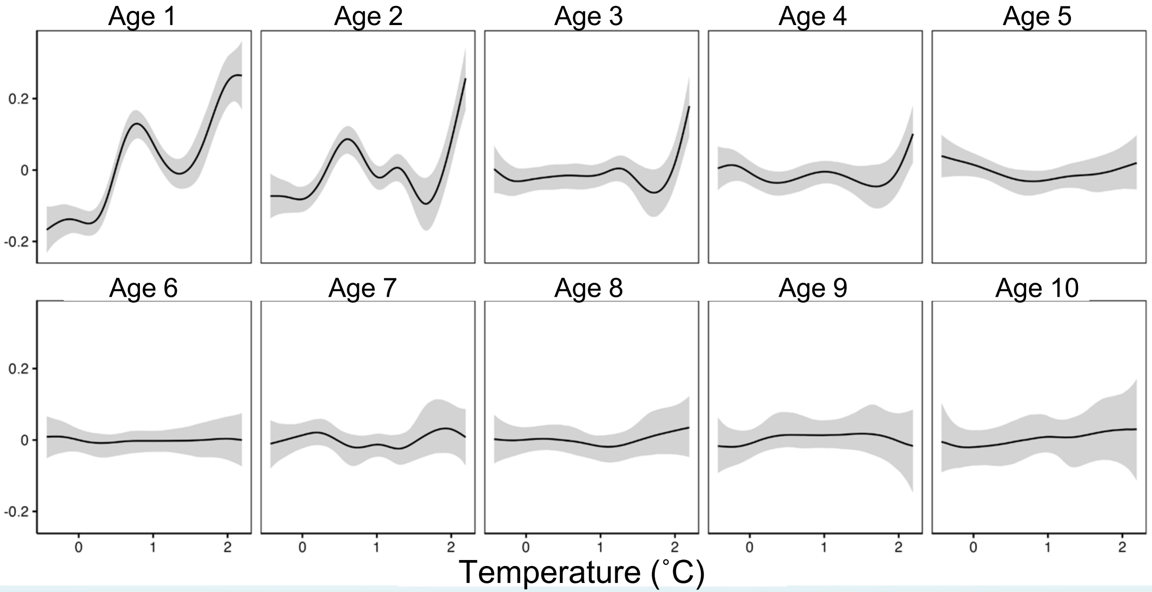
Yellowfin sole



Size-at-age model (J. Bigman)

For example, we see larger size-at-age for early life stages and around age-at-maturity, relationship changes for Pollock; use age-specific relationships with temperature to predict future size-at-age, as well as how reproductive output and spawning stock biomass may change

Partial effect on weight-at-age for pollock



Salmon & Communities (Yasumiishi & Wise et al.)

Identify candidate ROMS/NPZ indicators for Yukon River Chinook salmon survival based on scientific and traditional knowledge.

H1: Bering Sea temperature warming at 2-4 year lags increases marine growth & decreases age (size) at maturity resulting in smaller spawners and lower survival.

H2: Weaker north winds decrease run size.

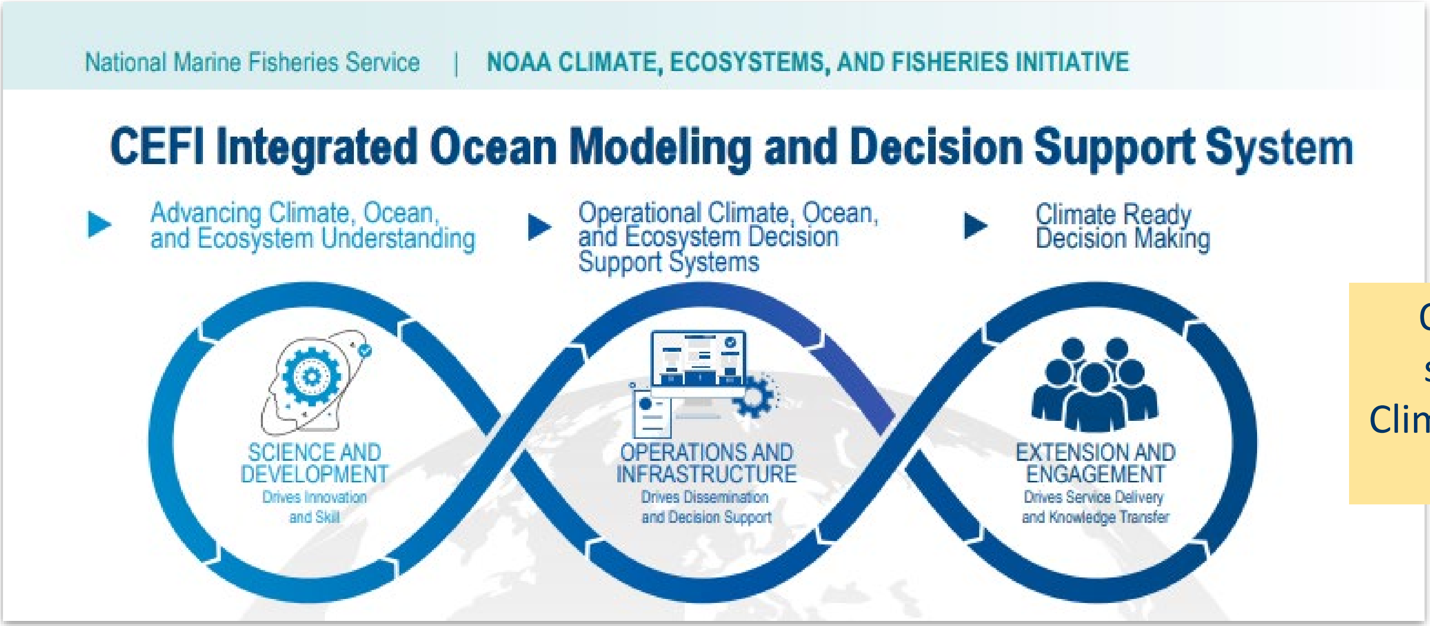
Produce recruitment projections under different climate & emission scenarios

Yasumiishi et al. in prep.
Draft results, please do not copy or distribute without permission of the author

Today's Talk

1. Brief introduction to climate planning, risk, adaptation, and CO2 mitigation
2. Linking to day 1: projected changes to NEBS conditions and carrying capacity
3. Actionable advice
   a. Climate informed control rules (ACLIM2 spring sprint)
   b. Climate informed spatial and scenario planning
4. Next steps, CEFI and ACLIM3

NOAA Climate, Ecosystems, & Fisheries Initiative (CEFI)



Operational support for Climate-informed EBFM

https://www.fisheries.noaa.gov/topic/climate-change/climate,-ecosystems,-and-fisheries

Regional ocean prediction capacity from seasons to centuries built from OAR's Modular Ocean Model 6 (MOM6)

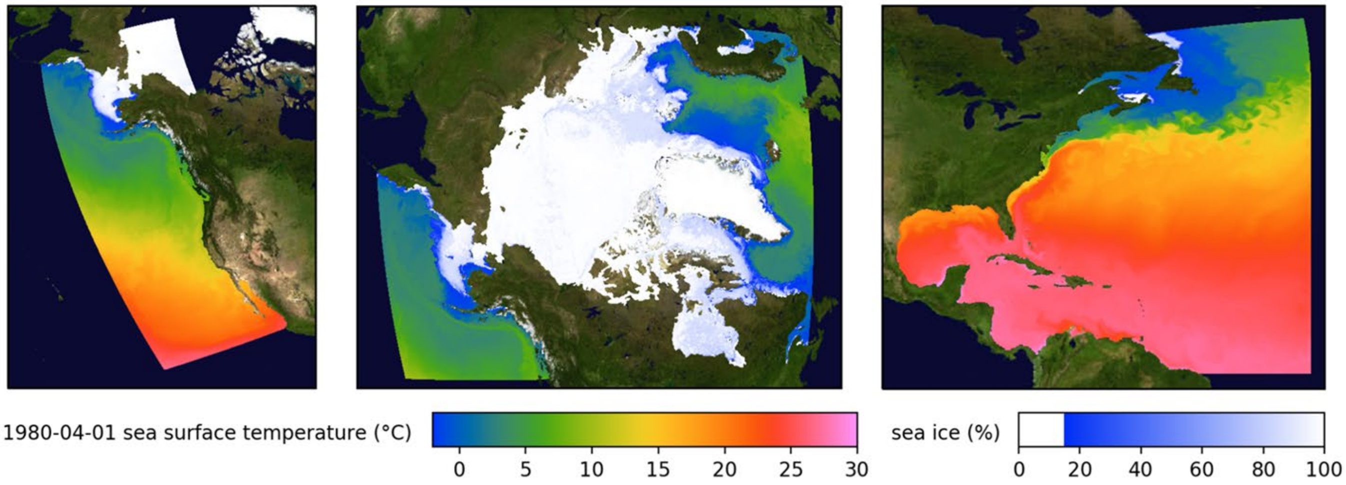


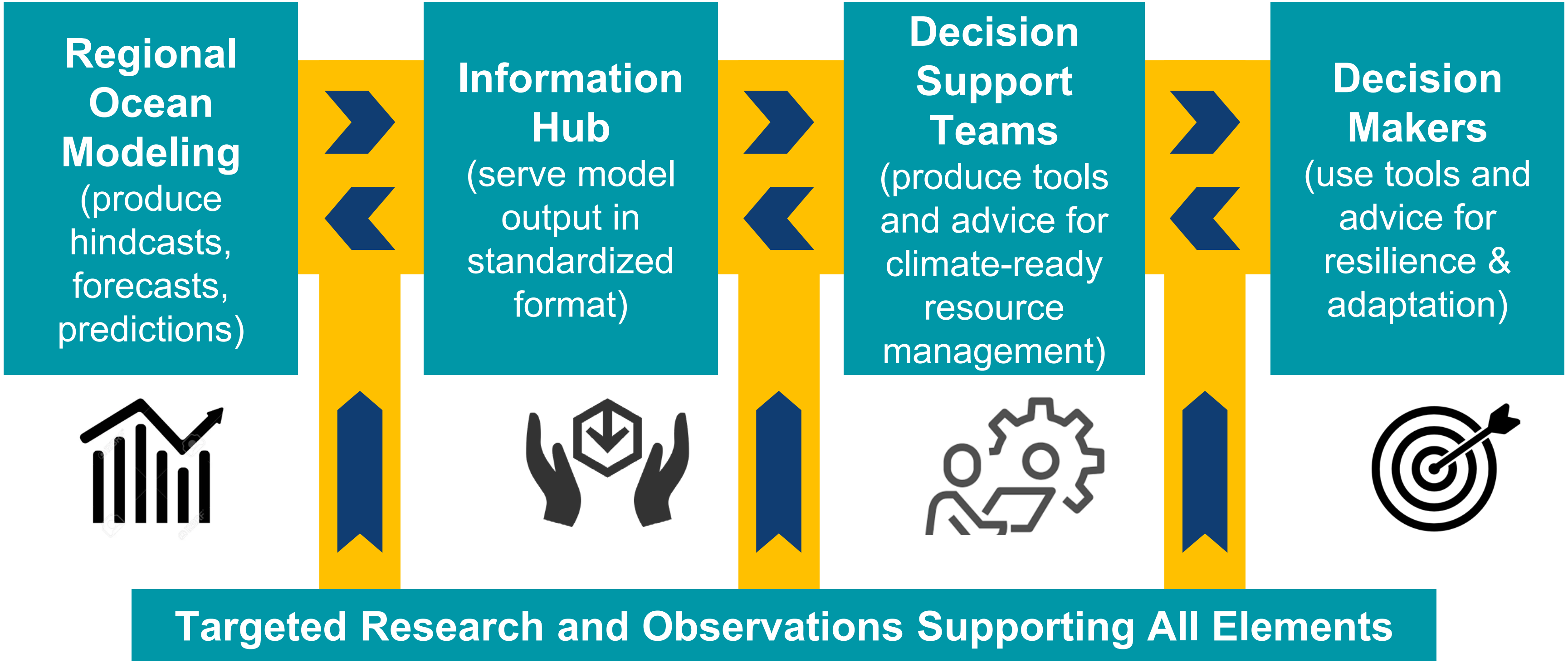
Figure from Andrew Ross (NOAA/GFDL)

Prototype MOM6 coast-wide domains for seasons to decades **(Great Lakes, Pacific Islands in progress)**

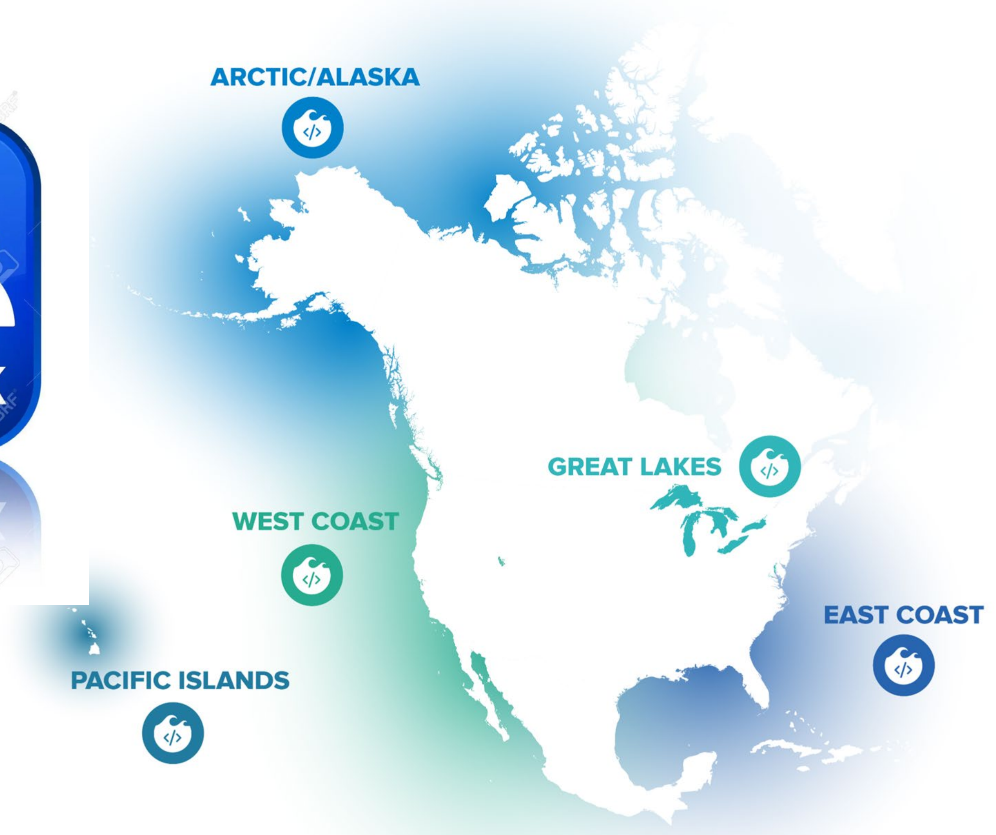
- **Ocean predictions spanning the range of ocean futures** powered by HPComputing.
- **Regional Ocean Modeling Teams** customize products for NMFS and other users.
- **CEFI Information Portal** provides easy access, efficiency and national data standards

https://www.gfdl.noaa.gov/improving-ocean-habitat-forecasts-for-the-northeast-u-s/

CEFI Decision Support System



Modeling Teams



Key elements of climate ready advice

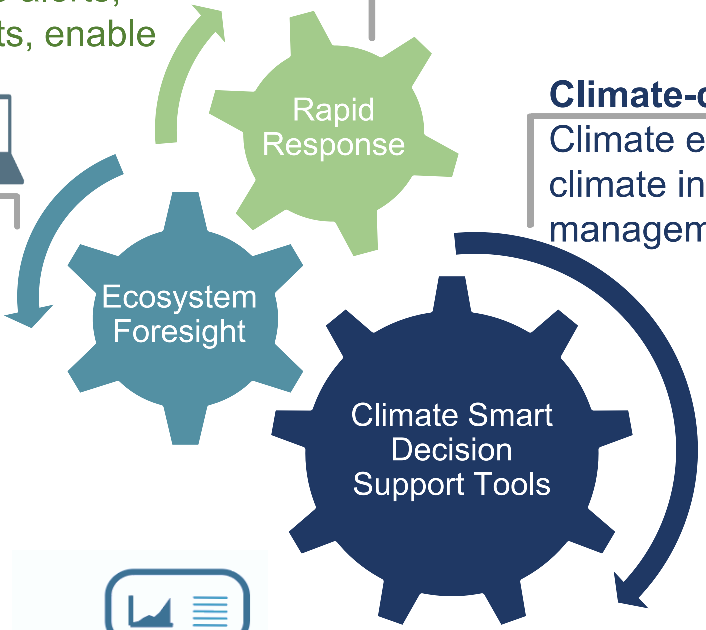
Holsman et al. in prep

Rapid response
Plan & predict, near-real time alerts, emergency aid, triage impacts, enable individual adaptation

e.g., Emergency relief

Ecosystem foresight

Social-ecological system forecasts & projections, tipping points & early warnings



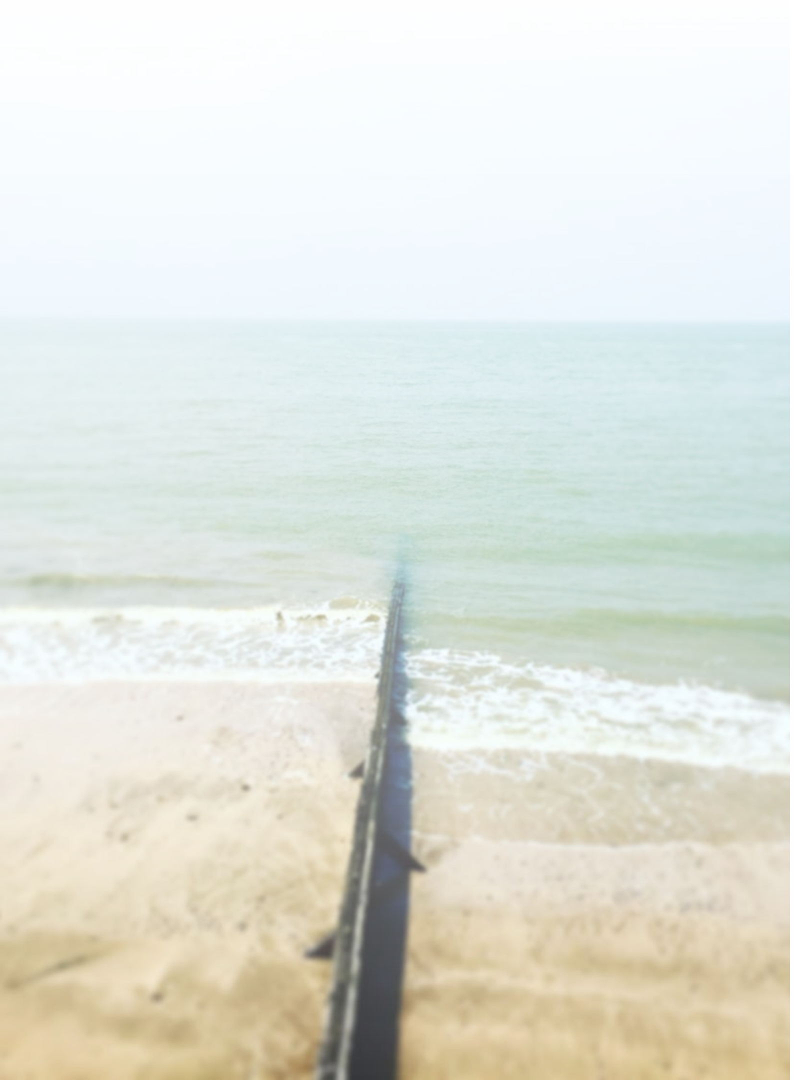
Climate-driven decision support tools
Climate enhanced stock assessments, climate informed advice & tools, dynamic management

e.g., Risk assessment & probability of increase or decrease

Coordinated science & advice

Inter- & intra-agency coordination, national strategies aligned with regional priorities, efficient information sharing, reduced redundancy

Effective monitoring & research
Improved research & climate-ready survey design, increased speed of response



ACLIM support

- ACLIM 1.0 funding:
  - Fisheries & the Environment (FATE)
  - Stock Assessment Analytical Methods (SAAM)
  - Climate Regimes & Ecosystem Productivity (CREP)
  - Economic and Human Dimensions Program, AFSC, OAR
  - NMFS Economics and Human Dimensions Program
  - NOAA Integrated Ecosystem Assessment Program (IEA)
  - NOAA Research Transition Acceleration Program (RTAP)
  - Alaska Fisheries Science Center
- ACLIM 2.0 funding:
  - NOAA's Coastal and Ocean Climate Applications (COCA) Climate and Fisheries Program
  - NOAA Integrated Ecosystem Assessment Program (IEA)
  - Alaska Fisheries Science Center

Collaboration support:

MAPP Bering Seasons & FATE EFH

- NPRB & BSIERP Team
- GOA-CLIM Team
- AFSC REEM, REFM, RACE
- ICES PICES Strategic Initiative on climate change and marine ecosystems (SICCME/S-CCME)
- NPFMC Climate change task force, the Ecosystem Committee of the NPFMC

Questions?

ACLIM1 Publications:

1. (in review) Torre, M. , W. T. Stockhausen, A. J. Hermann, W. Cheng, R. Foy, C. Stawitz, K. Holsman, C. Szuwalski, A. B. Hollowed. (In Review). Early life stage connectivity for snow crab, Chionoecetes opilio, in the eastern Bering Sea: evaluating the effects of temperature-dependent intermolt duration and vertical migration. Deep Sea Research II,
2. (in review) Whitehouse, G. A., K. Y. Aydin, A. B. Hollowed, K. K. Holsman, W Cheng, A. Faig, A. C. Haynie, A. J. Hermann, K. A. Kearney, A. E. Punt, and T. E. Essington. Bottom-up impacts of forecasted climate change on the eastern Bering Sea food web. Frontiers in Mar. Sci.
3. (2020) Holsman, K.K., A. Haynie, A. Hollowed, J. Reum, K. Aydin, A. Hermann, W. Cheng, A. Faig, J. Ianelli, K. Kearney, A. Punt. (2020) Ecosystem-based fisheries management forestalls climate-driven collapse. Nature Communications. DOI:10.1038/s41467-020-18300-3
4. (in review) Thorson, J., M. Arimitsu, L. Barnett, W. Cheng, L. Eisner, A. Haynie, A. Hermann, K. Holsman, D. Kimmel, M. Lomas, J. Richar, E. Siddon. Forecasting community reassembly using climate-linked spatio-temporal ecosystem models. Ecosphere
5. (Accepted) Szuwalski, W. Cheng, R. Foy, A. Hermann, A. Hollowed, K. Holsman, J. Lee, W. Stockhausen, J. Zheng. Climate change and the future productivity and distribution of crab in the Bering Sea. ICES JMS
6. (2020) Reum, J. C. P., J. L. Blanchard, K. K. Holsman, K. Aydin, A. B. Hollowed, A. J. Hermann, W. Cheng, A. Faig, A. C. Haynie, and A. E. Punt. 2020. Ensemble Projections of Future Climate Change Impacts on the Eastern Bering Sea Food Web Using a Multispecies Size Spectrum Model. Frontiers in Marine Science 7:1–17.
7. (2020) Hollowed, A. B., K. K. Holsman, A. C. Haynie, A. J. Hermann, A. E. Punt, K. Aydin, J. N. Ianelli, S. Kasperski, W. Cheng, A. Faig, K. A. Kearney, J. C. P. Reum, P. Spencer, I. Spies, W. Stockhausen, C. S. Szuwalski, G. A. Whitehouse, and T. K. Wilderbuer. 2020. Integrated Modeling to Evaluate Climate Change Impacts on Coupled Social-Ecological Systems in Alaska. Frontiers in Marine Science 6. https://doi.org/10.3389/fmars.2019.00775
8. (2019) Holsman, KK, EL Hazen, A Haynie, S Gourguet, A Hollowed, S Bograd, JF Samhouri, K Aydin, Toward climate-resiliency in fisheries management. ICES Journal of Marine Science. 10.1093/icesjms/fsz031
9. (2019) Hermann, A. J., G.A. Gibson, W. Cheng, I. Ortiz1, K. Aydin, M. Wang, A. B. Hollowed, and K. K. Holsman. Projected biophysical conditions of the Bering Sea to 2100 under multiple emission scenarios. ICES Journal of Marine Science, fsz043, https://doi.org/10.1093/icesjms/fsz043
10. (2019) Reum, J., JL Blanchard, KK Holsman, K Aydin, AE Punt. Species-specific ontogenetic diet shifts attenuate trophic cascades and lengthen food chains in exploited ecosystems. Okios DOI: 10.1111/oik.05630
11. (2019) Reum, J., K. Holsman, KK, Aydin, J. Blanchard, S. Jennings. Energetically relevant predator to prey body mass ratios and their relationship with predator body size. Ecology and Evolution (9):201–211 DOI: 10.1002/ece3.4715