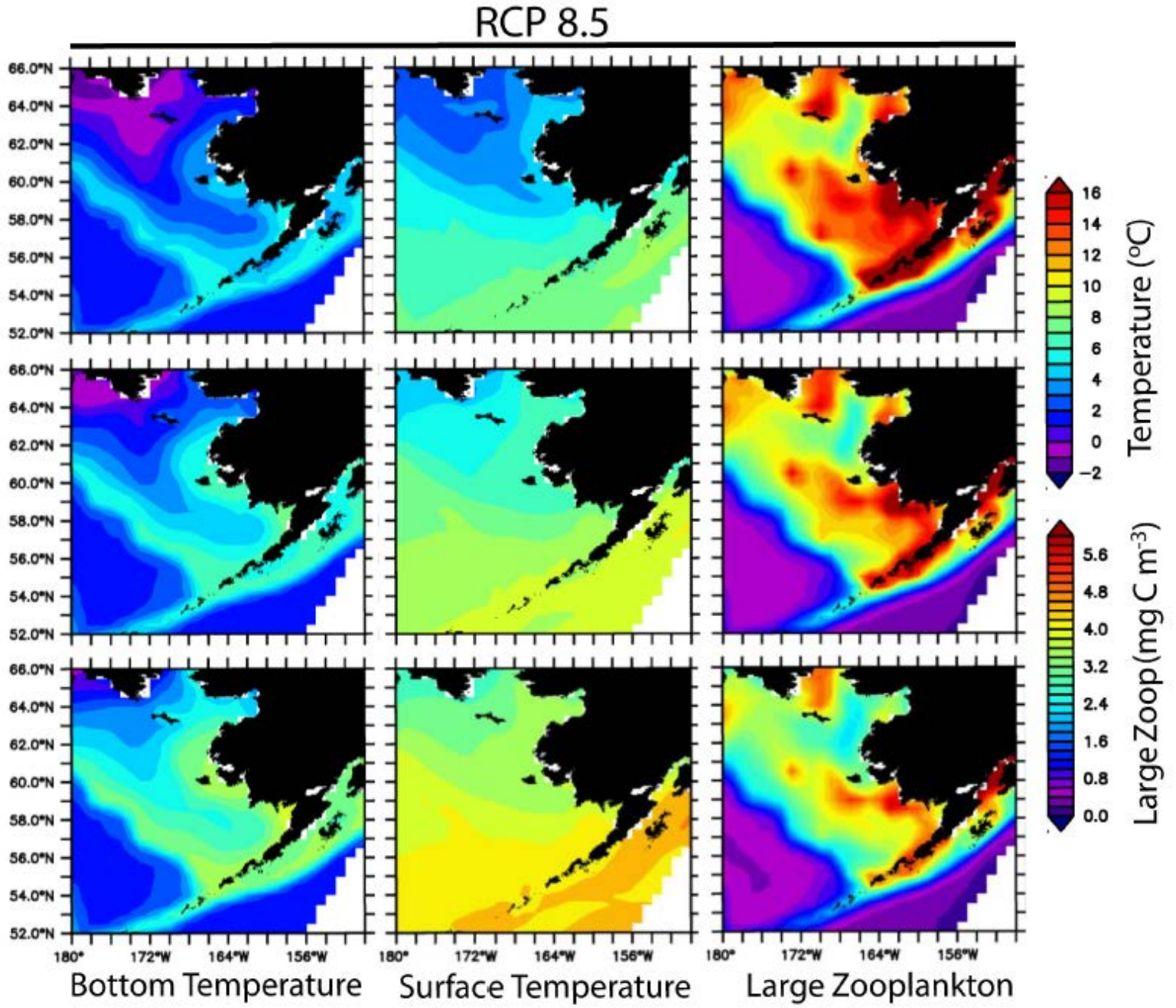
Climate change and fisheries management in the North Pacific

Cody Szuwalski

Climate is changing

- Warmer water
- Less ice
- Fewer large zooplankton



ICES Journal of Marine Science

ICES International Council for the Exploration of the Sea
CIEM Conseil International pour l'Exploration de la Mer

Climate change and the future productivity and distribution of crab in the Bering Sea

Cody Szuwalski [1]*, Wei Cheng[2,3], Robert Foy[4], Albert J. Hermann[2,3], Anne Hollowed [1], Kirstin Holsman[1], Jiwoo Lee[5], William Stockhausen[1], and Jie Zheng[6]

- How have the distribution and productivity changed for the major crab stocks in the Bering Sea?
- Can we explain any of these changes with environmental indices?
- Can we project what might be expected of these stocks in the future given observed relationships?

Dependent variables

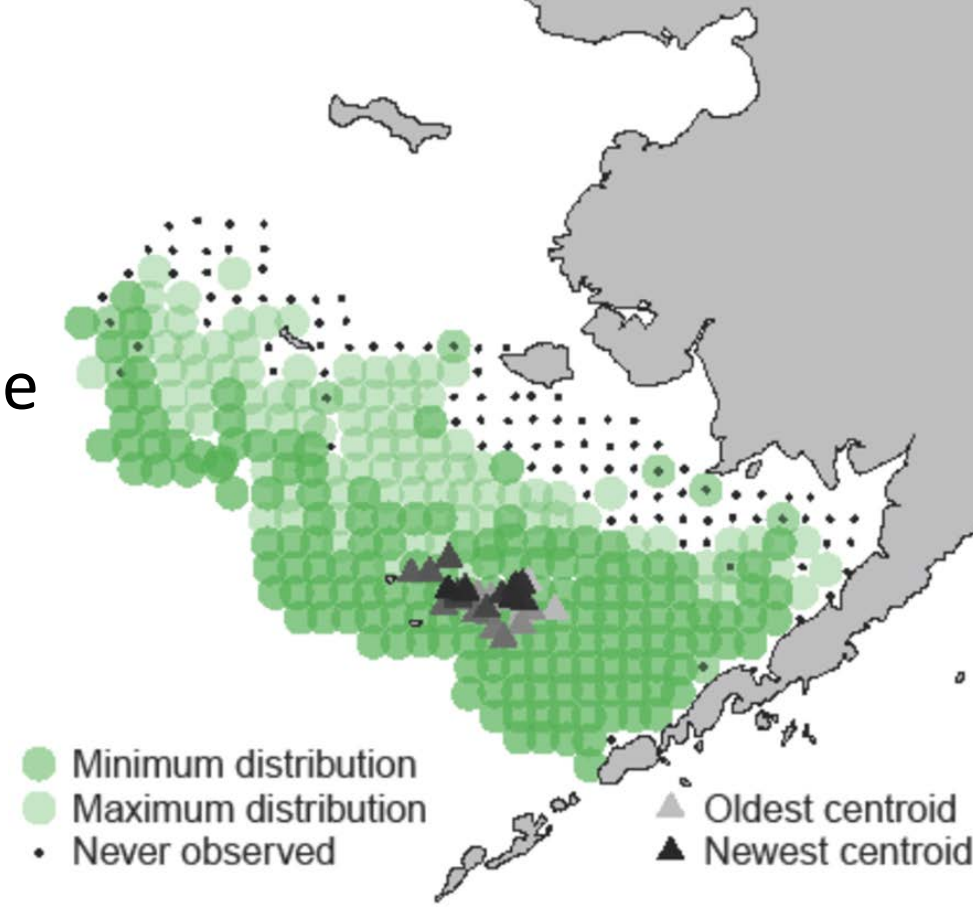
- Lagged MMB + estimated recruitment
- Latitudinal component of centroid of abundance
- Longitudinal component of centroid of abundance
- Number of stations observing crab

Predictor variables

- Local indices of environmental variation (4)
- Large-scale indices of environmental variation (4)
- Cod biomass

Modeling

- Simple linear models



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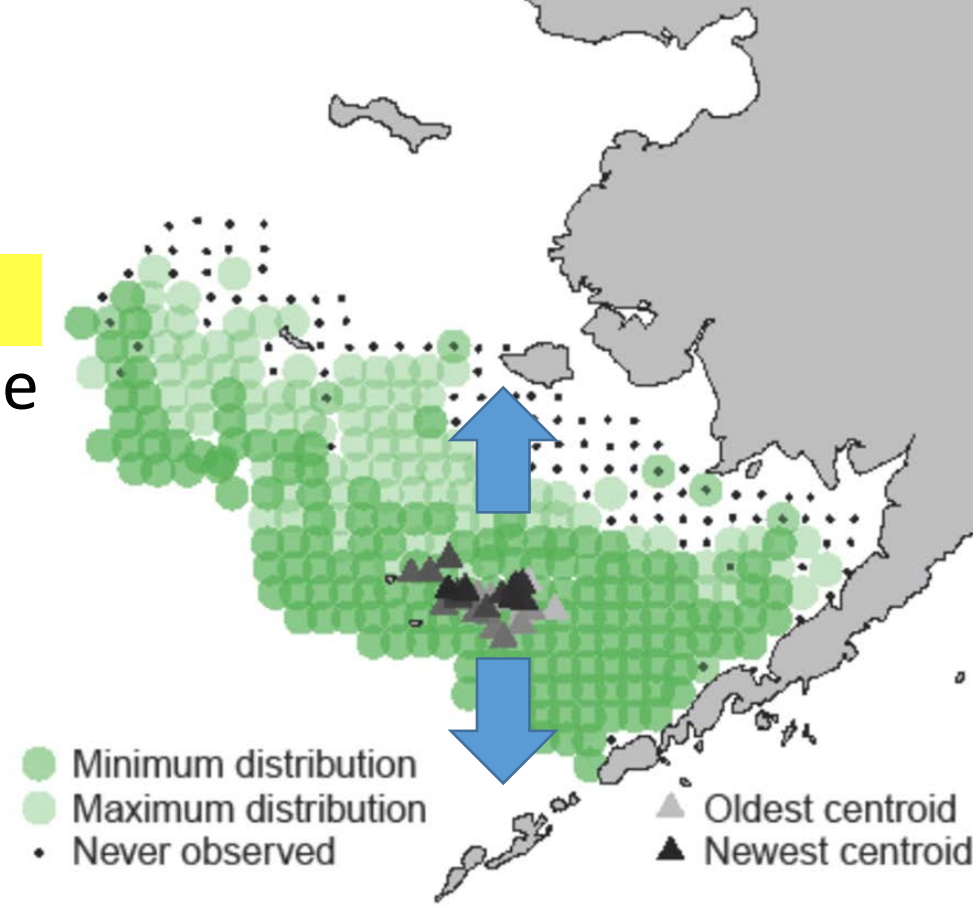

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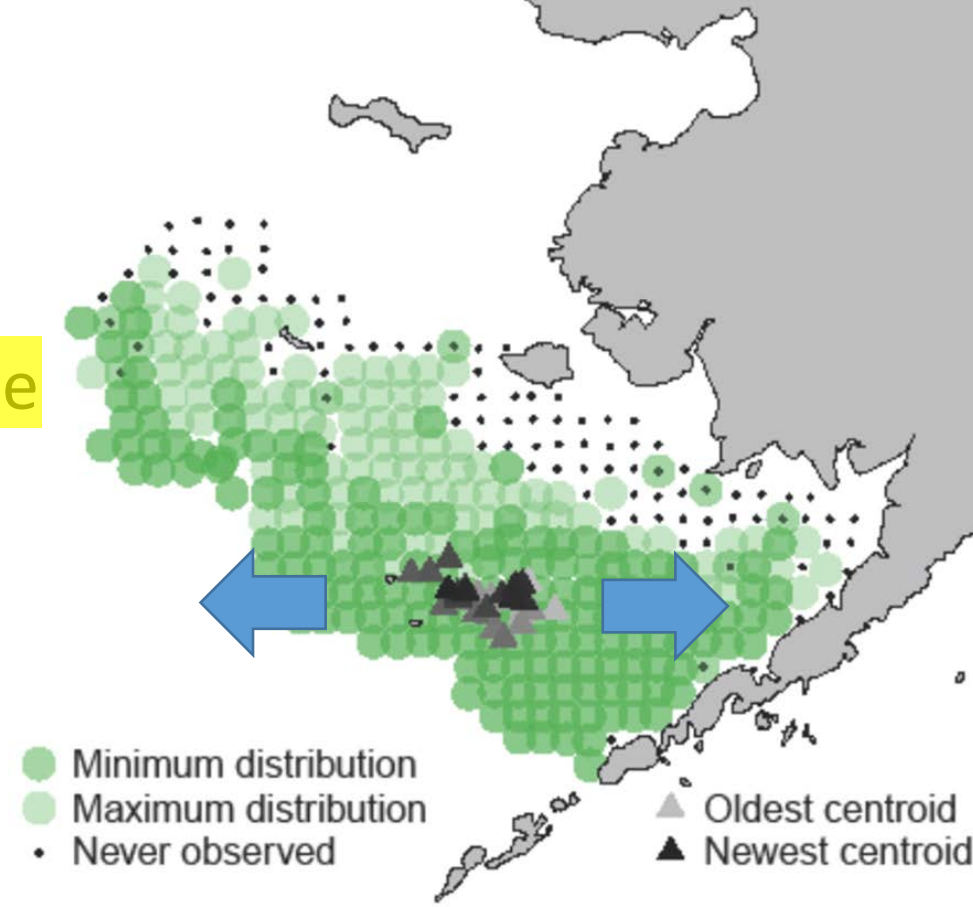

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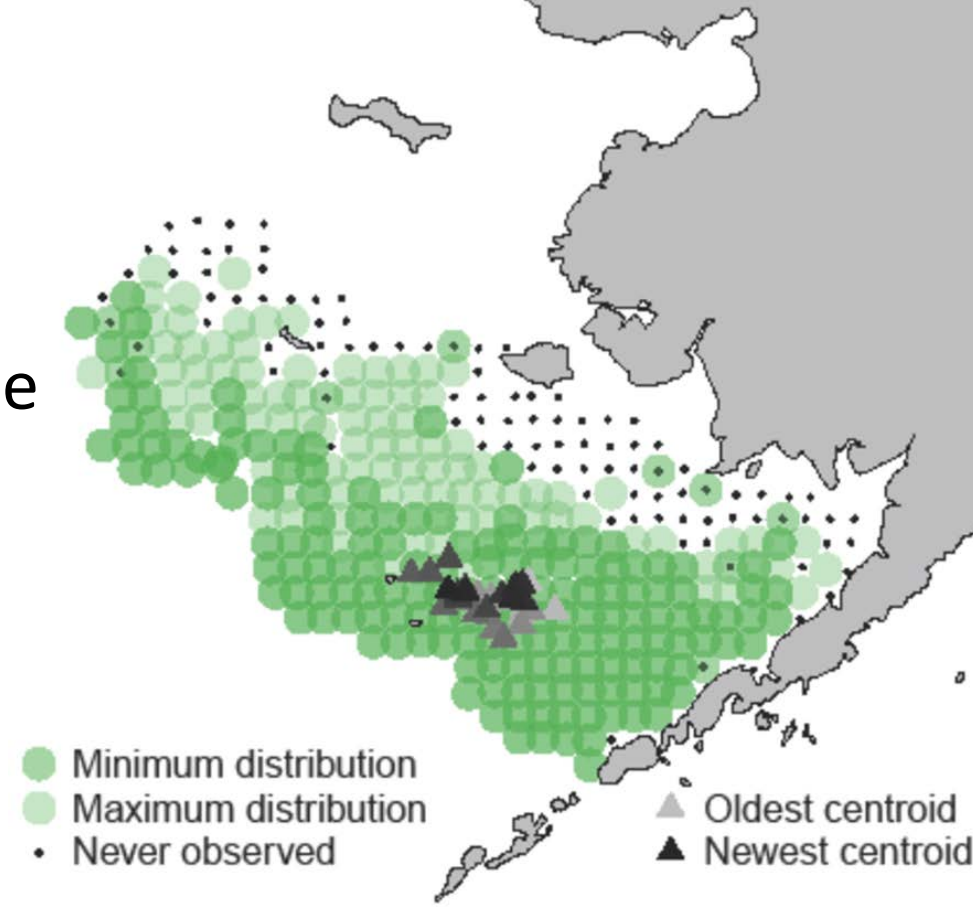

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Predictor variables

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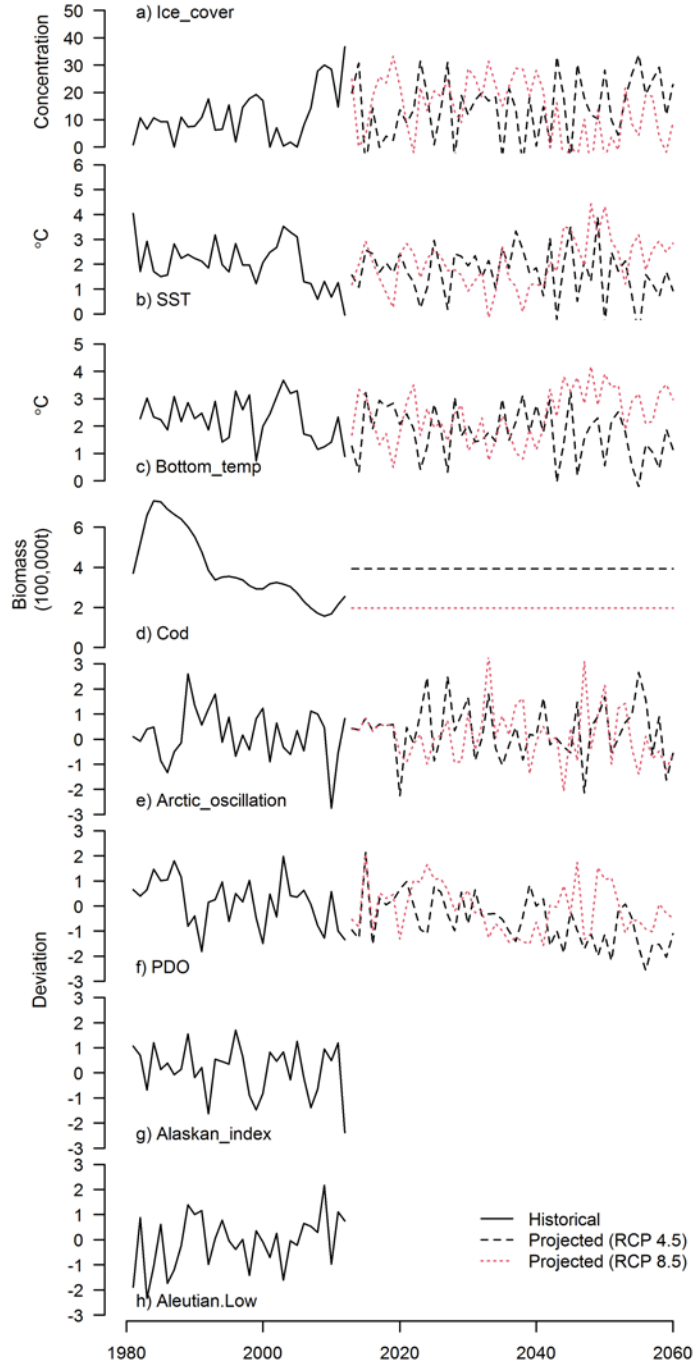
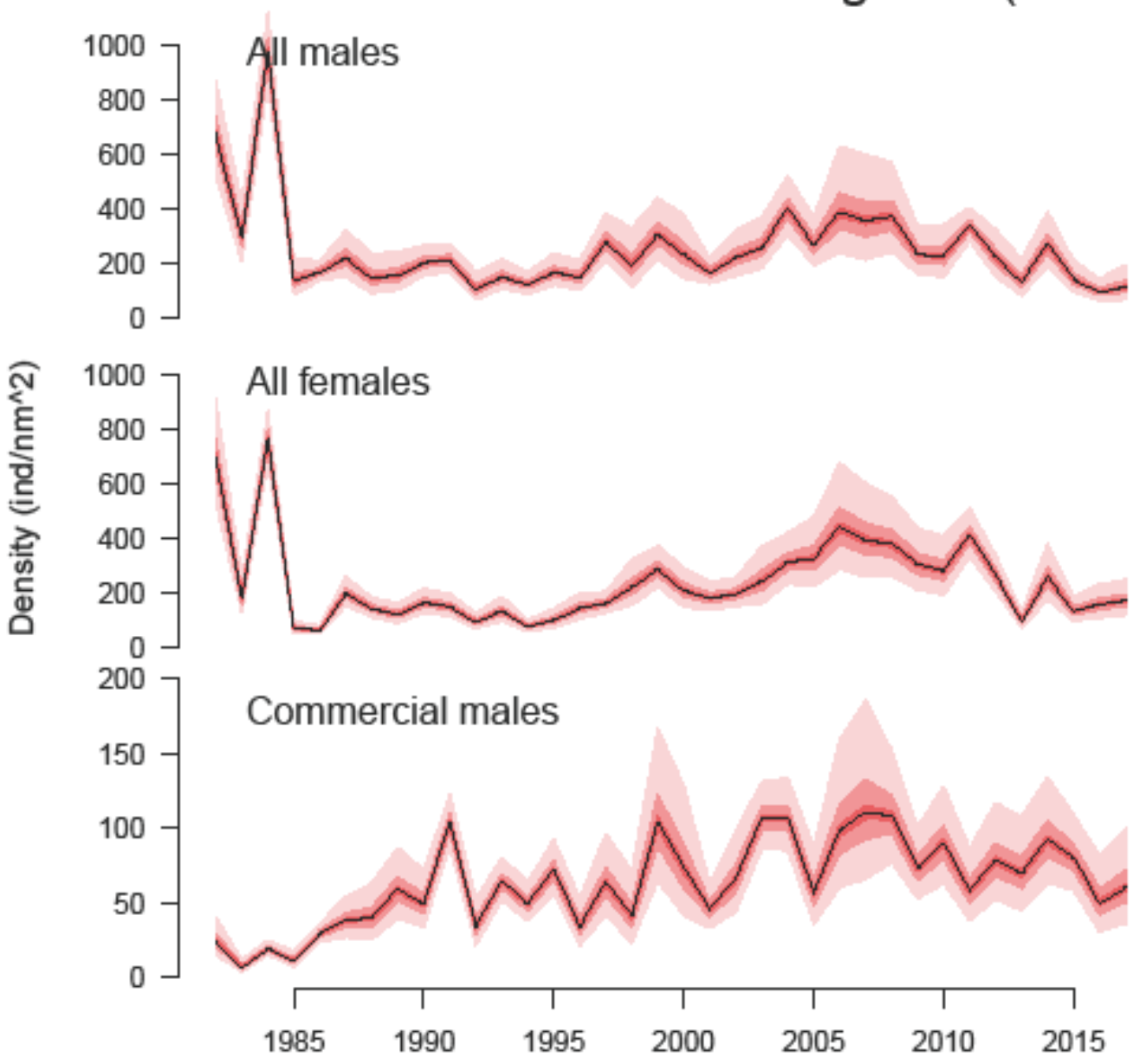
Modeling

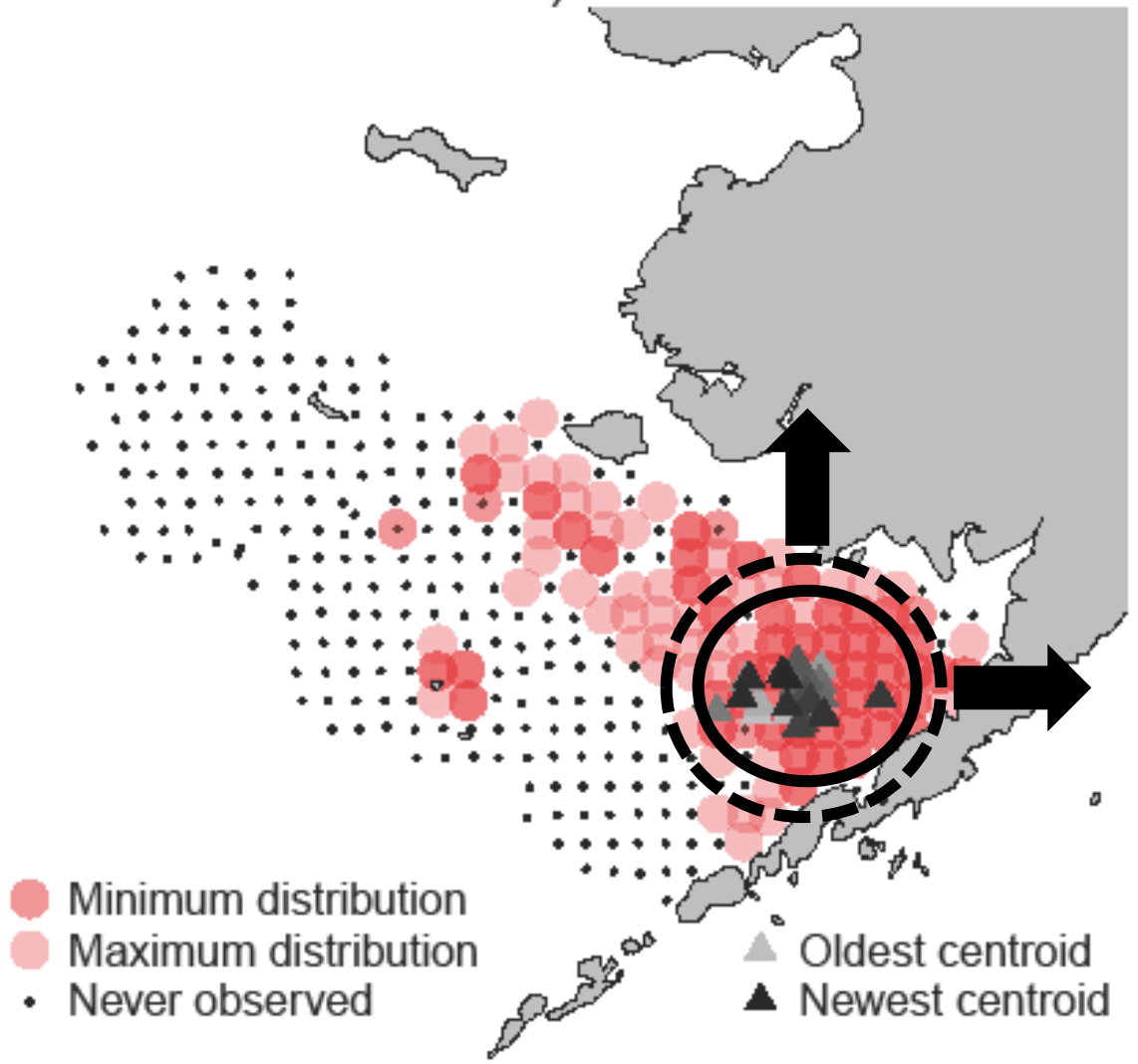
- Simple linear models
- Max of 3 predictors: one local, one large-scale, one bio
- AICc for model selection



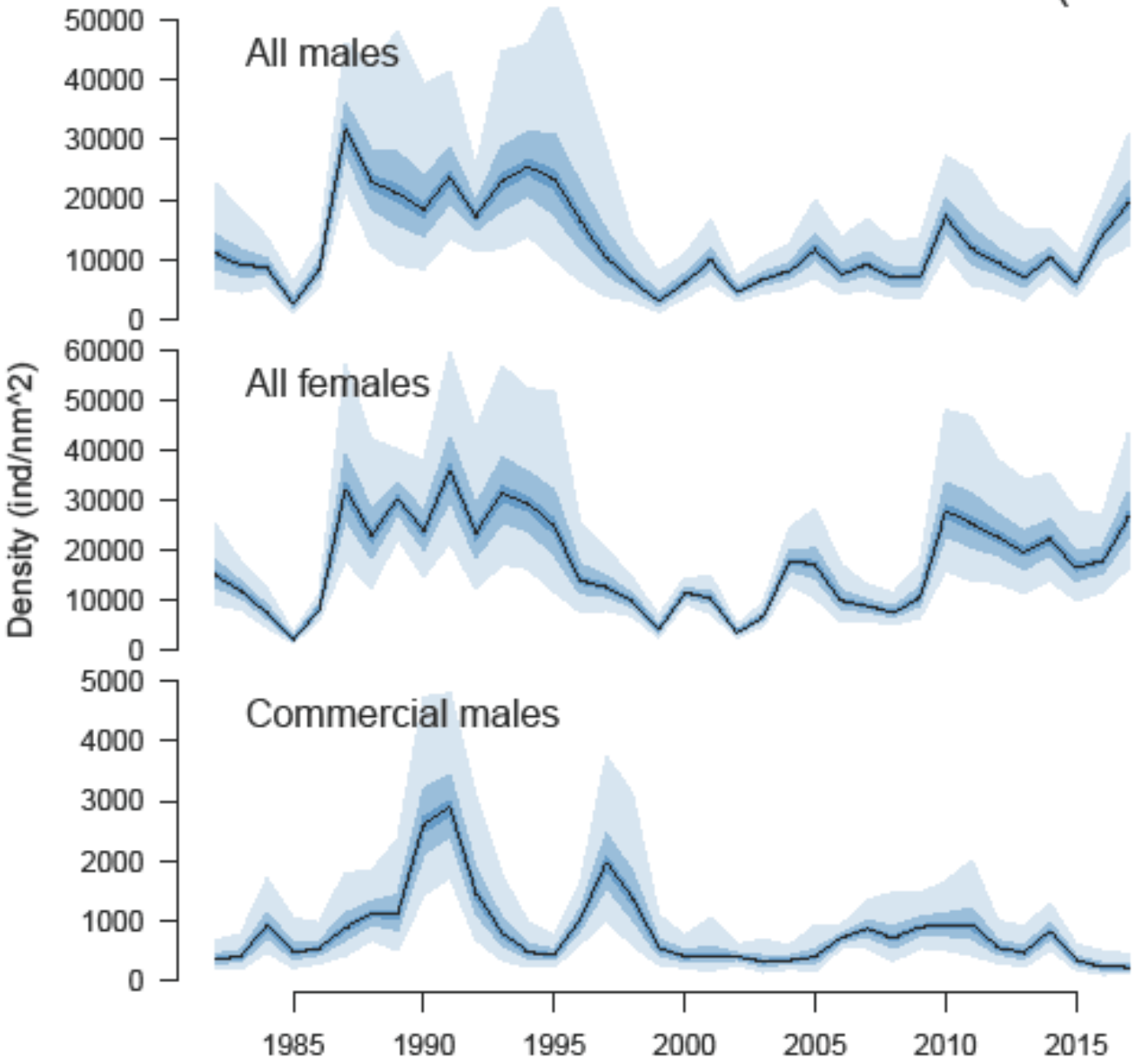
9 of 12 metrics were better explained by incorporating an environmental variable than a null model

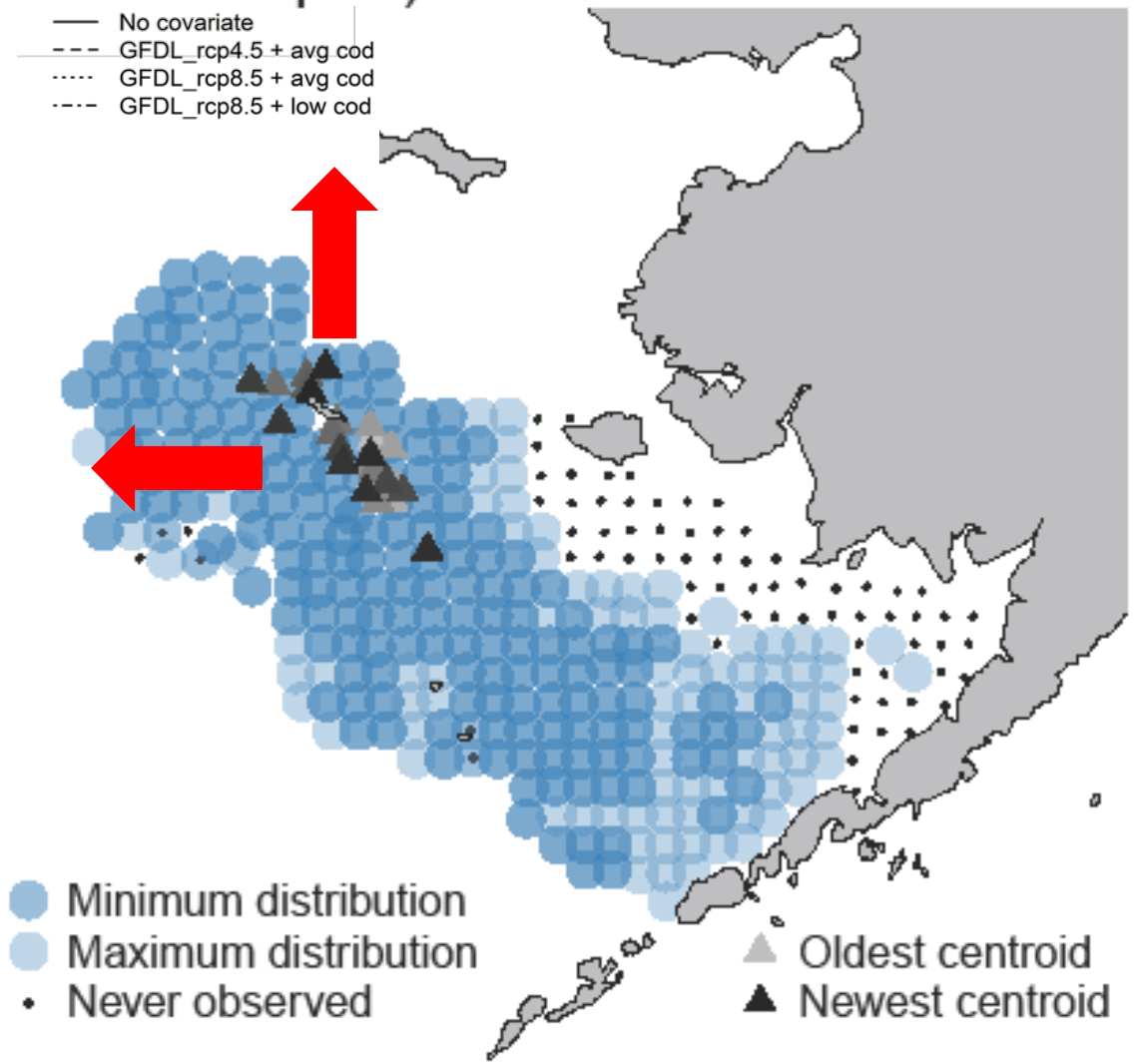
Red king crab (Paralithodes camtschaticus)



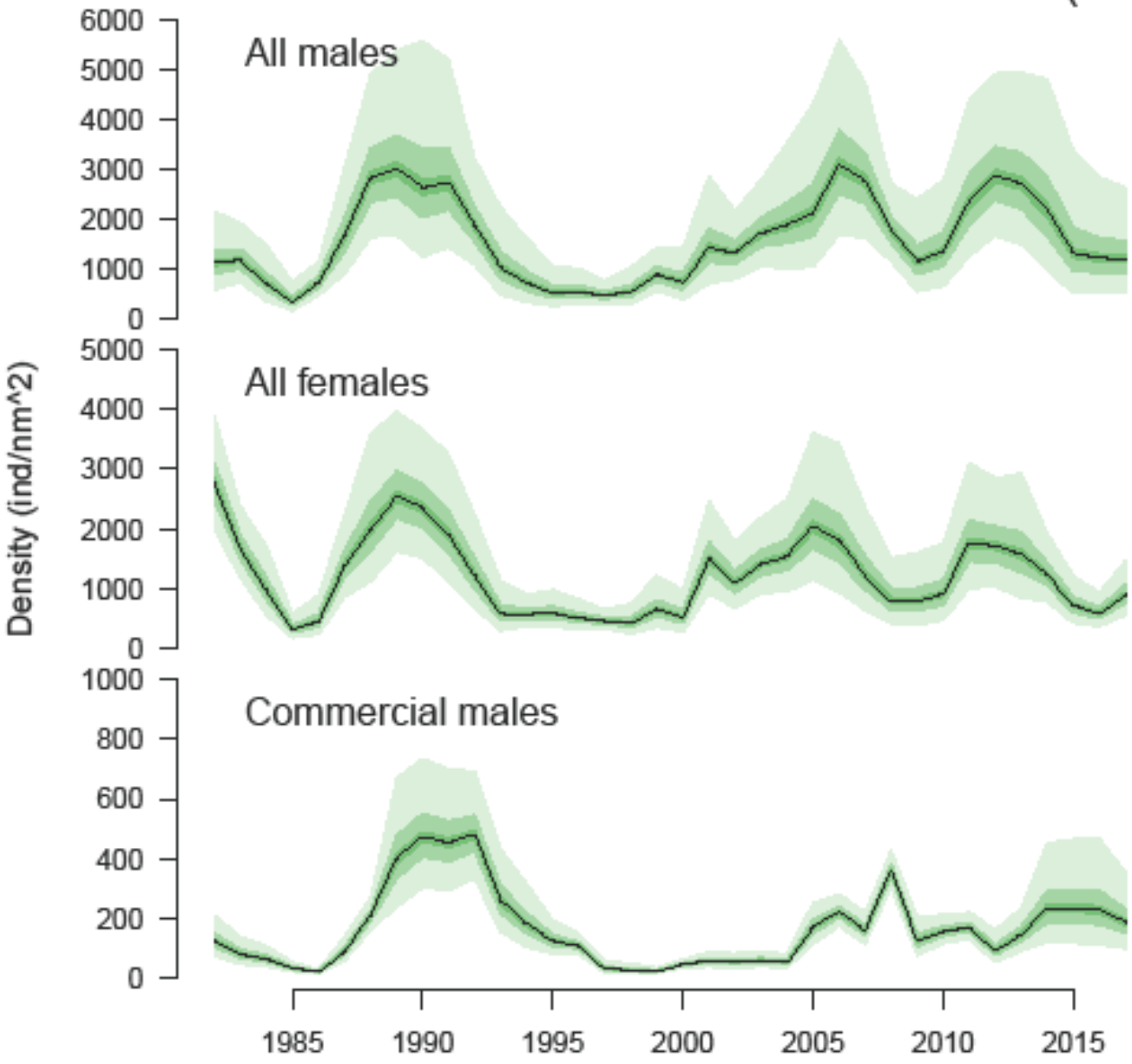


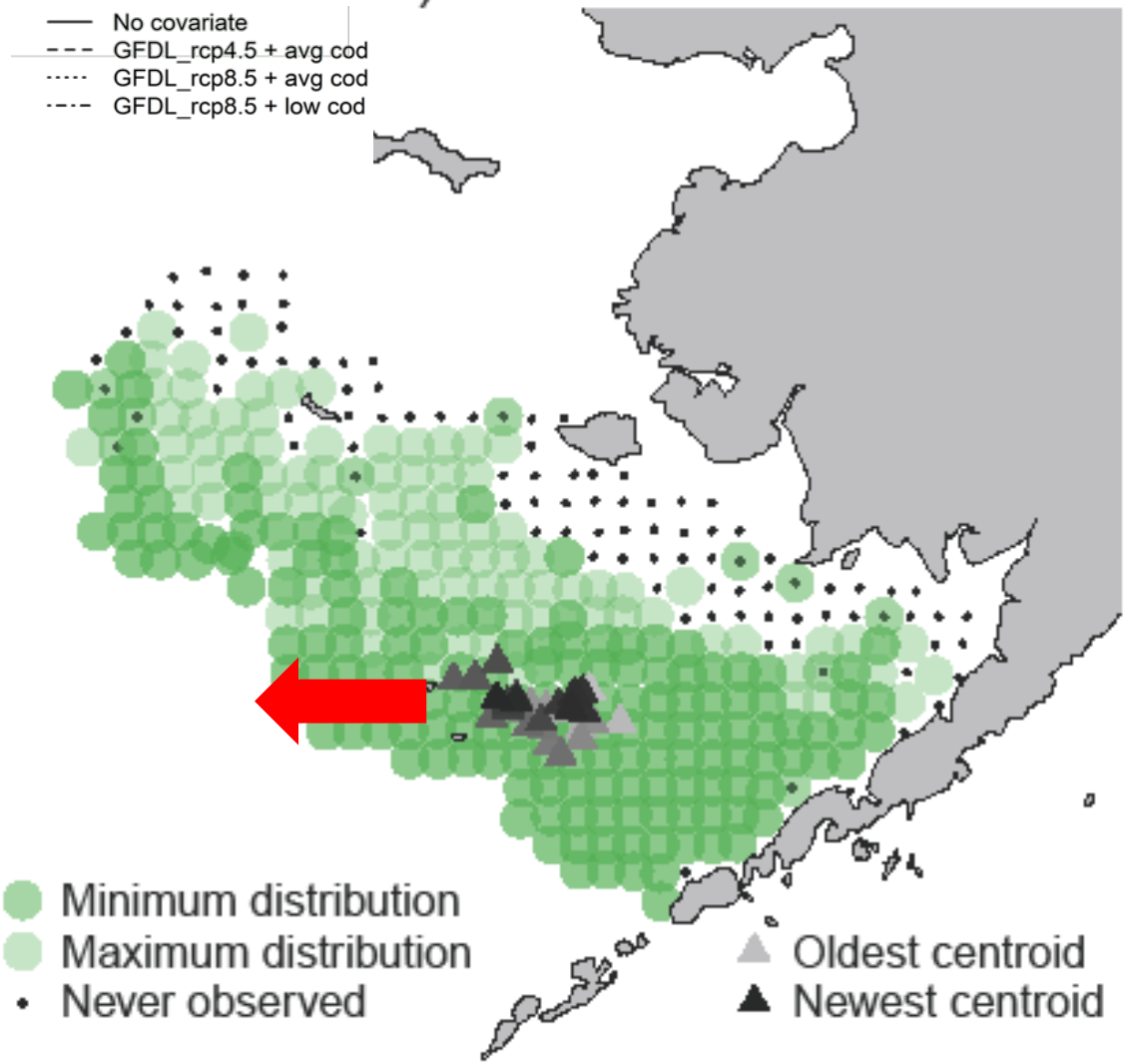
Snow crab (Chionoecetes opilio)

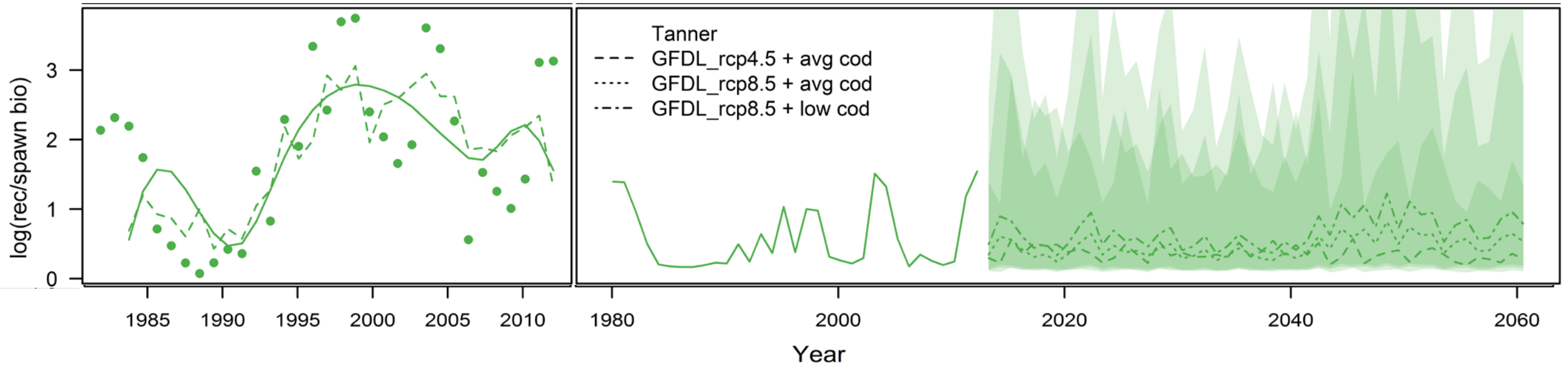




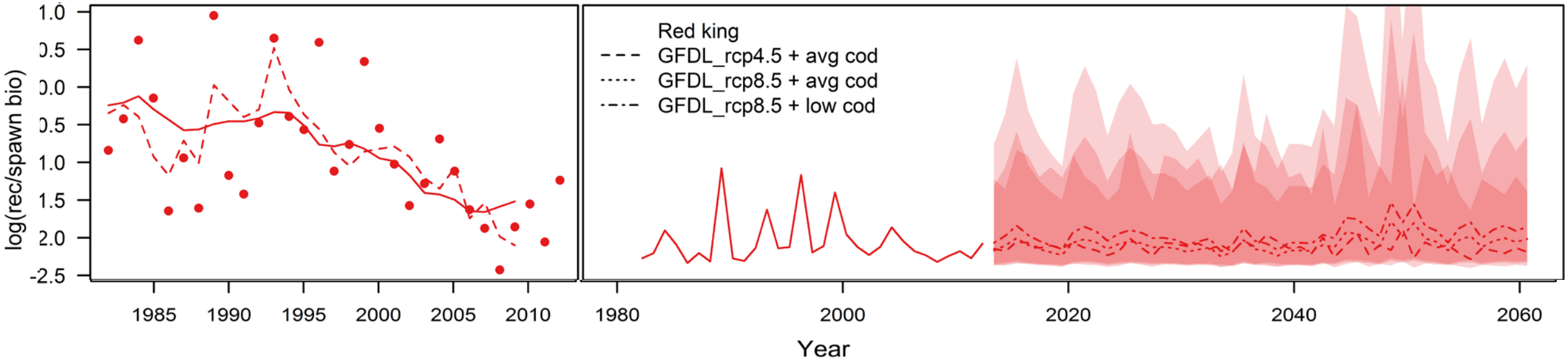
Tanner crab (Chionoecetes bairdi)



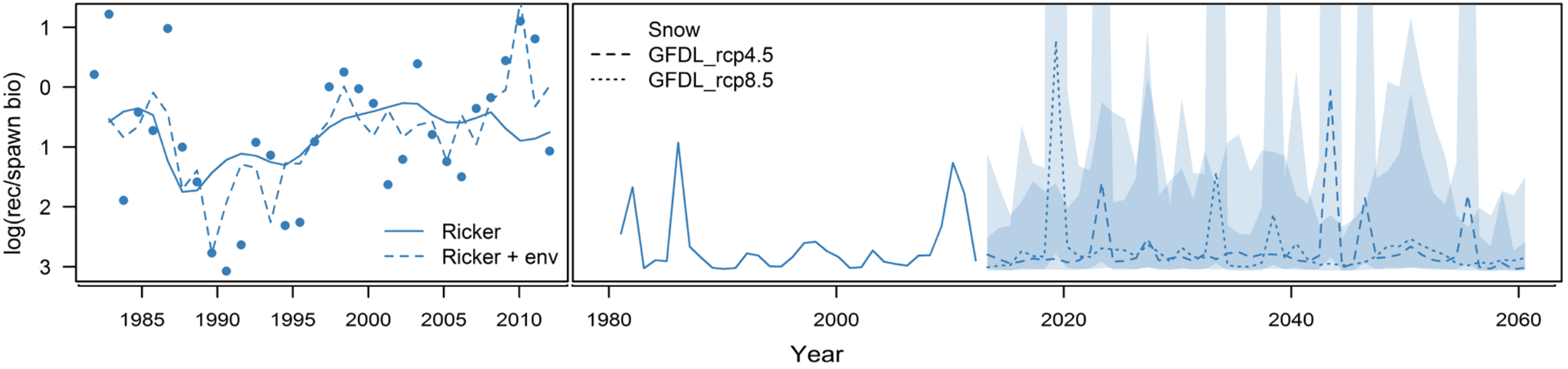




More productive long term related to projected increases in bottom temperature.



More productive long term related to projected decreases in ice cover.



Less productive in the long term in the current area due to decreased ice cover and changes in arctic oscillation

Management targets are linked to recruitment

What are we going to do?

What have we already done?

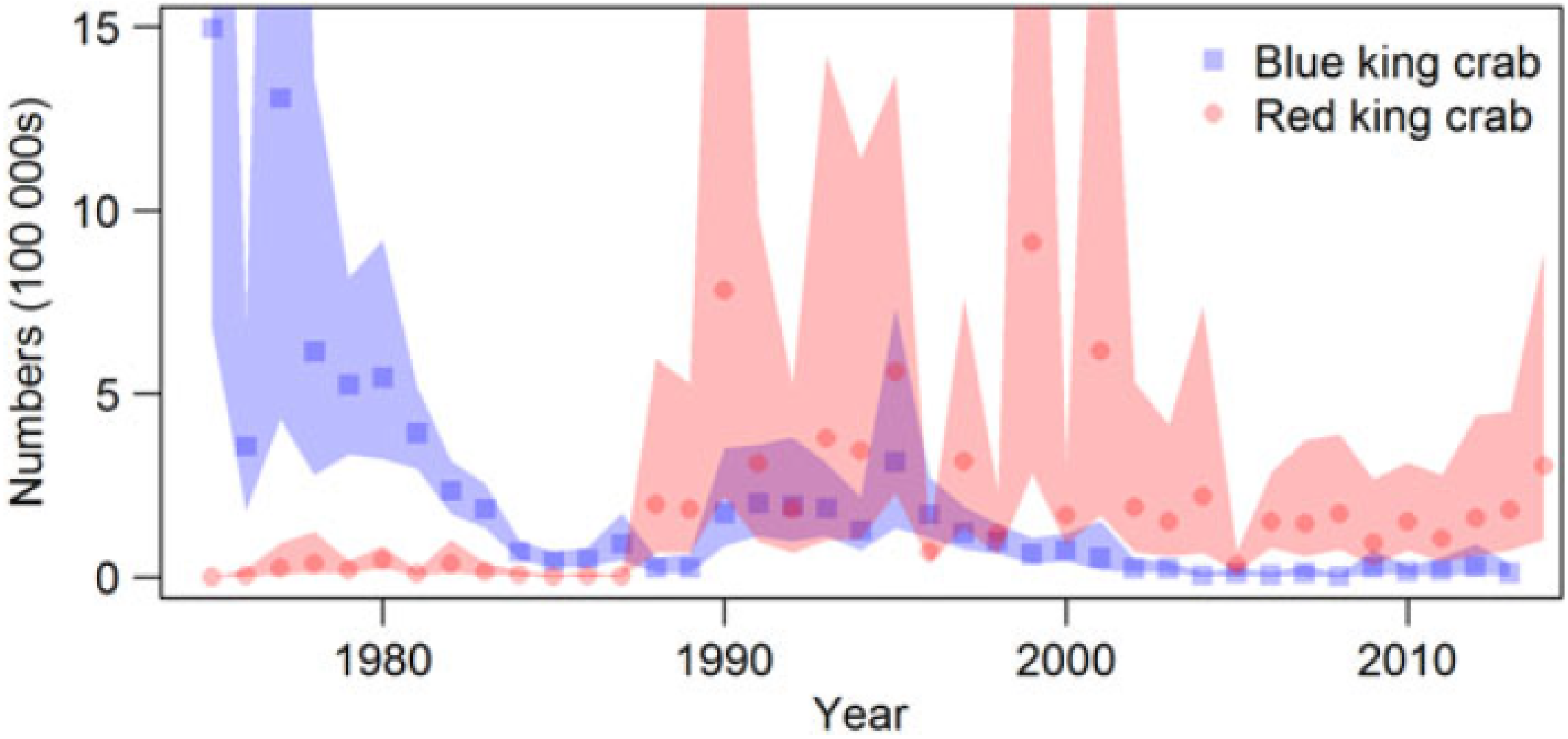
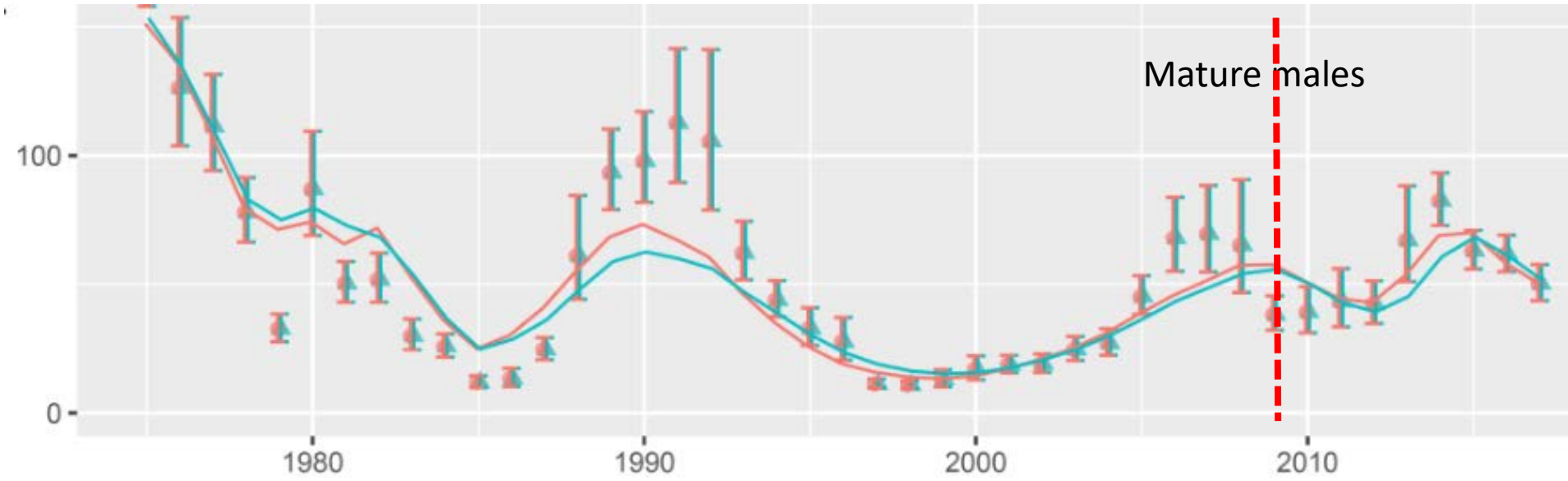
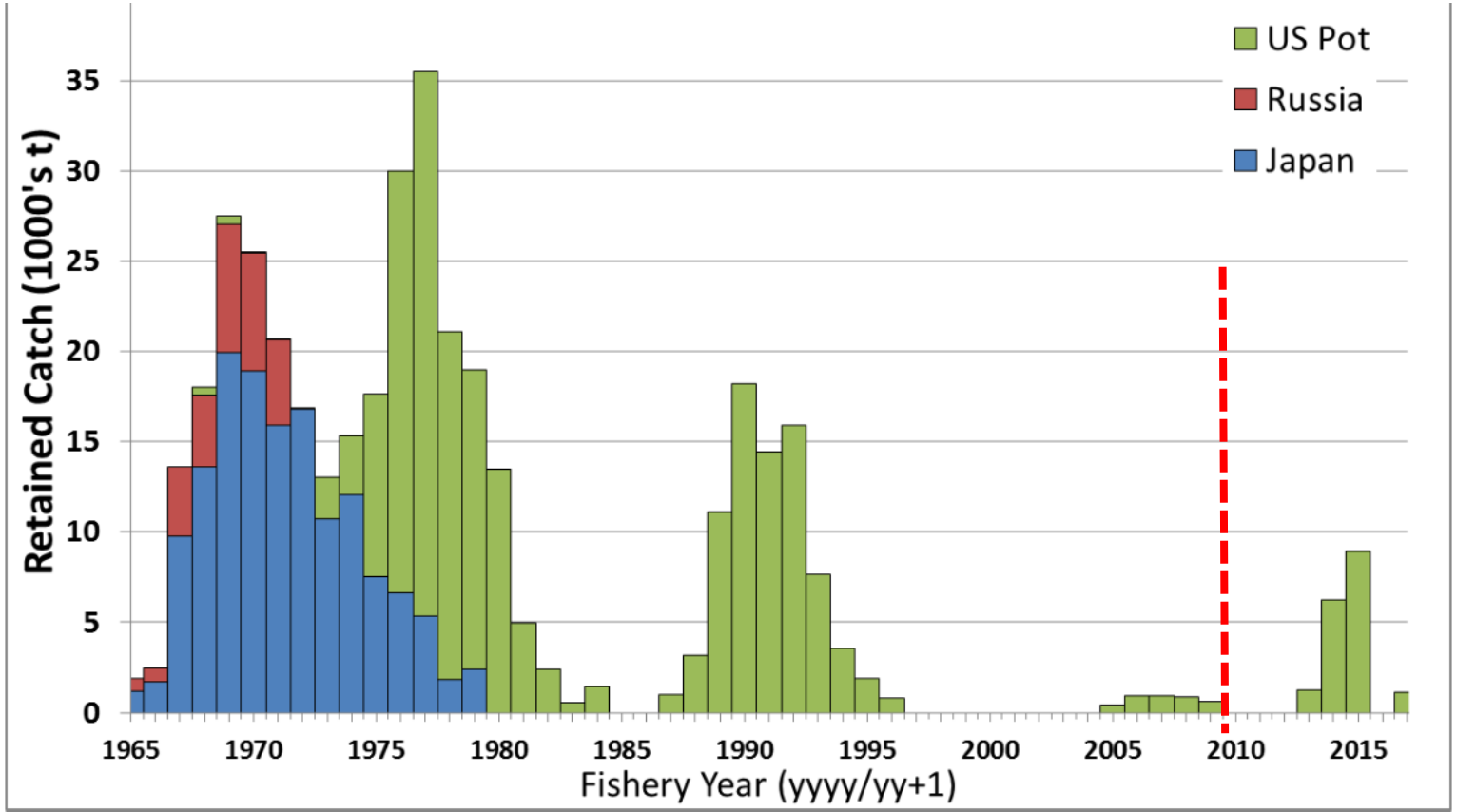


Figure 5. NMFS summer survey estimates of abundance (points) and confidence intervals (shaded areas) for blue king crab and red king crab

Tanner crab



- Declared overfished in 2011
- Rebuilt in 2014 after moving to a different tier and assessment (which prompted a revision of reference points)



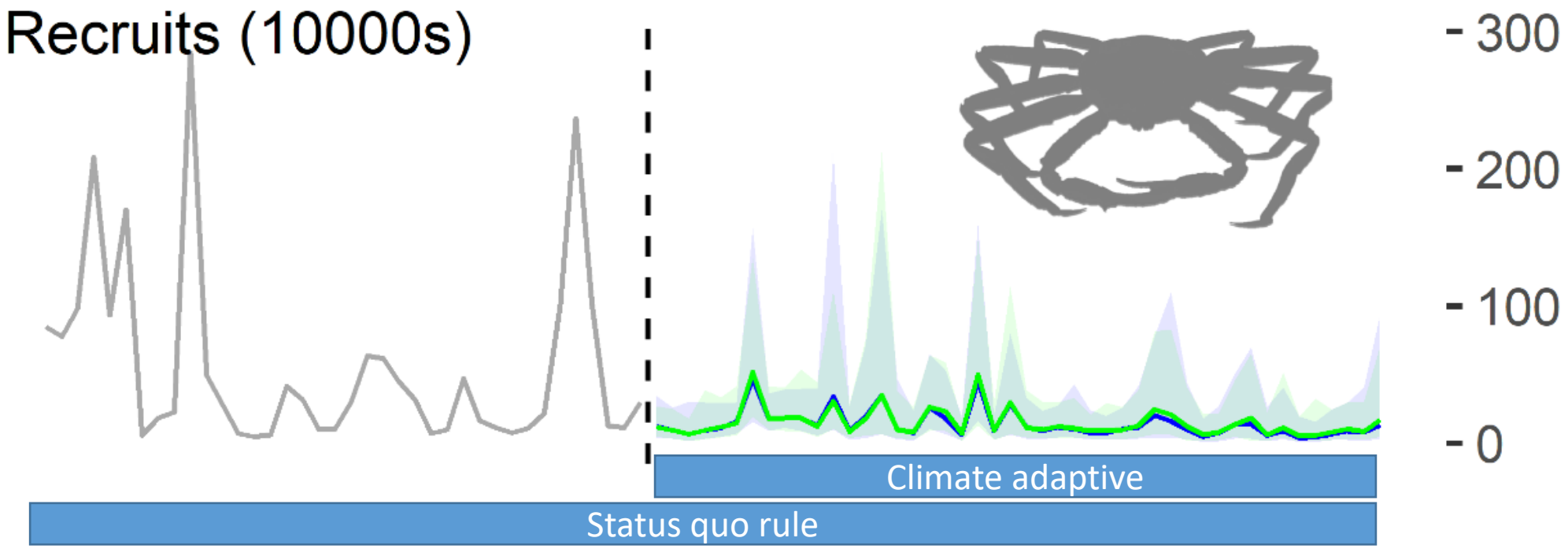
What are we going to do?

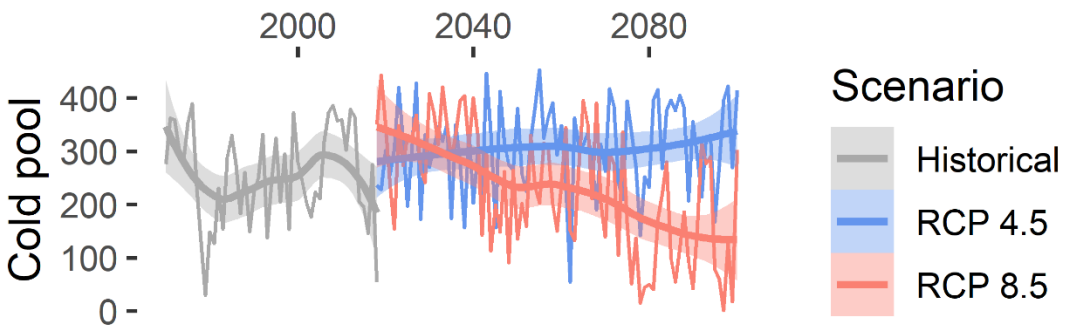
Projections

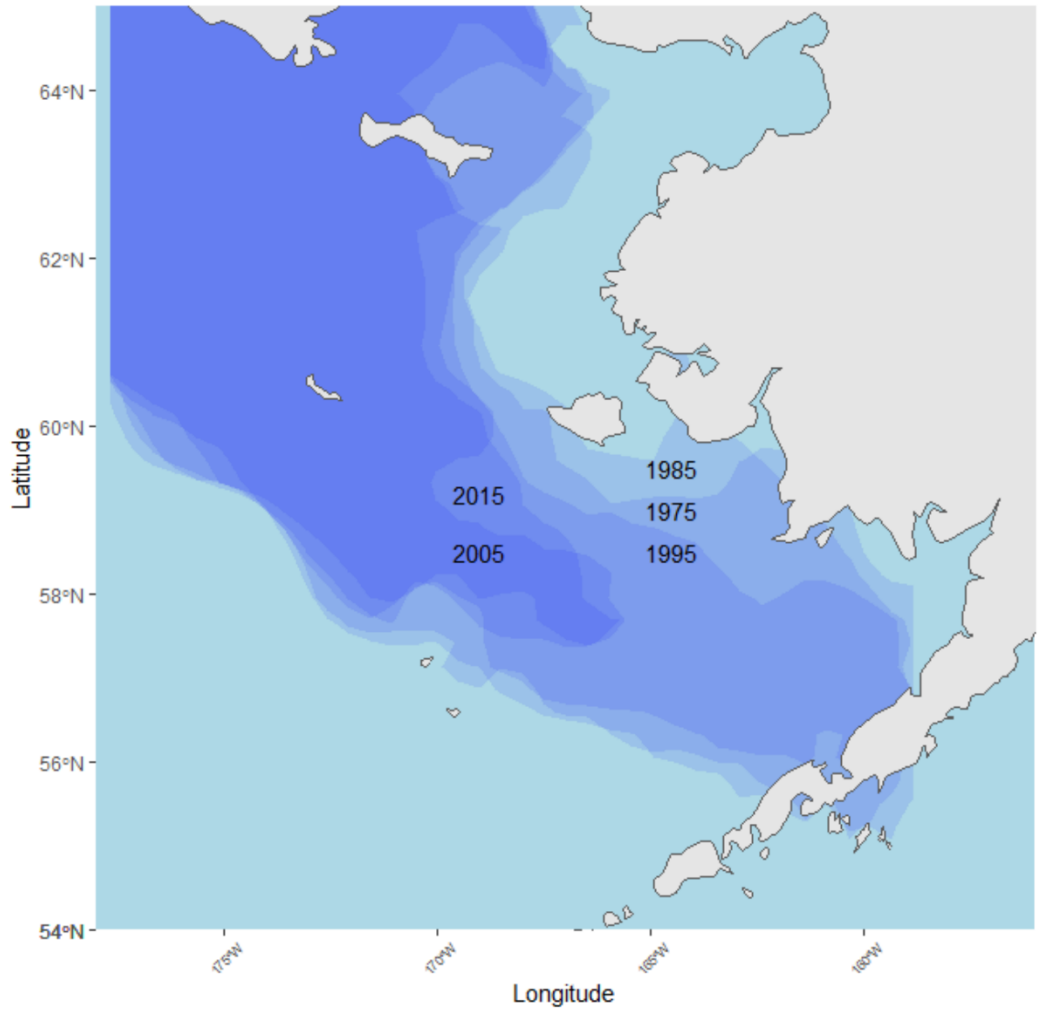
- Recruitment: Ricker stock recruit curve + projected environmental driver
  - Note that the harvest control rule does not consider an SRR
- Fishing mortality determined by harvest control rule
- All other population processes time invariant
- Comparing exploitation rates, yields, and MMB

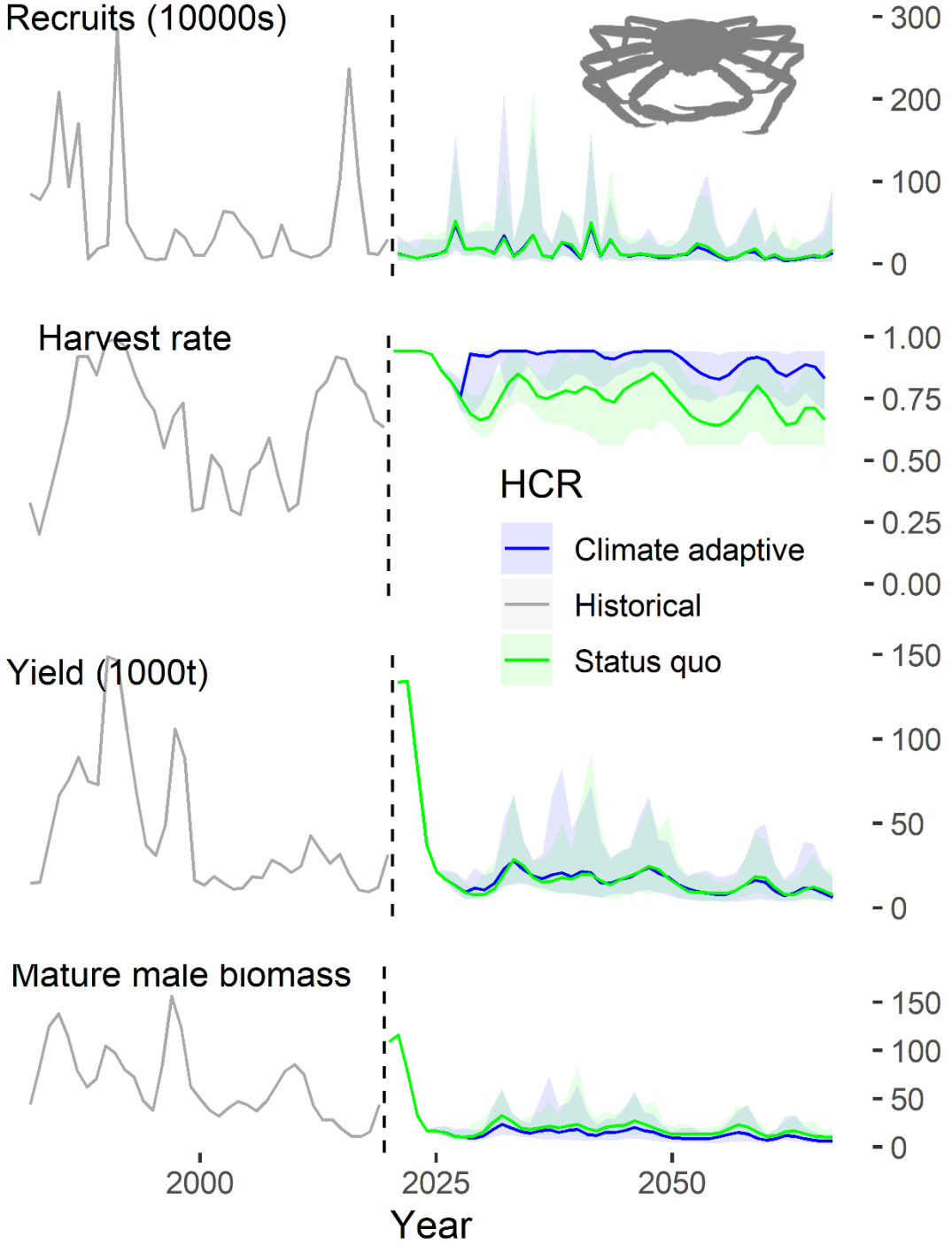
Harvest control rule

- Status quo: biomass target uses the entire time series of recruitment
- Climate adaptive: biomass targets uses only the time series of recruitment from 2025 on (once past 2030)




2000
2040
2080
Cold pool
400
300
200
100
0
Scenario
Historical
RCP 4.5
RCP 8.5


64°N
62°N
60°N
58°N
56°N
54°N
Latitude
175°W
170°W
165°W
160°W
Longitude
2015
2005
1985
1975
1995


Recruits (10000s)
300
200
100
0
Harvest rate
1.00
0.75
0.50
0.25
0.00
HCR
Climate adaptive
Historical
Status quo
Yield (1000t)
150
100
50
0
Mature male biomass
150
100
50
0
2000
2025
2050
Year

Status quo outcomes relative to climate-adaptive

- Lower exploitation rates
- Higher mature male biomass
- Higher recruitment
- Yield often higher, but not always

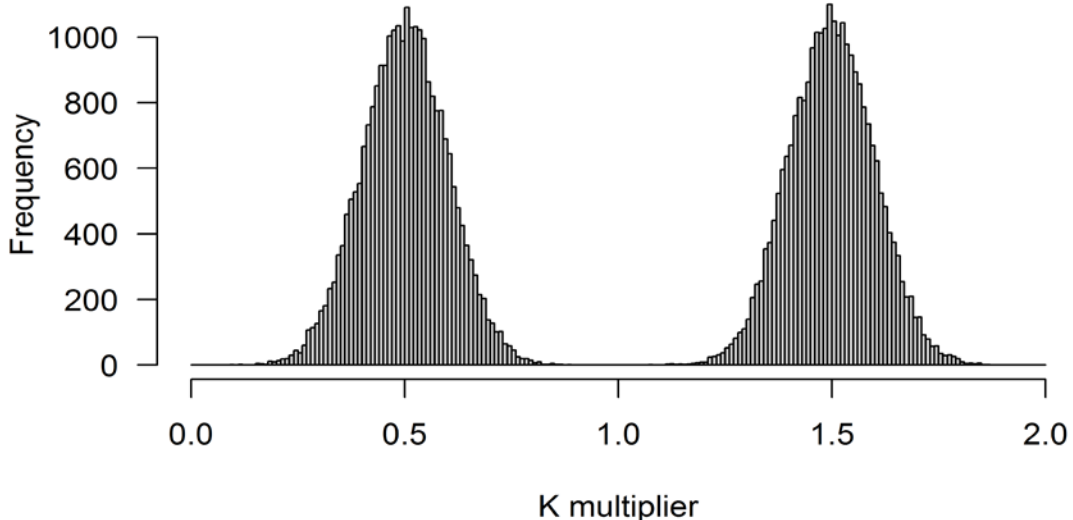
Adapting to decreasing productivity results in higher exploitation rates?

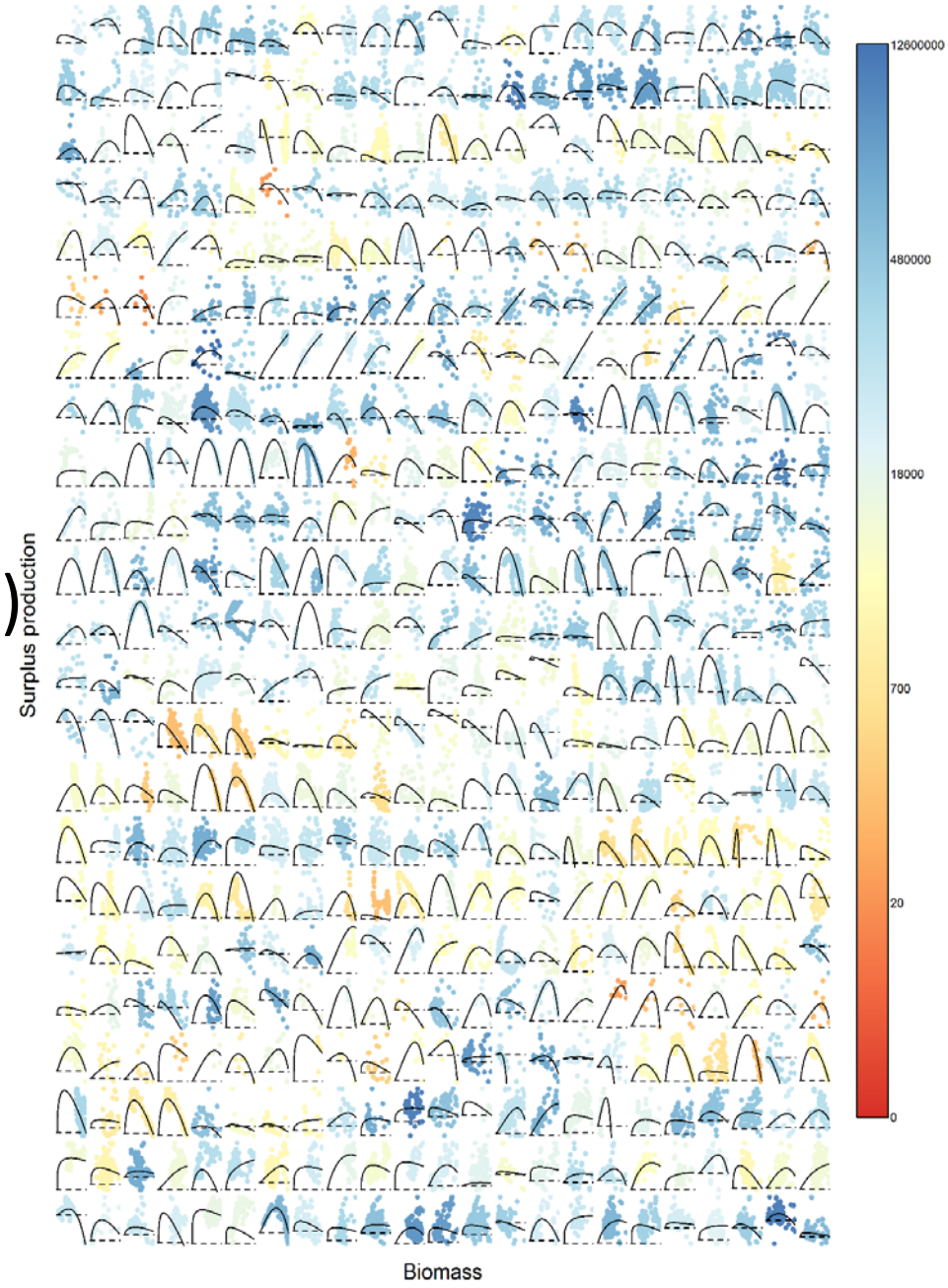
“Productivity paradox”

- Climate adaptive harvest control rules can result in higher exploitation rates than the status quo control rule.
- Can arise when reference points adapt to a change in:
  - Recruitment (when using a sloped harvest control rule; Szuwalski and Punt, 2013)
  - Growth (Szuwalski et al., in prep)
  - Natural mortality (Legault et al. 2016)
  - Maturity
- Layers to the paradox

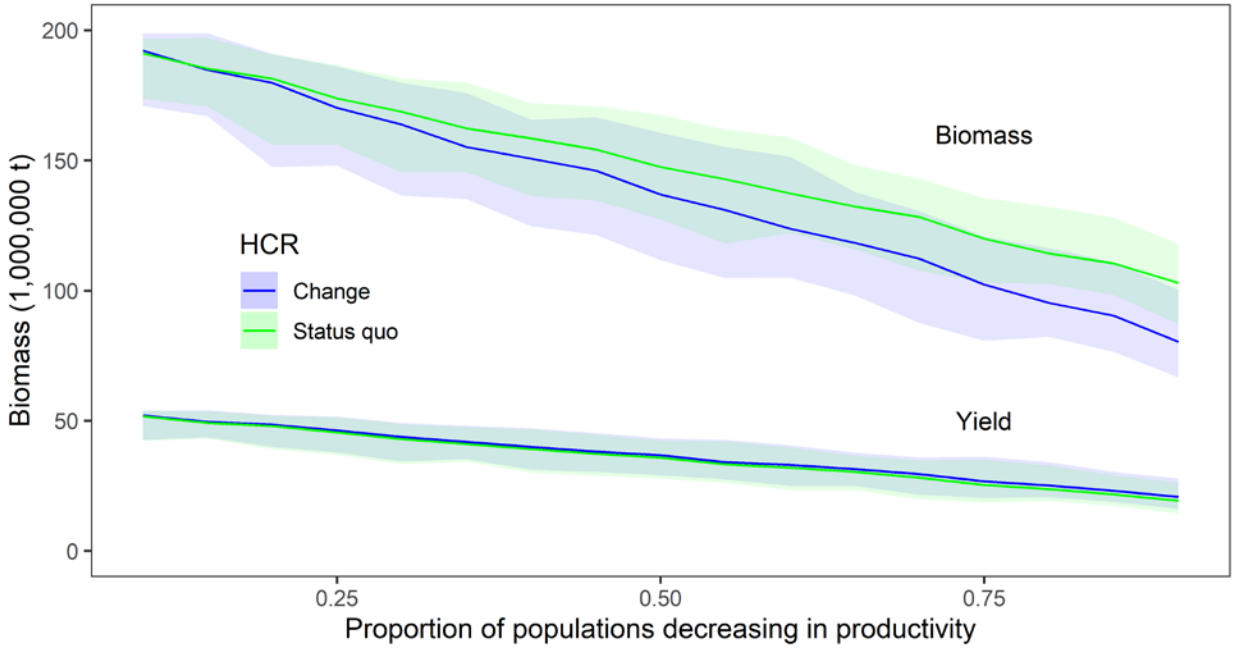
Global fisheries

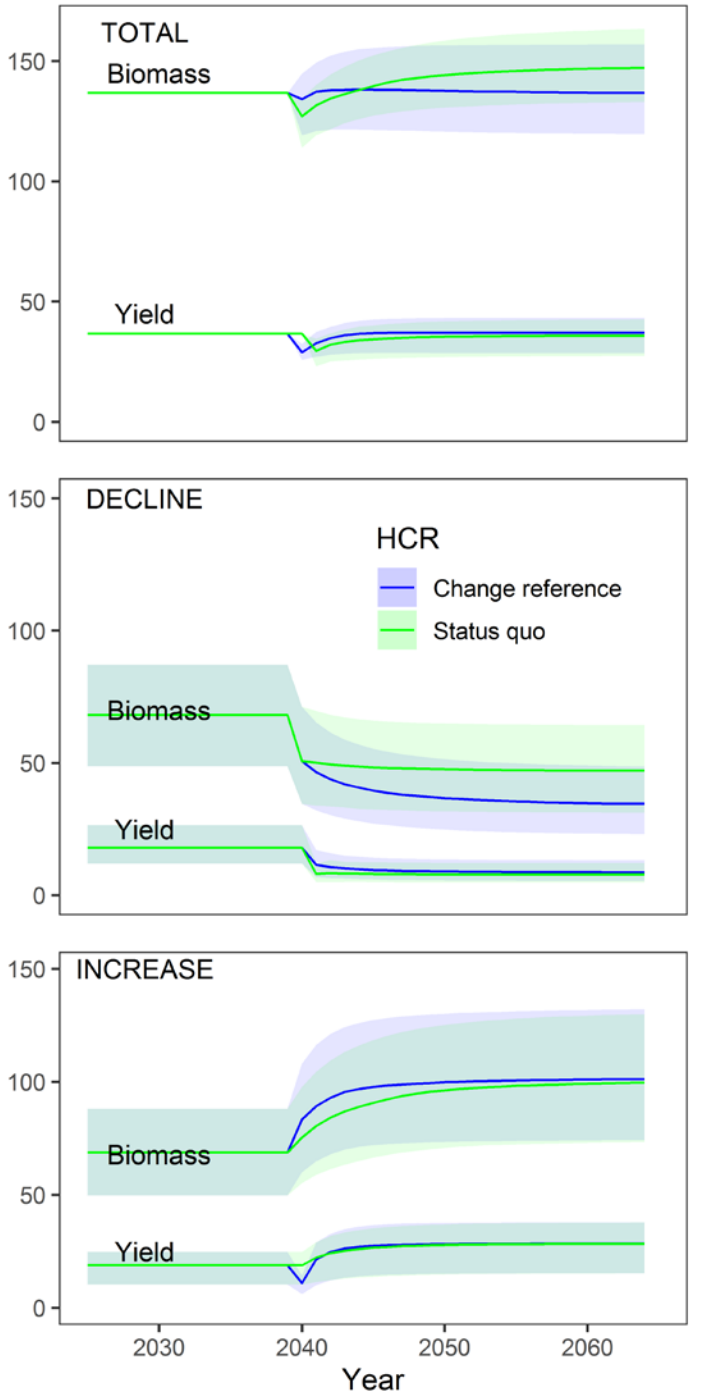
- RAM Legacy Database
- Fit Pella-Tomlinson surplus production models
- Change K at some point in the projection
- Climate-adaptive vs. status quo HCR (both sloped)
- Monte Carlo simulation x100





- Total yields similar under SQ and climate adaptive
- Total biomass higher under SQ than climate adaptive
- Stocks with declining productivity fared much worse under climate adaptive rules
- The protective benefit of the status quo rule is larger as more populations are declining in productivity.



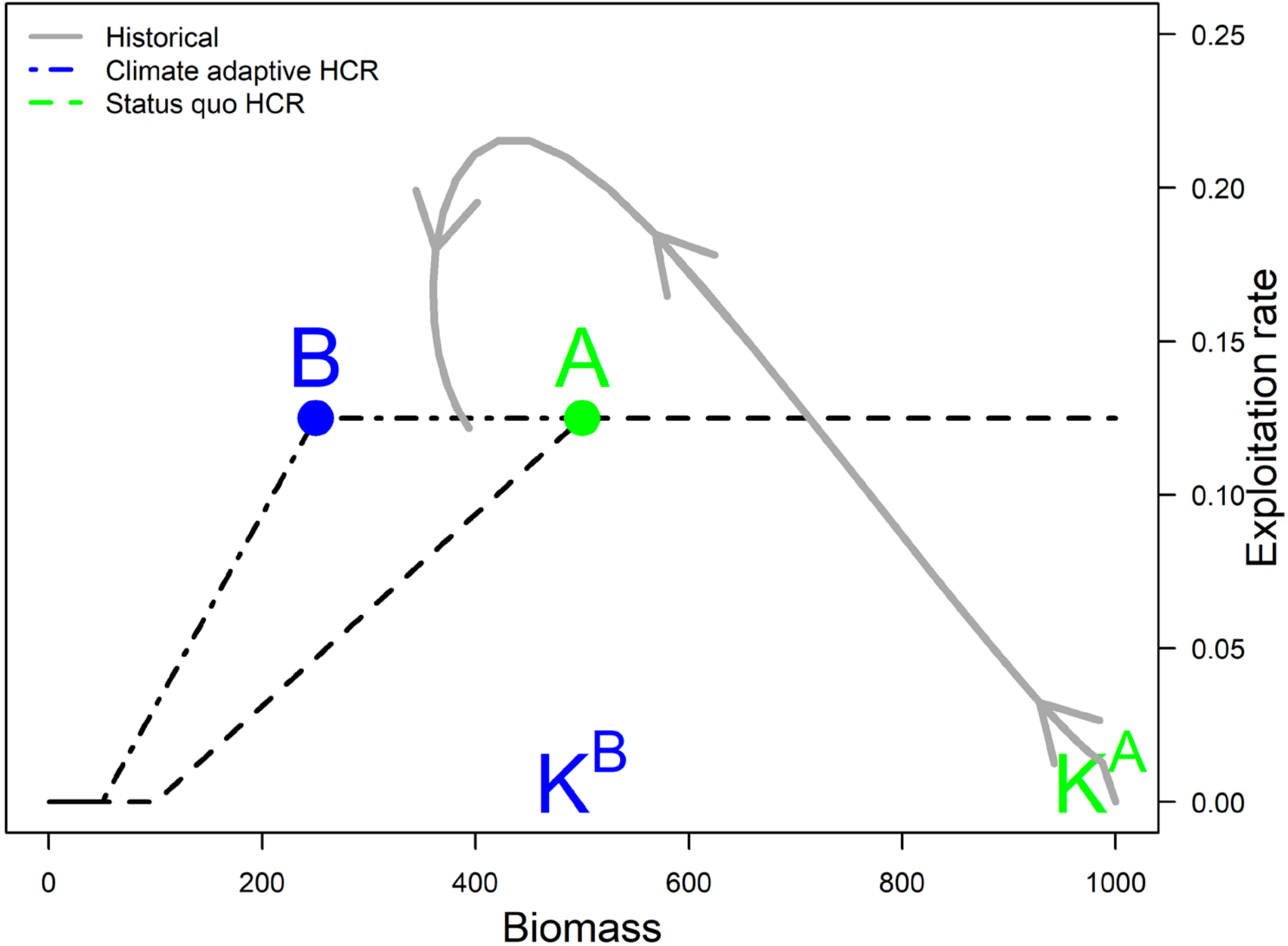


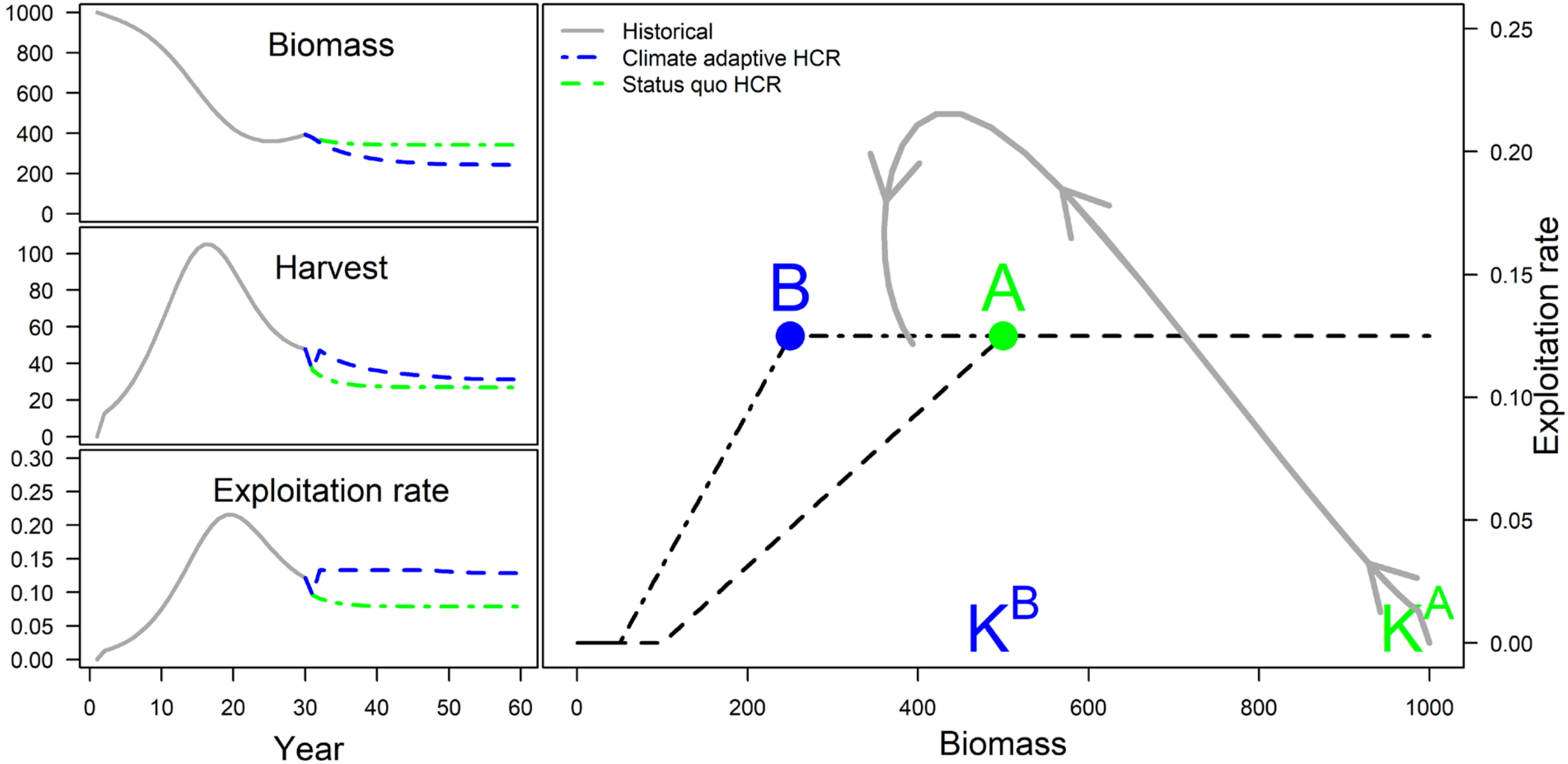
Take homes

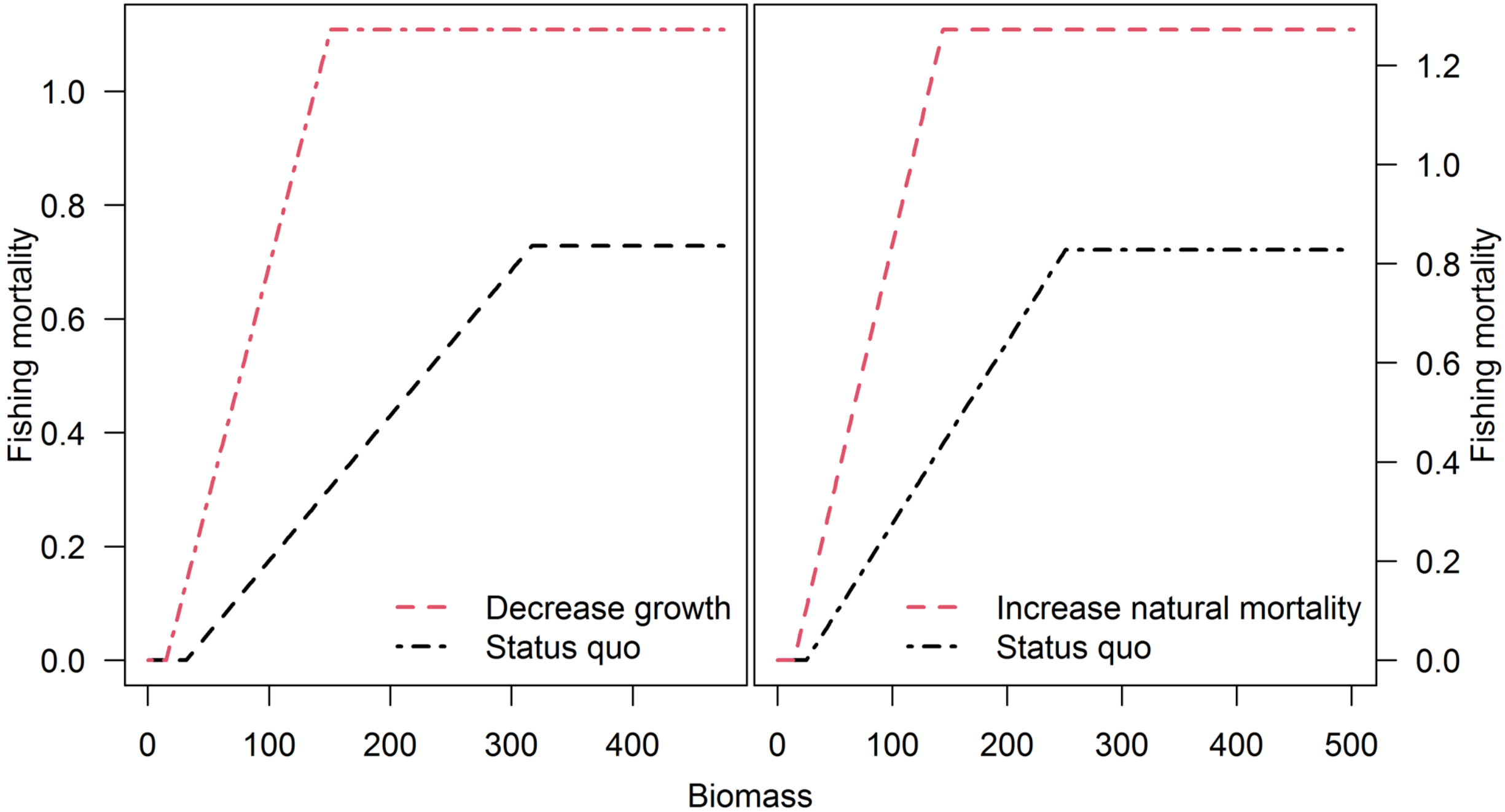
- Change is coming
- Adapting to change in the current framework may not produce the expected results
- We need a plan
- The plan should probably consider the entire system, rather than stock by stock

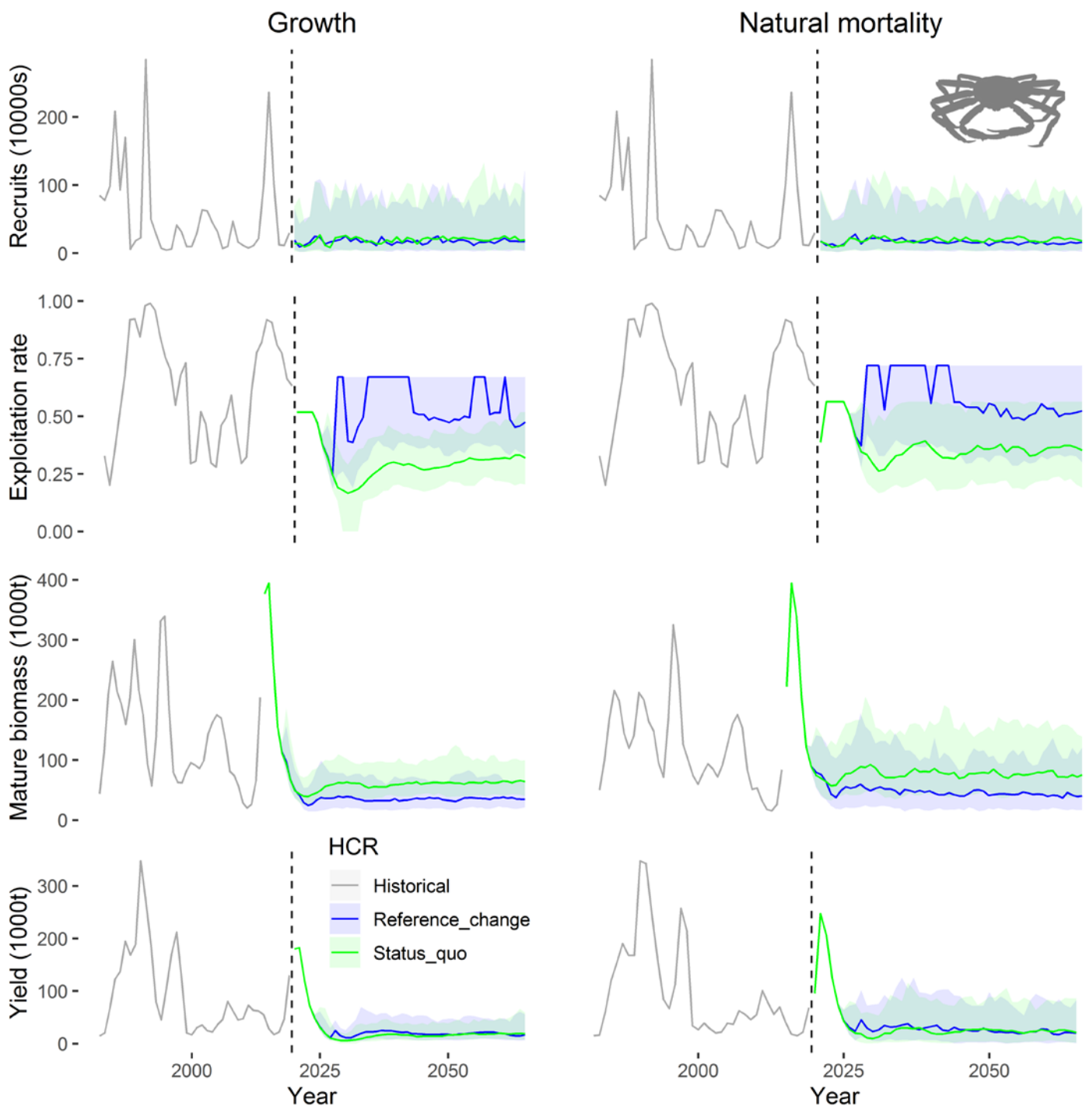
Perspectives

- If there is a fishery that is closed because another population in the same area is overfished, should the overfished population ever be written off? If so, when?
- Under what sorts of circumstances should reference points be changed? What criteria must be met?
- Should a management target always be tied to the productivity of a population? If not, what other metrics could be used?
- Does this information change the emphasis one might put on understanding the impact of climate on stocks?


Historical
Climate adaptive HCR
Status quo HCR
B
A
K^B
K^A
0.25
0.20
0.15
0.10
0.05
0.00
Exploitation rate
0
200
400
600
800
1000
Biomass


Biomass
Harvest
Exploitation rate
Year
Historical
Climate adaptive HCR
Status quo HCR
B
A
K^B
K^A
Biomass
Exploitation rate


Fishing mortality
0.0
0.2
0.4
0.6
0.8
1.0
Decrease growth
Status quo
0
100
200
300
400
Increase natural mortality
Status quo
0
100
200
300
400
500
Biomass
Fishing mortality
0.0
0.2
0.4
0.6
0.8
1.0
1.2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100
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Yield (1000t)
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200
100
0
HCR
Historical
Reference_change
Status_quo
2000
2025
2050
Year