The influence of fishing and climate on North Sea cod stocks : A view from the FishClim model

Grégory Beaugrand, Alexis Balembois, Loick Kléparski, Richard R Kirby

NSAC Webinar on North Sea Fisheries and Climate Change
7th December 2022

The Plankton Pundit Dr Richard R Kirby

Introduction (1)

- Difficult to separate the influence of fishing and climate on changes in fish stocks
- As a result, climate has not been explicitly implemented in management models.
- We have developed a simple model that can be used to consider the joint influence of fishing and climate and to separate their respective effects on fish stocks.
- Here we apply our model to the North Sea cod stock.

Introduction (2)

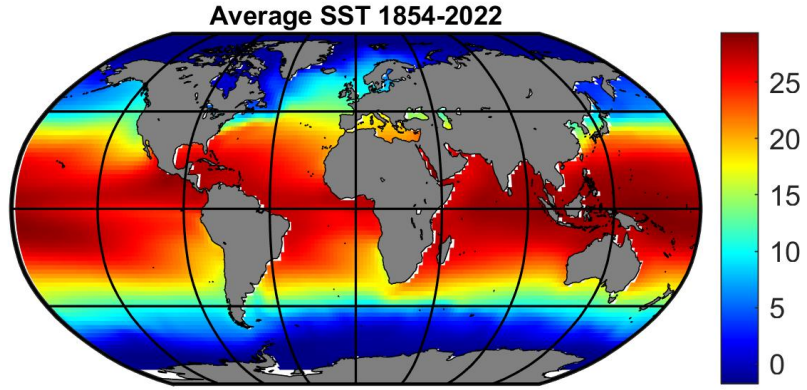
Strong and widespread impact of fishing

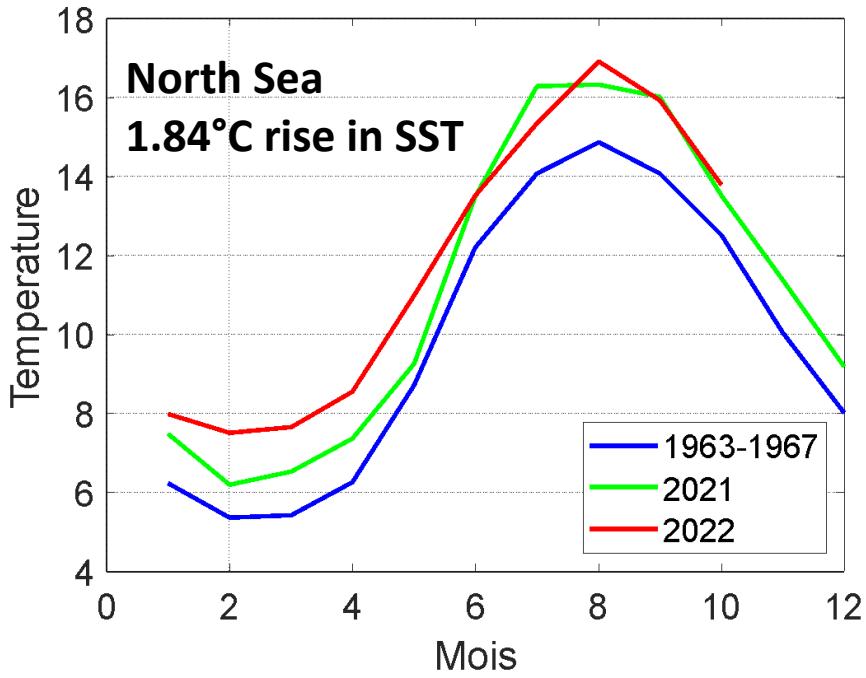
Fishing Down Marine Food Webs

Daniel Pauly,* Villy Christensen, Johanne Dalsgaard,
Rainer Froese, Francisco Torres Jr.

The mean trophic level of the species groups reported in Food and Agricultural Organization global fisheries statistics declined from 1950 to 1994. This reflects a gradual transition in landings from long-lived, high trophic level, piscivorous bottom fish toward short-lived, low trophic level invertebrates and planktivorous pelagic fish. This effect, also found to be occurring in inland fisheries, is most pronounced in the Northern Hemisphere. Fishing down food webs (that is, at lower trophic levels) leads at first to increasing catches, then to a phase transition associated with stagnating or declining catches. These results indicate that present exploitation patterns are unsustainable.

Strong and widespread impact of climate change





Key questions

- What is the respective influence of fishing and climate in the long-term changes in fish stocks?

- How can we include the climatic regime in fish stock management?

Any model should be simple and be widely applicable

What is FishClim?

Fishclim is a model that assesses changes in the standardised spawning stock biomass (SSB, dSSB, between 0 and 1) by estimating the maximum dSSB (or mdSSB) that a stock can reach for a given environmental regime, gain (growth of dSSB, depending upon mdSSB) and loss (fishing intensity).

Growth rate
(depends upon species and stock)

$$X_{t+1} = X_t + rX_t\left(1 - \frac{X_t}{K_t}\right) - \alpha X_t$$

dSSB time t+1

dSSB time t+1

Maximum dSSB
(for a given environmental regime)

Fishing intensity

K_t = maximum dSSB is assessed from the knowledge of the niche of the species using our published MacroEcological Theory on the Arrangement of Life (METAL)

https://biodiversite.macroecologie.climat.cnrs.fr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Addressing the dichotomy of fishing and climate in fishery management with the FishClim model

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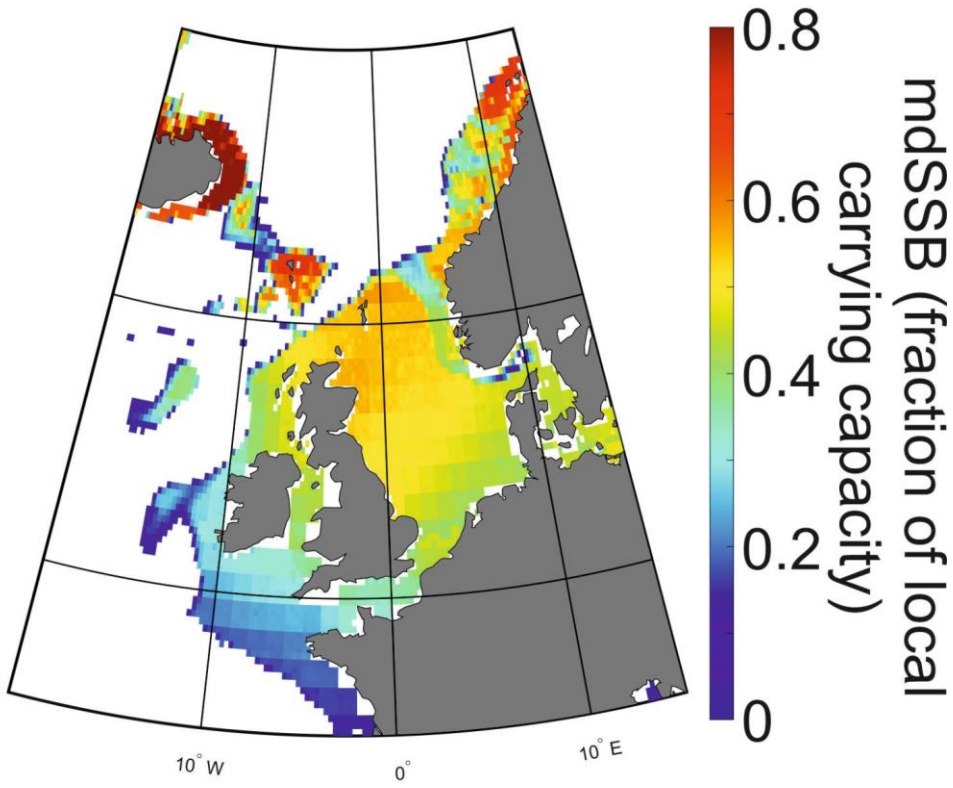
Results

Maximum dSSB in the Northeast Atlantic



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$$X_{t+1} = X_t + rX_t\left(1 - \frac{X_t}{K_t}\right) - \alpha X_t$$

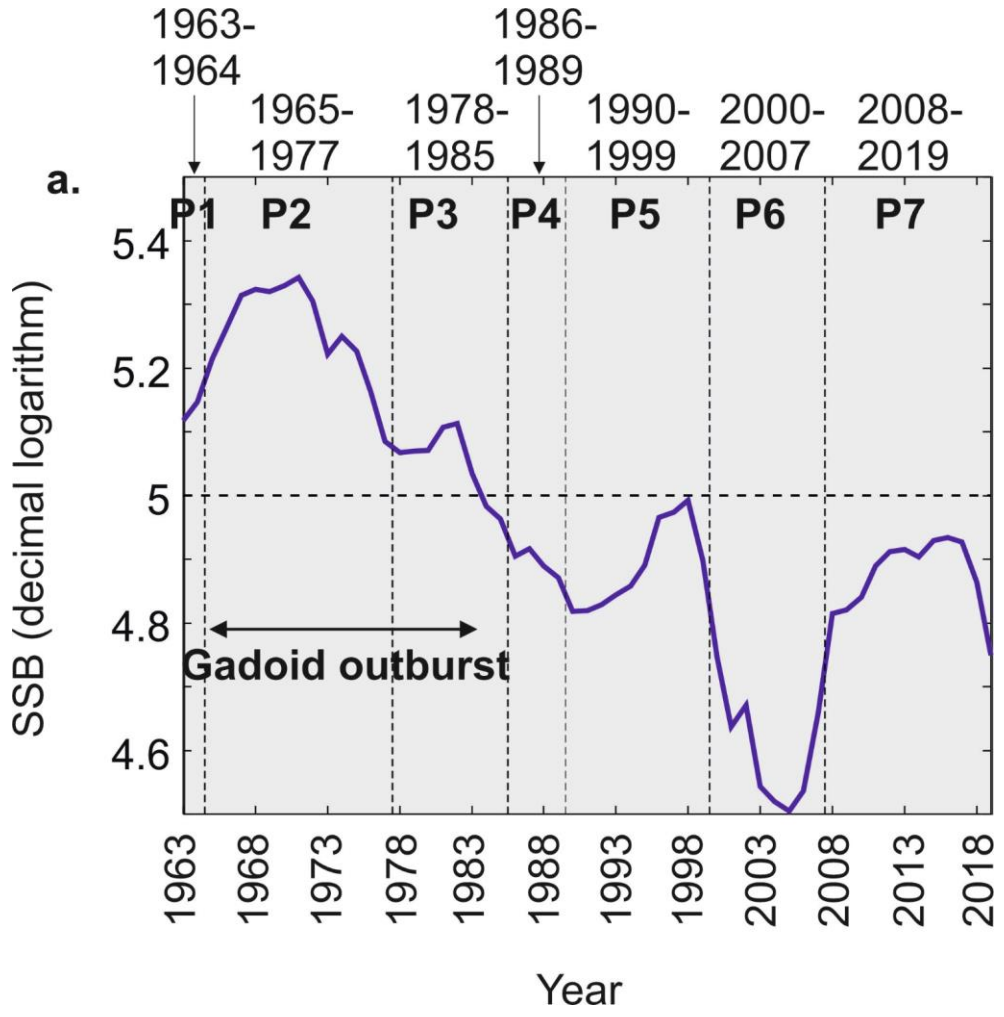
dSSB time t+1

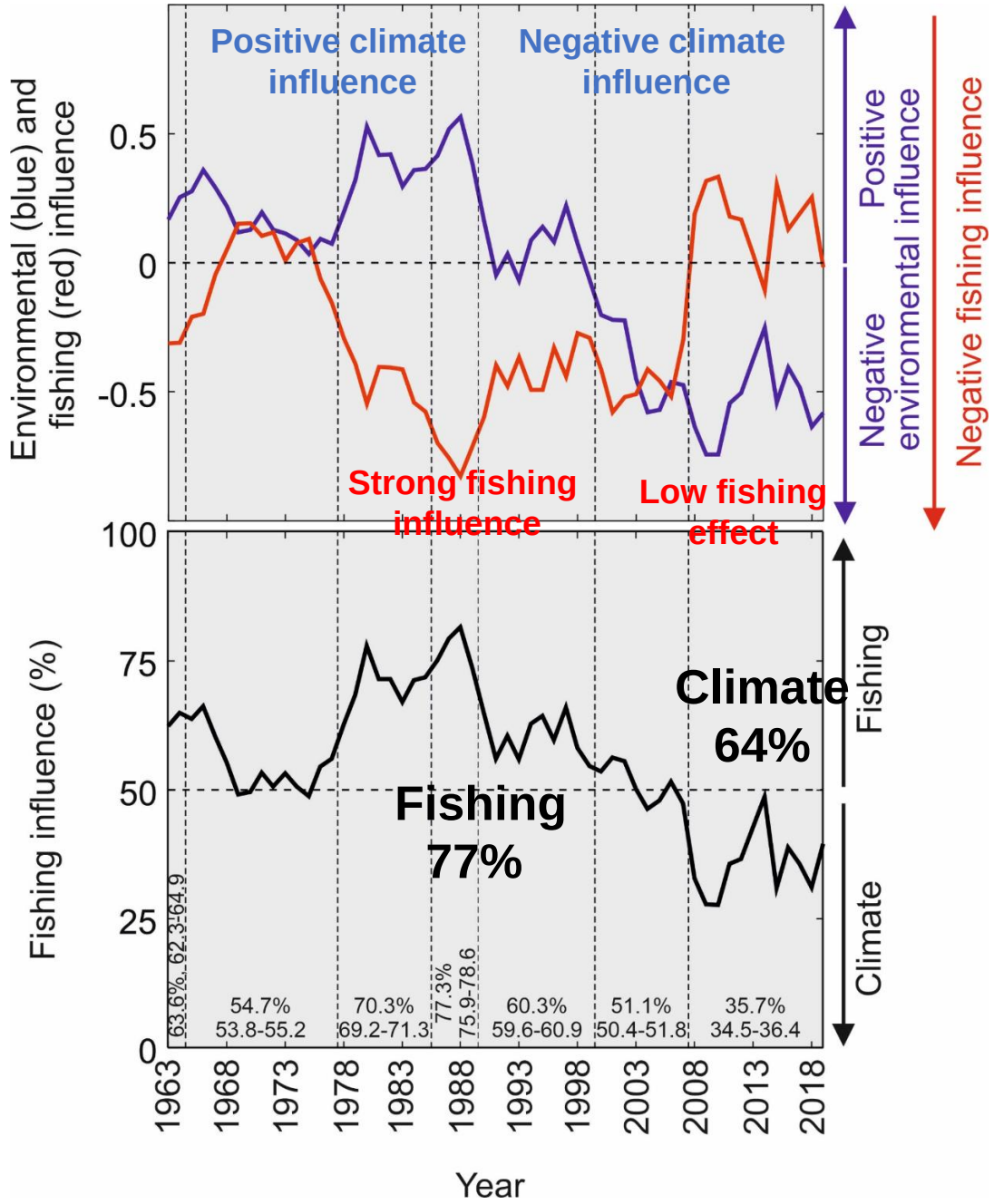
dSSB time t+1

Maximum dSSB (for a given environmental regime)

- Higher maximum dSSB (Kt) in the northern North Sea
- Lower maximum dSSB (Kt) in the southern North Sea
- Lowest maximum dSSB (Kt) in the English Channel and the Celtic Sea
- Highest maximum dSSB (Kt) around Iceland

Quantification of the effect of fishing and climate

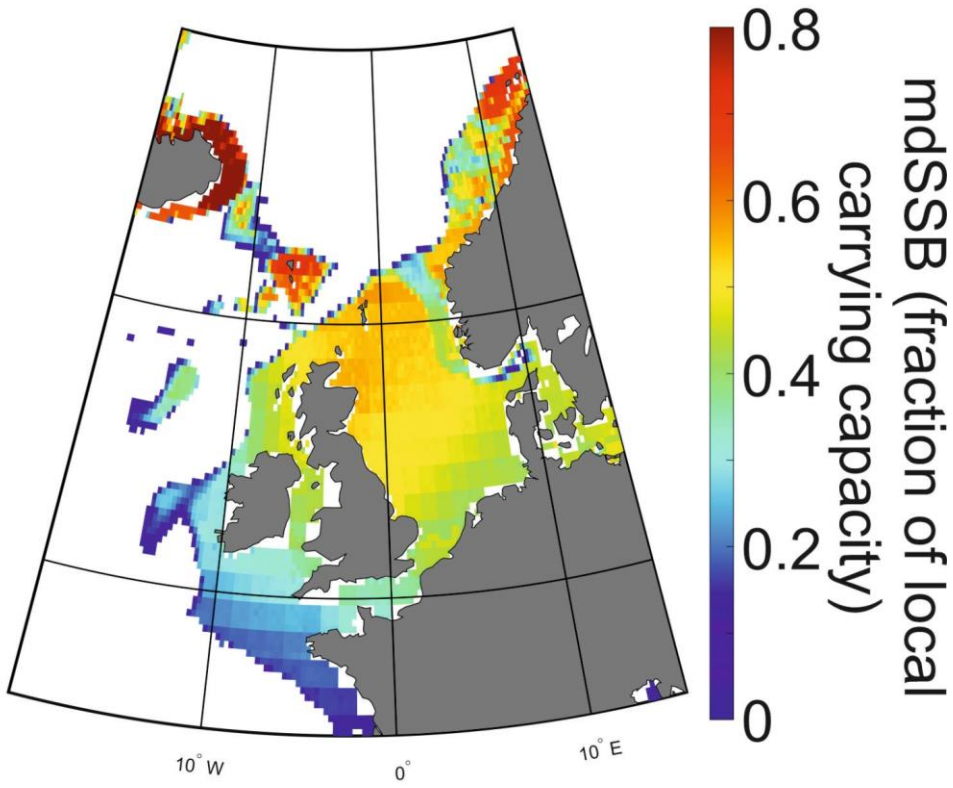


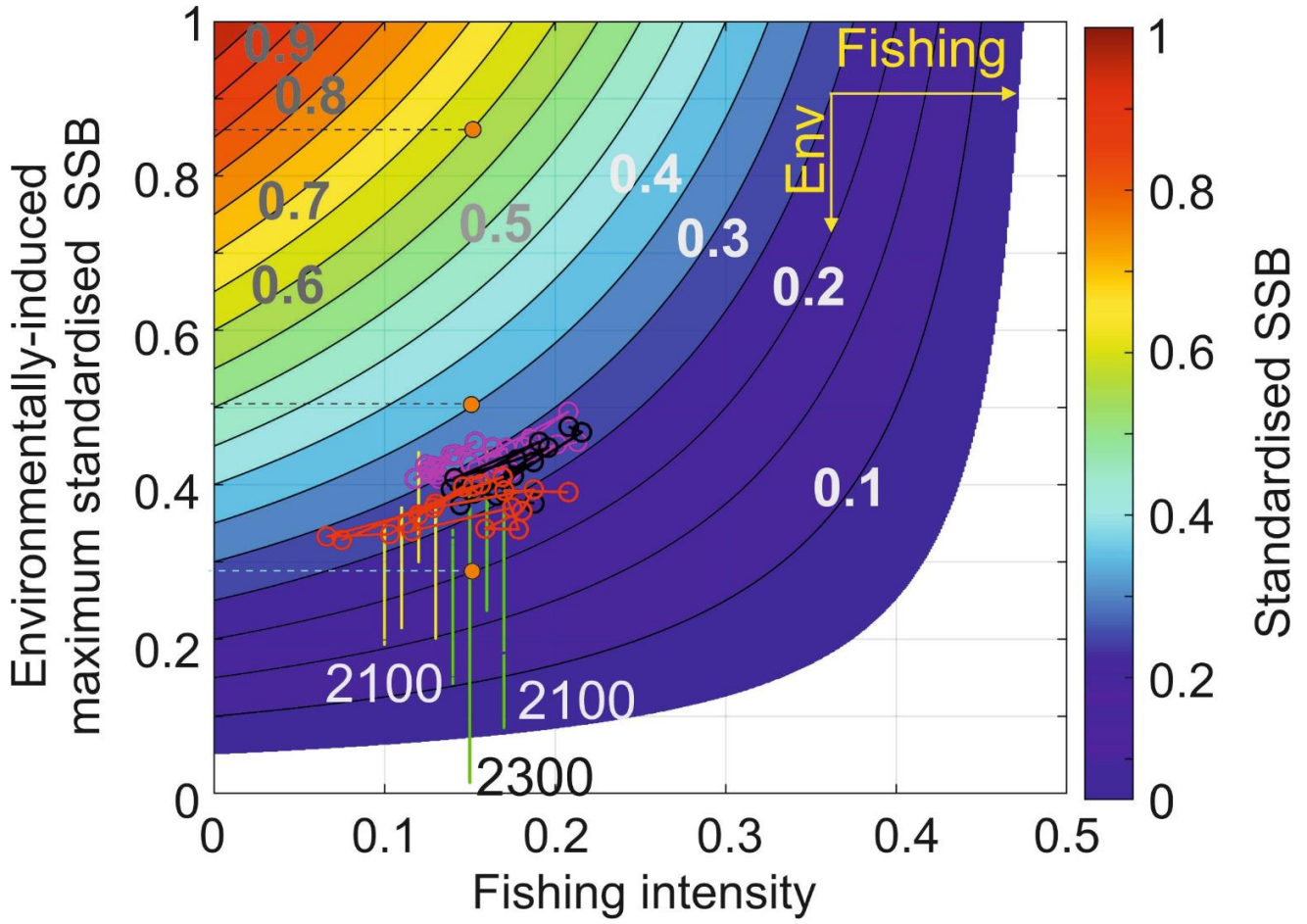


1963-2019 : 55% fishing and 45% climate

Understanding fishing and climate interaction

Maximum dSSB in the Northeast Atlantic





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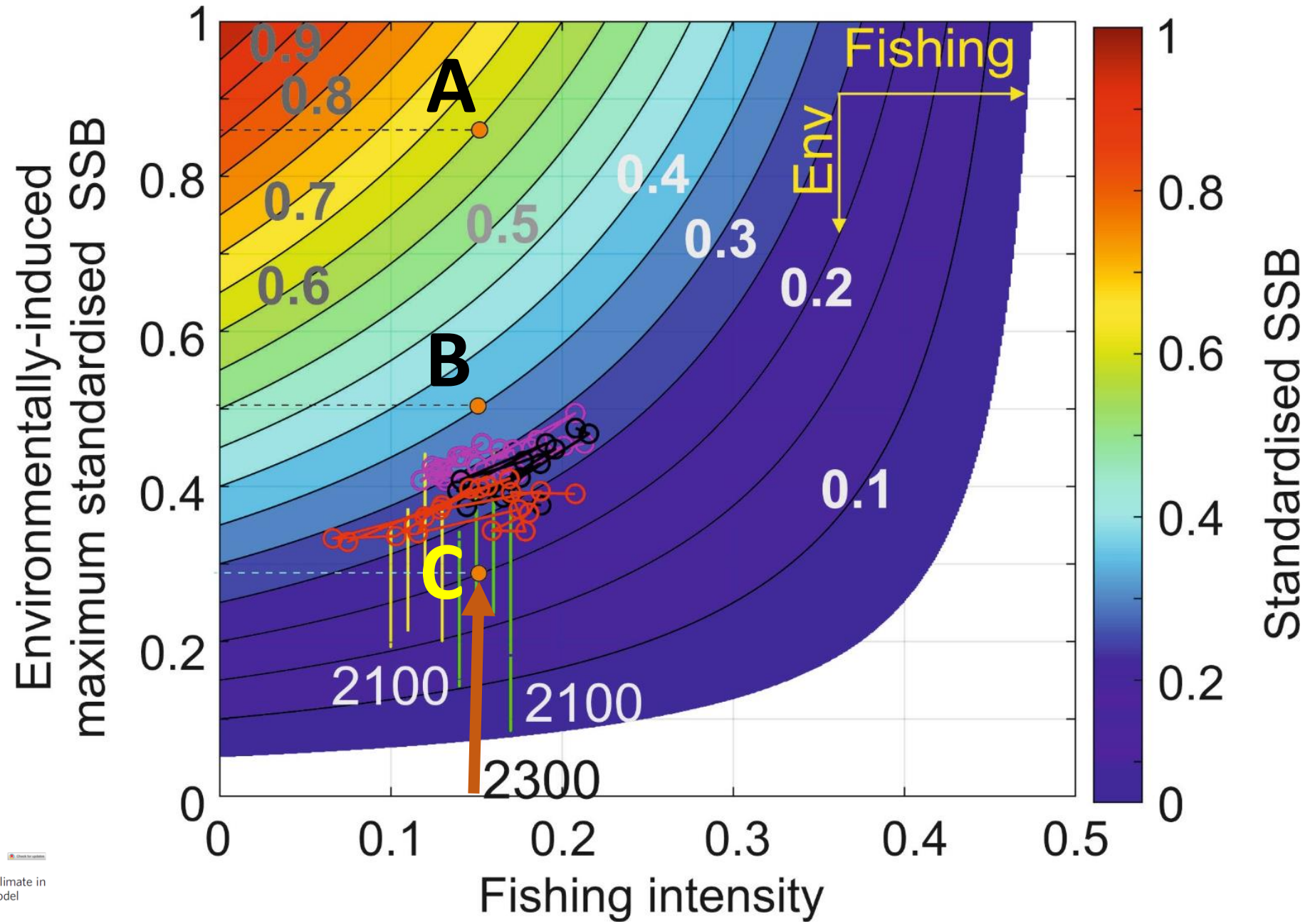

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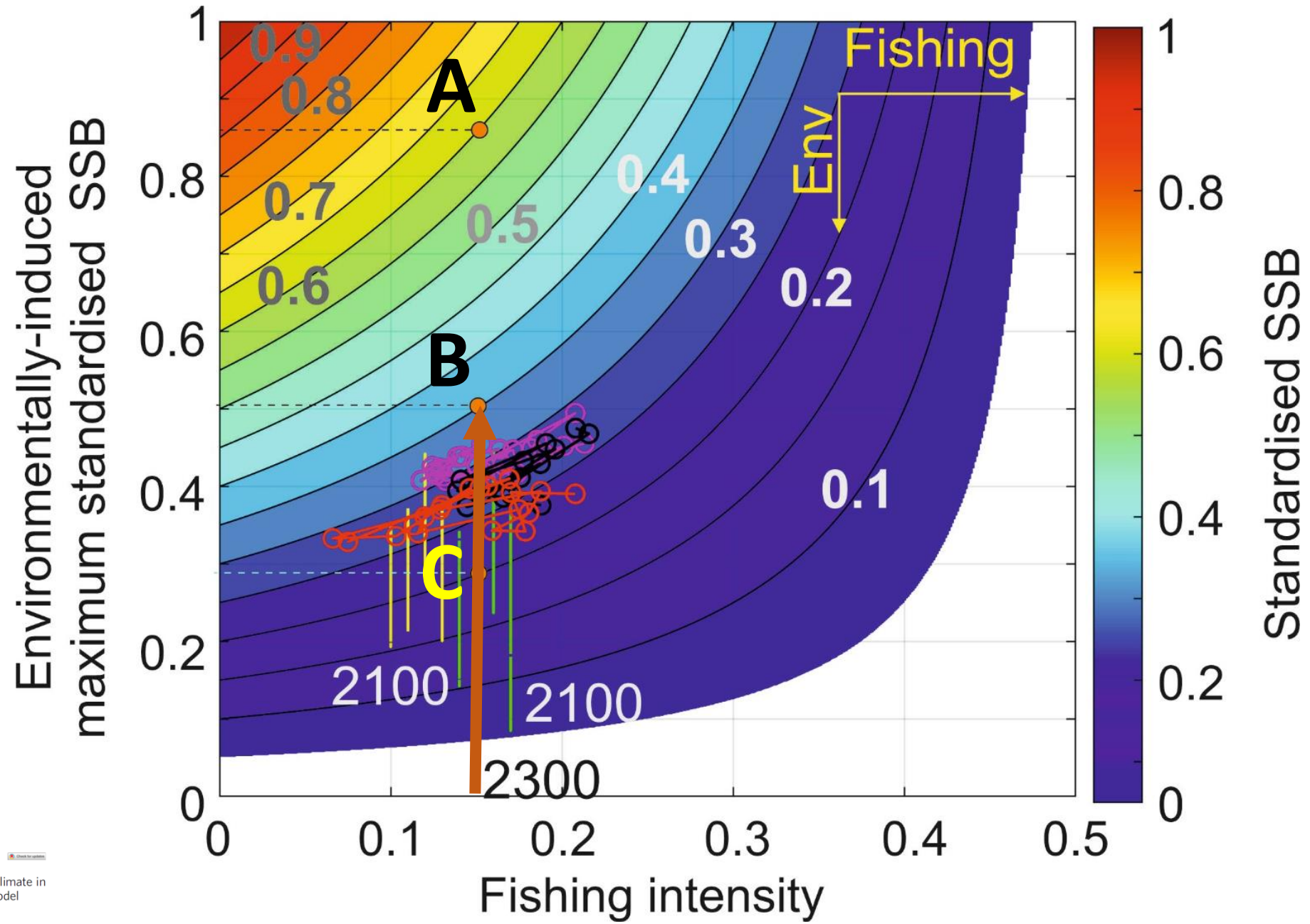

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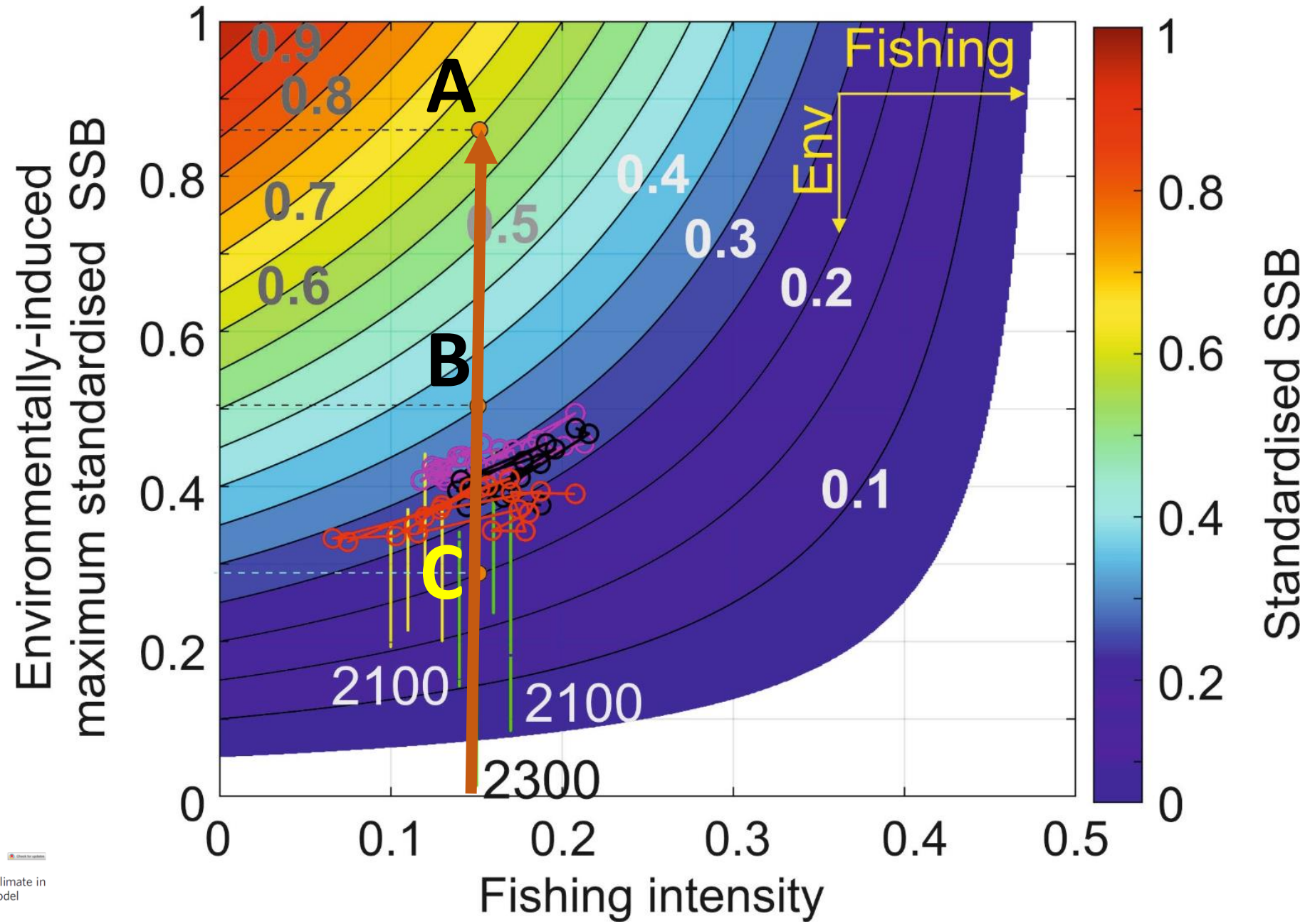

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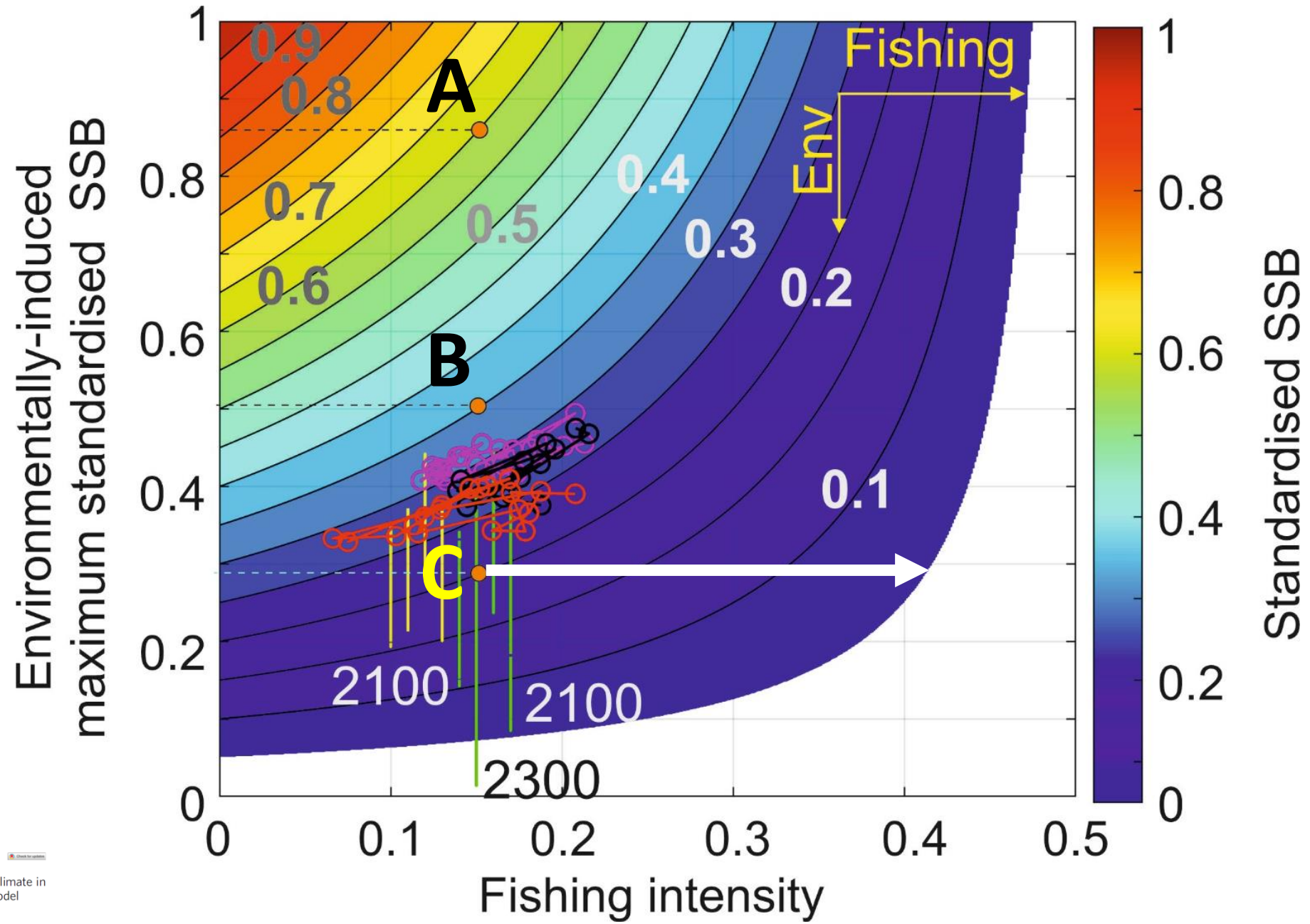

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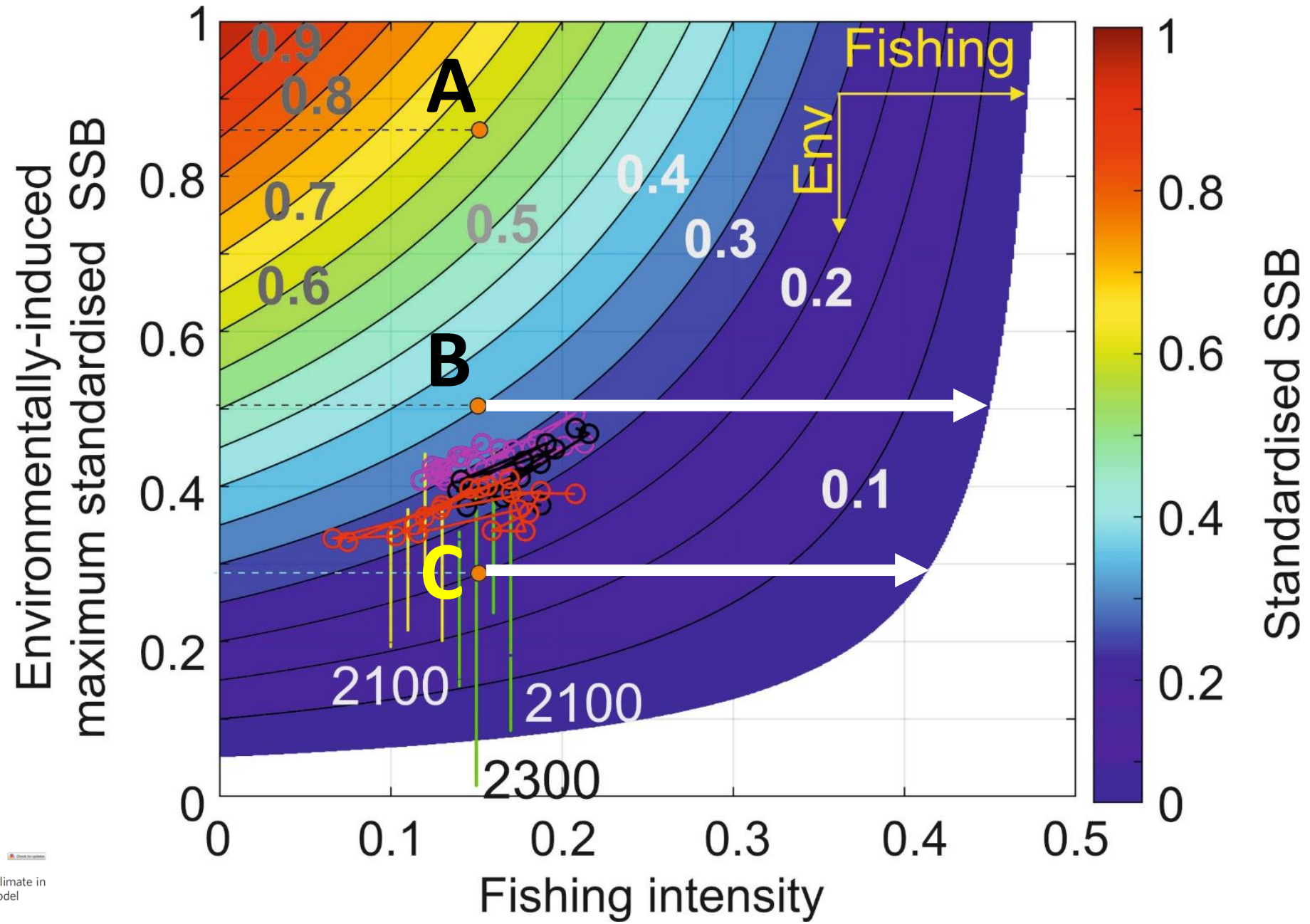

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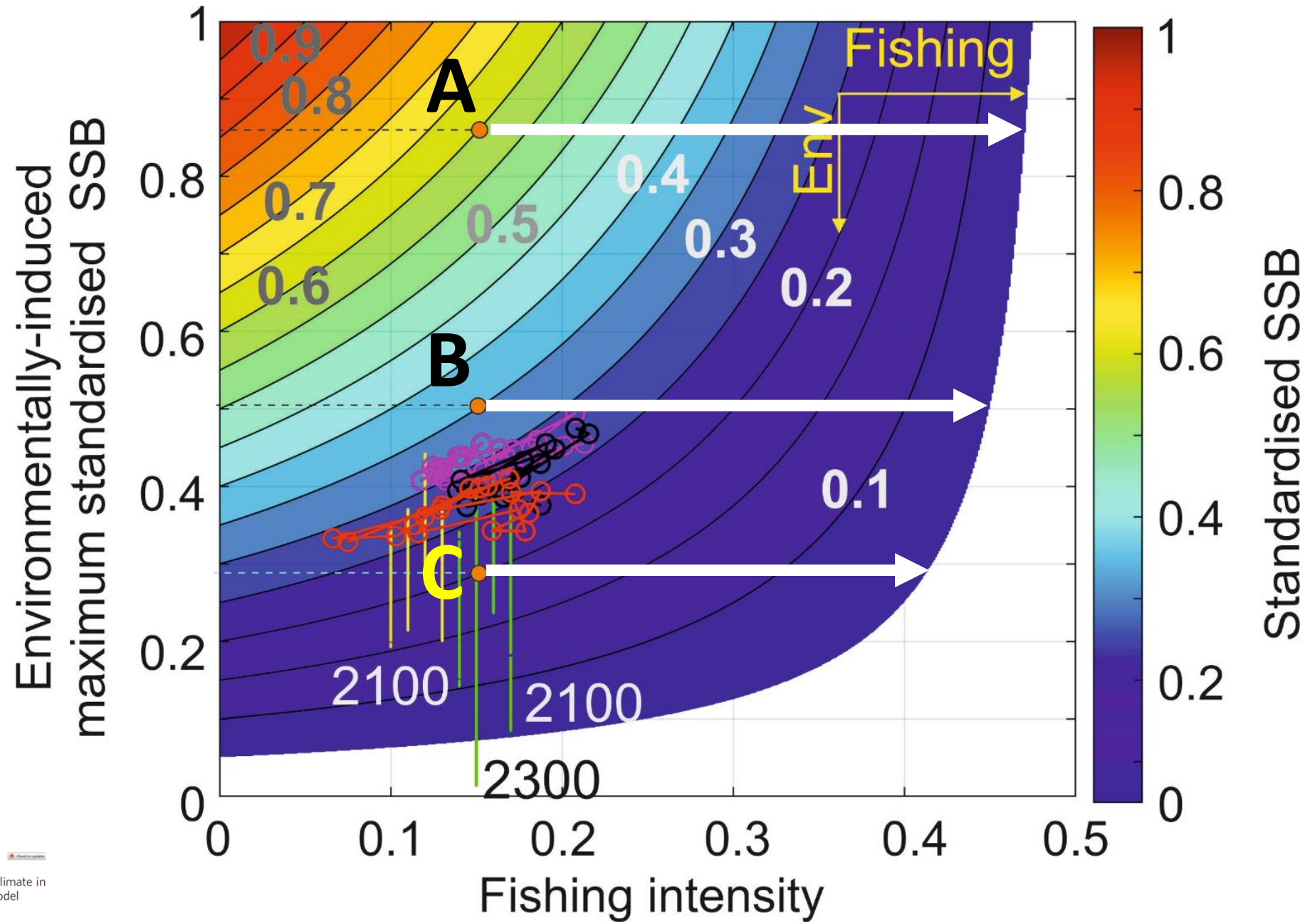

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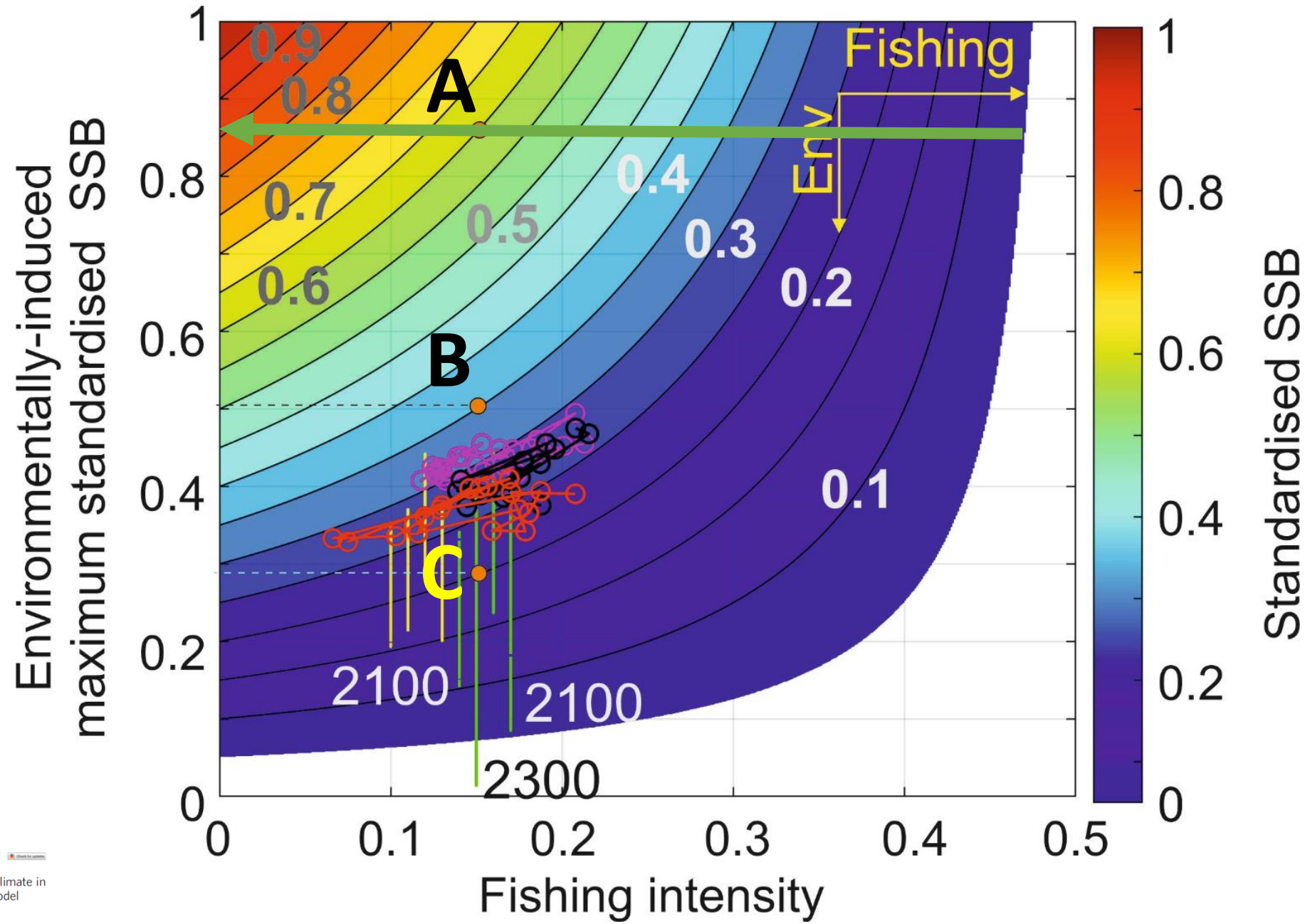

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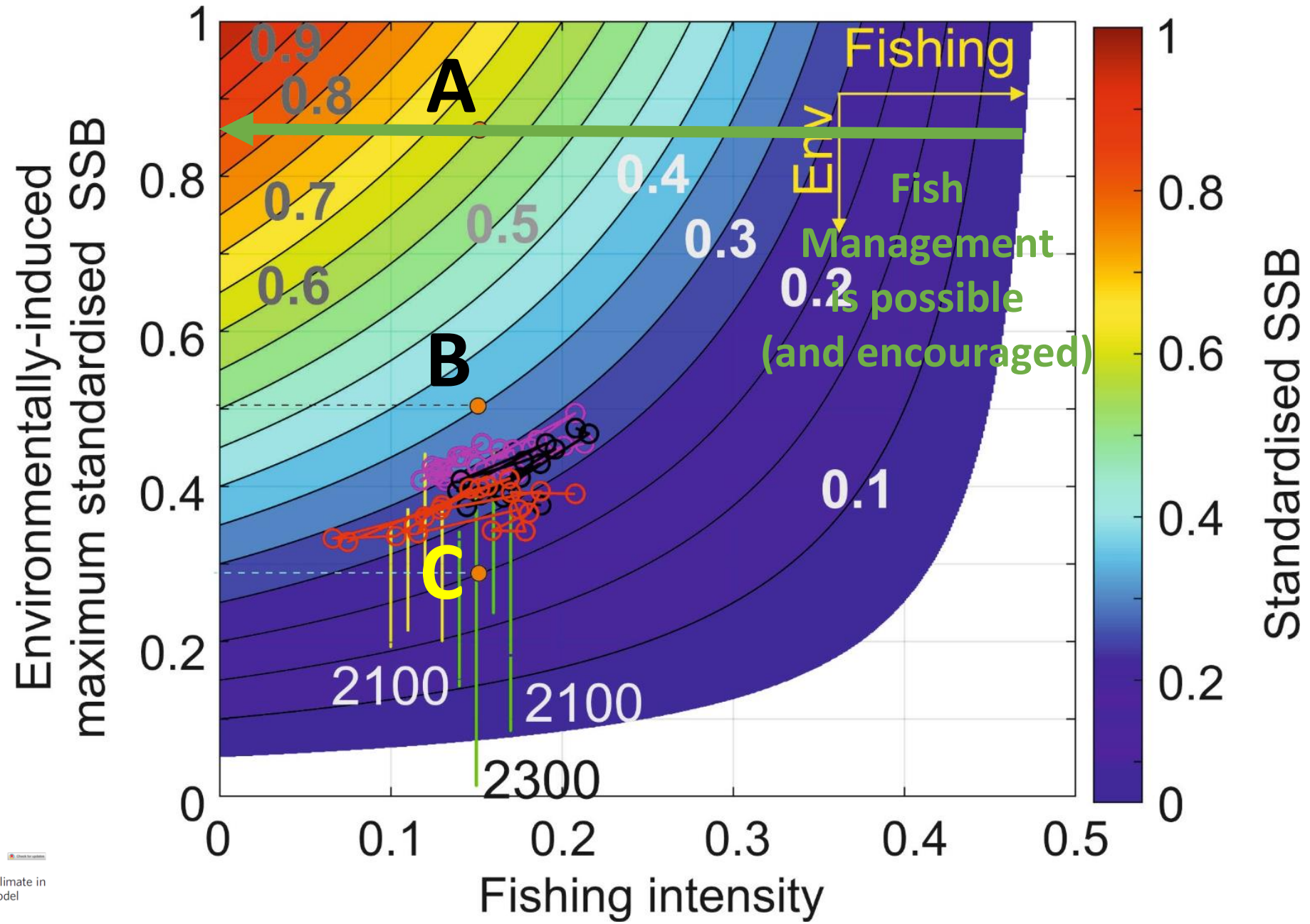

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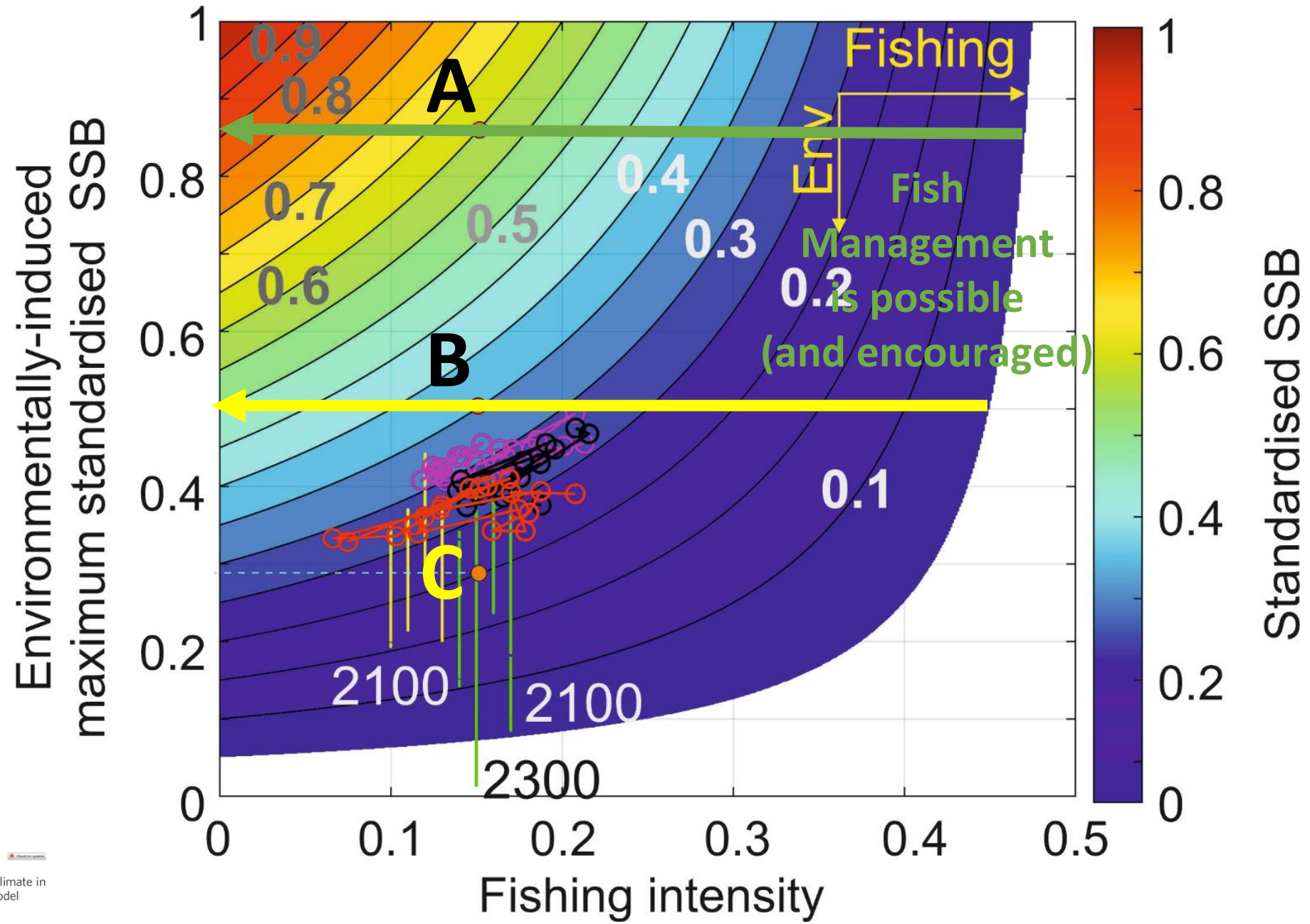

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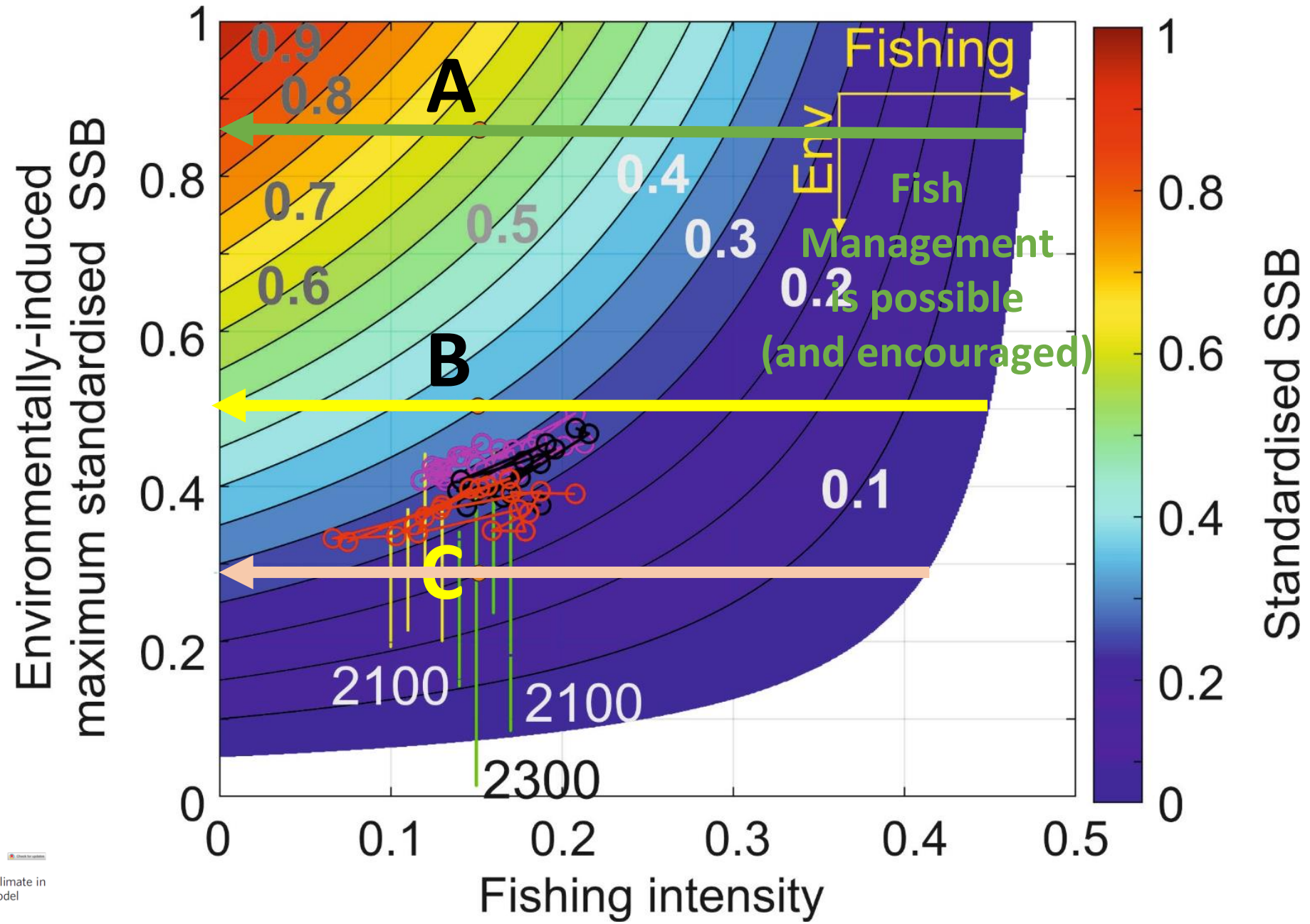

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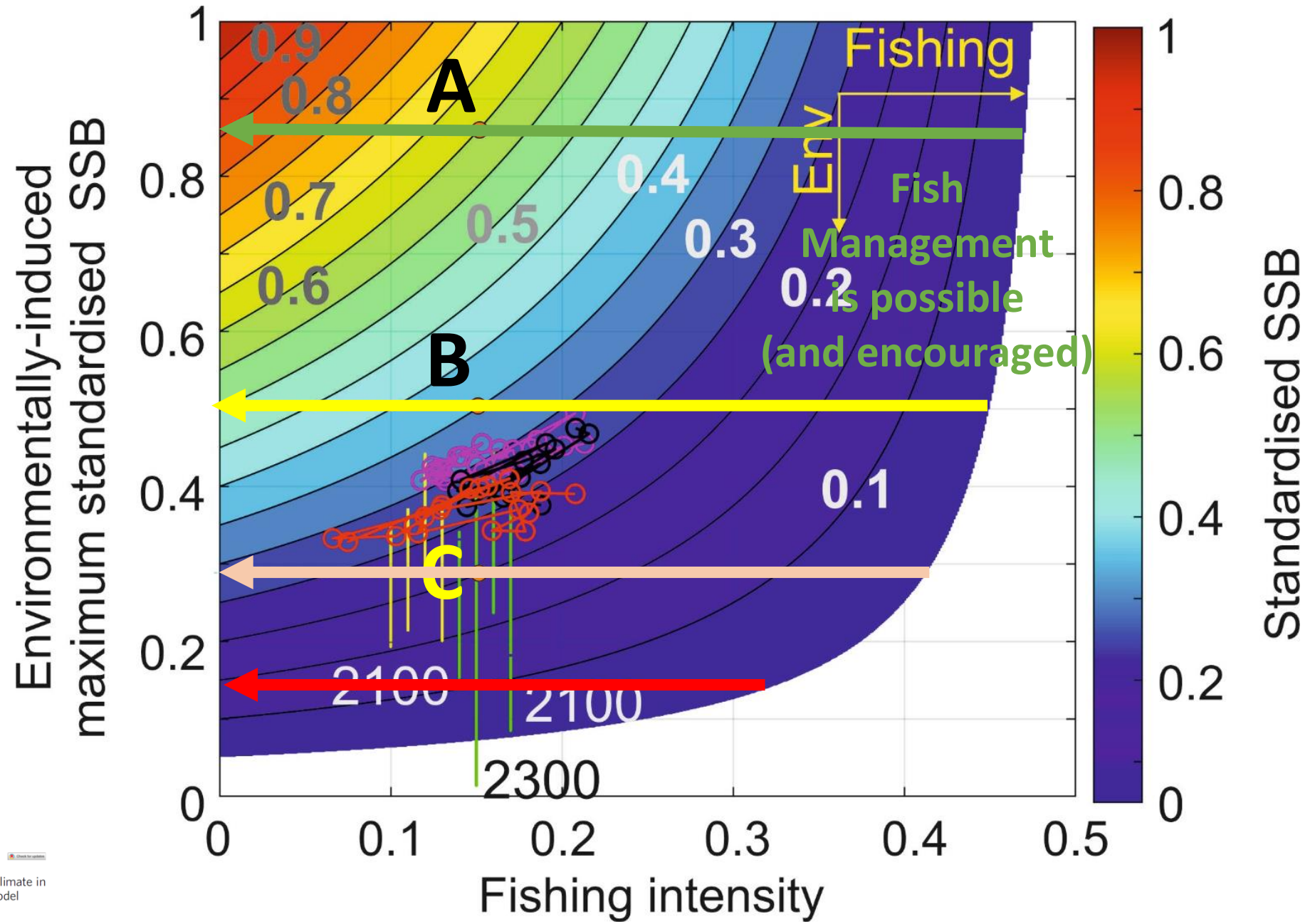

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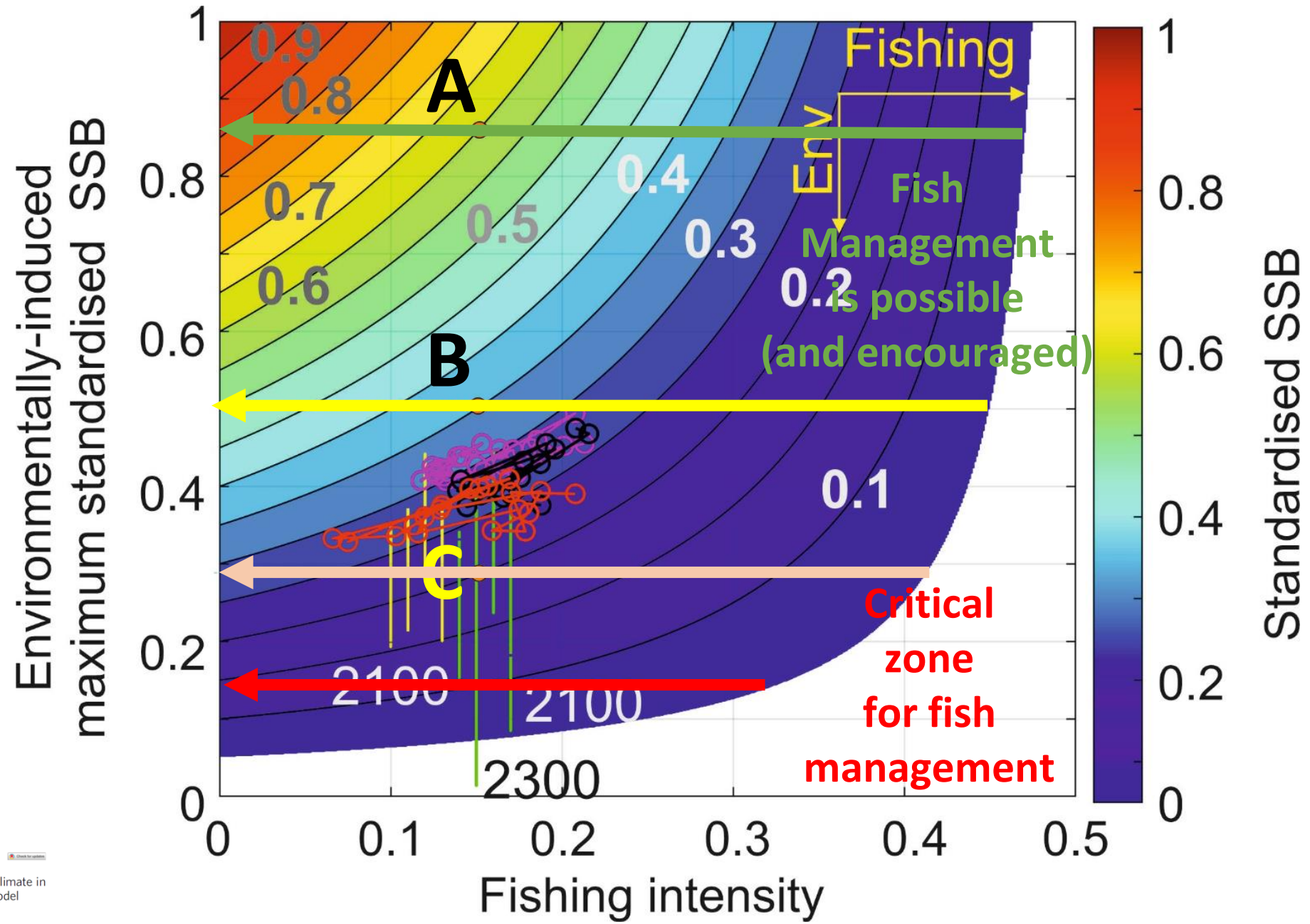

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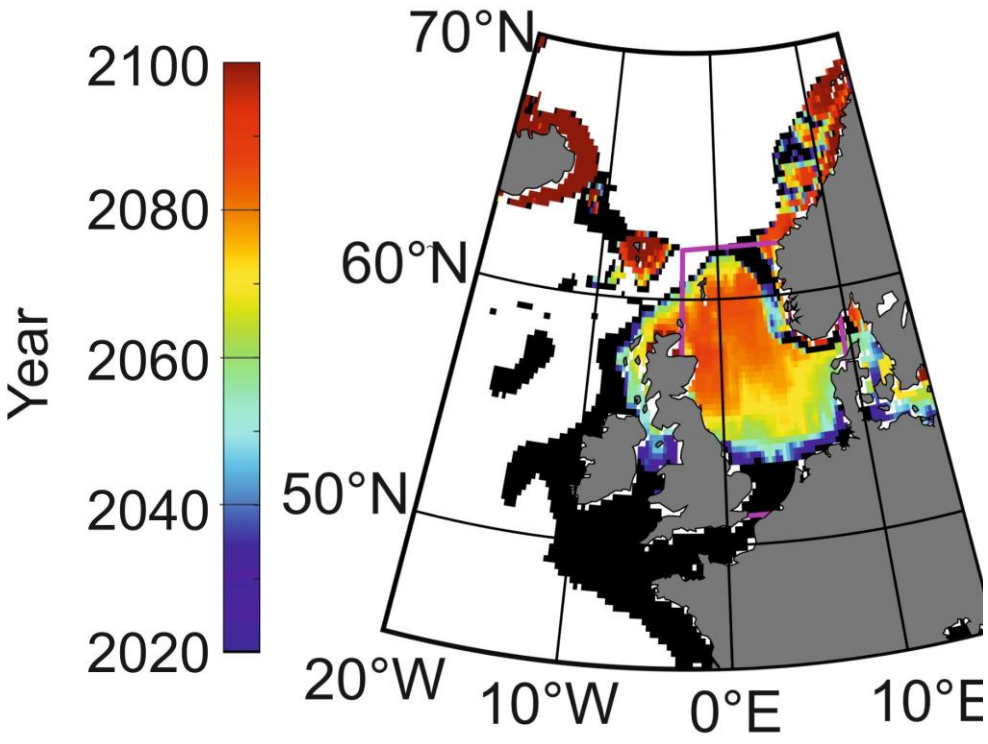
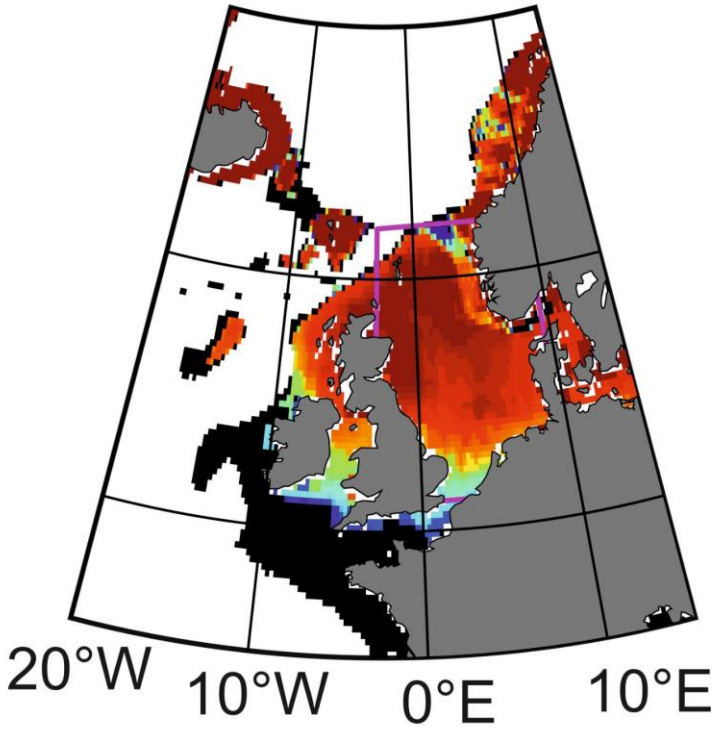
Time to extirpation for a high-warming scenario (SSP585)

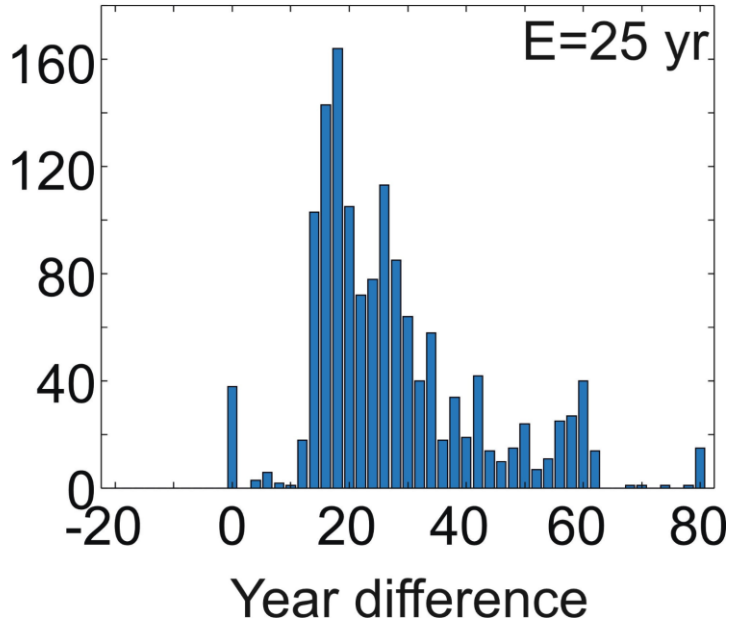
No fishing adjustment to the climate regime



With fishing adjustment to the climate regime



Year difference



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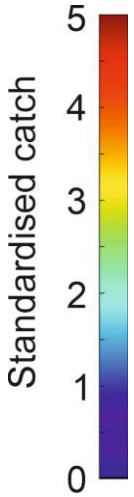
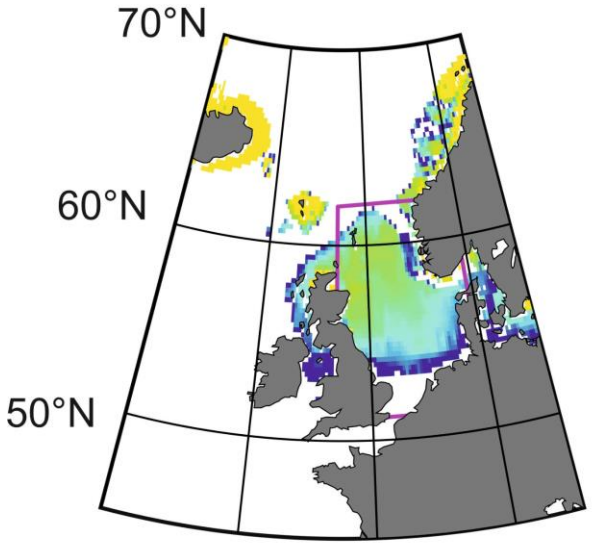
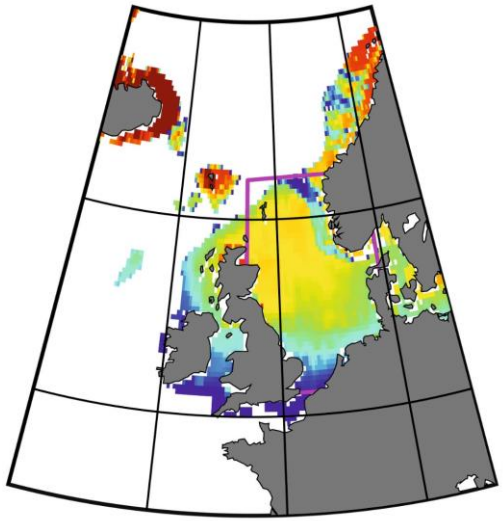
Pooled catch (SSP585, 2020-2100)



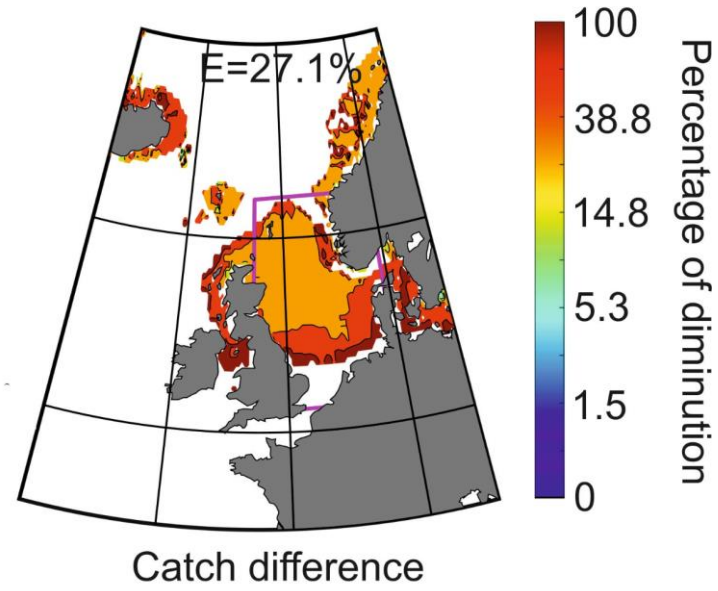
No fishing adjustment to the climate regime



With fishing adjustment to the climate regime



Difference in pooled catch



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Conclusion

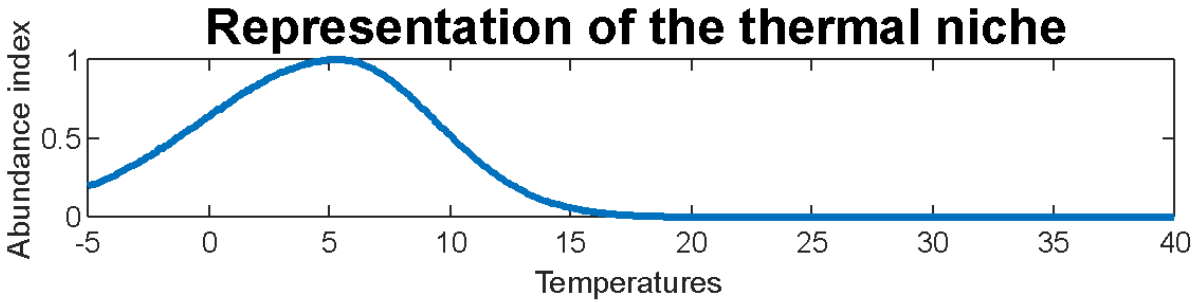
- One of the main sustainable development goals of the United Nations is to manage fish stock sustainably
- In a context of rapid climate change, we need to urgently consider explicitly the climatic regime in fish management
- By adding climate in fish management, we can exploit stocks longer and optimise pooled catch
- As climate will warm, we need to recognise that some stocks will disappear, with or without fishing
- Anticipate stock disappearance and the establishment of new stocks
- Fishclim can be applied to many stocks (exploited species for which there is enough knowledge of the biology and the ecology)

Thank you !

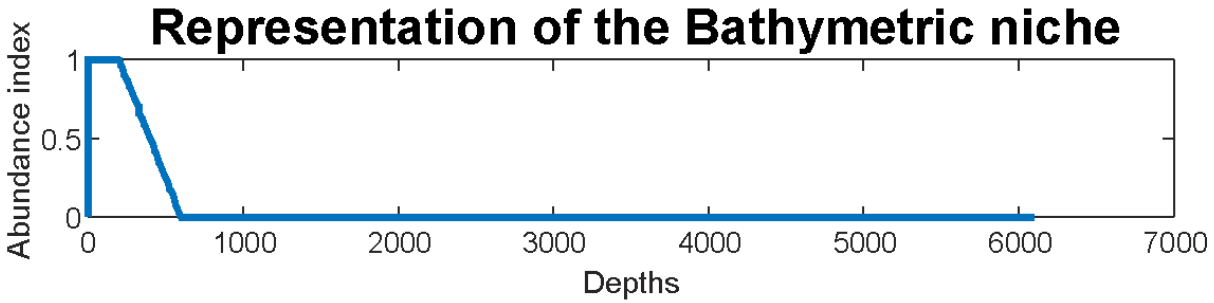
What is FishClim? (2)

How K_t (maximum dSSB) is assessed?

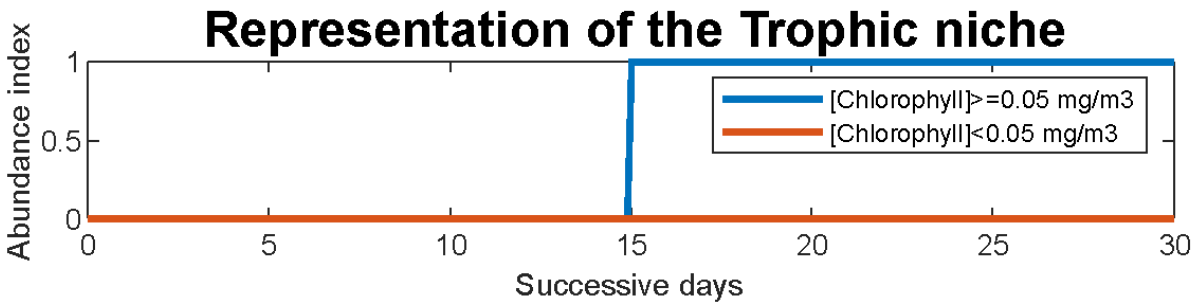
We use a niche-based procedure run at a daily scale.
(Our method is based upon our previously published METAL model.)



Asymmetrical Gaussian niche (values between 0 and 1)



Trapezoidal niche (values between 0 and 1)

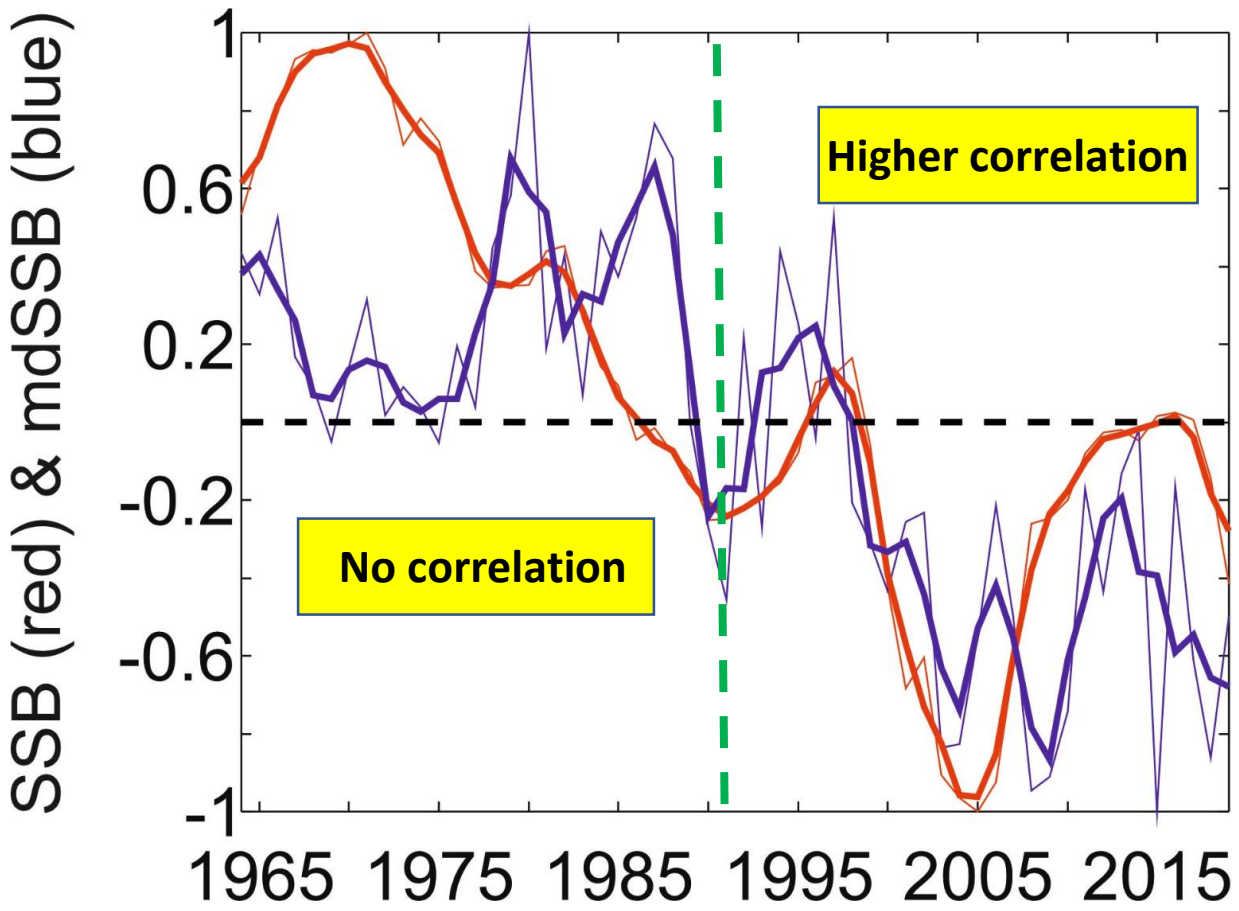


Rectangular niche (values between 0 and 1)

We then multiply the three individual niches (values are between 0 and 1)

Results (3)

ICES SSB and **maximum dSSB (no fishing)**



$$X_{t+1} = X_t + rX_t\left(1 - \frac{X_t}{K_t}\right) - \alpha X_t$$

SSB time t+1

SSB time t+1

Maximum SSB (for a given environmental regime)

Fishing intensity

No consideration of fishing

Whole time series : correlation = 0.52 (not significant)

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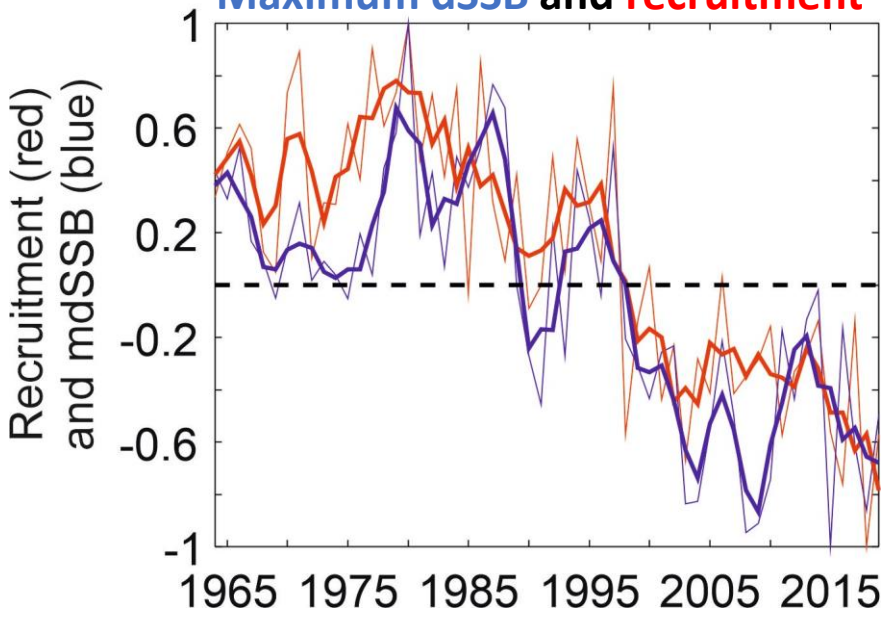
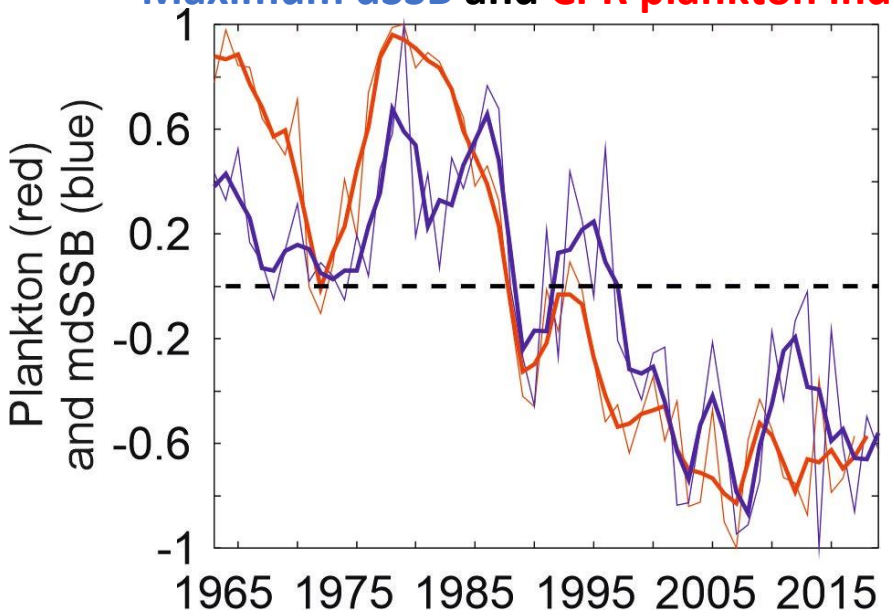
Results (2)

Maximum dSSB and recruitment



Maximum dSSB and CPR plankton index



Based on daily SST, daily modelled chlorophyll (>0,05 mg,m-3 for 15 days) and bathymetry

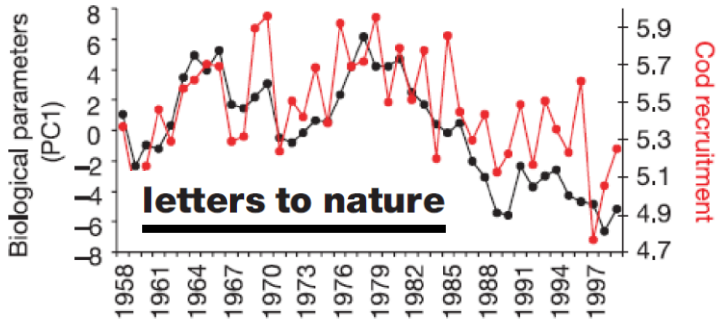
$$X_{t+1} = X_t + rX_t\left(1 - \frac{X_t}{K_t}\right) - \alpha X_t$$

dSSB time t+1

dSSB time t+1

Maximum dSSB (for a given environmental regime)

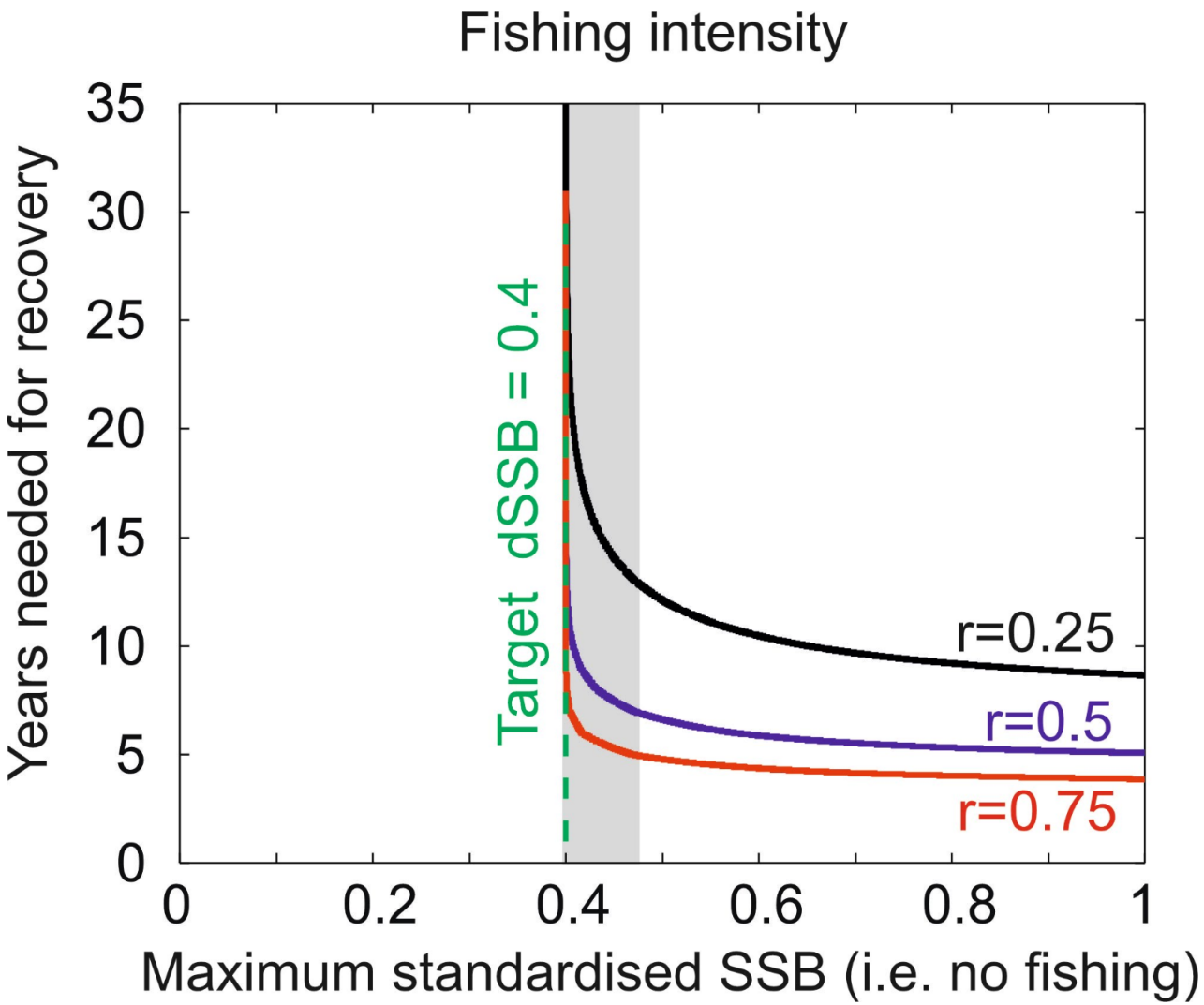
Based on monthly abundance of *C. finmarchicus*, *C. helgolandicus*, mean biomass, mean size of copepods, and euphausiids



Plankton effect on cod recruitment in the North Sea

Grégory Beaugrand[1,2], Keith M. Brander[3], J. Alistair Lindley[2], Sami Souissi[1] & Philip C. Reid[2]

Time to stock recovery at target dSSB = 0.4



$$X_{t+1} = X_t + rX_t\left(1 - \frac{X_t}{K_t}\right) - \alpha X_t$$

dSSB time t+1

dSSB time t+1

Maximum dSSB (for a given environmental regime)

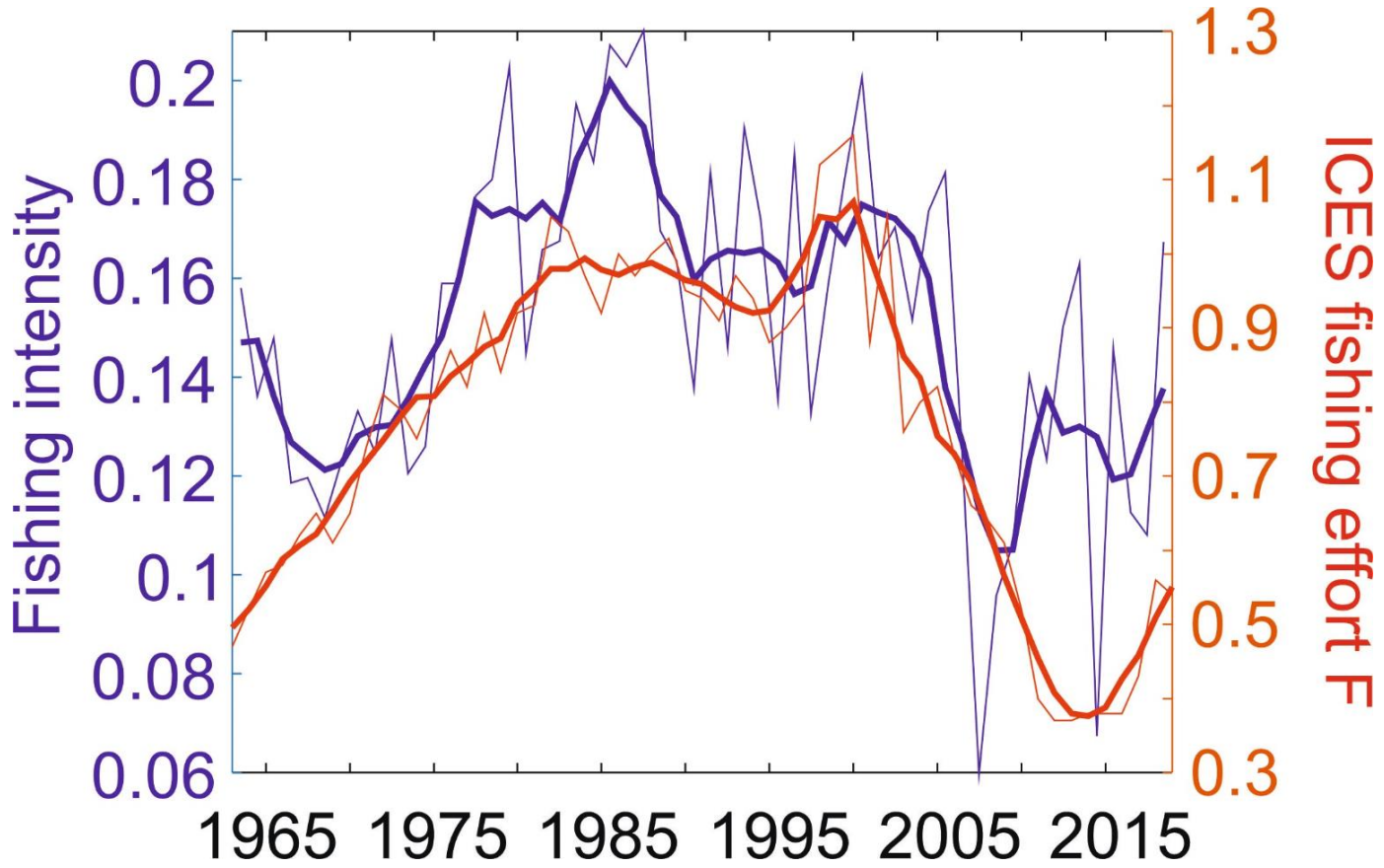
Fishing intensity

- **Recovery is only possible when mdSSB>>dSSB**
- **When mdSSB≈dSSB, recovery can take decades**
- **When mdSSB<dSSB, recovery is impossible**

Results (4)

Fishing intensity

$$\alpha = 1 + r\left(1 - \frac{X_t}{K_t}\right) - \frac{X_{t+1}}{X_t}$$



Significant correlation between fishing intensity (Fishclim) and ICES fishing effort

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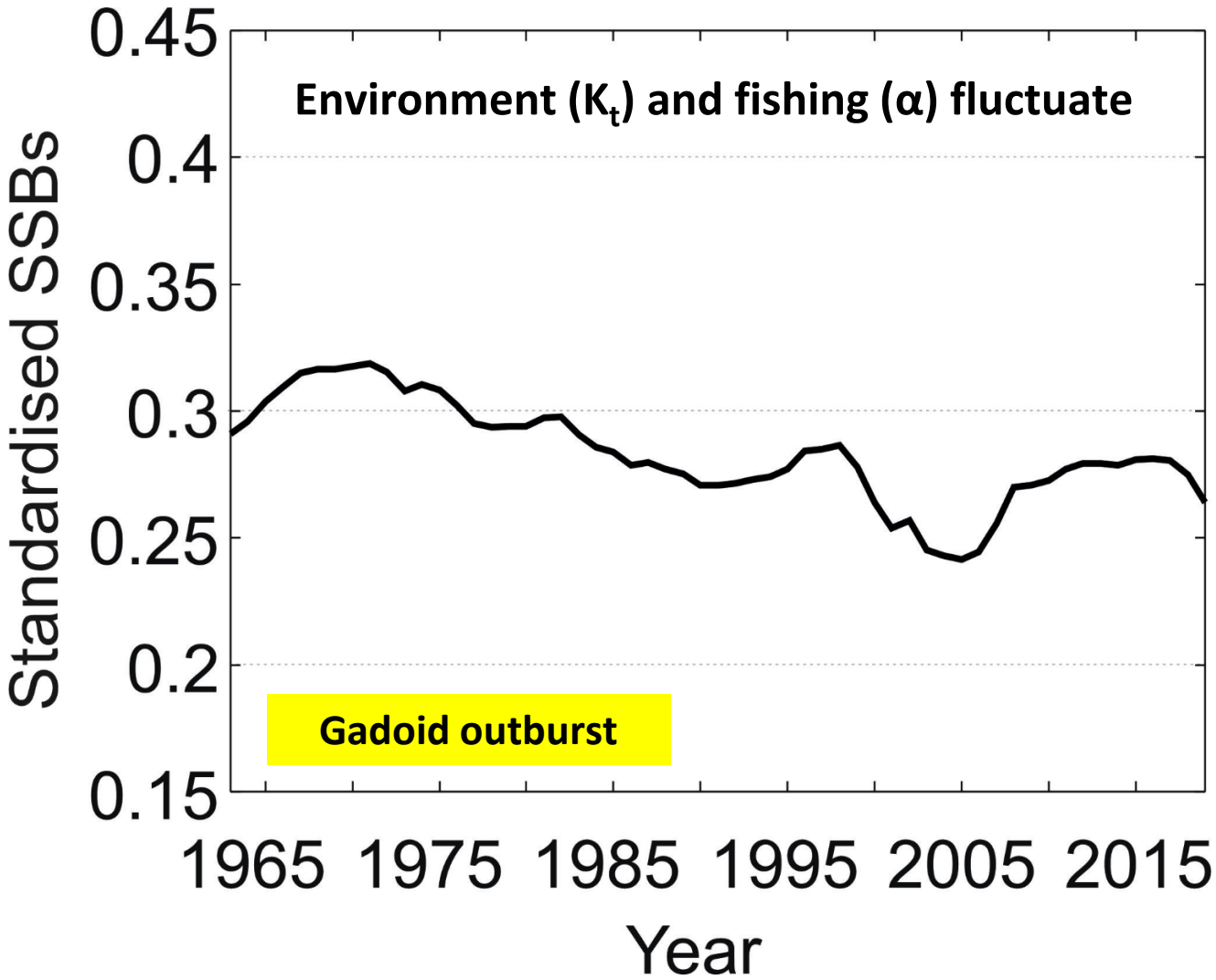
Results (5)

$$X_{t+1} = X_t + rX_t\left(1 - \frac{X_t}{K_t}\right) - \alpha X_t$$



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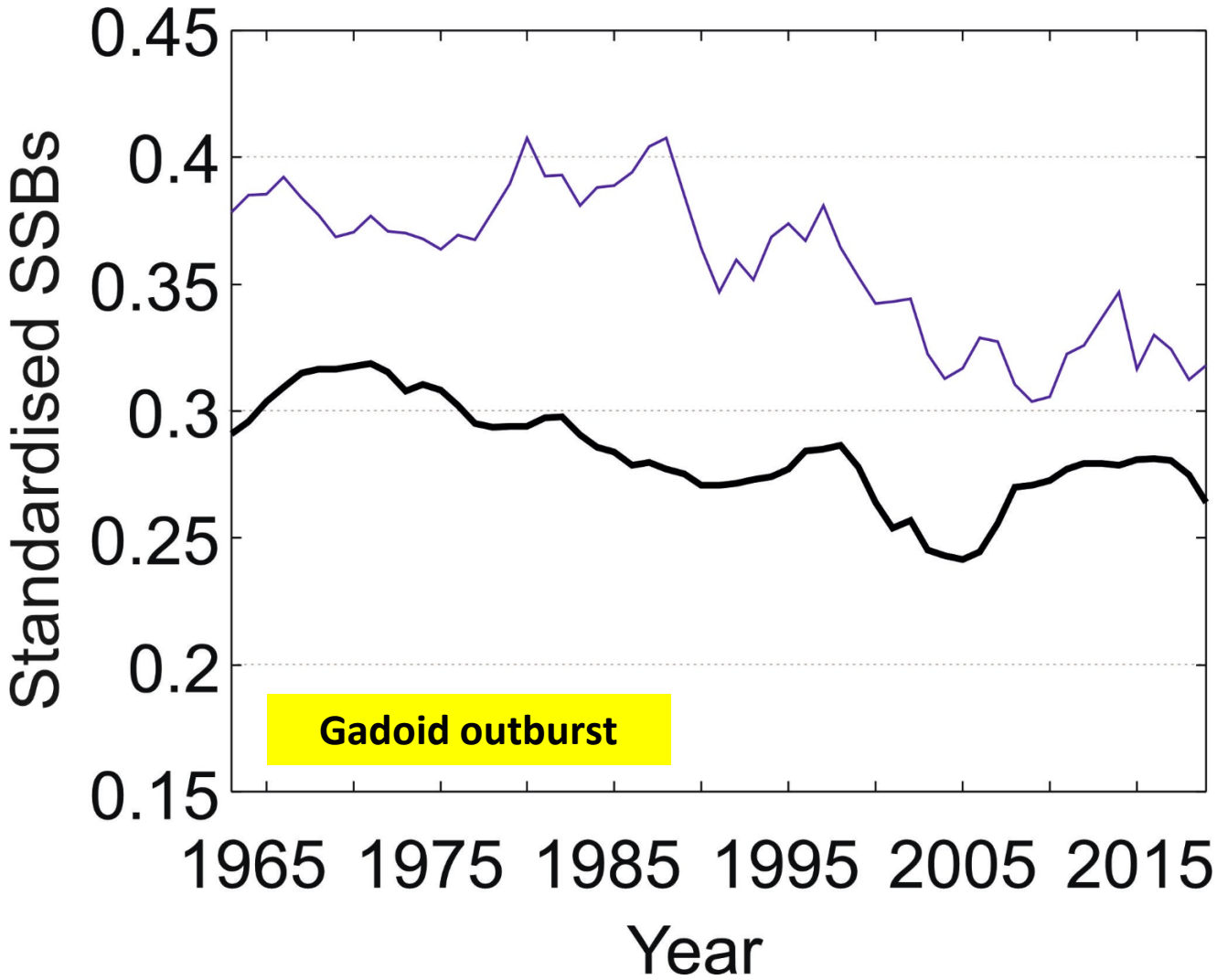
Results (5)

$$X_{t+1} = X_t + rX_t\left(1 - \frac{X_t}{K_t}\right) - \alpha X_t$$



Case 1 : minimum/constant F and fluctuating E

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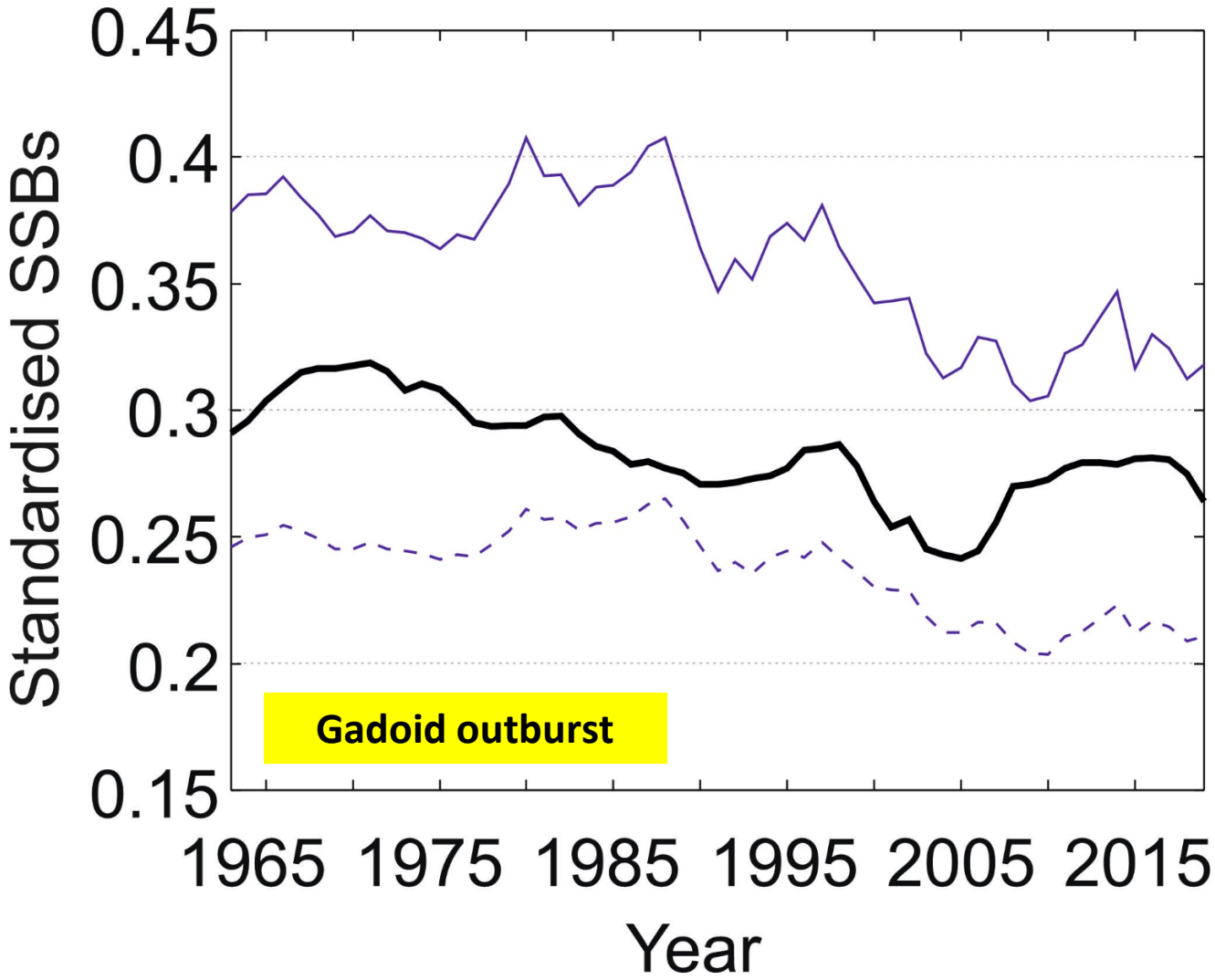
Results (5)

$$X_{t+1} = X_t + rX_t\left(1 - \frac{X_t}{K_t}\right) - \alpha X_t$$



Case 1 : minimum/constant F and fluctuating E

Case 2 : maximum/constant F and fluctuating E

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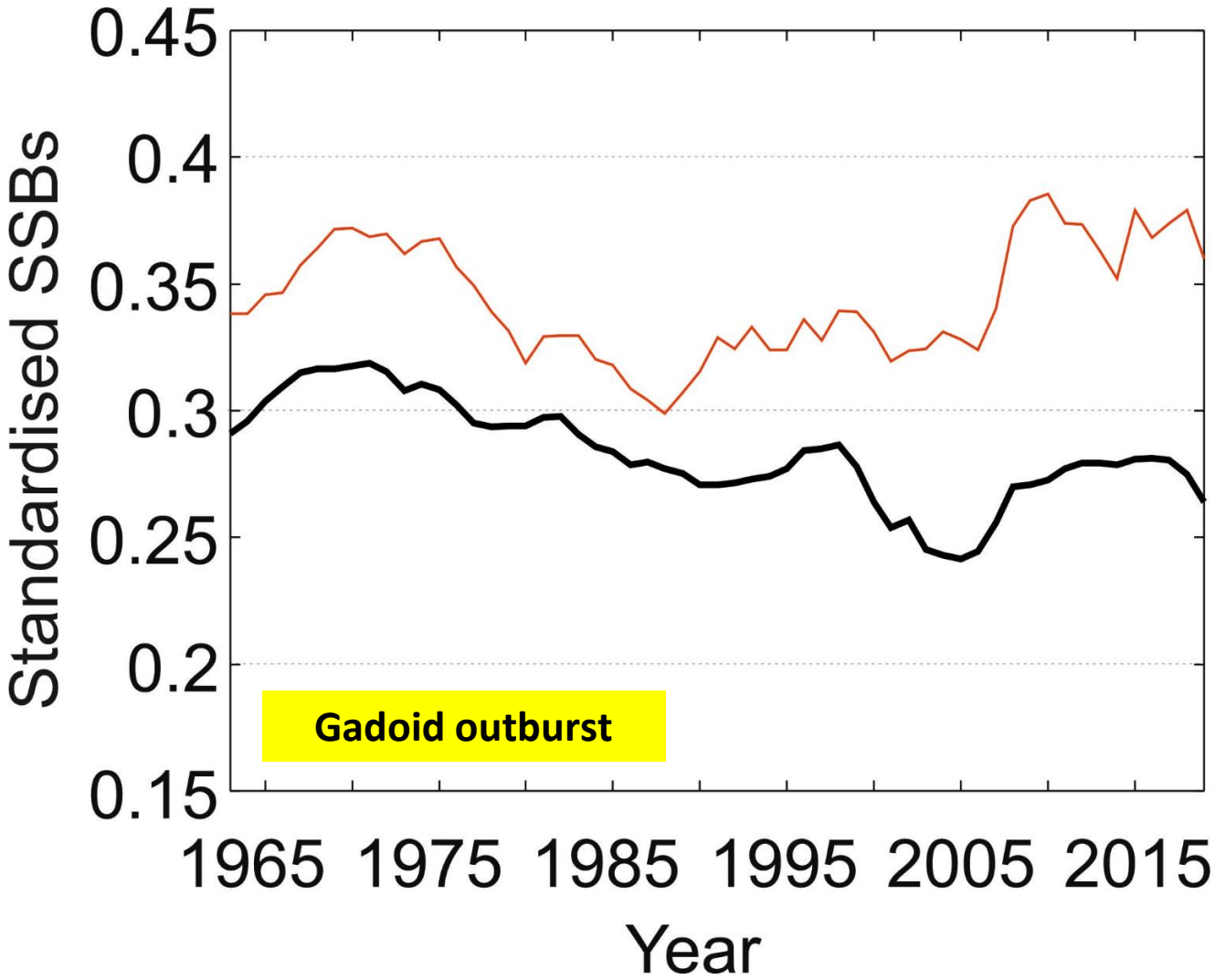
Results (5)

$$X_{t+1} = X_t + rX_t\left(1 - \frac{X_t}{K_t}\right) - \alpha X_t$$



Case 3 : fluctuating F and highly suitable/constant E

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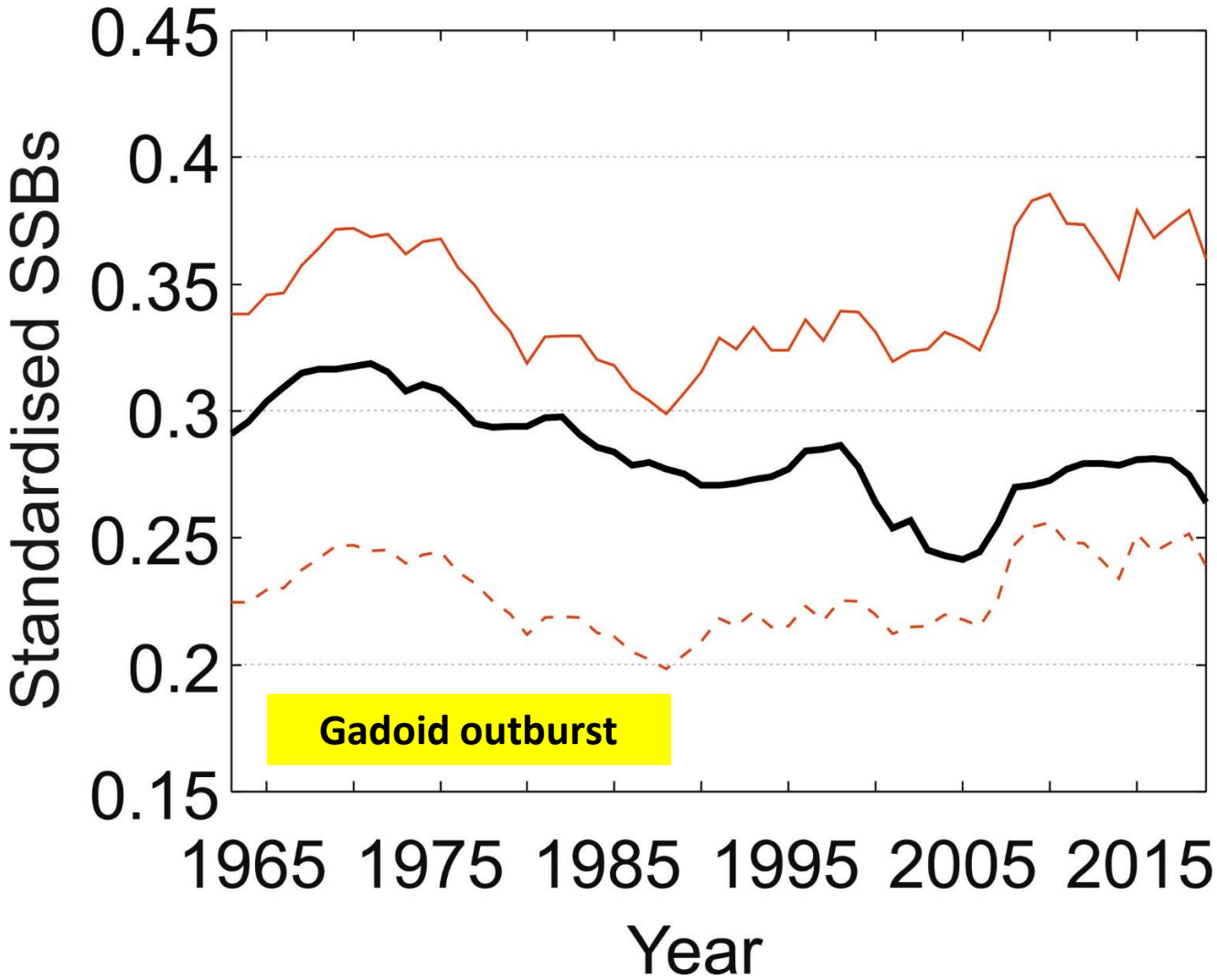
Results (5)

$$X_{t+1} = X_t + rX_t\left(1 - \frac{X_t}{K_t}\right) - \alpha X_t$$



Case 3 : fluctuating F and suitable/constant E

Case 4 : fluctuating F and less suitable/constant E

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