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Ecosystem-based fisheries management in the Baltic

Possible contributions of ecological-economic modeling to advance EBFM

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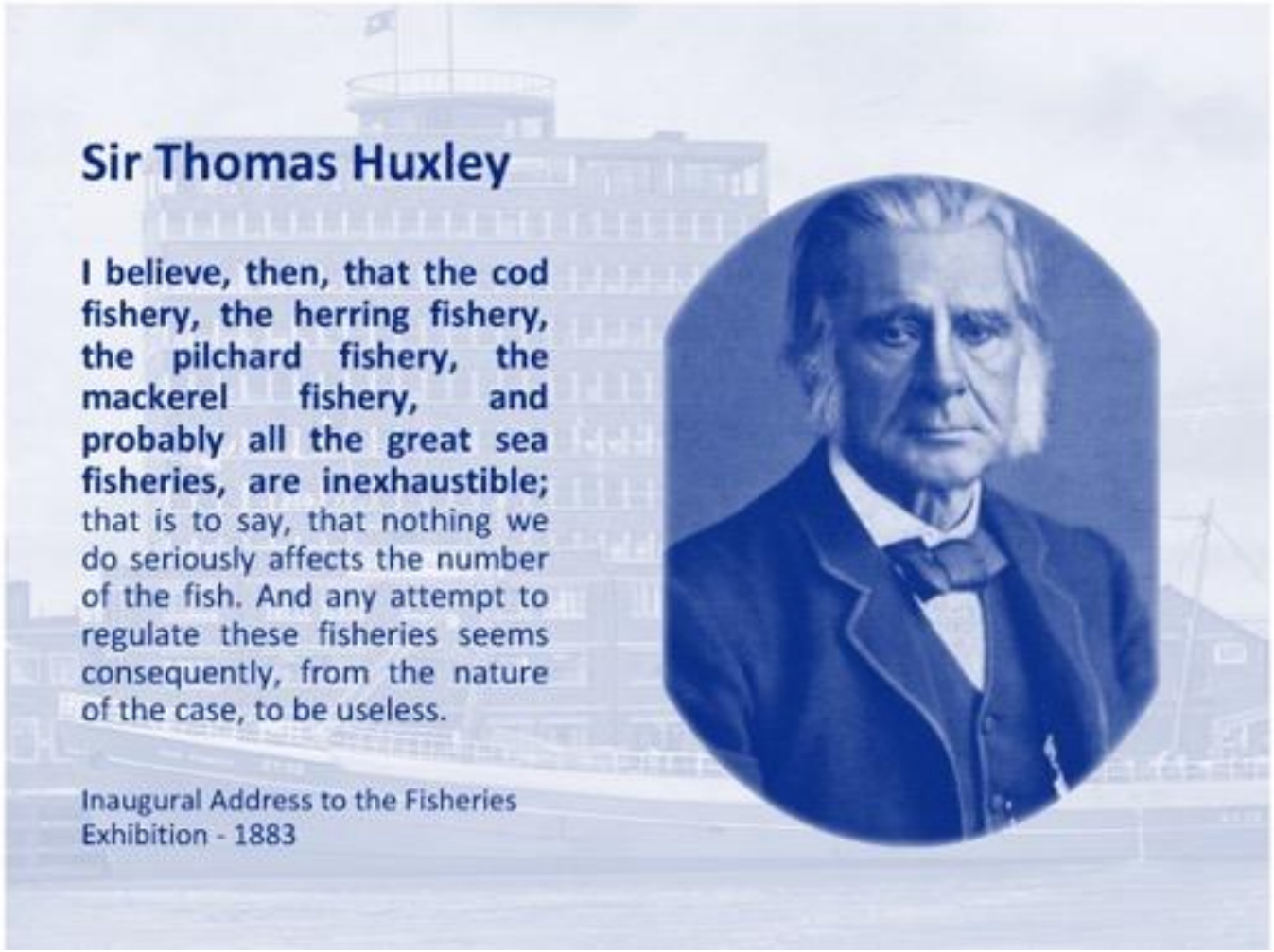
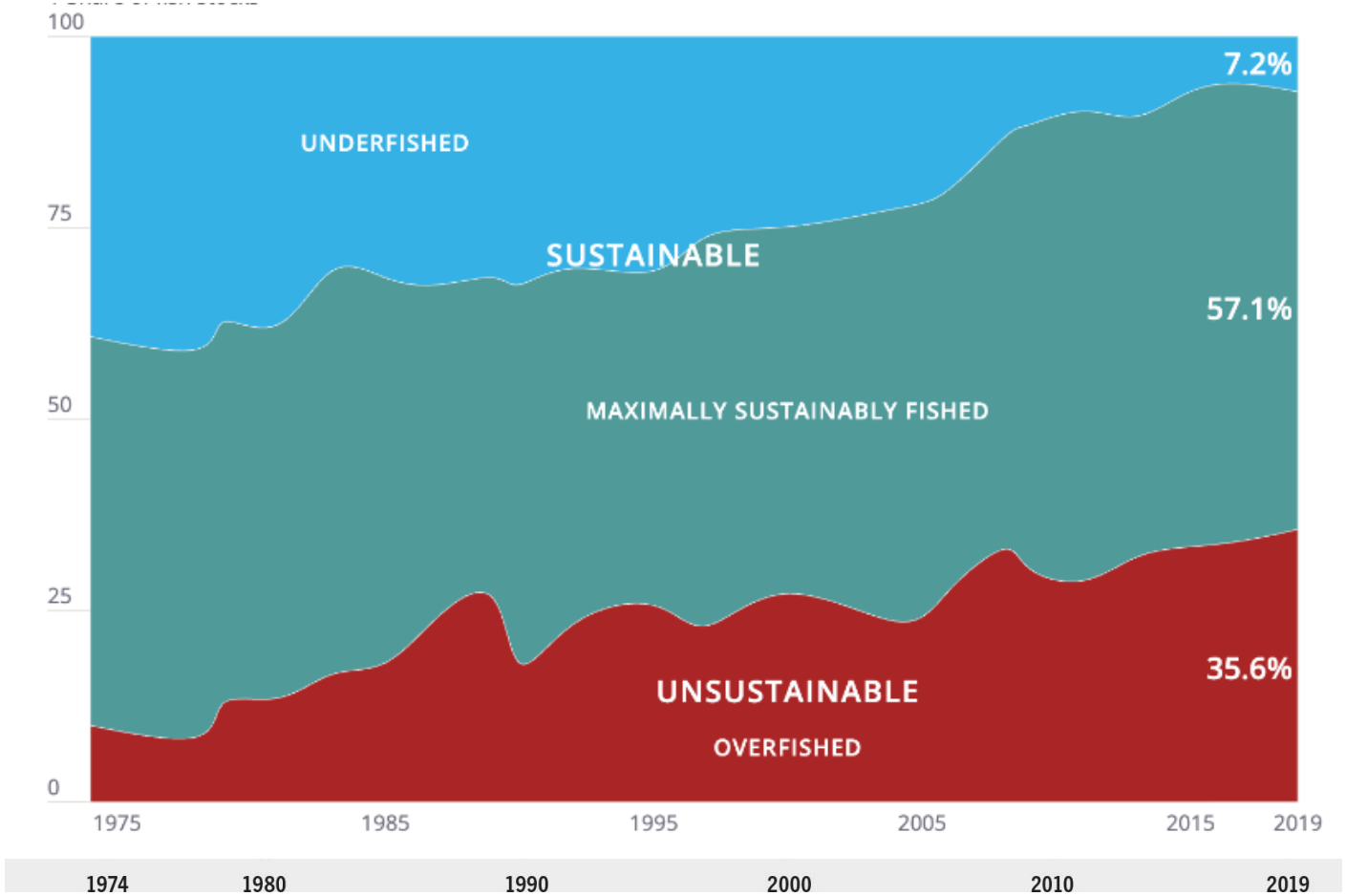
Is there a problem?



On the way to sustainability?

- Global imperative on sustainable fisheries since 2002 (**M**aximum **S**ustainable **Y**ield concept)
- Confirmed and reinforced during the Rio+20 conference in 2012
- Needs:
  - Include species interaction
  - Include ecosystem interaction
- Advice is based on biological data - not accounting for economic and social needs and drivers
  - A main reason for failing fisheries management in the past – and ongoing

On the way to sustainability?



Unbroken trend to overfishing in FAO assessment

- Strong impacts on ecosystems, biodiversity, economics and social systems

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On the way to sustainability?

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- Needs:
  - Include species interaction
  - Include ecosystem interaction
- Advice is based on biological data - not accounting for economic and social needs and drivers
  - A main reason for failing fisheries management in the past – and ongoing
- **Successful, commonly accepted fisheries management needs to include economics!**

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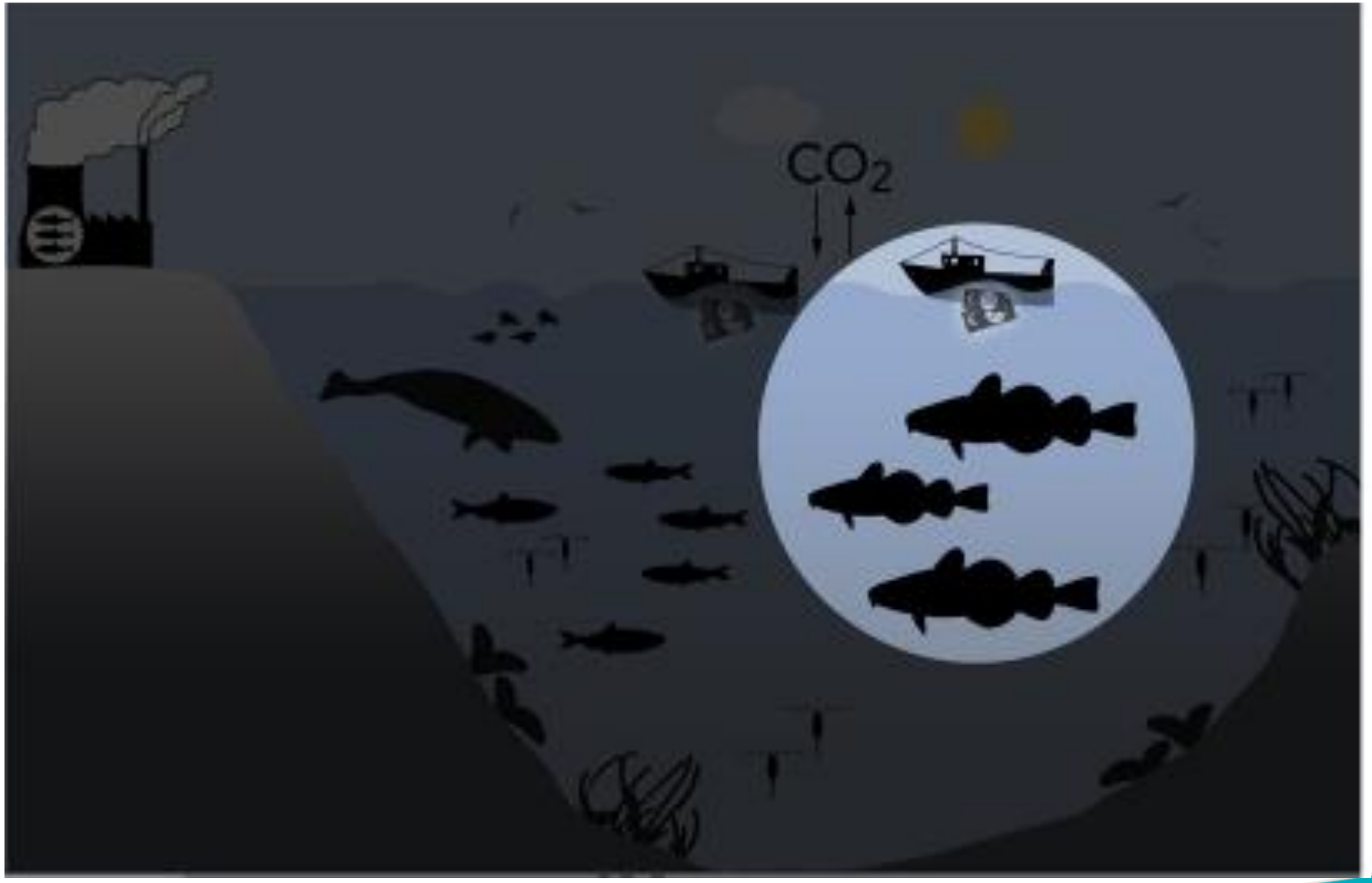
Current state of the art



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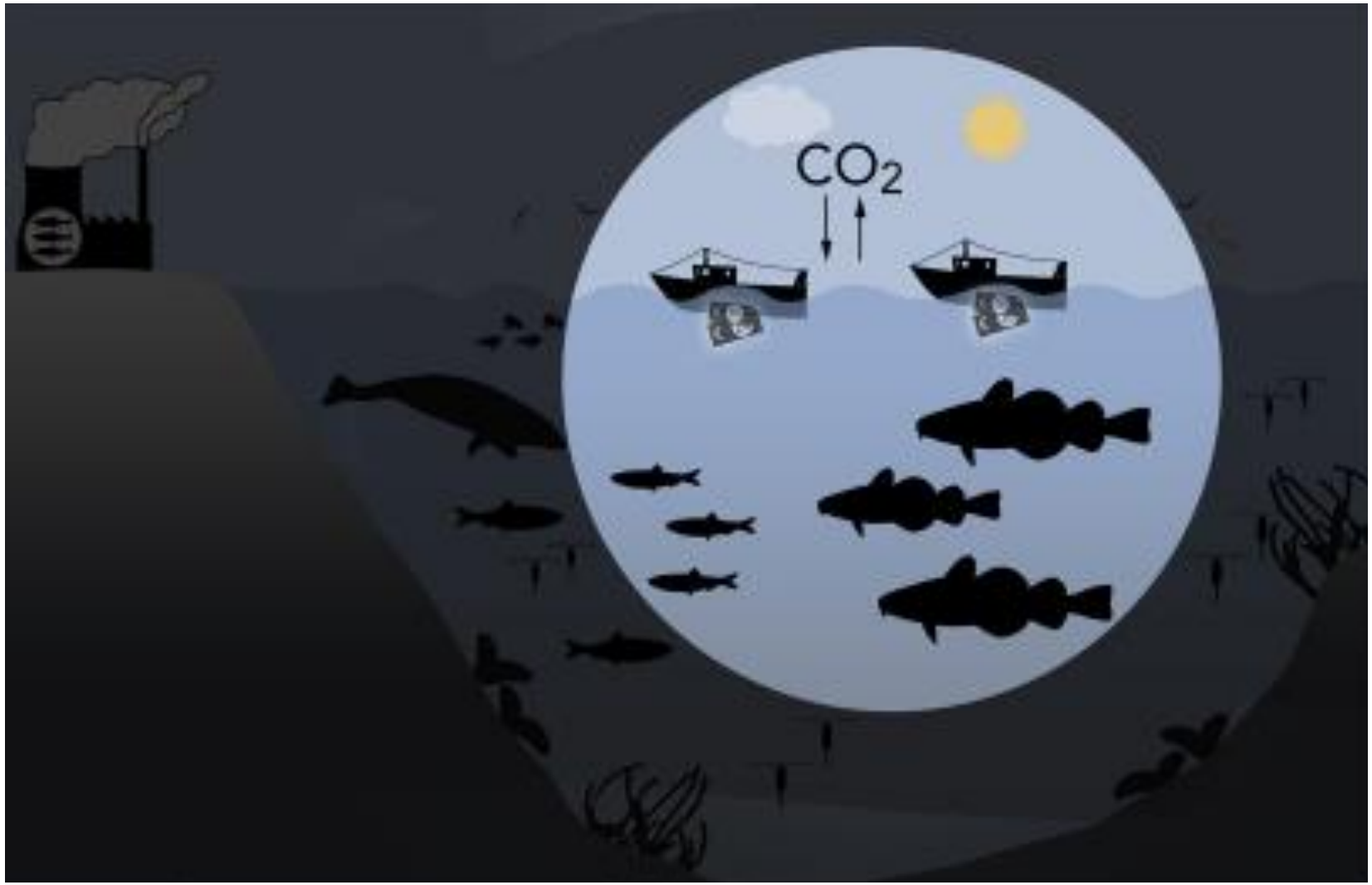
Recent efforts: include env. change & species intercation



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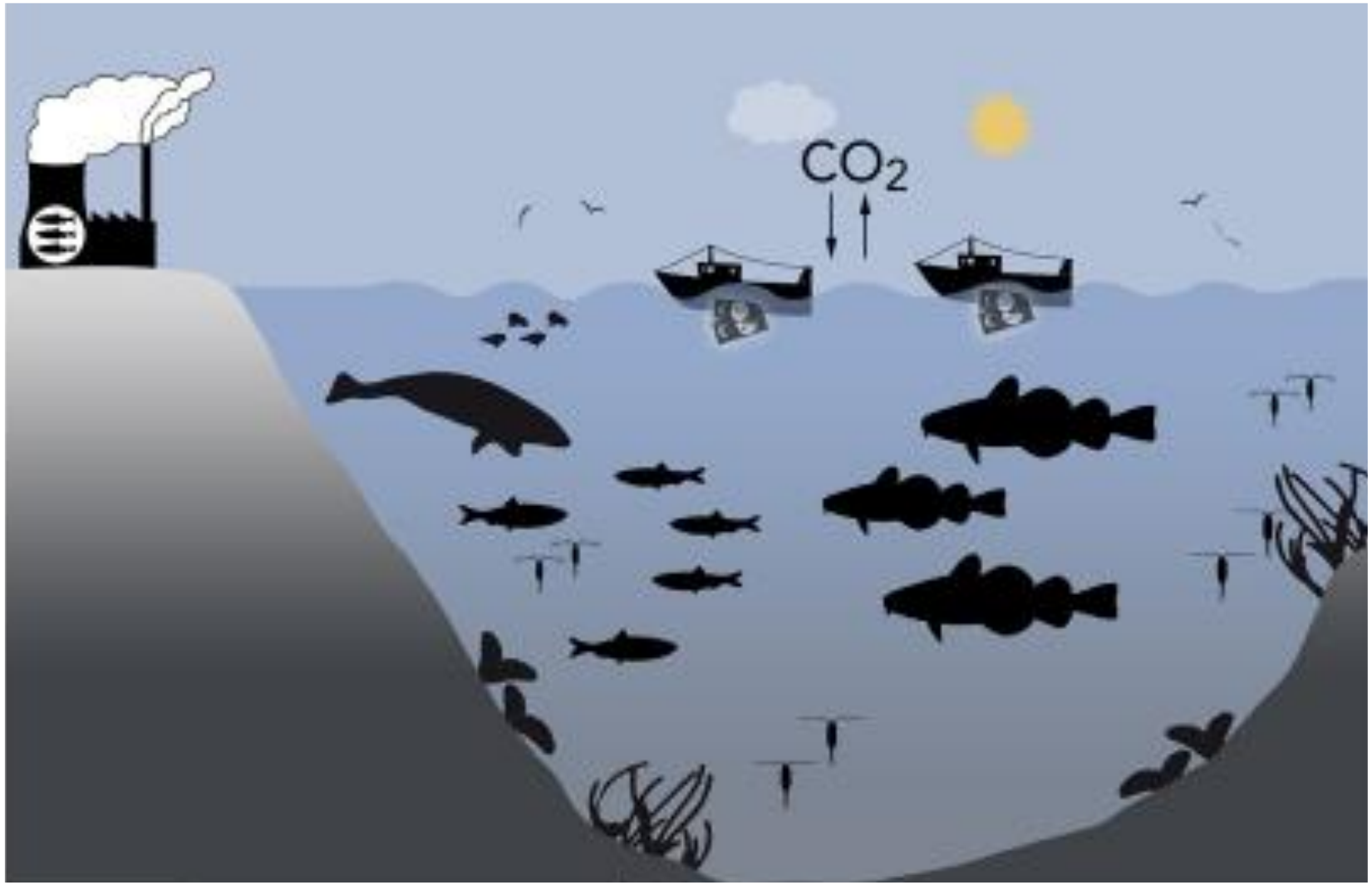
Needed: incl. socio-economics & ecosystem



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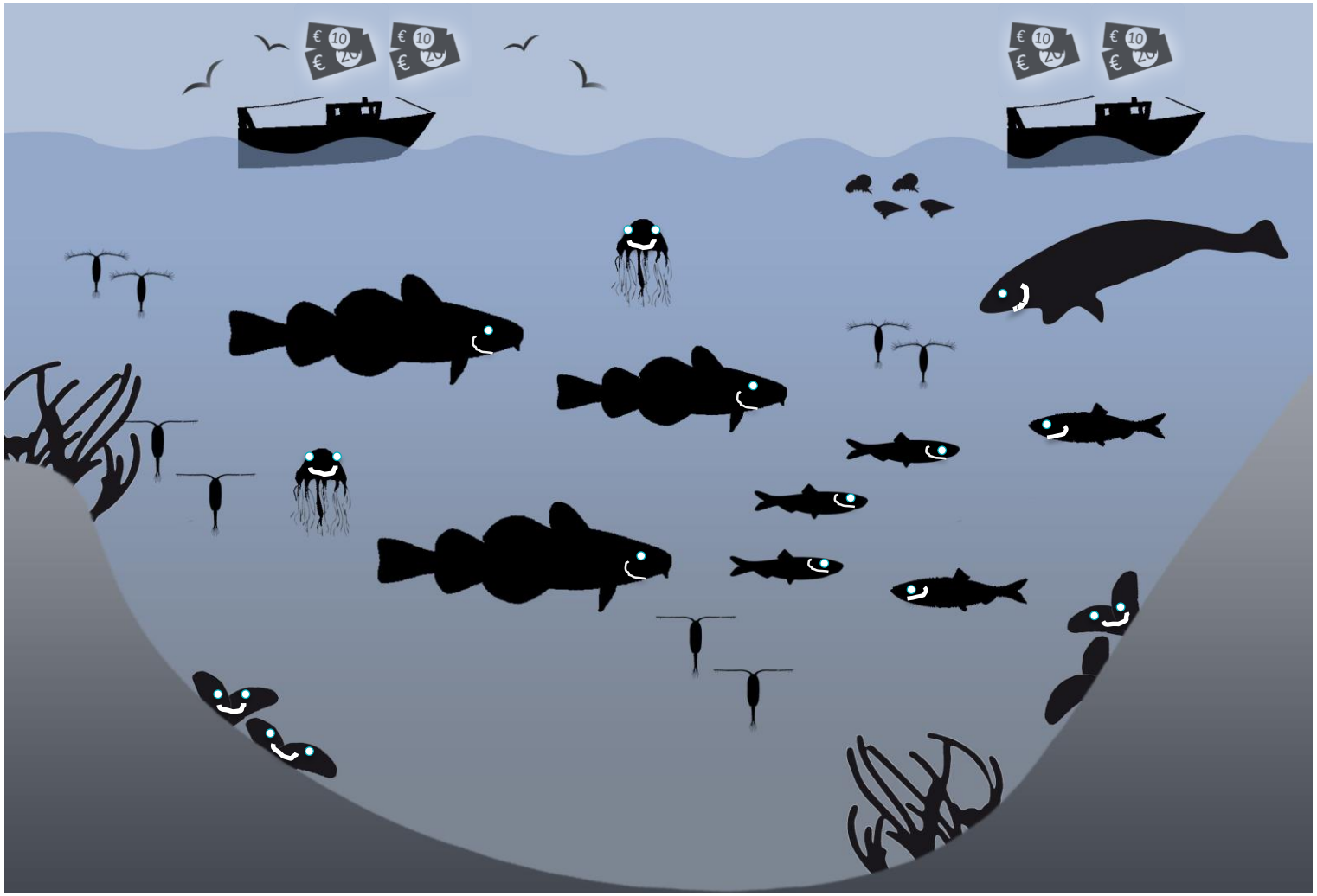
Needed: incl. socio-economics & ecosystem



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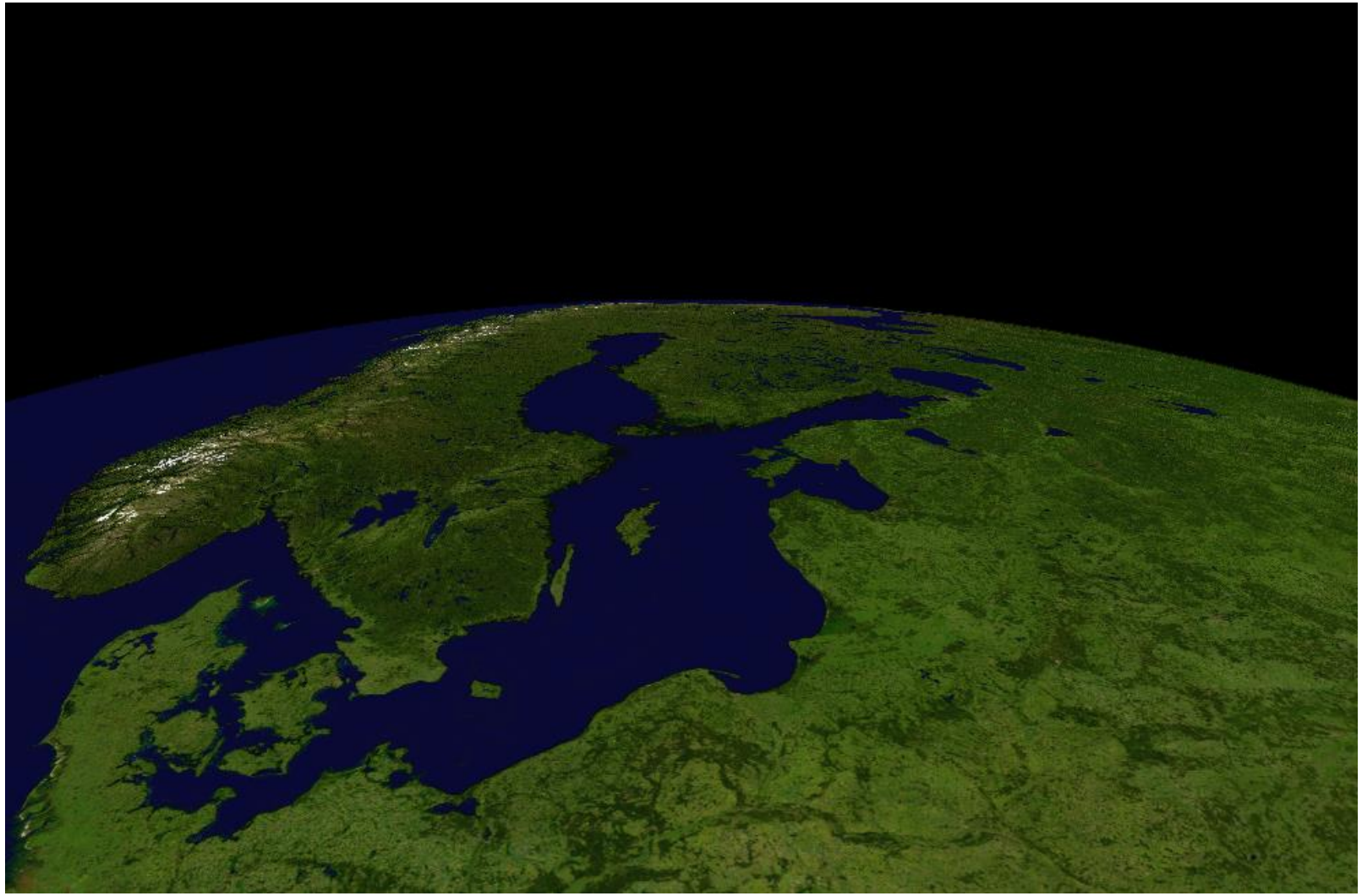
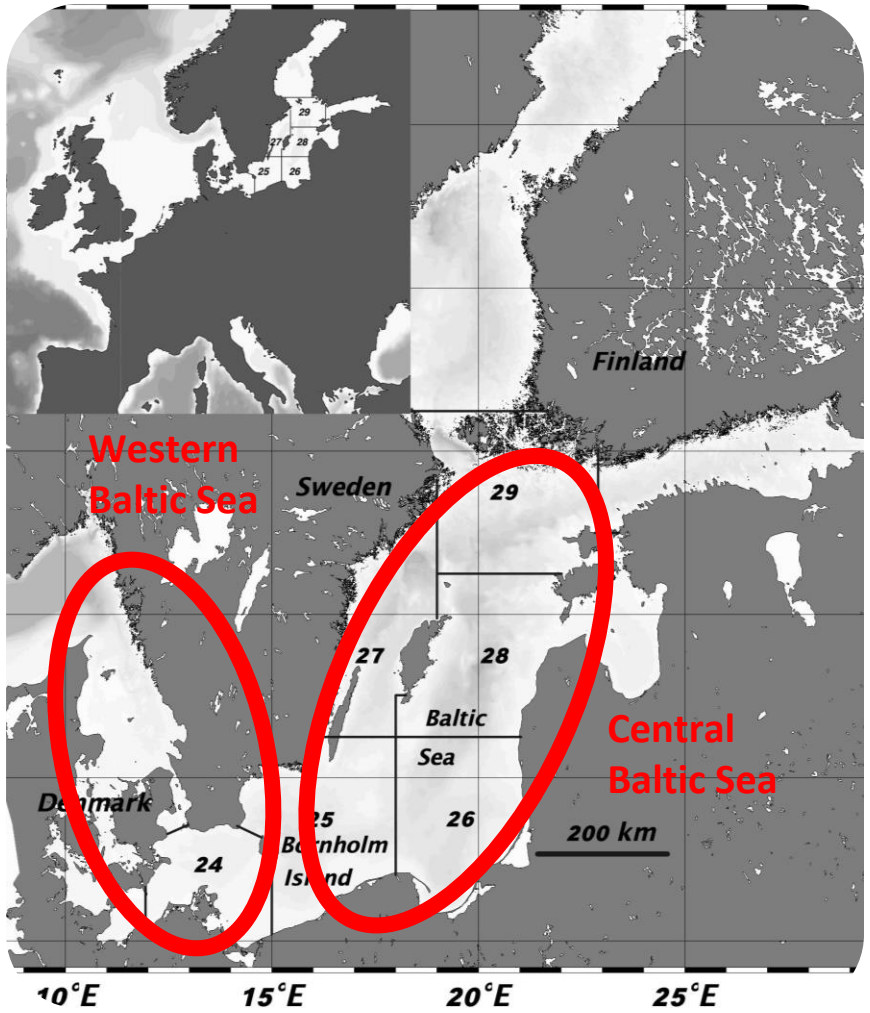
Baltic Sea Case Study

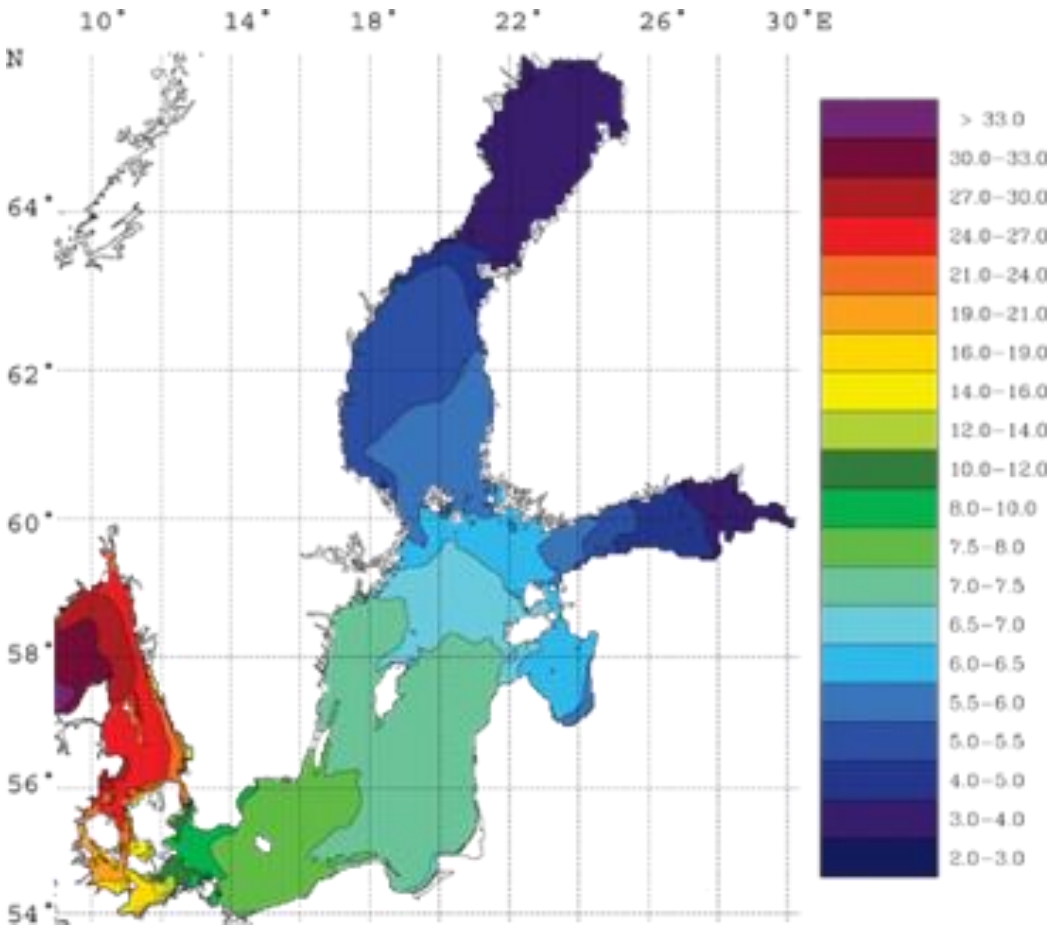


Baltic Sea – the largest brackish water body of the world



Max. depth:
Arkona Basin: 48 m
Bornholm Basin: 92 m

Salinity at the surface



Gdansk Deep: 112 m
Eastern Gotland Basin: 248 m
Western Gotland Basin: 460 m

Species of interest: a riddle

Sprat

Species of interest

Owner

Her ring

Species of interest

Biscaja

Or

Ostsee

Was soll ich kochen?
Que cuisiner?

Cabillaud **O**r **D**orsch

Cod

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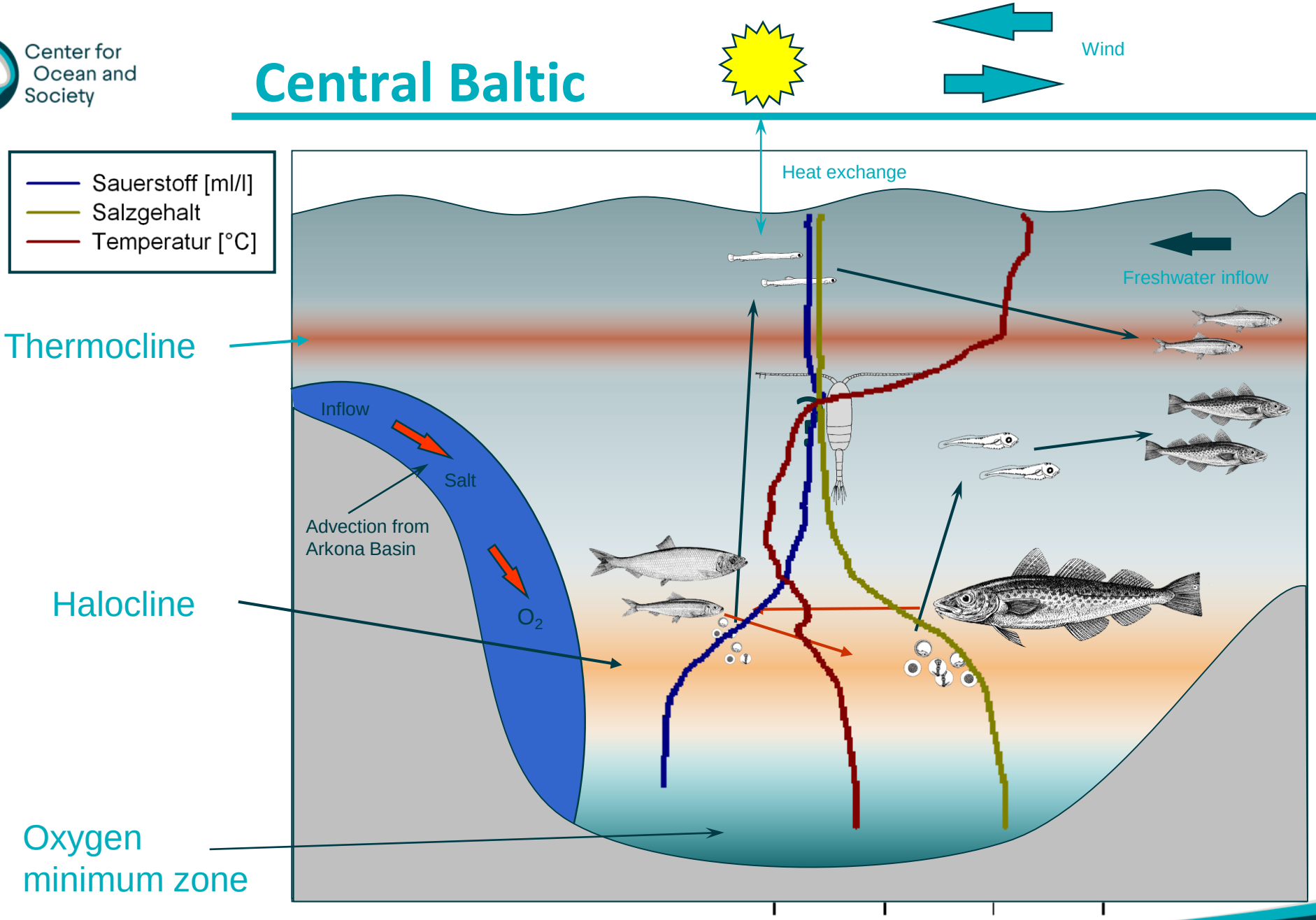
Central Baltic



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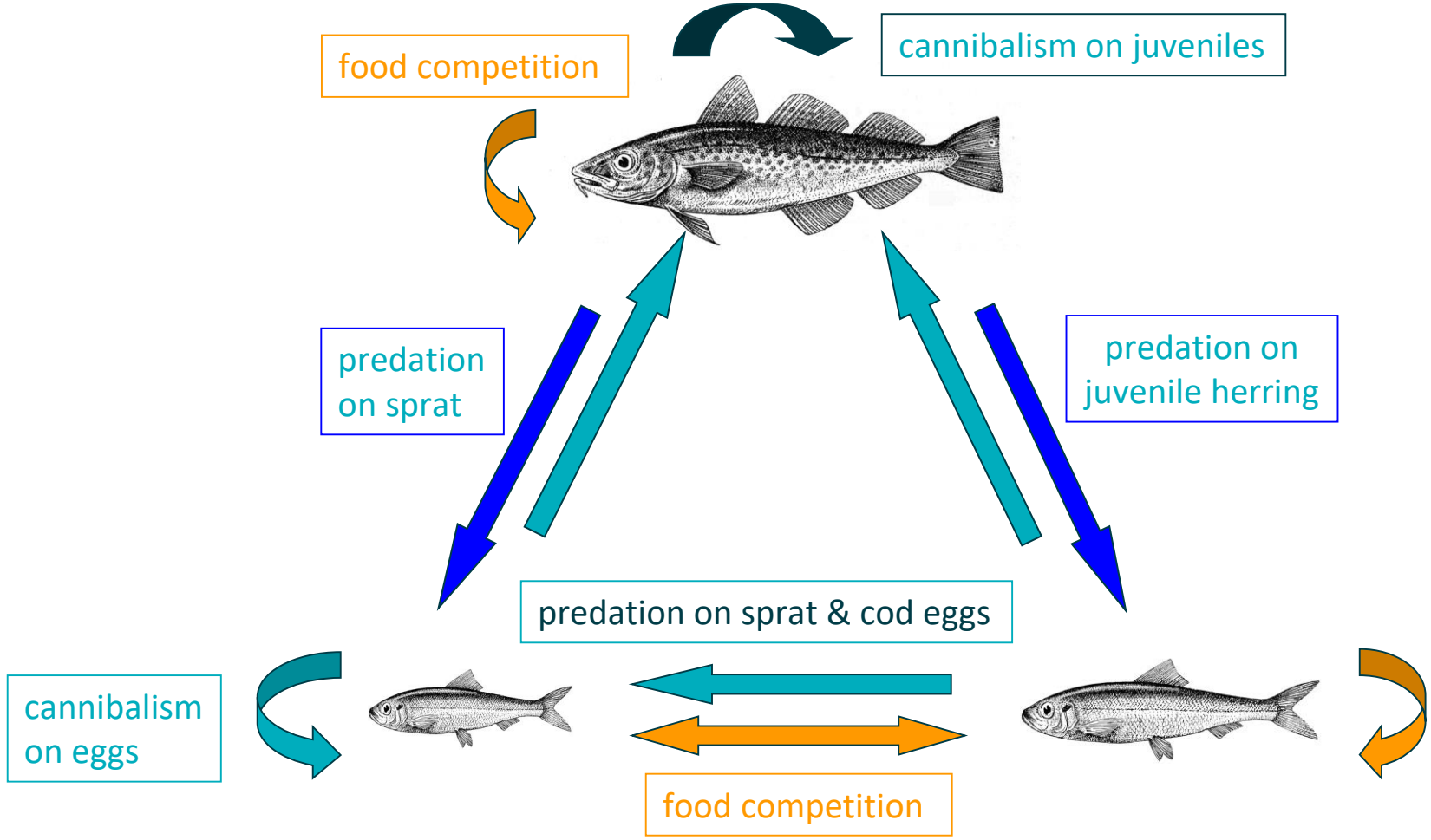
Central Baltic multi-species fishery: three dominant species



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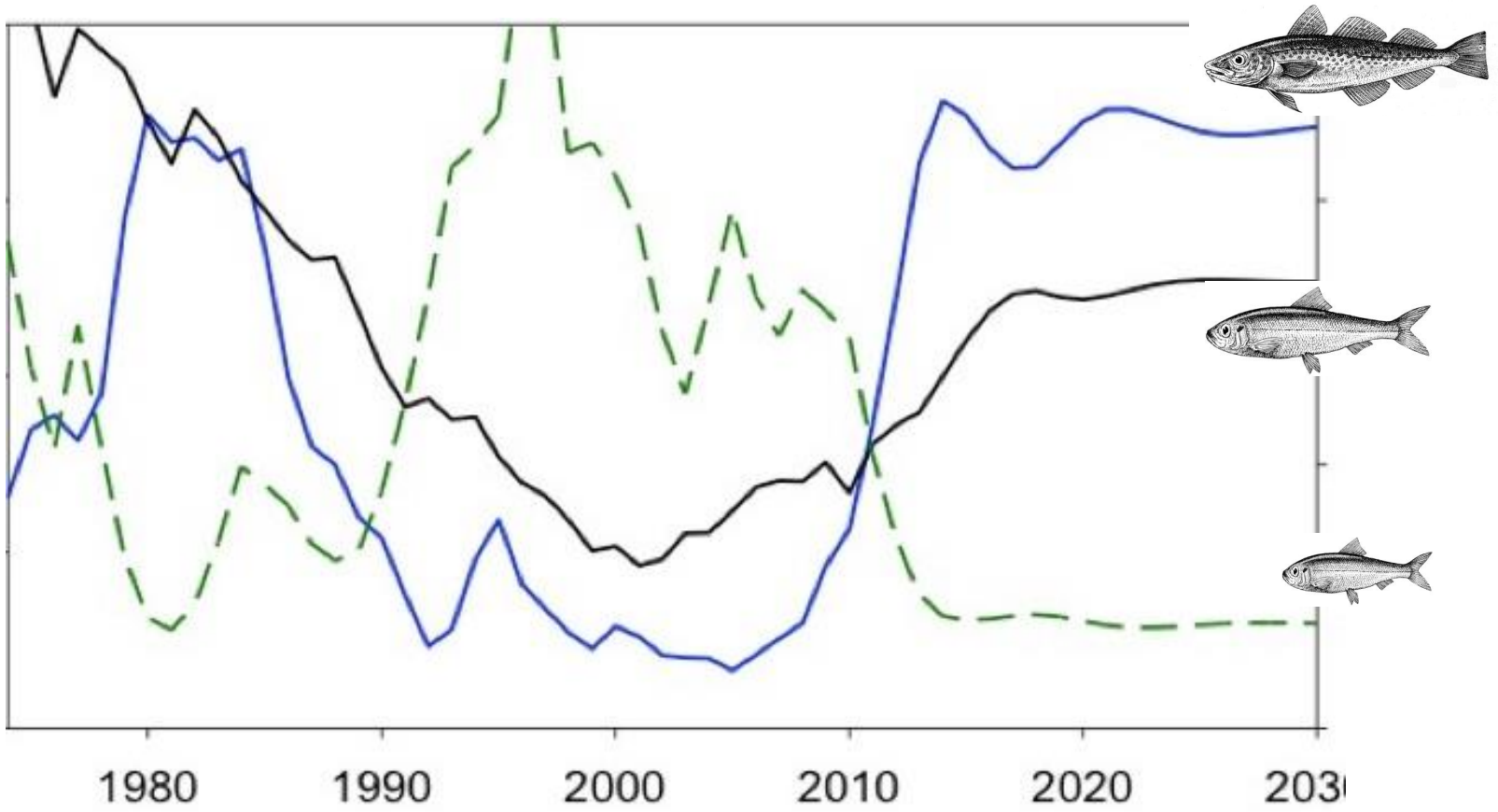
Ecological-economic model

- Combined model for sprat, herring, and cod
- Predation mortality as central interaction (SMS output)
- Age-structured (8 age-classes) to meet standard assessment
- Cost functions dependent on stock size and effort
- Dynamic optimization of F in every fishing period
- Standard objective: Maximize present value of profits
- Desire for catch stability (max. changes 15% per year) built in
- Variation of interest rate & prices possible

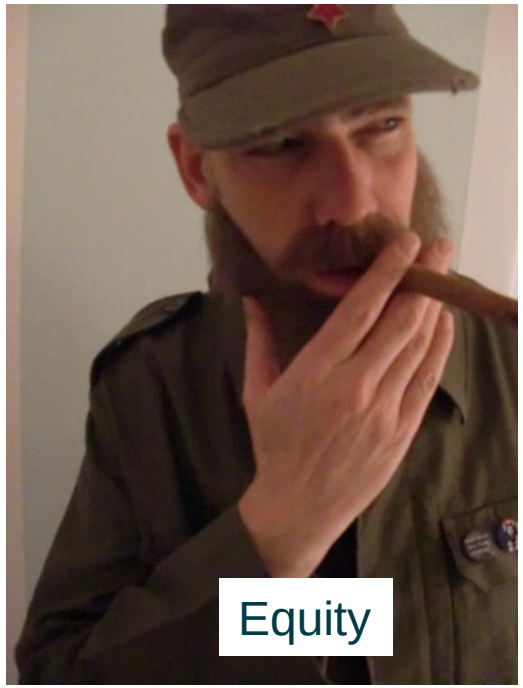
Optimal multi-species management: profit maximization



- Incorporation of side conditions needed
- Other objectives, e.g. conservation goals, equity considerations

Optimal multi-species management: profit maximization

Multispecies MSY: Trade-offs in management



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Wake up! YEAH! Formula!

Multispecies MSY: Trade-offs in management

Objective:

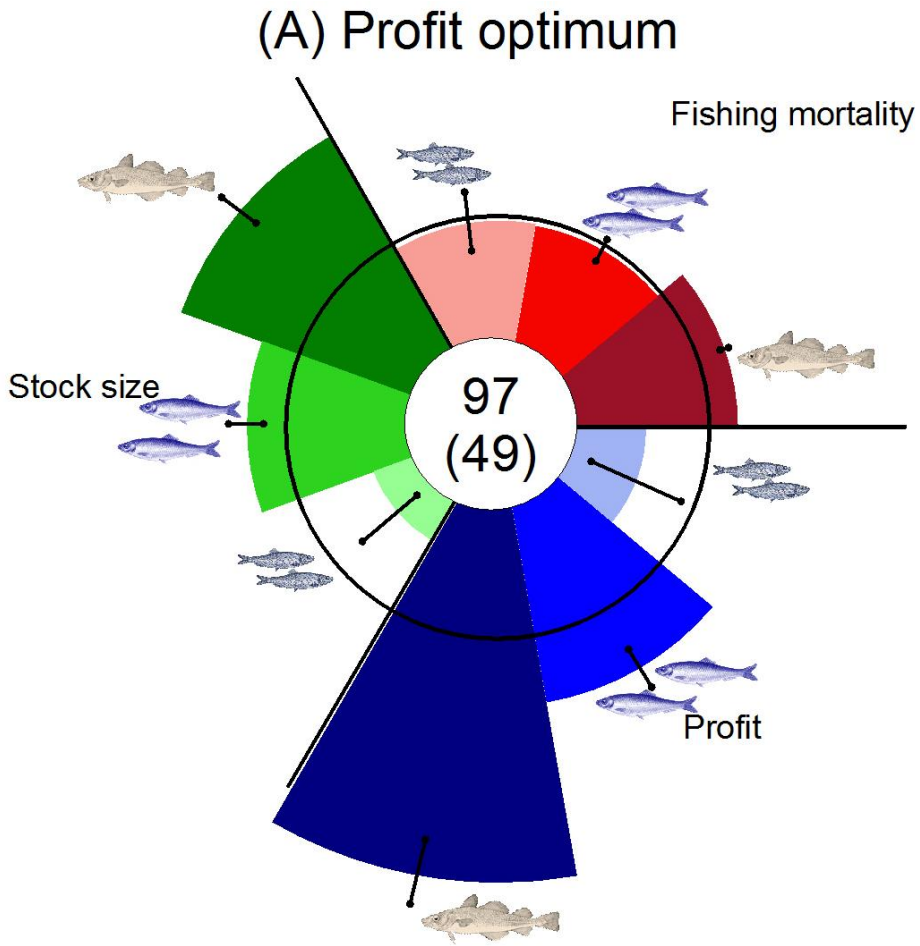
$$V = \sum_{t=0}^{\infty} \rho^t \frac{1}{1-\eta} \left(\Pi^{1-\eta} + (\lambda x_{S0})^{1-\eta} \right)$$

Intertemporal utility of fishing income:

$$\Pi = \left(\frac{1}{3} \pi_C^{1-\theta} + \frac{1}{3} \pi_S^{1-\theta} + \frac{1}{3} \pi_H^{1-\theta} \right)^{\frac{1}{1-\theta}}$$

ρ	Discount factor
η	Representative fisherman's aversion against intertemporal income fluctuations
$\theta \geq 0$	Social aversion against inequality of incomes for the three different fisheries
x_{S0}	Spawning stock
$\lambda \geq 0$	willingness to pay for sprat ecosystem services

Optimal multi-species management: Profit maximization



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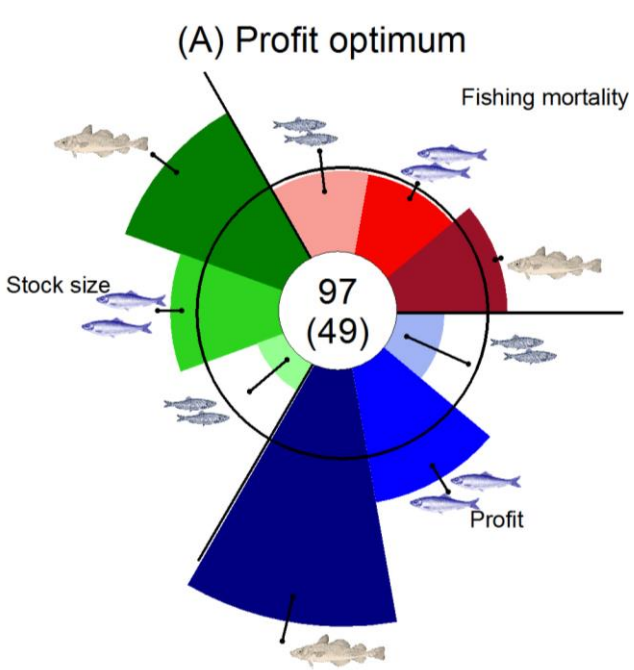
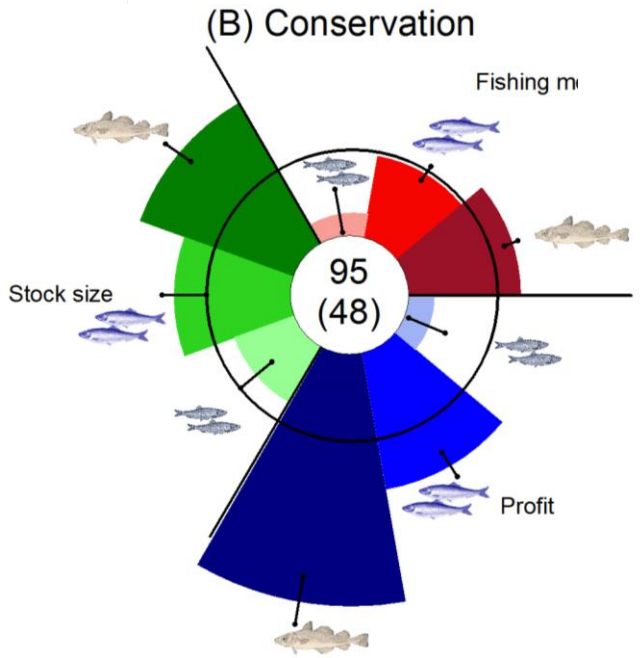
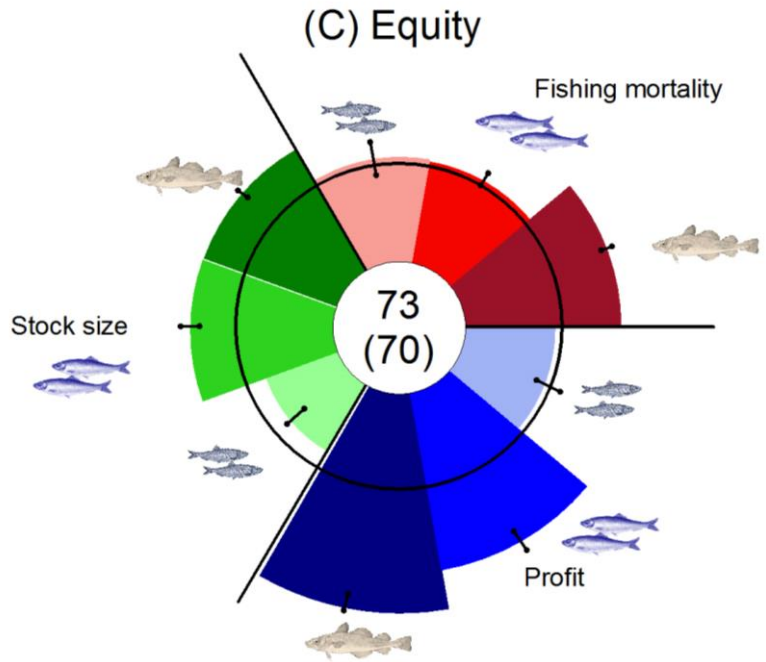
Optimal multi-species management:







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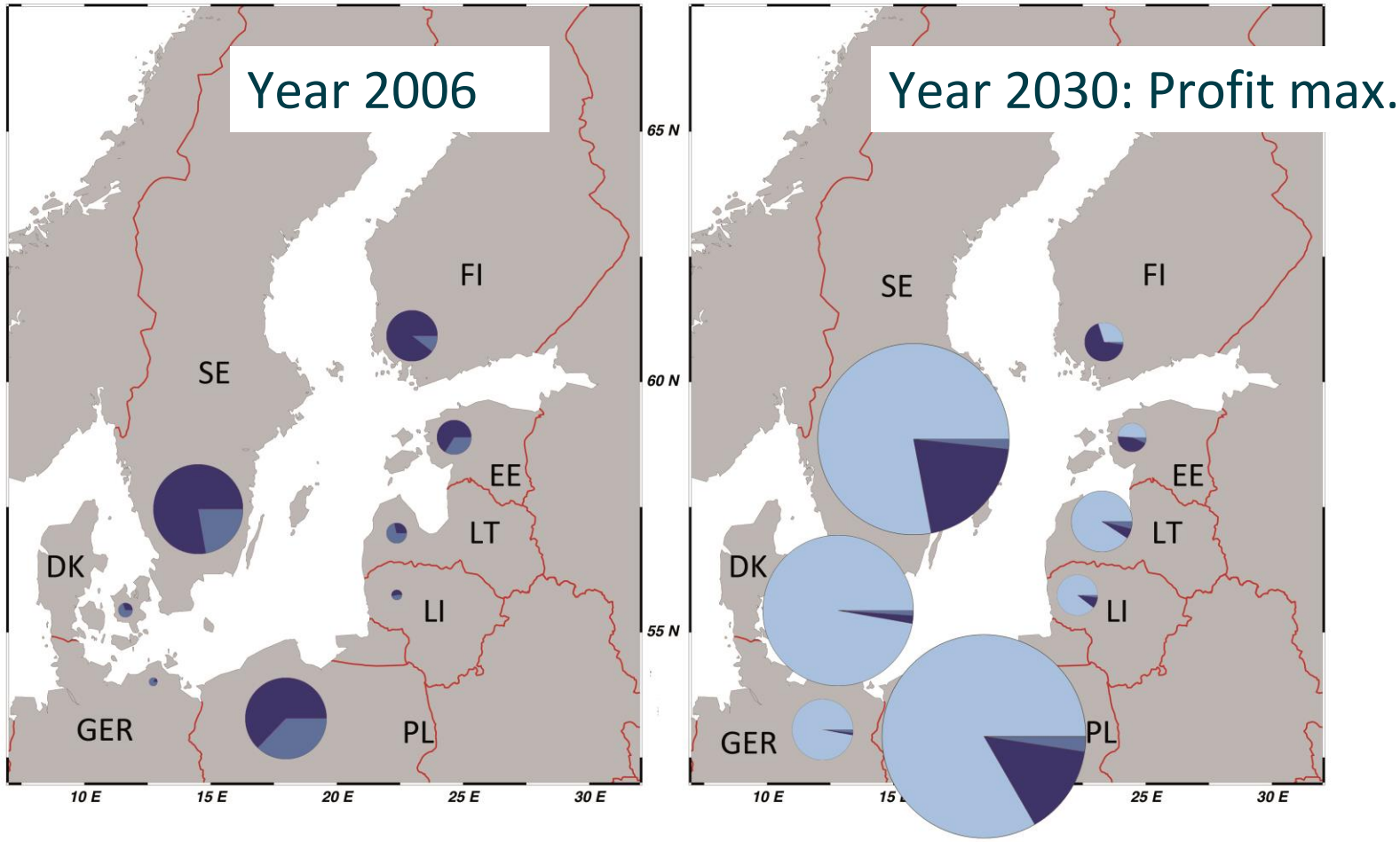
Regional distribution of profits:



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Limitations

- Spatial resolution
  - Current changes in predator-prey overlap?
- Rate of cannibalism in cod
- Food limitation of cod (benthic component)
- Competition between clupeids
- Feed-back from clupeids->cod
- Demand side interactions
- Technological progress

- **Environmental change**

Baltic Sea is highly stratified

Sprat larvae

Cod larvae

Sprat eggs

Cod eggs

Temp. conditions

Oxygen conditions

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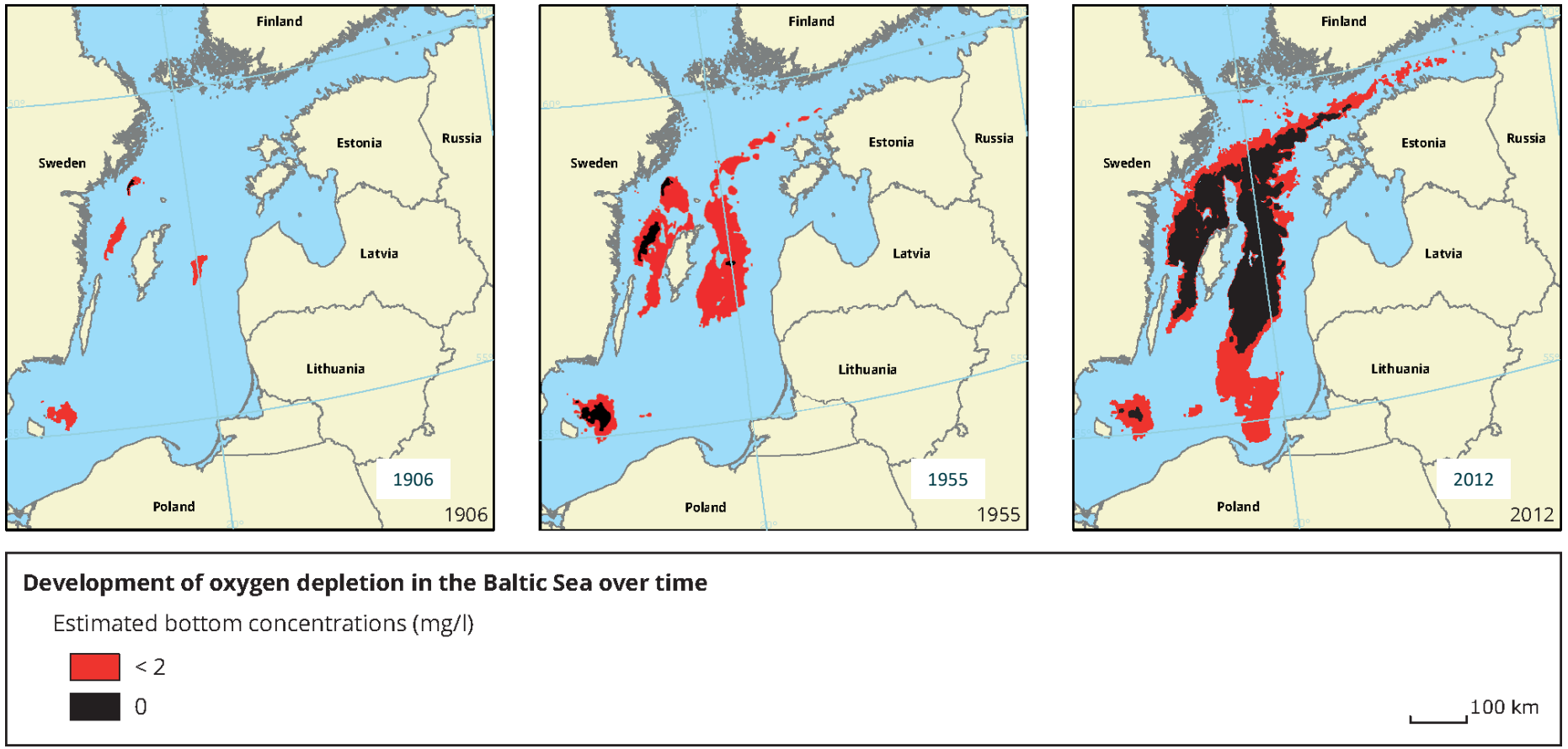
Dead zones in the Baltic



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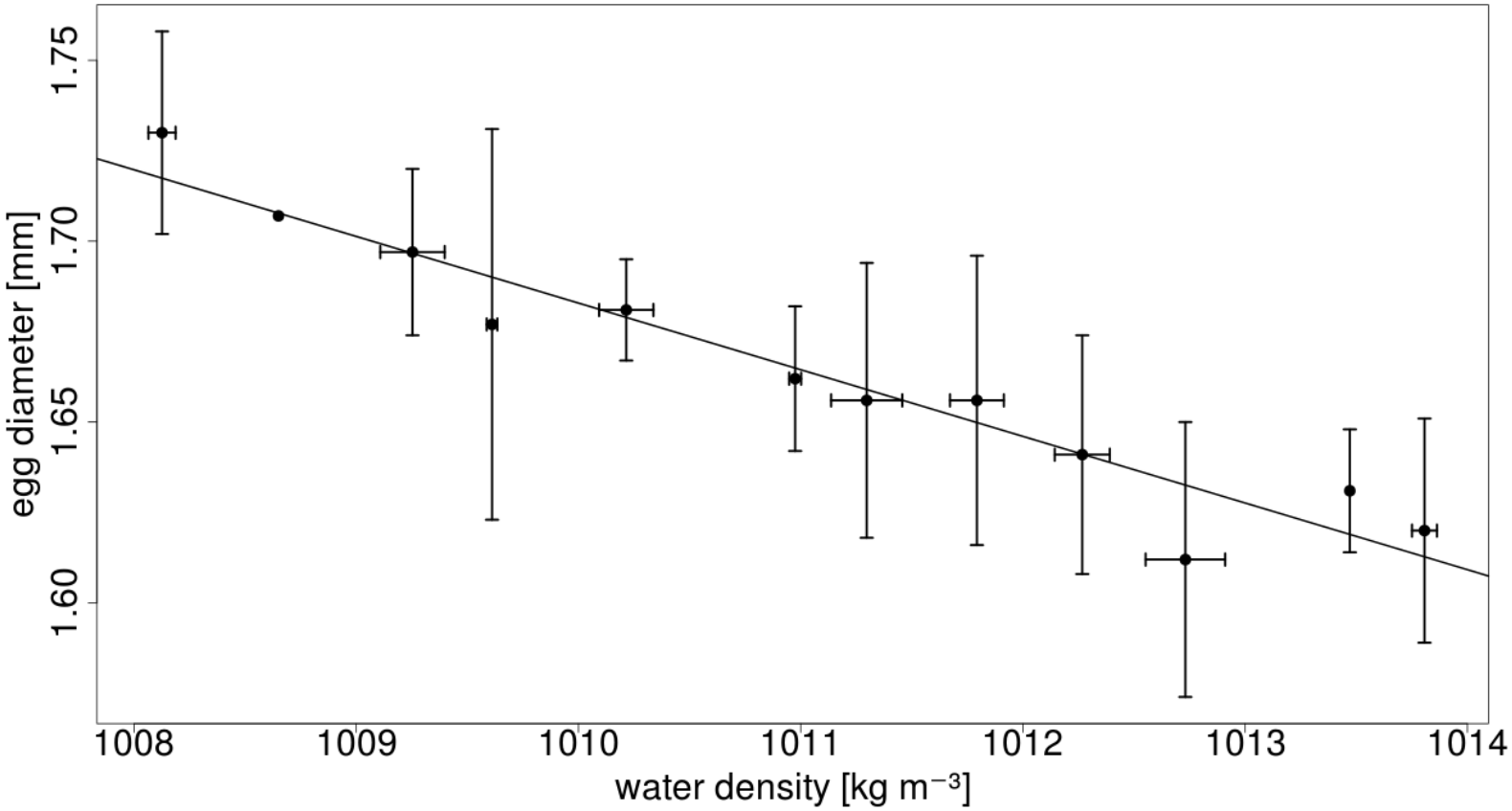
Older cod have larger eggs



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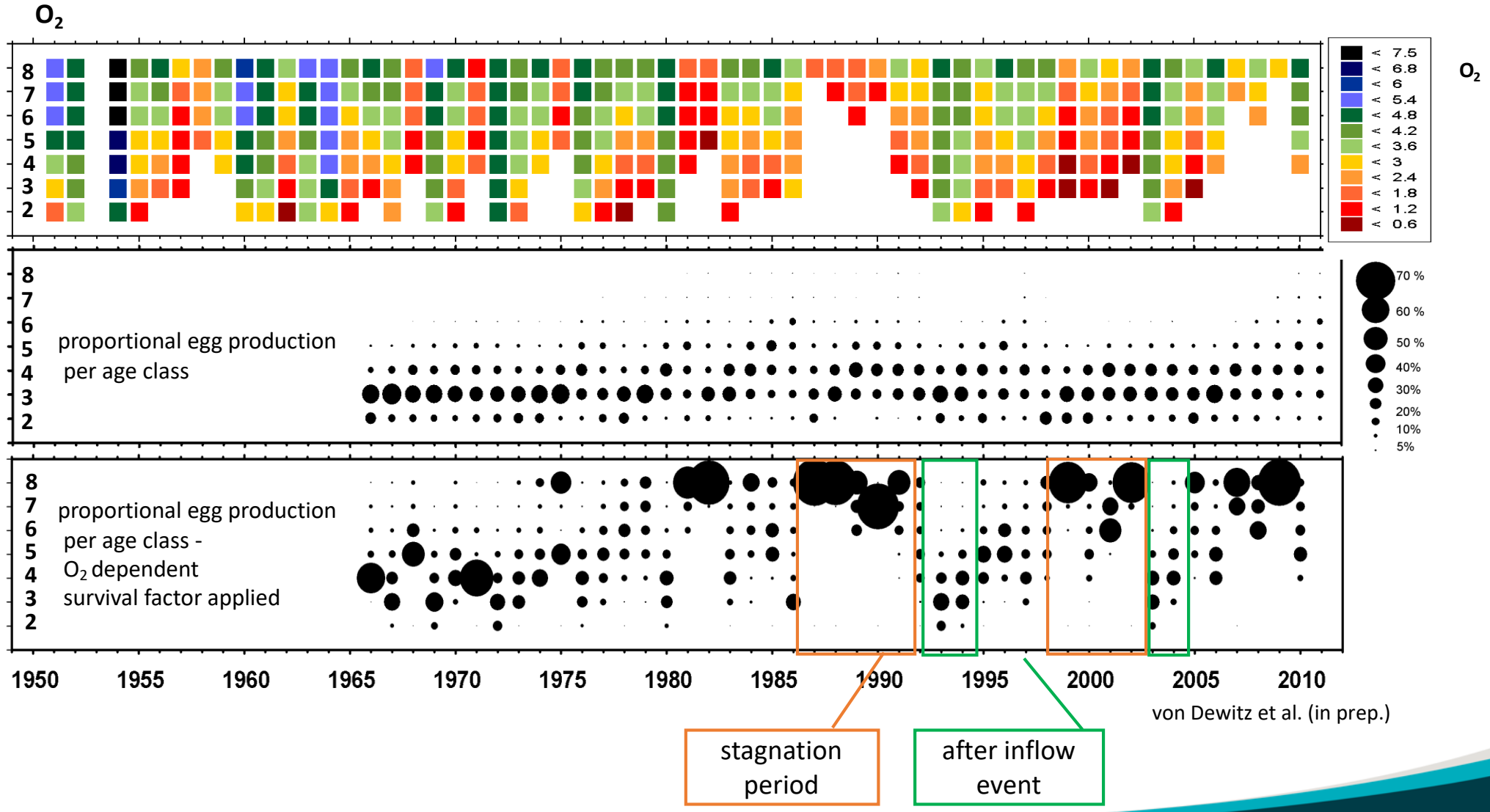
Egg survival: environmental selection



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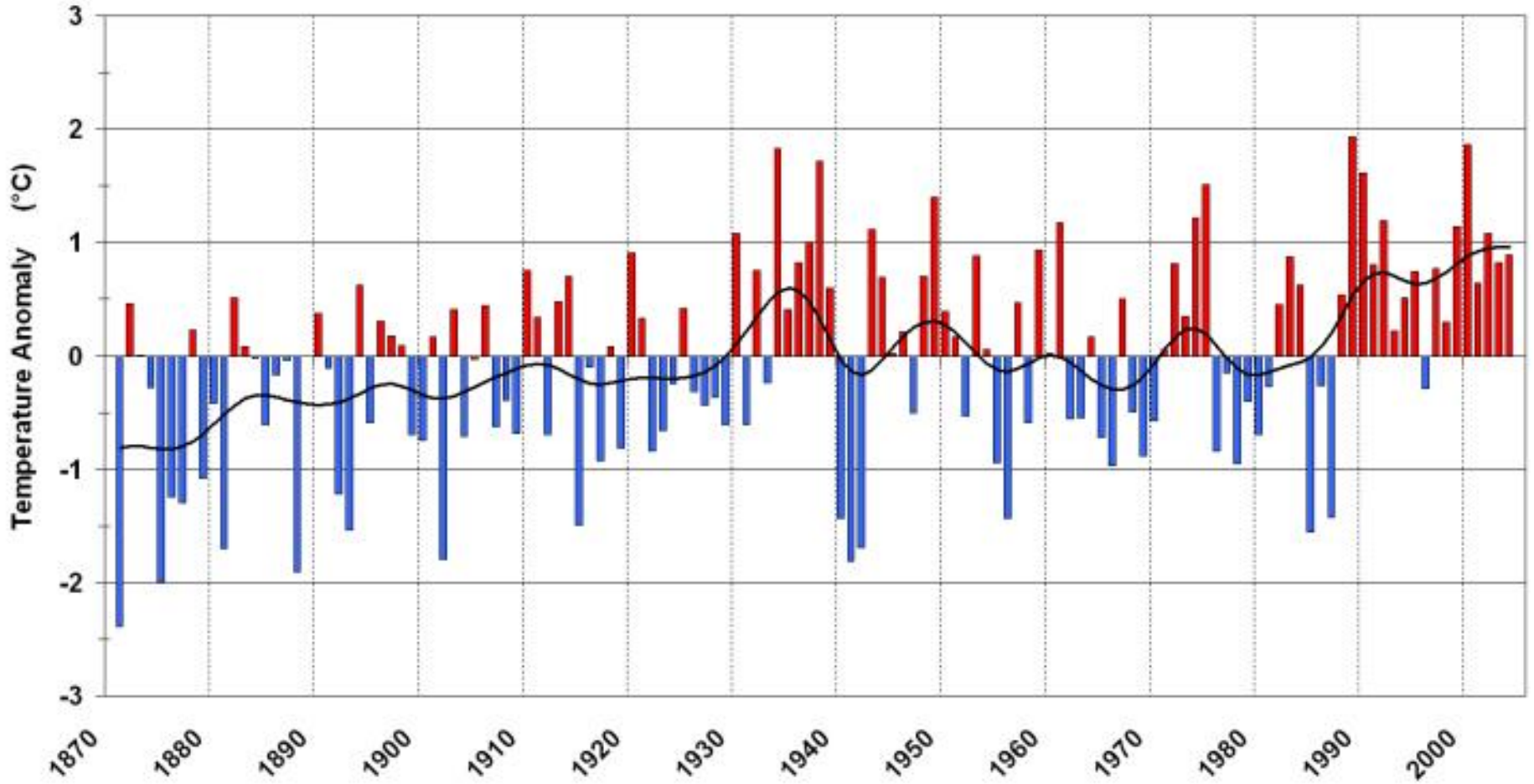
Temperature development in the Central Baltic



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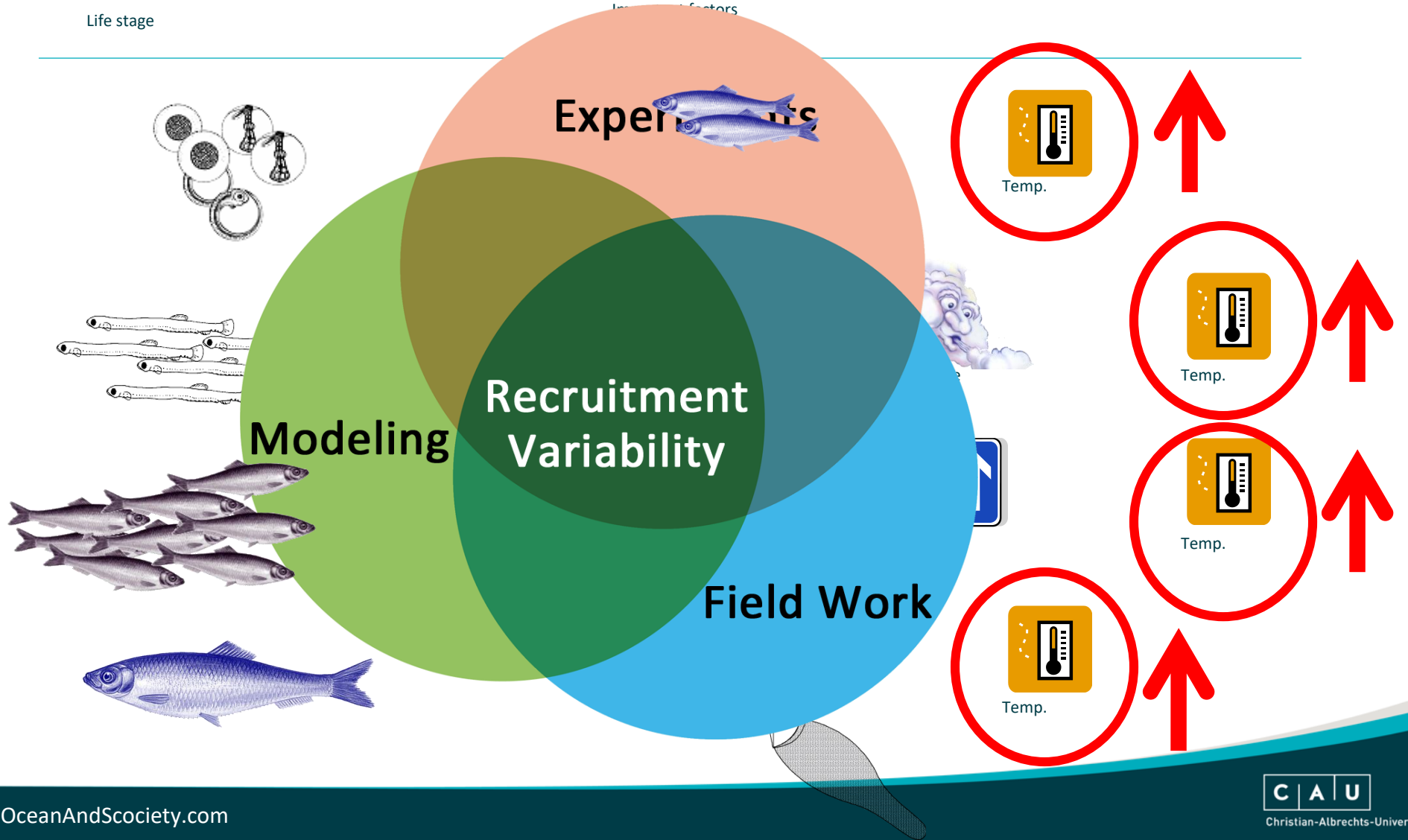
Sprat recruitment variability



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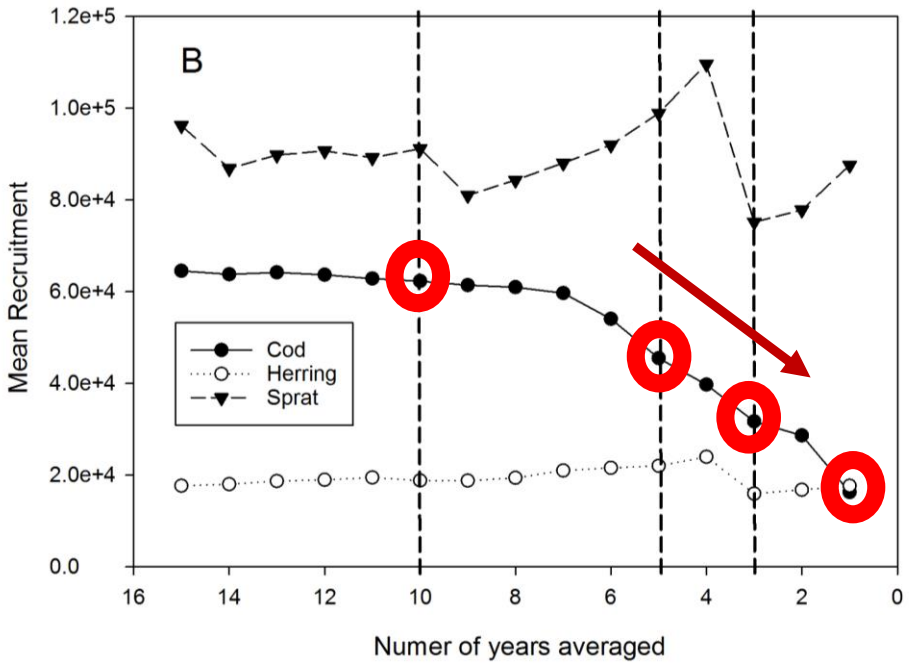
Including environmental change

Including environmental change: trends



- Recruitment (R) of herring is stable / decreasing
- R of sprat is highly variable
- R of cod is decreasing
- ICES uses 5y averages for short-term forcast & advice
- New stock productivity and predation rates for cod available

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Model?

Model?

What we do NOT use:

End

End

End-to-end model

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Model?

What we use:

Model of intermediate complexity
Prof. Martin Quaas

What we do NOT use:

Simplyfied model

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Model!

- Age-structured, multispecies optimization model
- Biological input based on ICES data & predation rates

- Fishing costs are stock-dependant; prices sensitive to supply
- Overall welfare can be separated to producer and consumer surplus
- Analysis of total profits, trade-offs and synergies

- Comparison of situation in 2014 vs 2019
- Long-term targets & short-term advice

Management scenarios

Ähmm, ...
why?

M ME Y

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Management scenarios

Scenario 1	**Multispecies Maximum Economic Yield (MMEY) - unconstrained**
Scenario 2	Multispecies Maximum Sustainable Yield (MMSY) - unconstrained
Scenario 3	MMSY respecting minimum biomass reference points (MMSY B_{lim})
Scenario 4	MMSY respecting minimum biomass reference points and yielding non-negative profits (MMSY B_{lim} econ)
Scenario 5	MMEY respecting minimum biomass reference points (MMEY B_{lim})

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Cod recruitment scenarios

Recruitment level 1	**Average R over 10 years (2009-18)**
Recruitment level 2 (ICES standard)	Average R over 5 years (2014-18)
Recruitment level 3	Average R over 3 years (2016-18)

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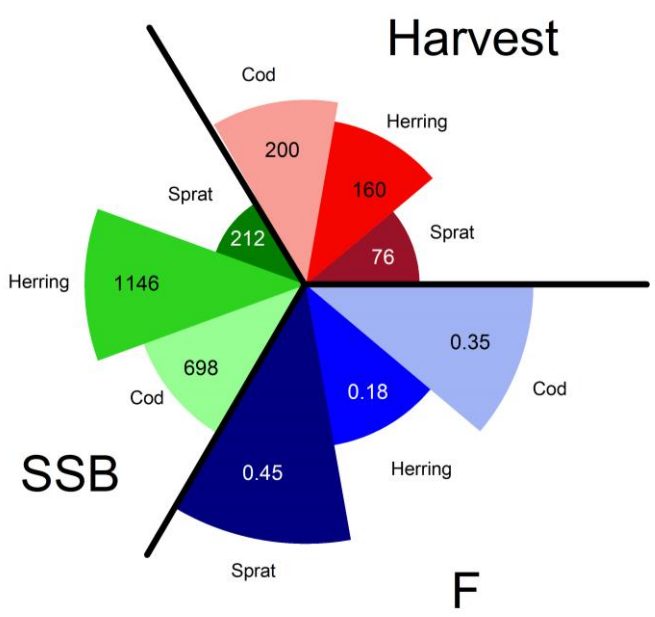
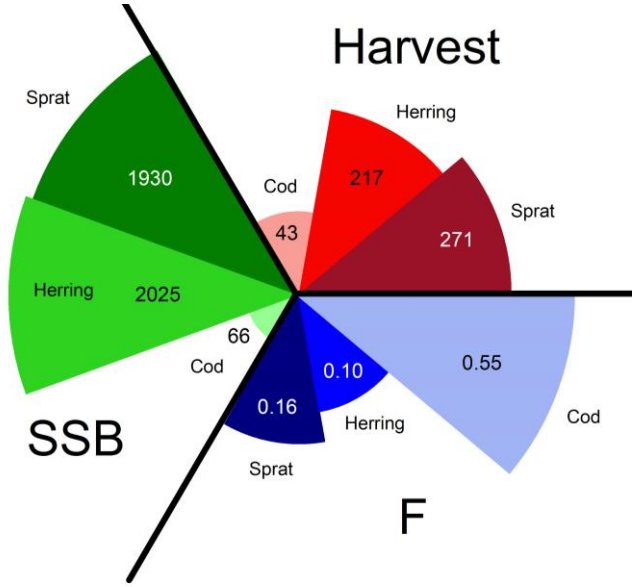
Long-term effects

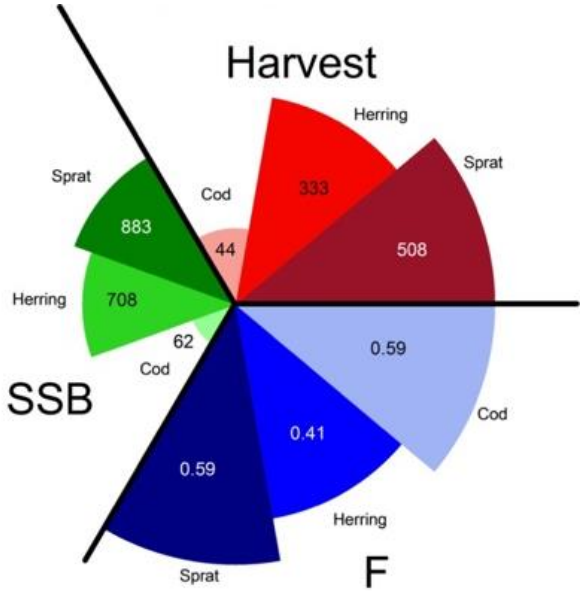
Long-term effects: changed biological input data



2014
MMEY



2020
MMEY



2020
MMSY

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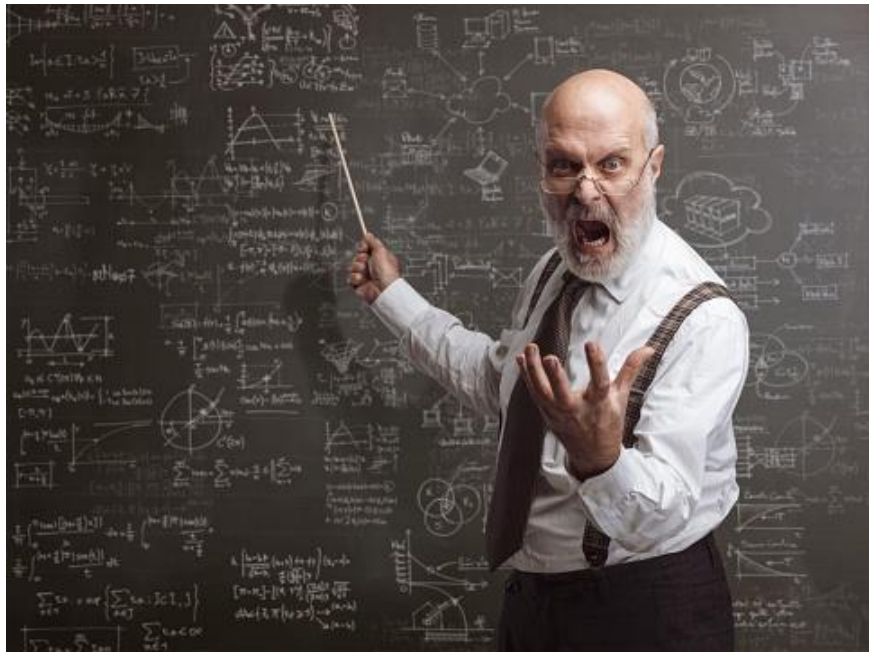
What we are also interested in:



Prof it

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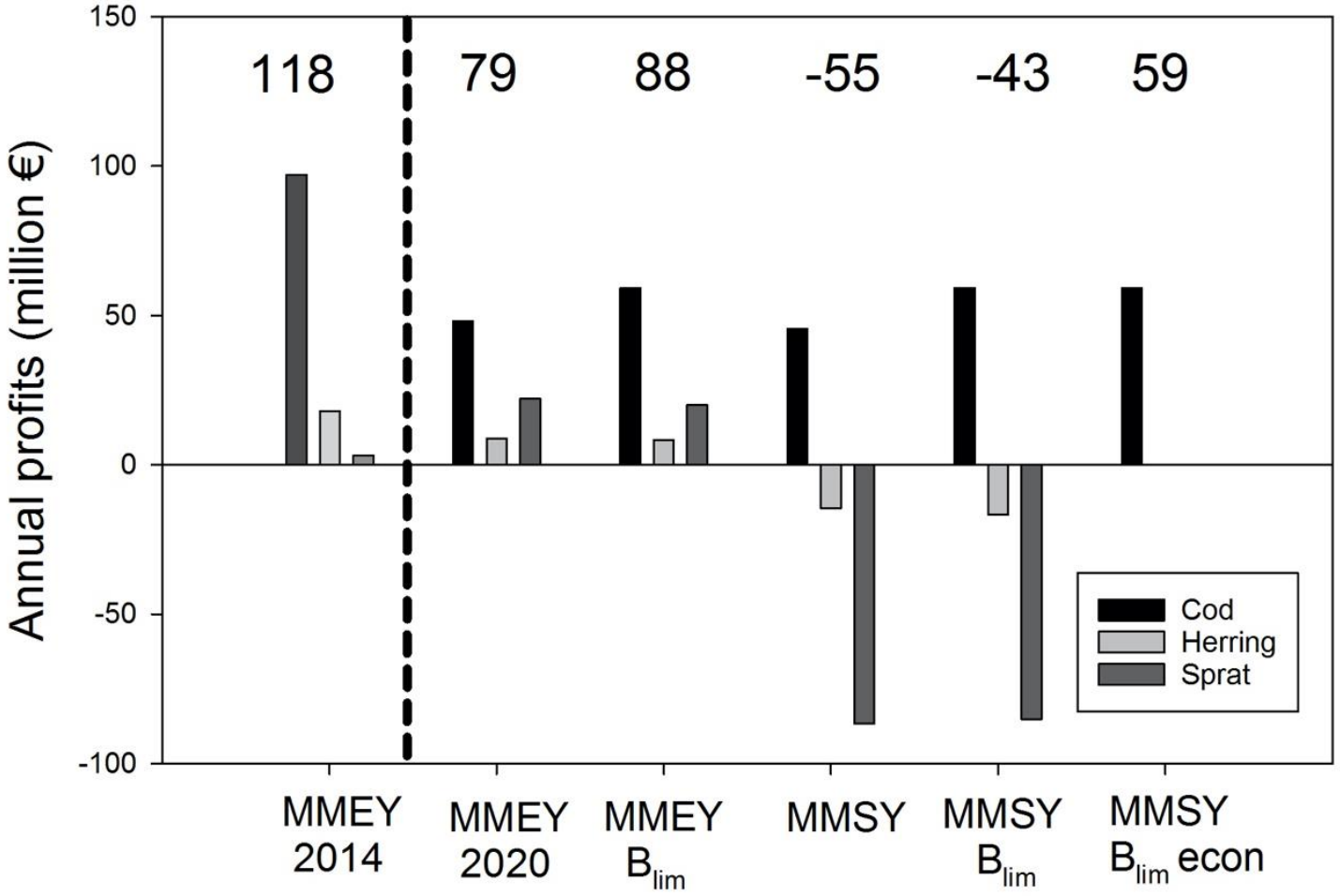
Annual profits



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What about ... ?

+

... Alec Guinness

Sir plus Sur plus

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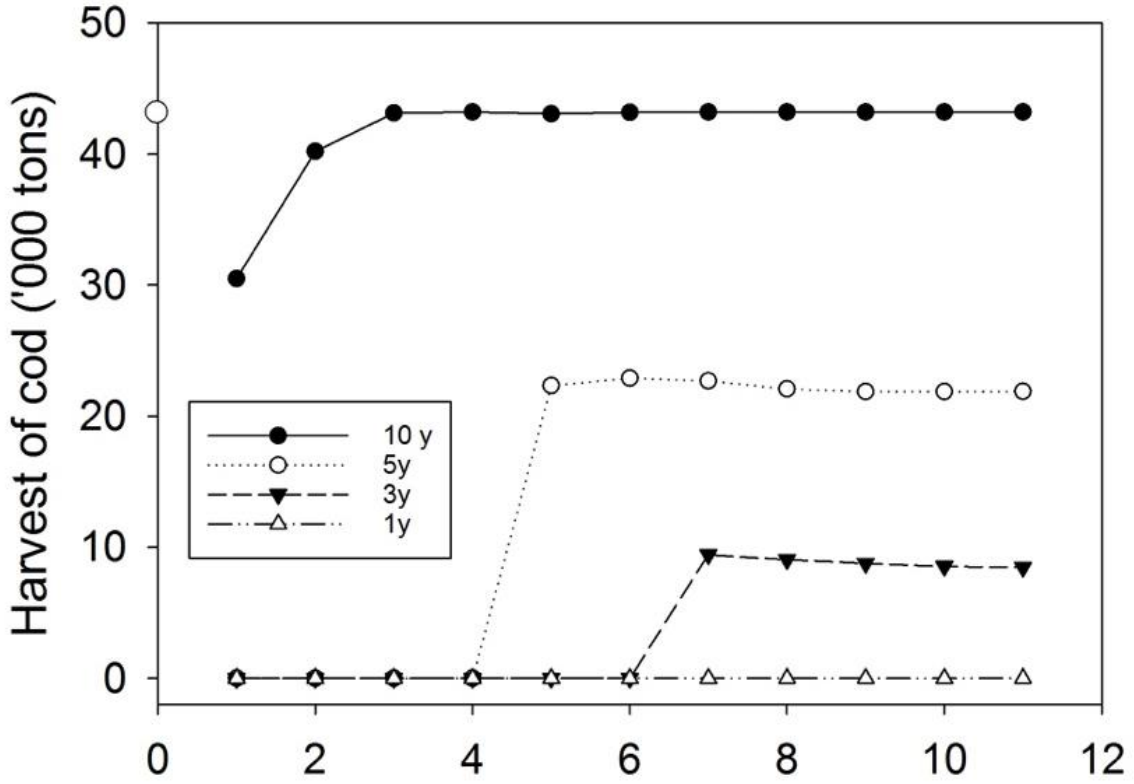
	Total Welfare	Producer Surplus	Consumer Surplus
MMEY	397.1	79.2	317.9
MMEY robust	396.8	83.5	313.3
MMEY B_{lim}	391.1	87.6	303.5
MMSY	301.1	-55.5	356.5
MMSY B_{lim}	298.4	-42.6	341.0
MMSY B_{lim} econ	380.9	59.2	321.6

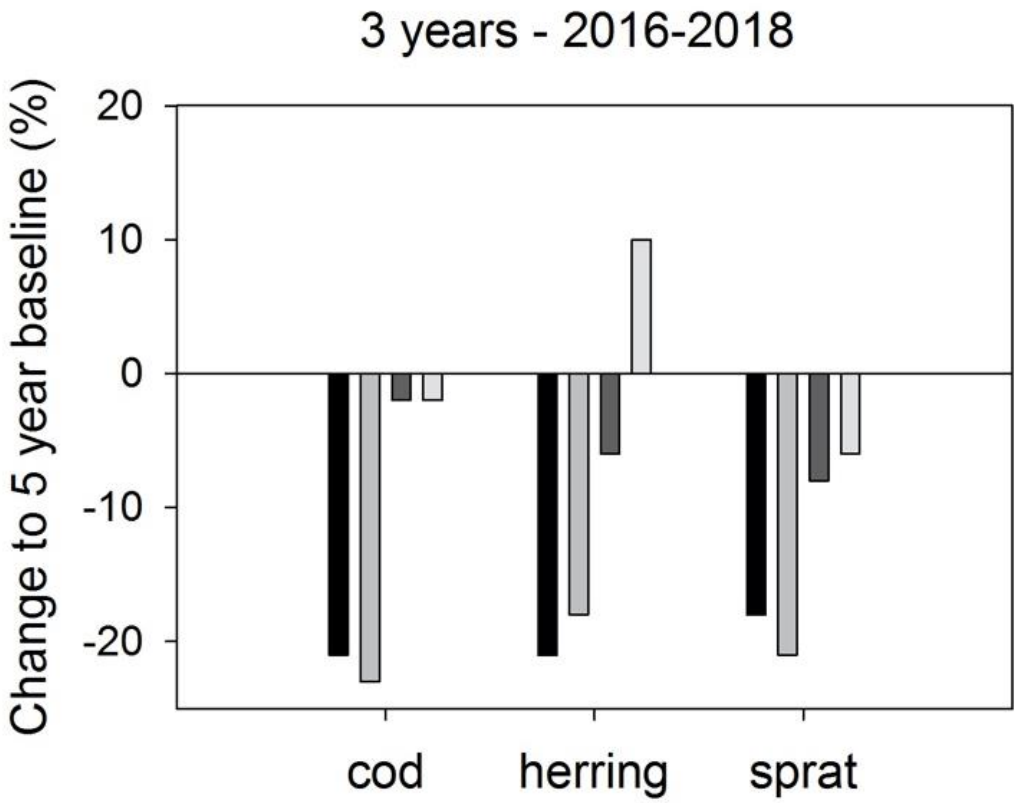
Short-term effects

Short-term effects



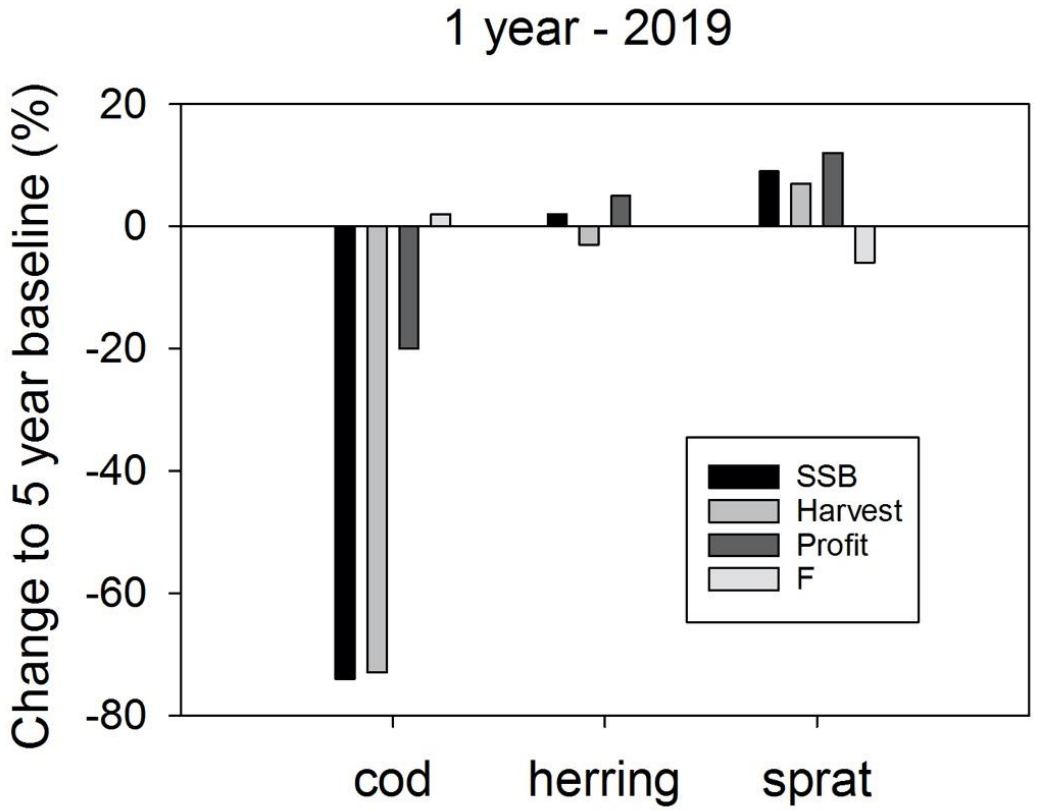
- Closure of cod fishery needed

Effects of varying time span of R averaging



- Varying the timespan of averaging has large effects
- Last 3 years below-average R for all species

Effects of varying time span of R averaging



- Simulation with (low) 2019 recruitment of cod
- Last 3 years below-average R for all species

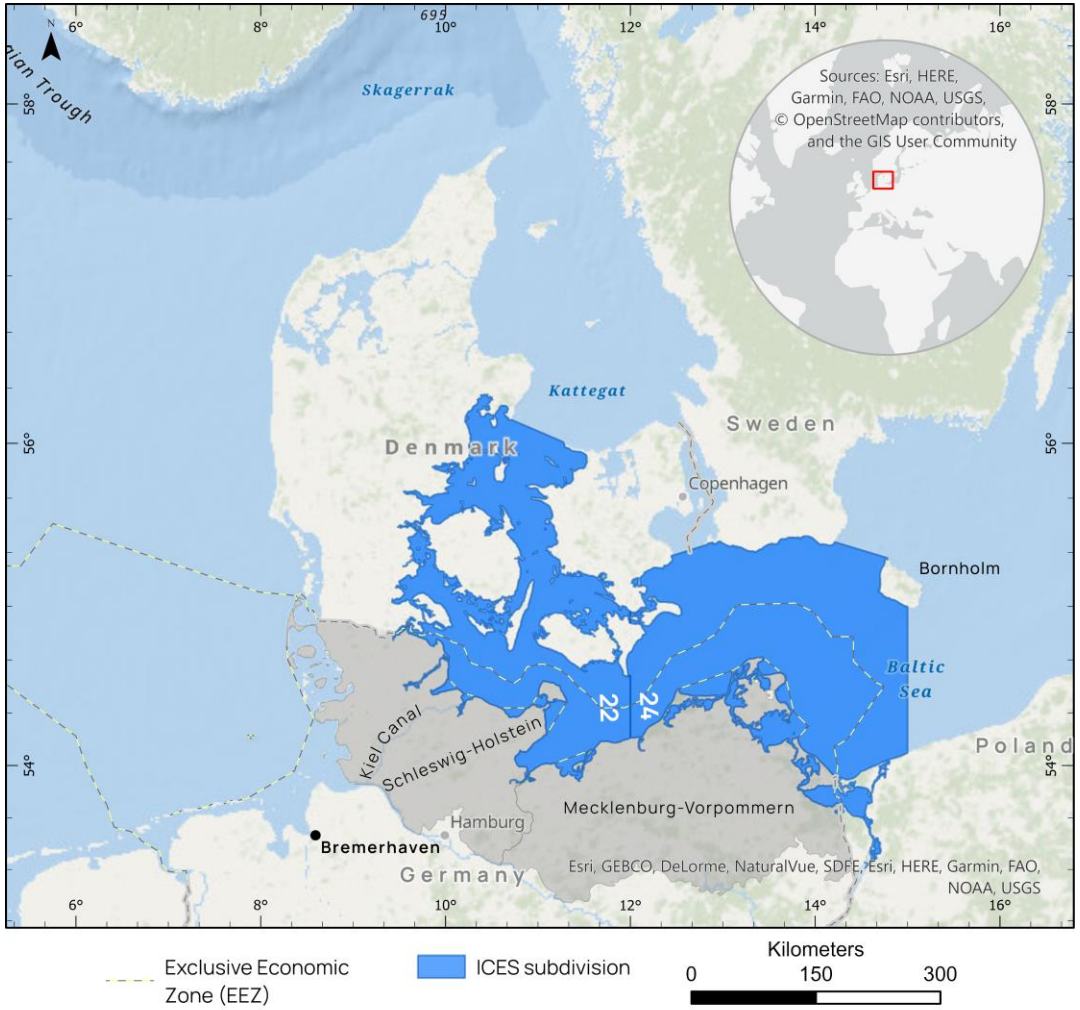
Conclusions Central Baltic

- Management targets need to be adapted
- Synergy between fishery profits and respecting Blim
- If cod stock dynamics further worsen -> Brave New Baltic

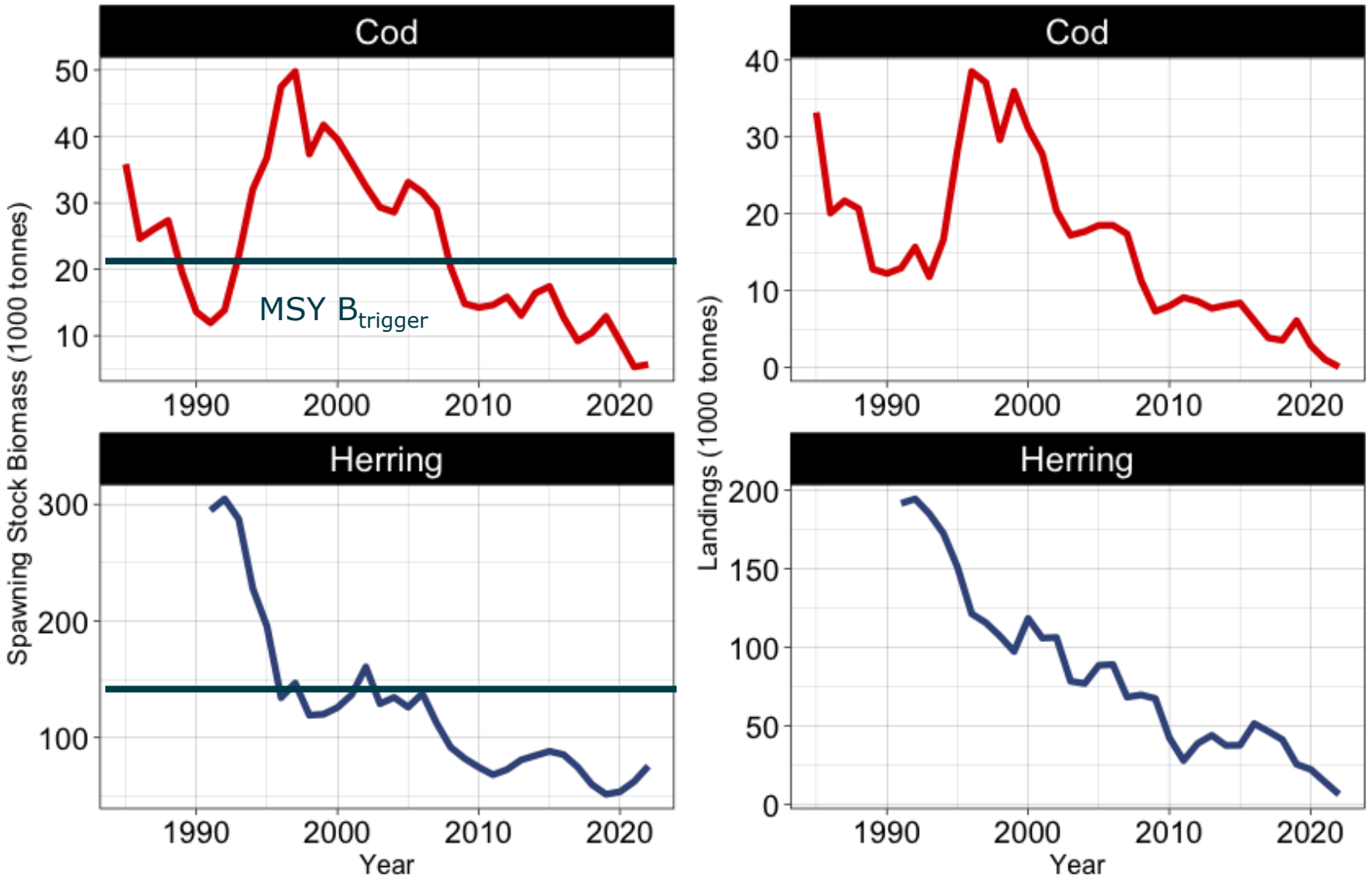
- Environmental effects can be included, e.g. in S/R relationship

- This is what we did recently in the Western Baltic ...

The Western Baltic Sea



Cod & herring collapse



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Crisis of the German Baltic fisheries

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Fleet development

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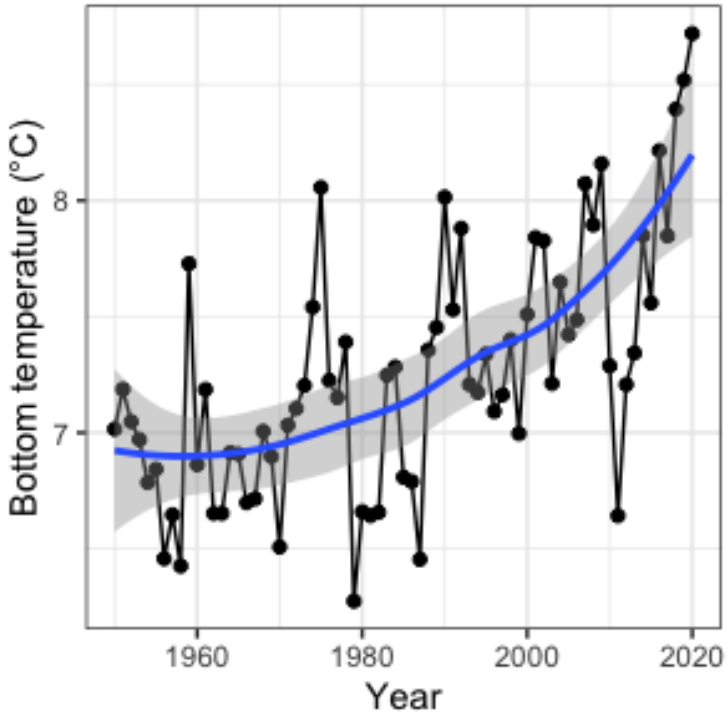
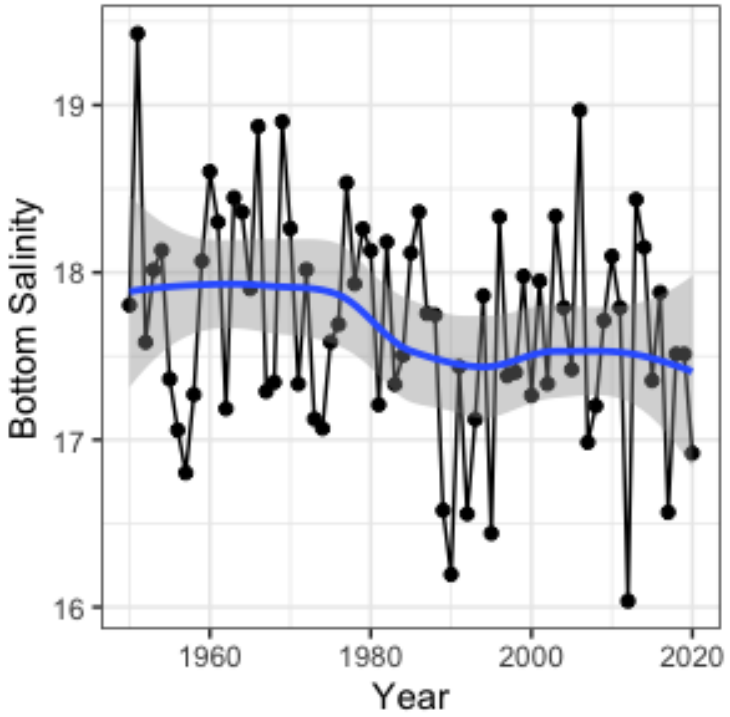
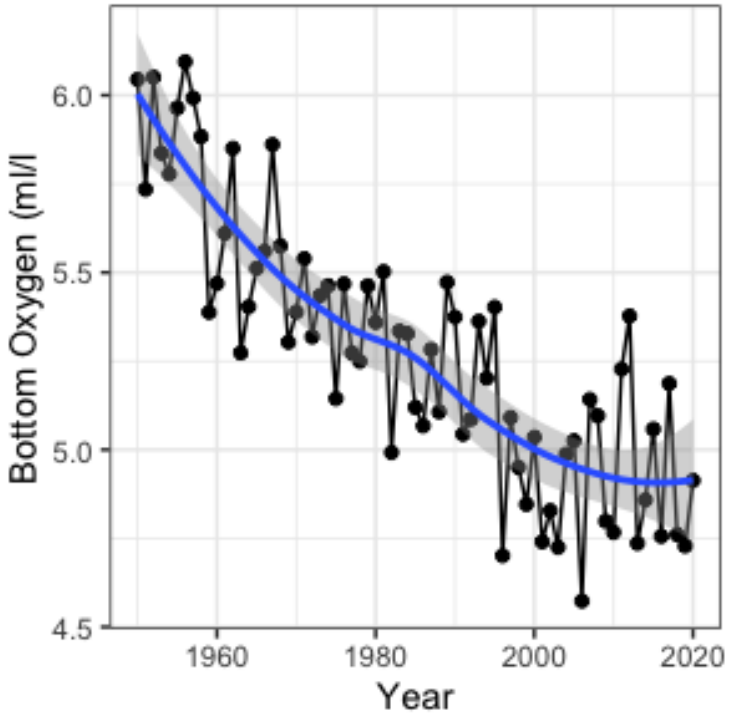
Long-term change in physics







Mean **increase** in SST: 1.3 C°

Mean **increase** in bottom Temp.: 0.89 C°

Mean **decrease** in bottom O_2 (ml/L^{-1}): 0.90

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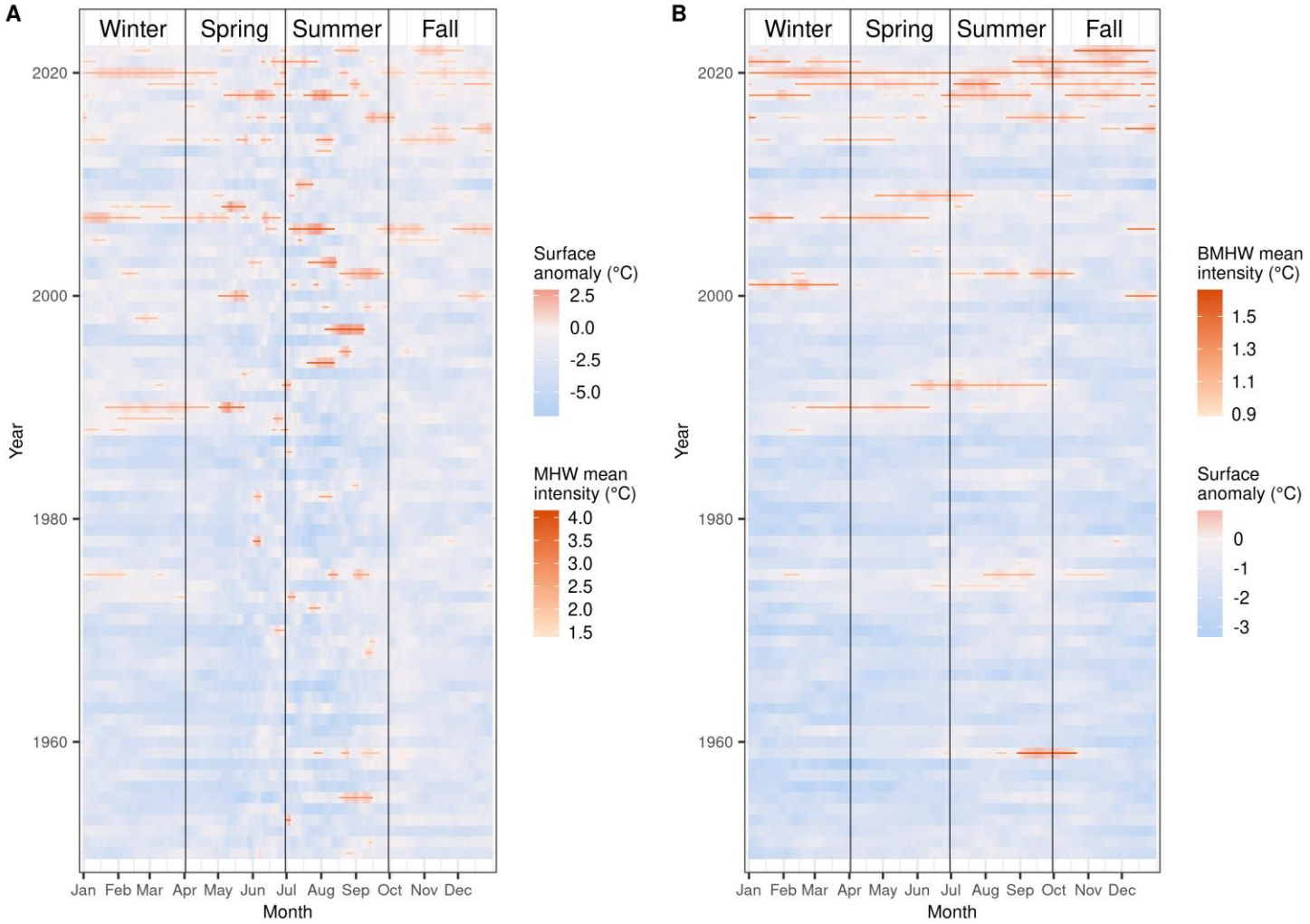
Marine heatwaves

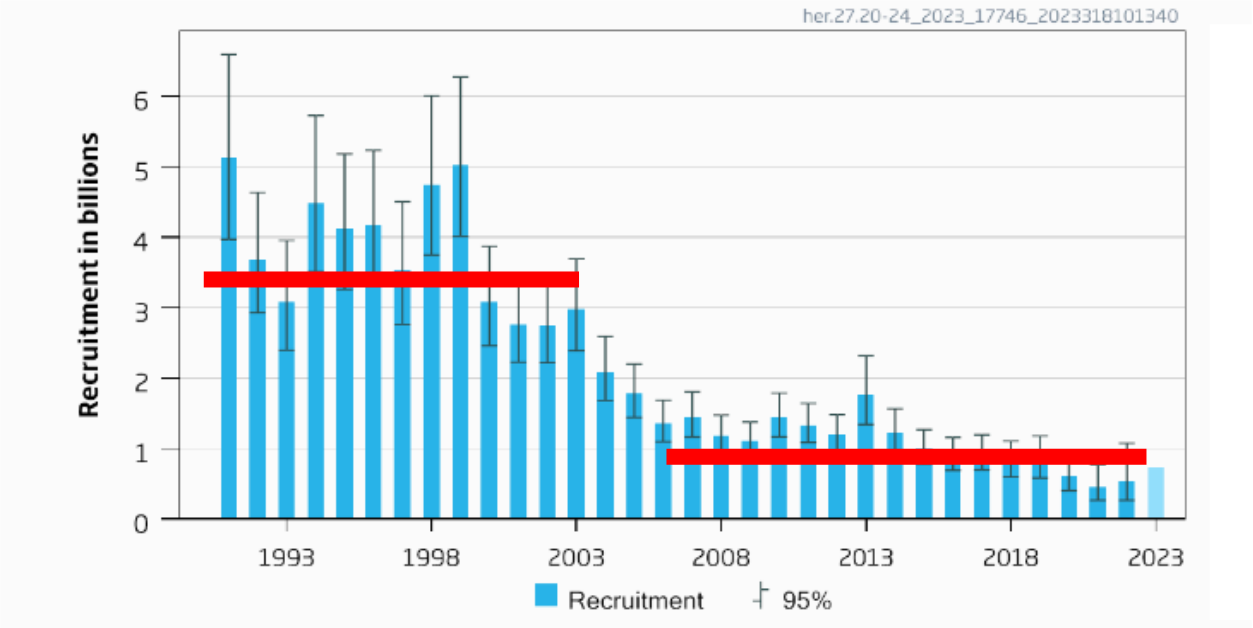
Oberfläche

Boden

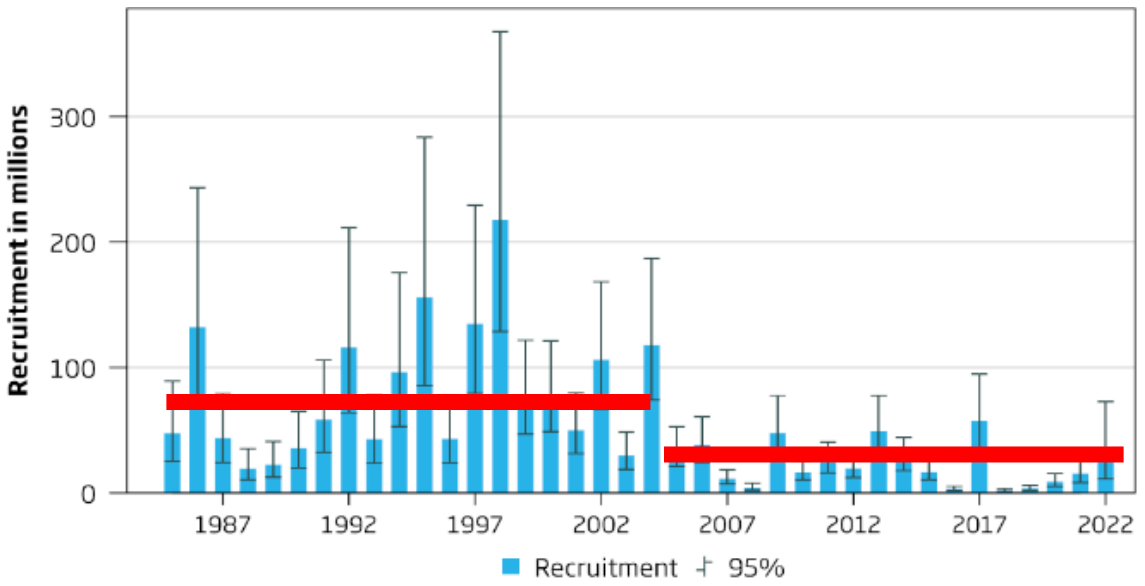


Climate impact on stocks: recruitment

Herring

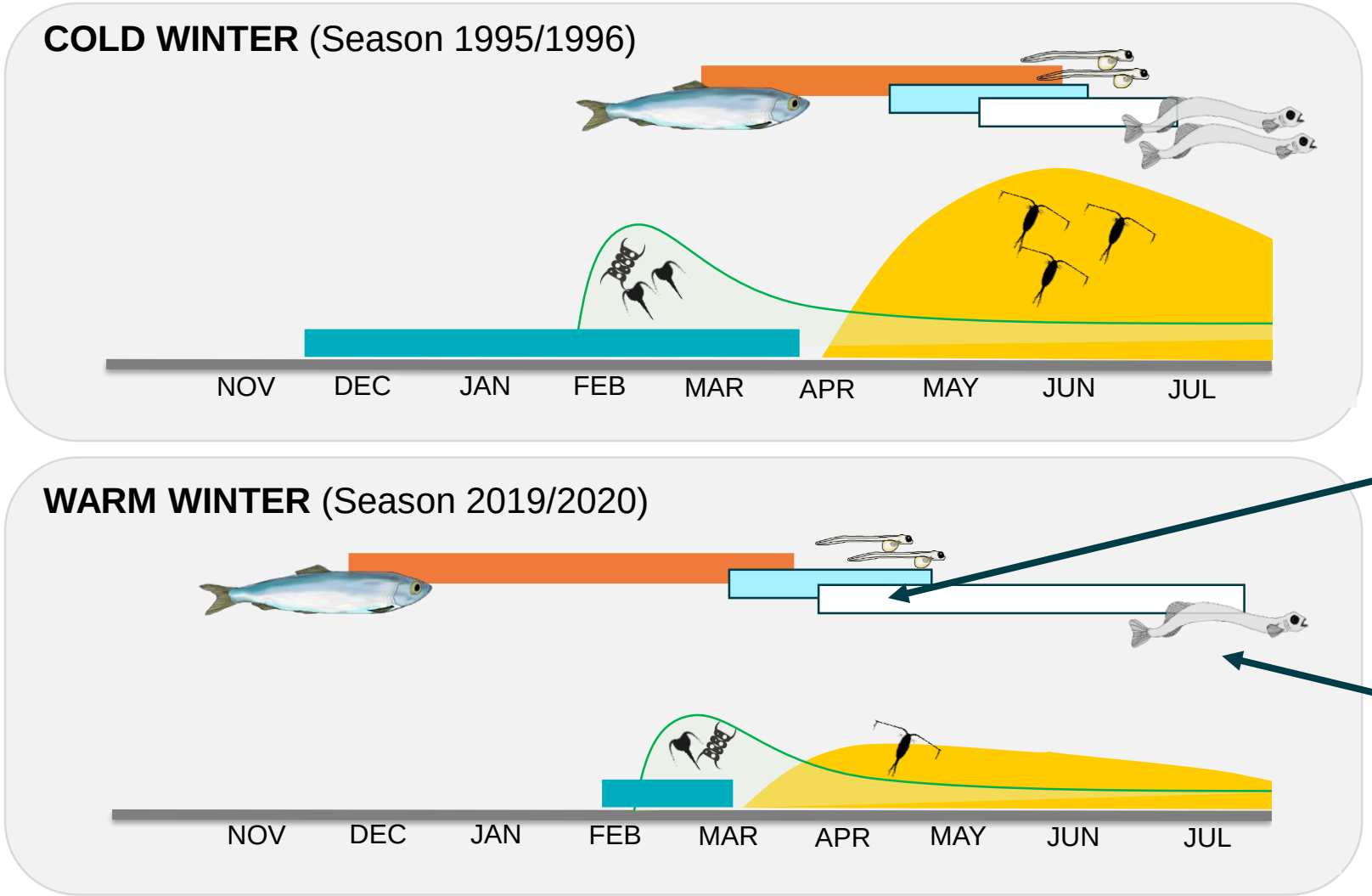


Cod



- Both stocks showed reduced recruitment in recent years

Herring: mismatch between larvae & prey

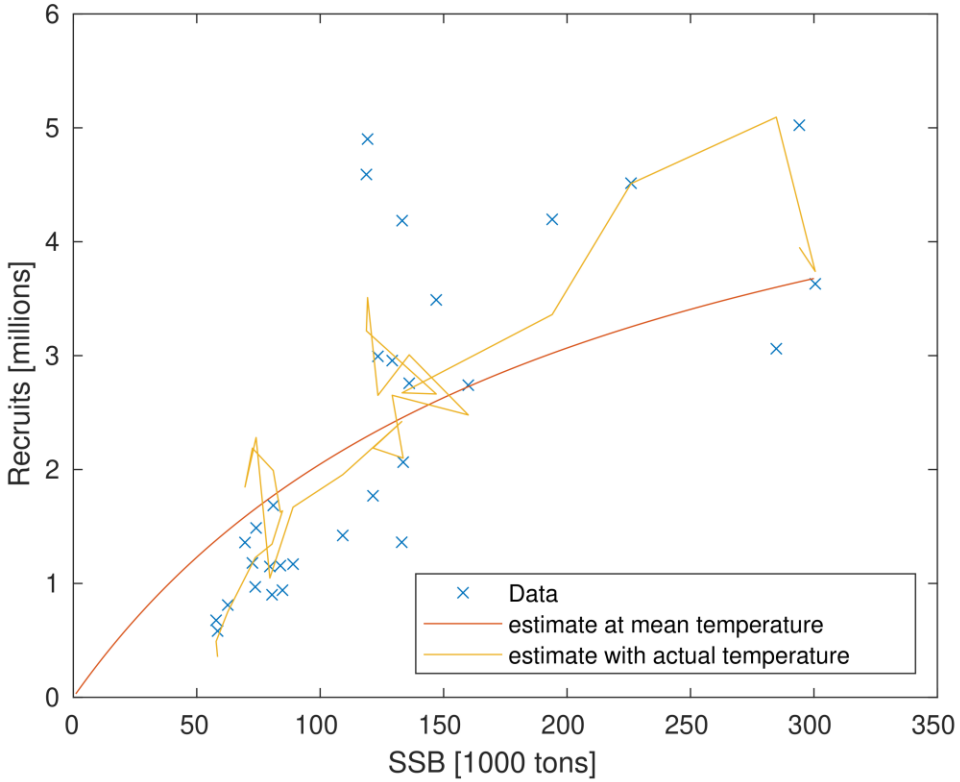


Bloom dynamics still under study but substantial decrease in zooplankton biomass since 2013

Early larvae may experience mismatch with food

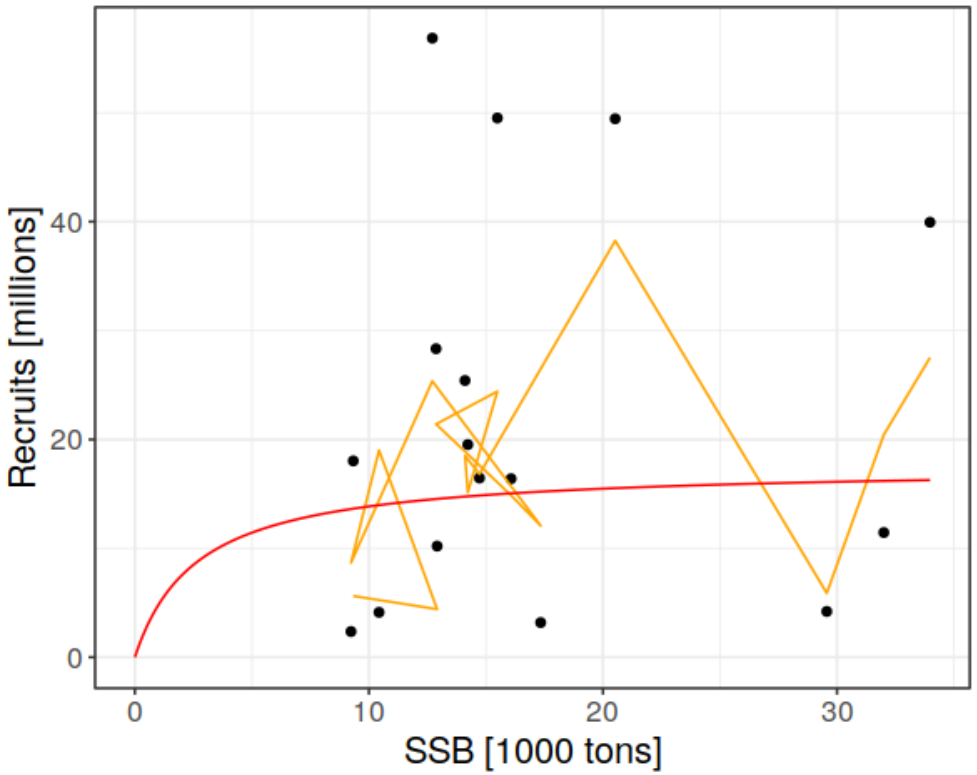
Is it too warm for late larvae?

Temperature-dependent Stock-Recruitment



Nonlinear regression model:
R ~ ((b1 + b3*temp_bottom_q4)*SSB/(1 + b2*SSB))

Herring: bottom temperature, 4th quarter!



Nonlinear regression model
model: log(R1) ~ (cc * q3_SST) + log(ac * SSB) - log(1 + bc * SSB)

Cod: Sea surface temperature, 3rd quarter!

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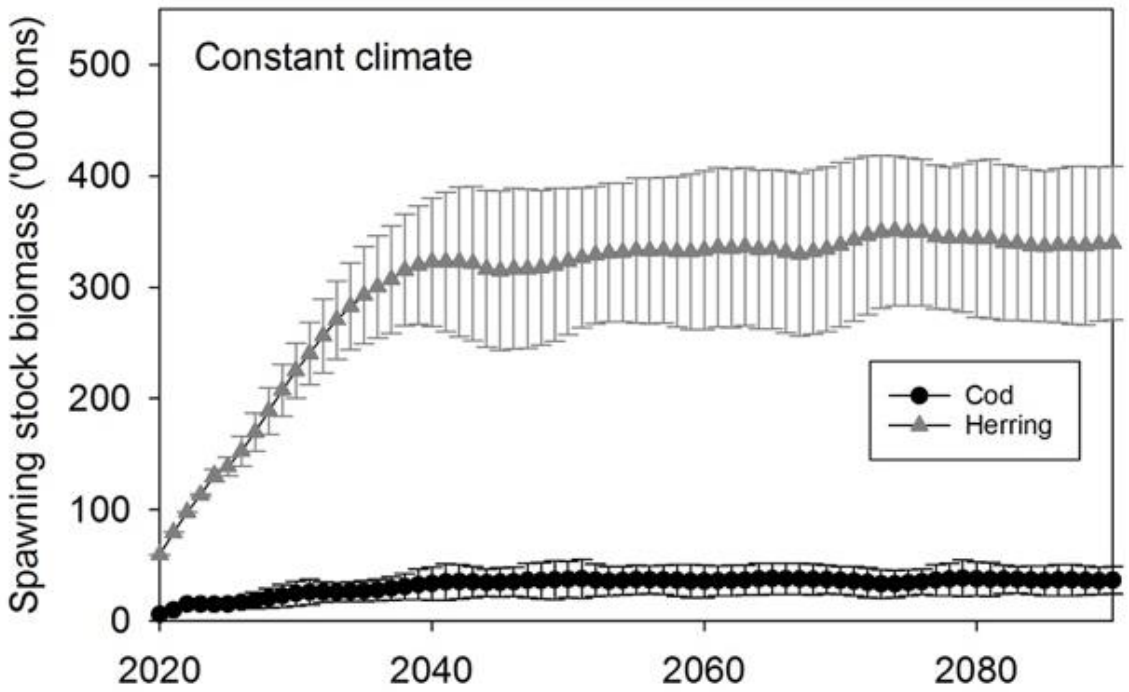
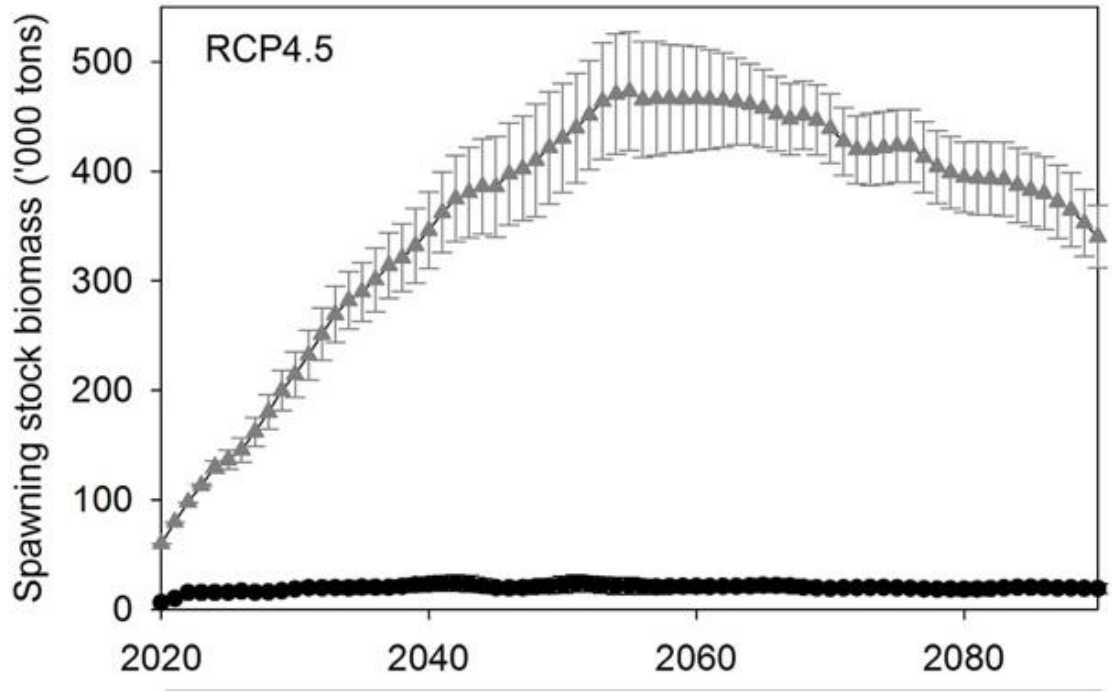
Climate scenarios: Optimal stock size





- Under no climate change, cod will slightly recover – but not to former levels
- Herring recovers; under RCP4.5 rebuilding to higher stock size is optimal
- Negative temperature impact from mid-century onwards

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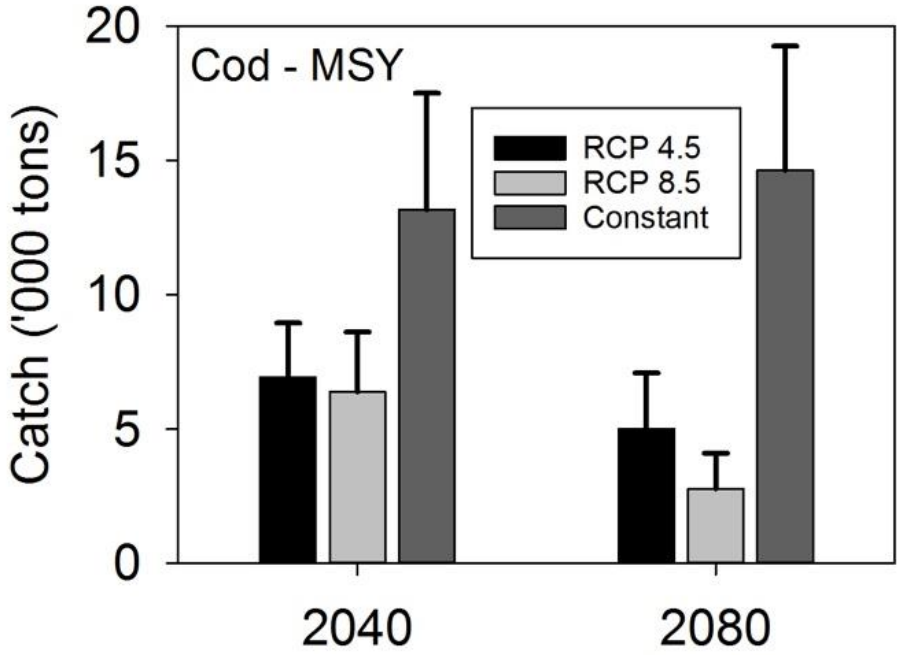
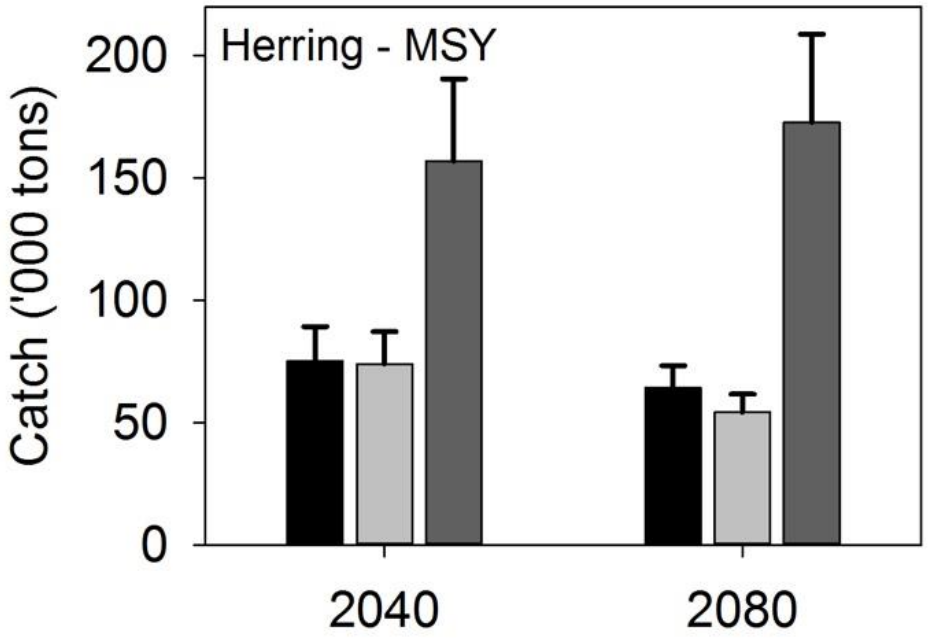
Future catch potential





- Strong climate impact
- Future catch potential for cod is low
- RCPs differ significantly from mid-century onwards

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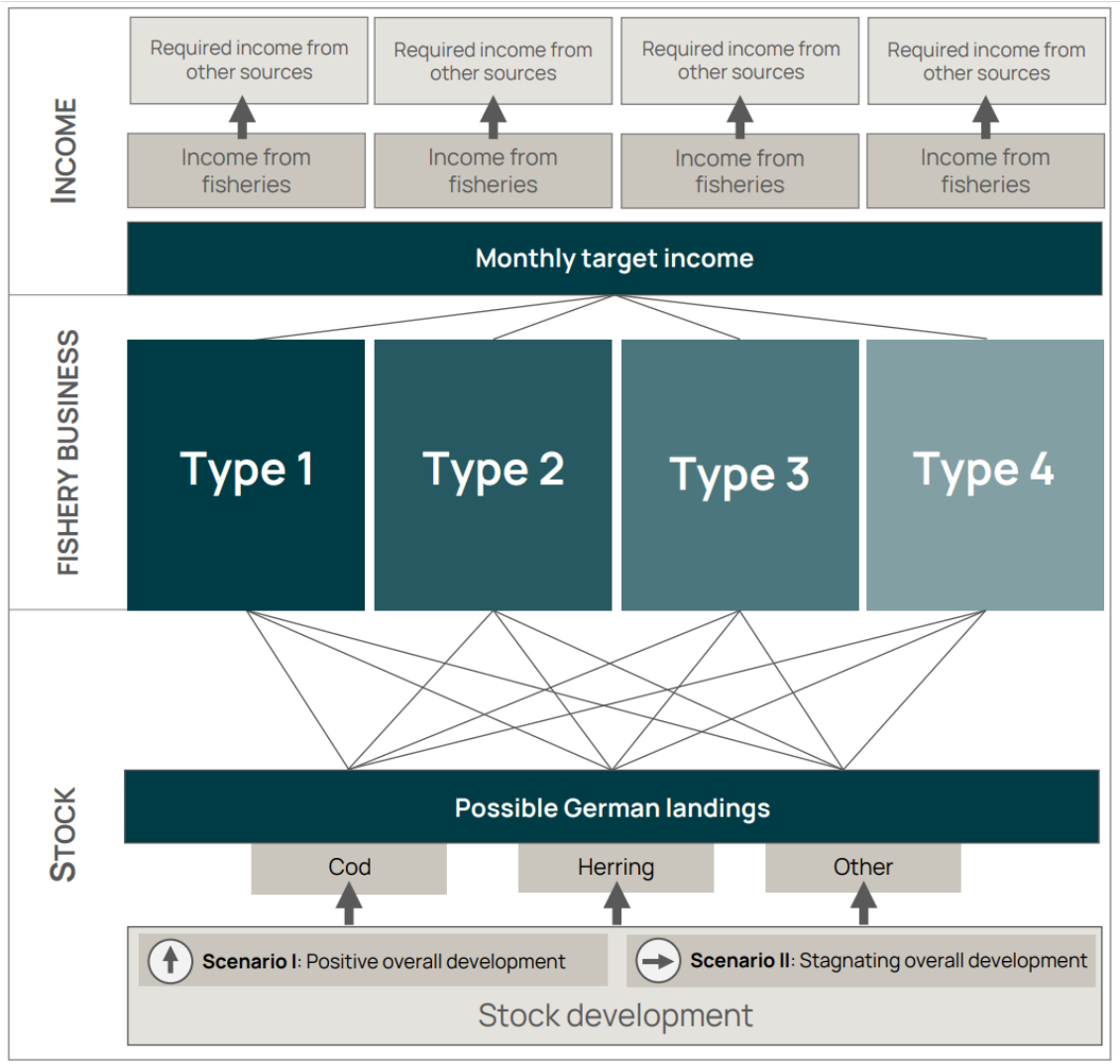
How many fishers the resources may support?

Social

Economy

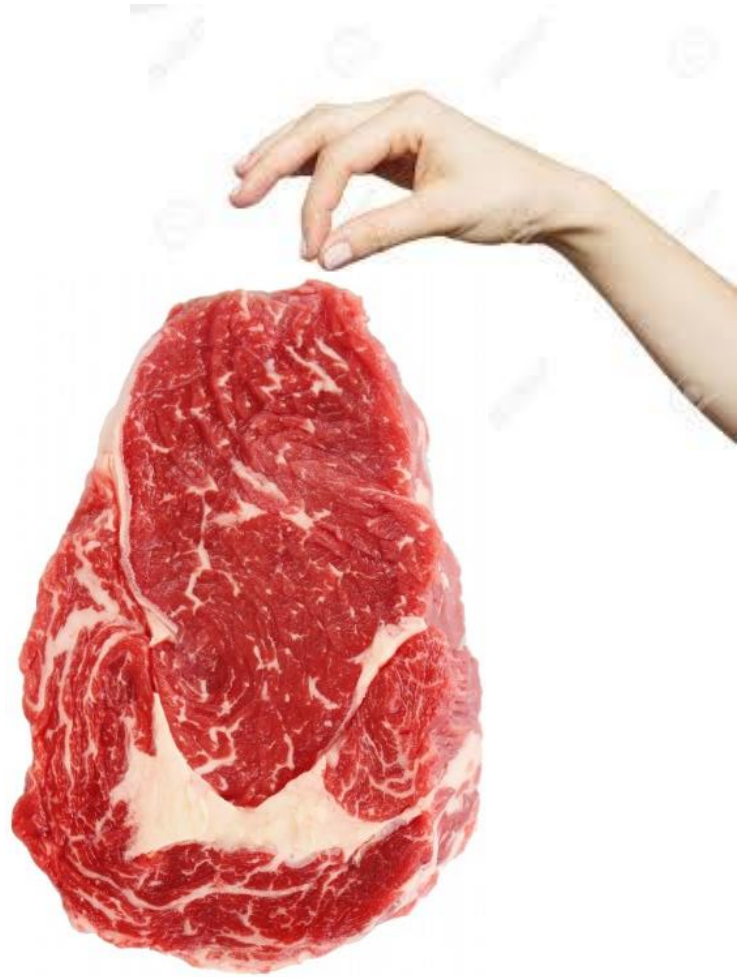
Governance

Ecology

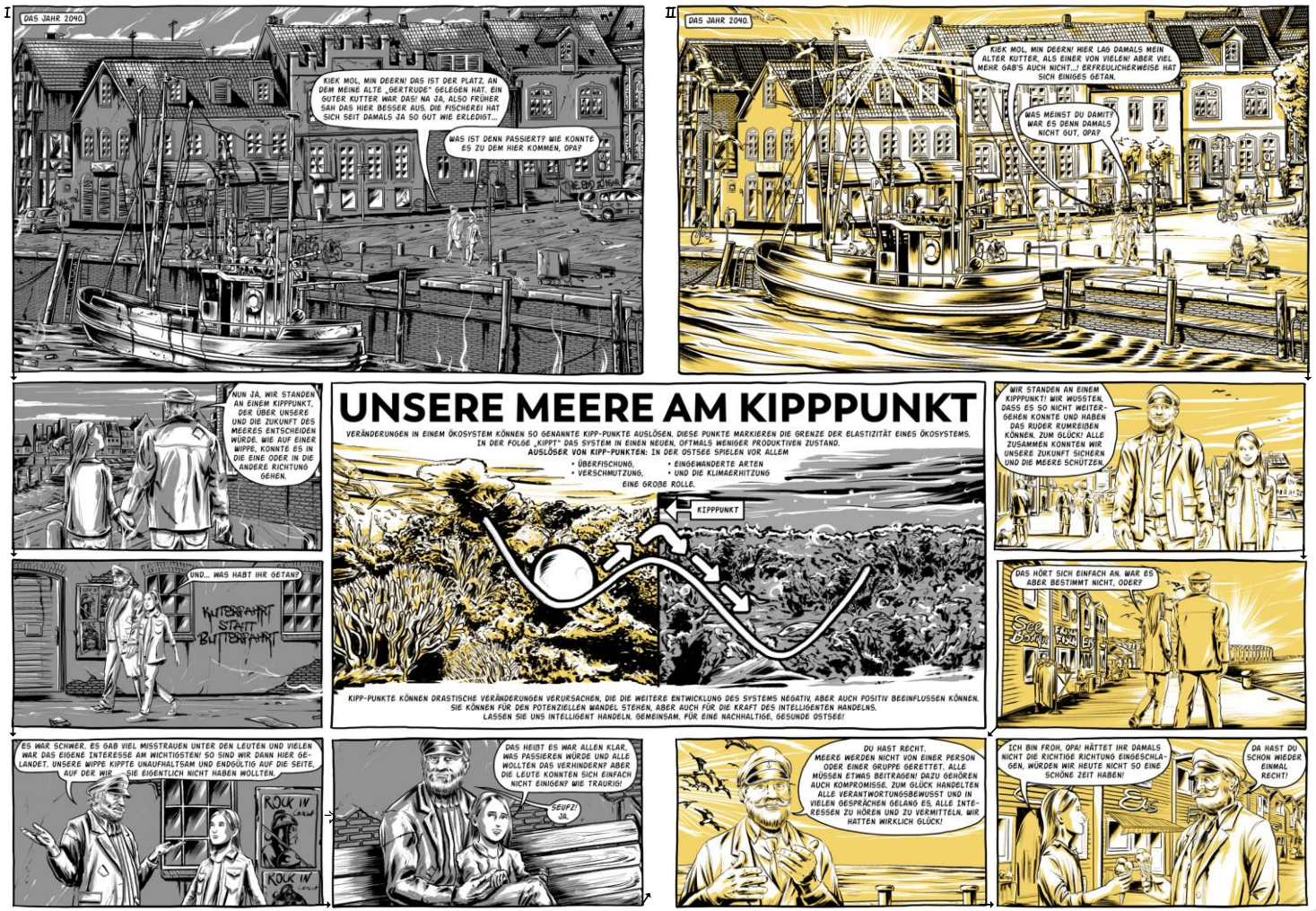


Christian-Albrechts-Universität zu Kiel

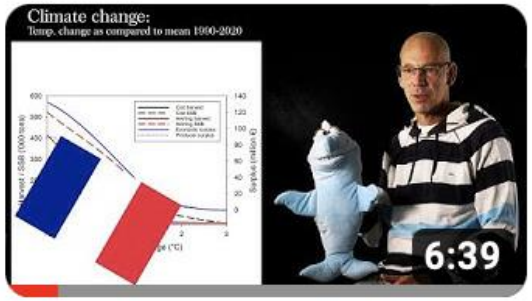
KIEL MARINE SCIENCE CONNECTED RESEARCH



Finally: Fun stuff



Finally: Fun stuff



Baltique occidentale, gestion des pêches, changement…

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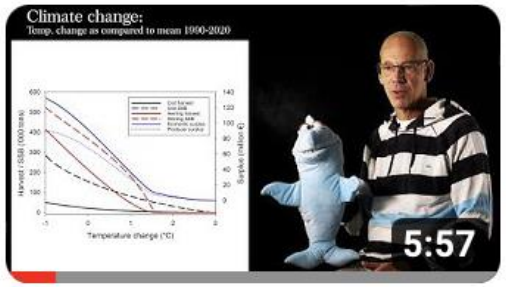

Western Baltic, fisheries management, climate change,…

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Playmobil goes Science: Fishing past a tipping point

Brave New Baltic - Optimal multispecies fisheries…

Thanks a lot!!

How many fishers the resources may support?

Szenarienrechner für die deutsche Küstenfischerei