Match-Mismatch: Trophic interactions and climate change

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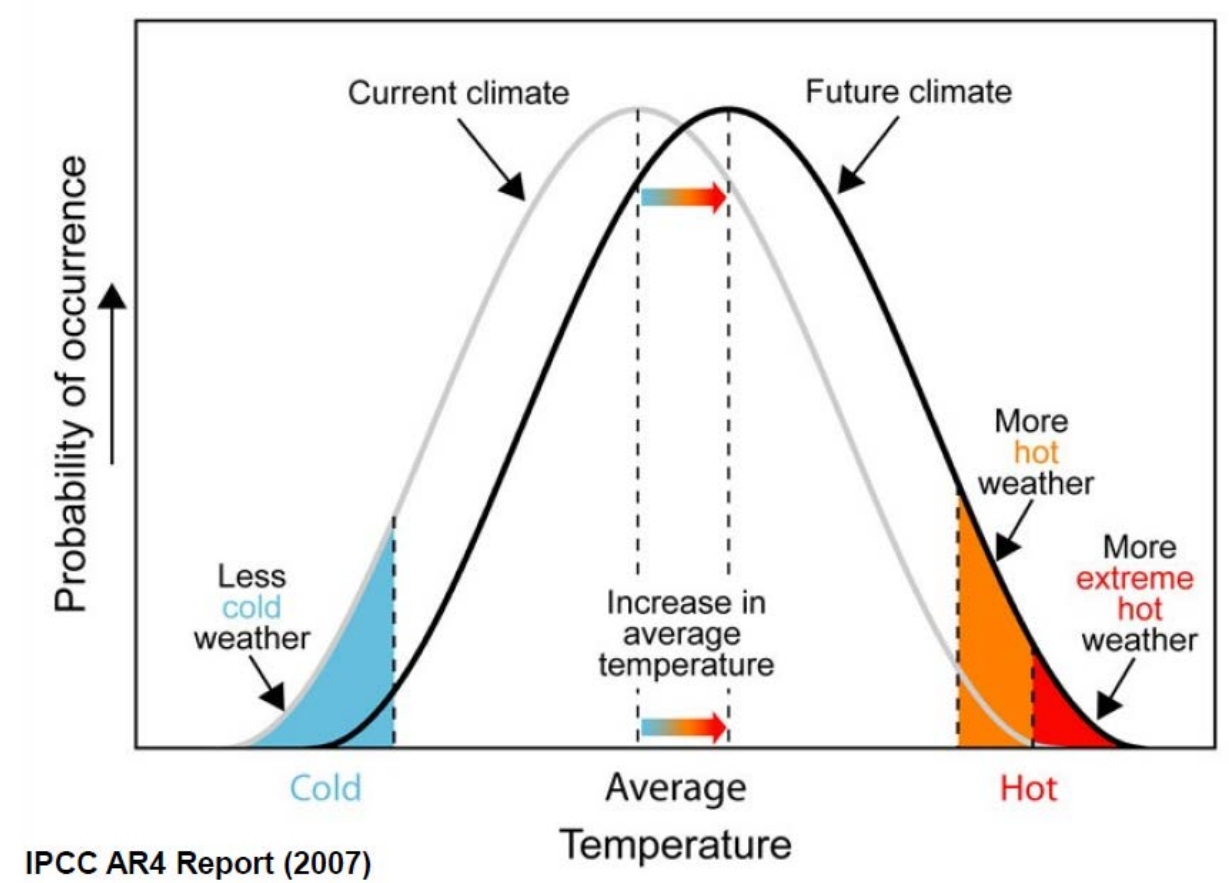
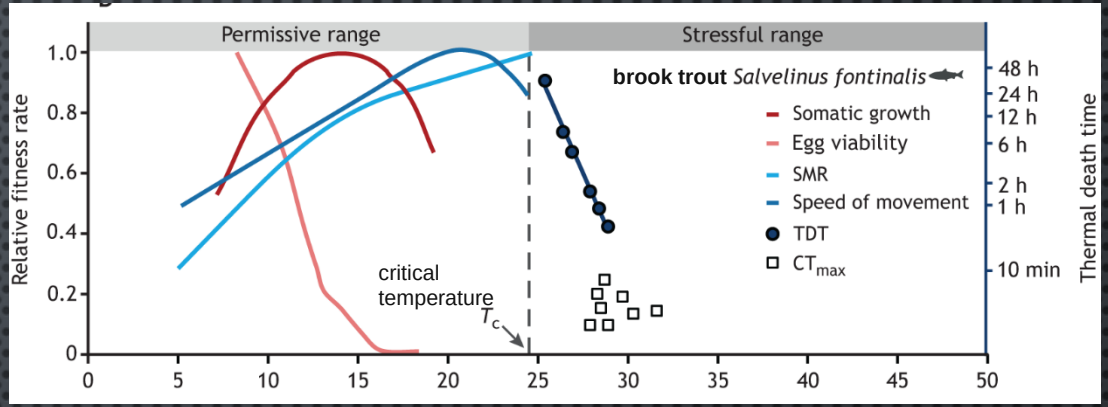
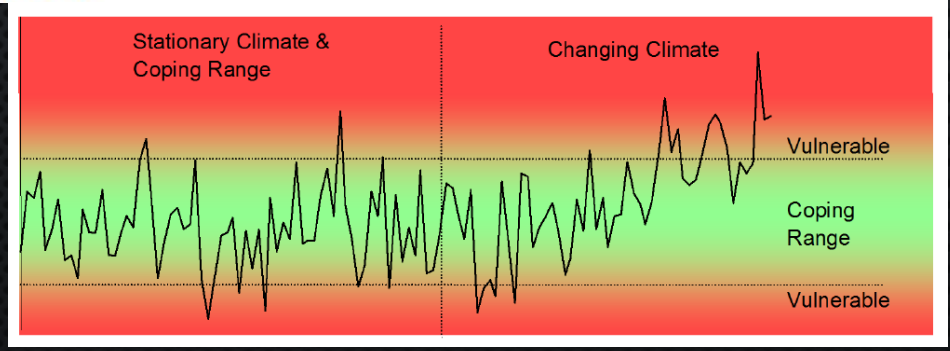
Extremes and climate variability



IPCC AR4 Report (2007)

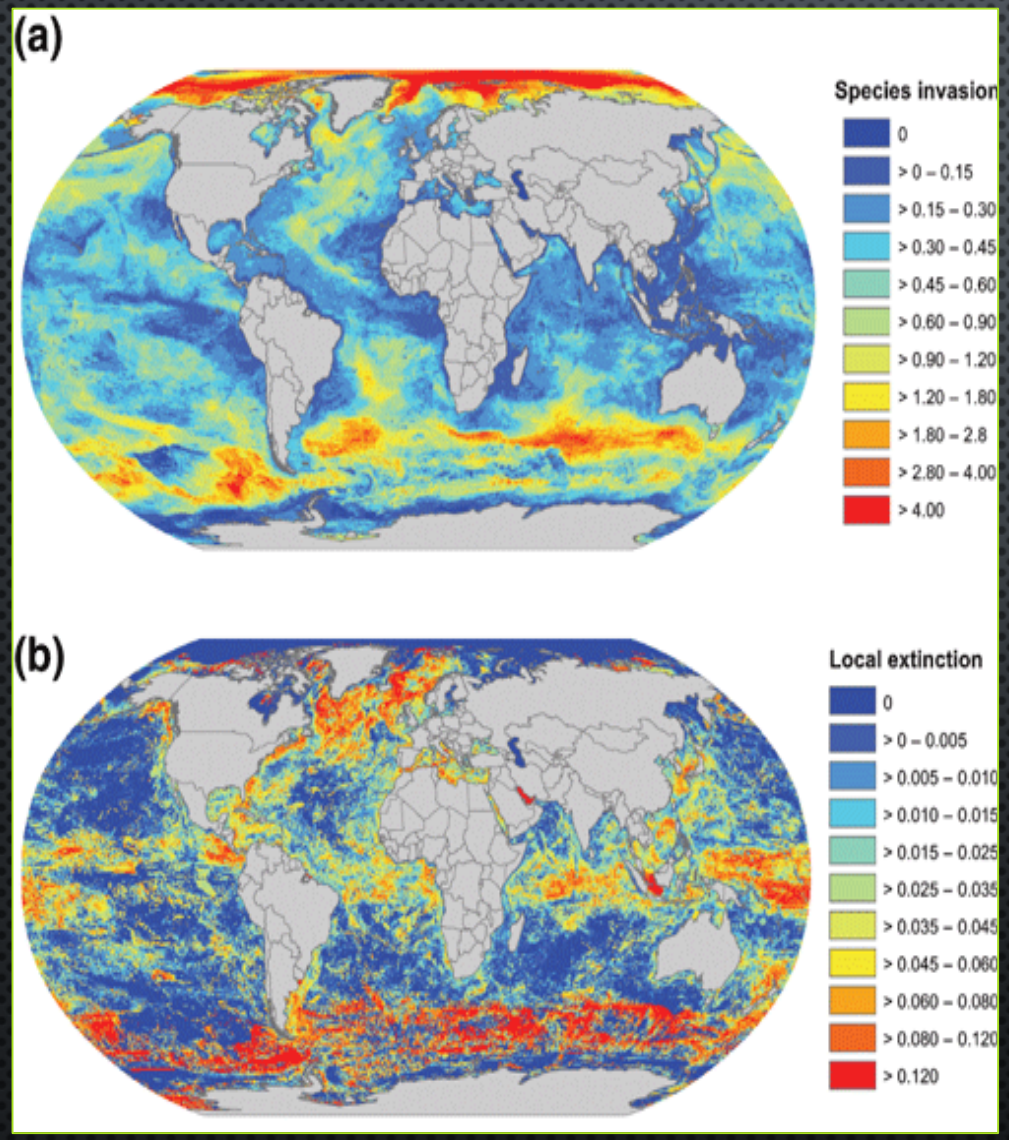


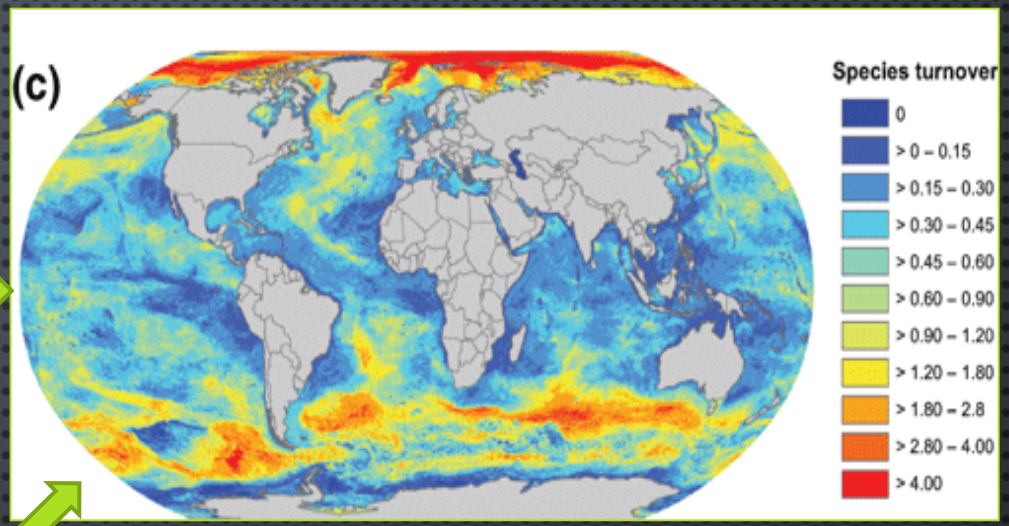
Ørsted *et al*. 2022



Jones & Mearns 2005

Climate and population displacement



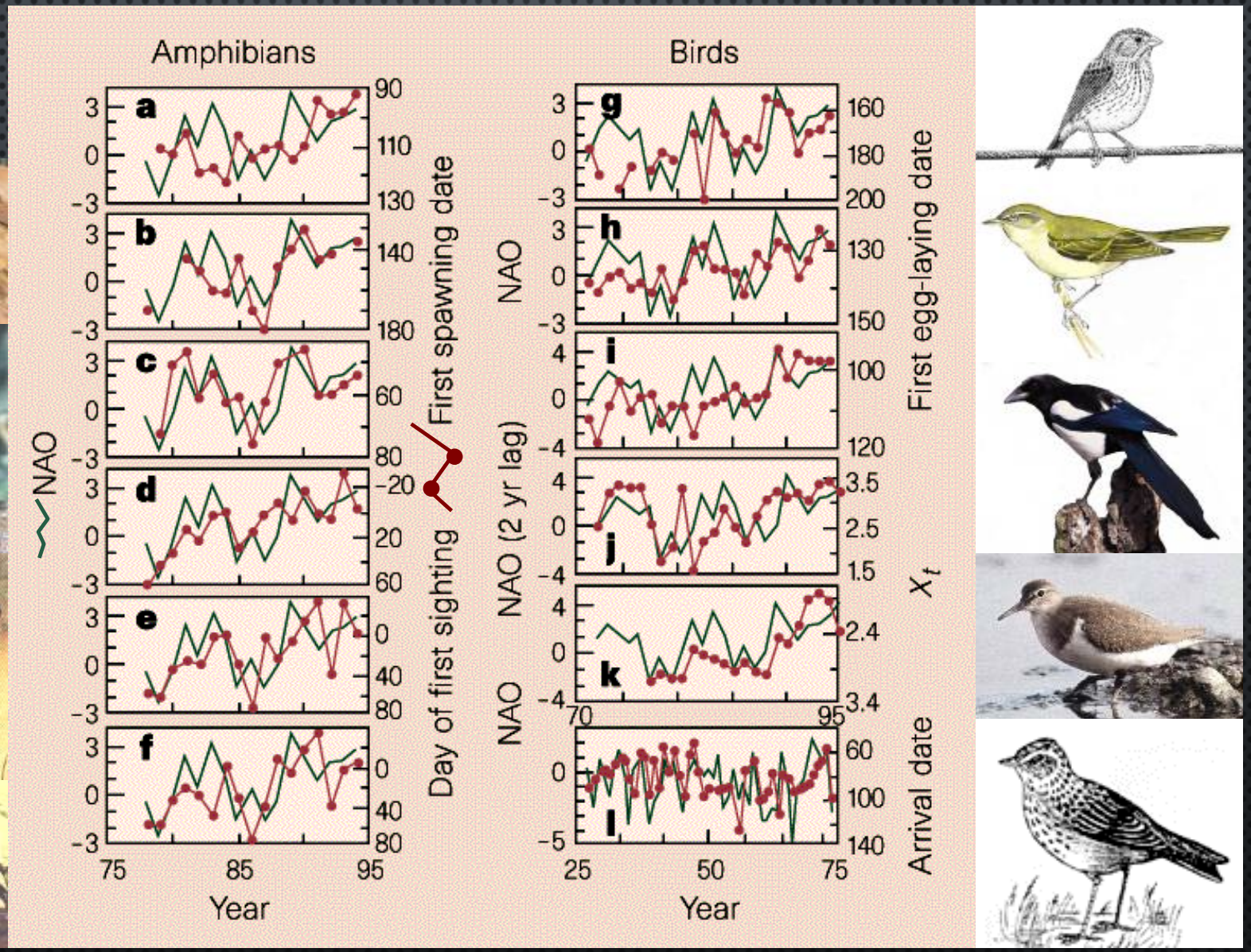


In 2050 relative to the mean of 2001–2005

- Species are moving and disappearing particularly at the poles
- High turnover in some regions

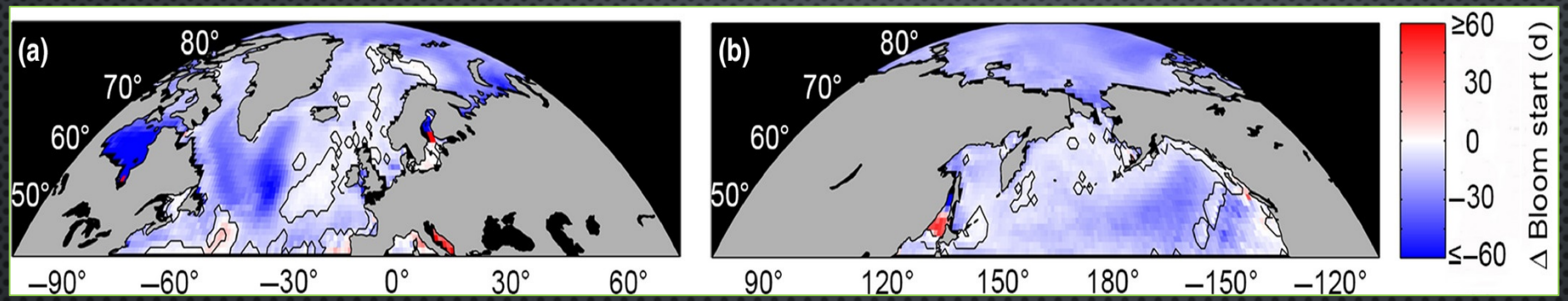
Cheung *et al*. 2009

Climate change and breeding phenology

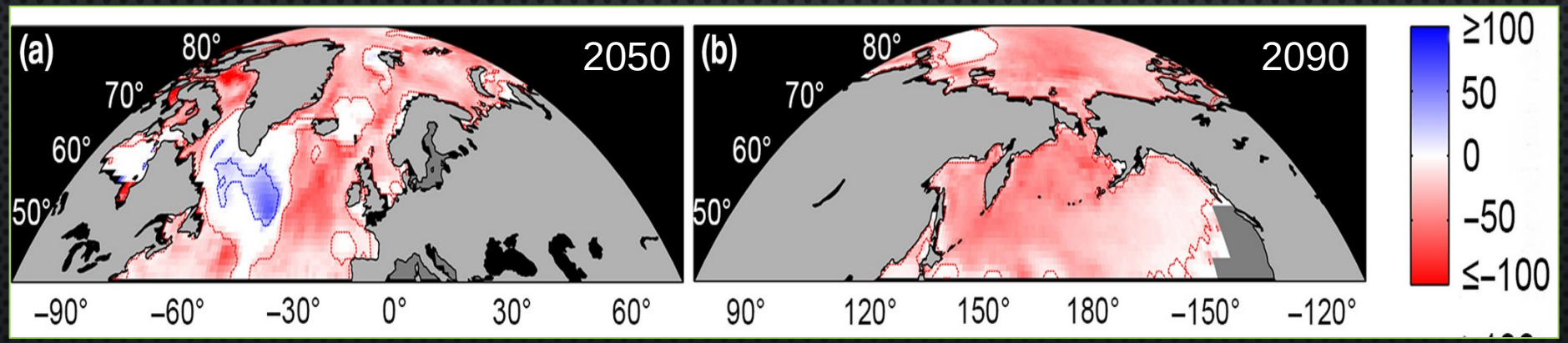


Forchhammer *et al*. 1998

Climate change impacts on mismatches between phytoplankton blooms and fish spawning phenology



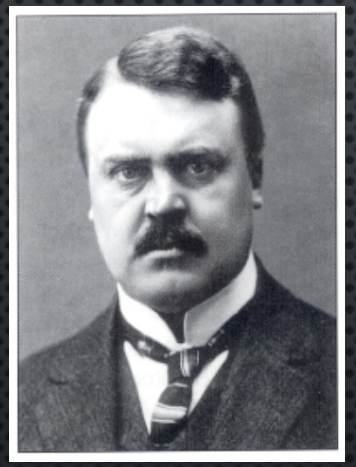
Phytoplankton blooms will start earlier in 2050–2099 compared to 1901–1950



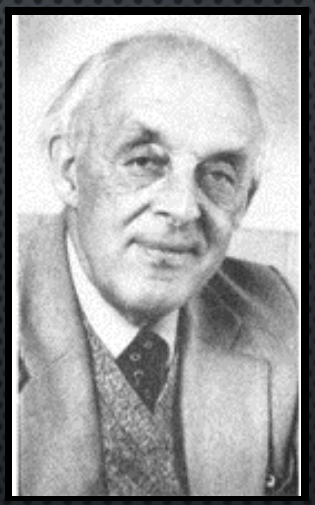
Synchrony between the two trophic levels

Asch *et al*. 2019

Match-Mismatch Hypothesis: Origins



Pacific cod yolk sac larva
Photo: NOAA Fisheries



1914: Johan Hjort adopts the concept that understanding cod and other fishes survival at younger stages is critical.
The critical period hypothesis

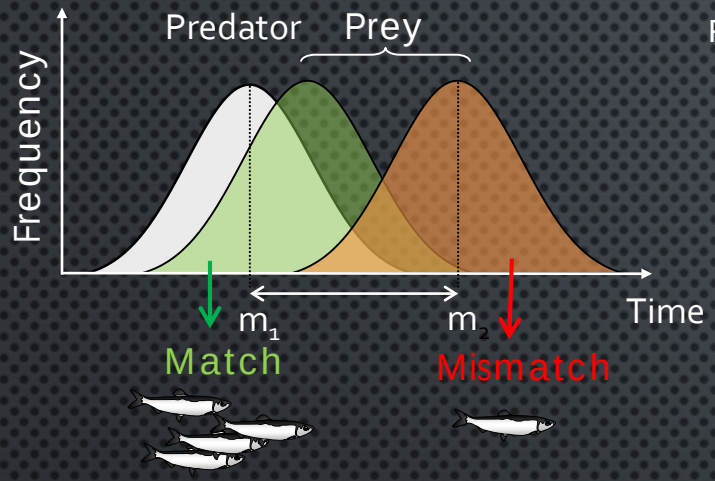
1969: David Cushing formulates the *Match-Mismatch hypothesis* that implies that variability in timing of plankton production leads to variability in larval mortality and hence possibly year class strength.

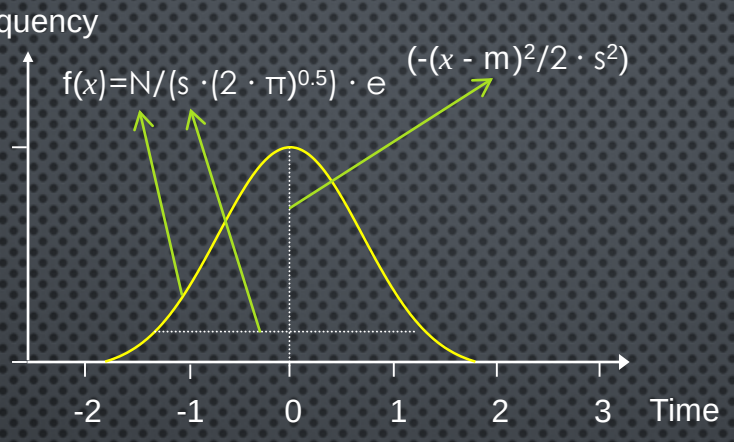
Match-mismatch, trophic interactions and climate change

Is the Match-Mismatch hypothesis a useful tool?

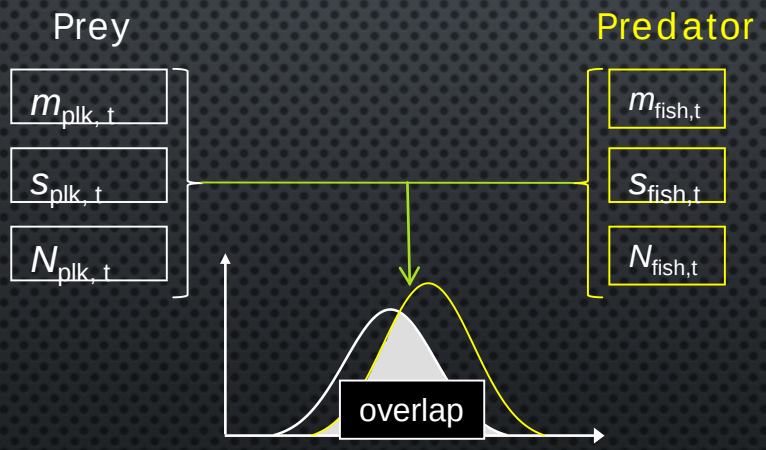
- What did we add?
  - Effect of abundance
  - An ecosystem approach
  - Spatial mismatch
- Can we use the match-mismatch hypothesis for projections?

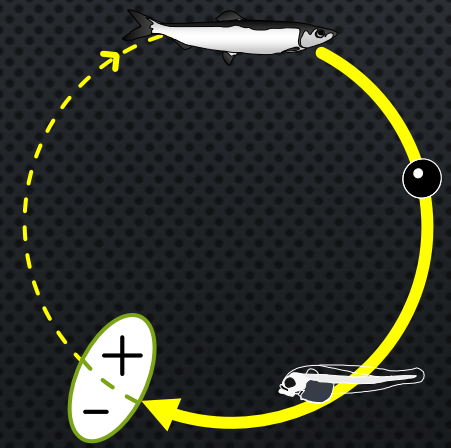
The Match Mismatch Hypothesis (MMH)

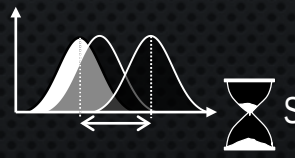




Cushing *et al.* 1969
Durant *et al.* 2007

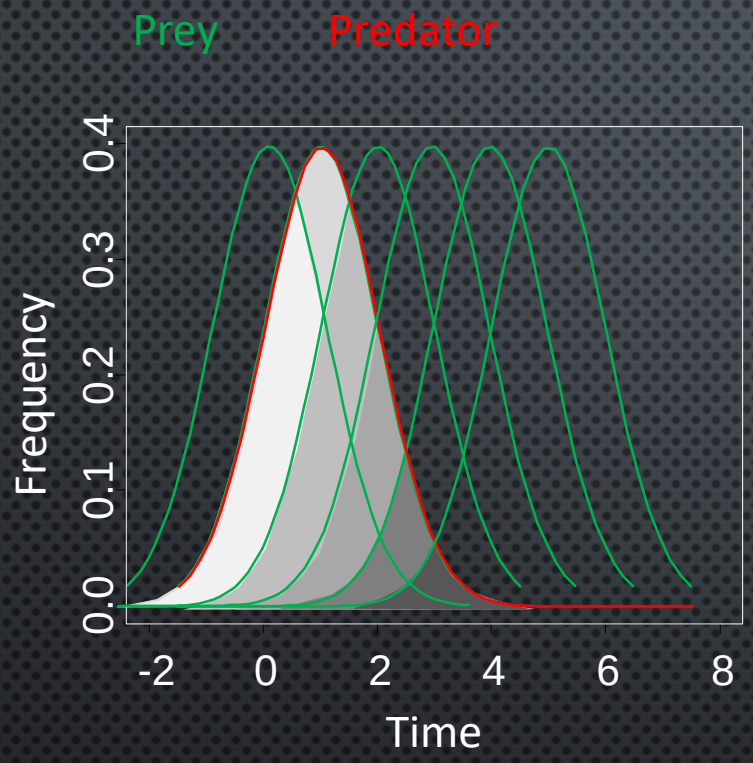






Synchrony/Asynchrony

What we added to the discussion

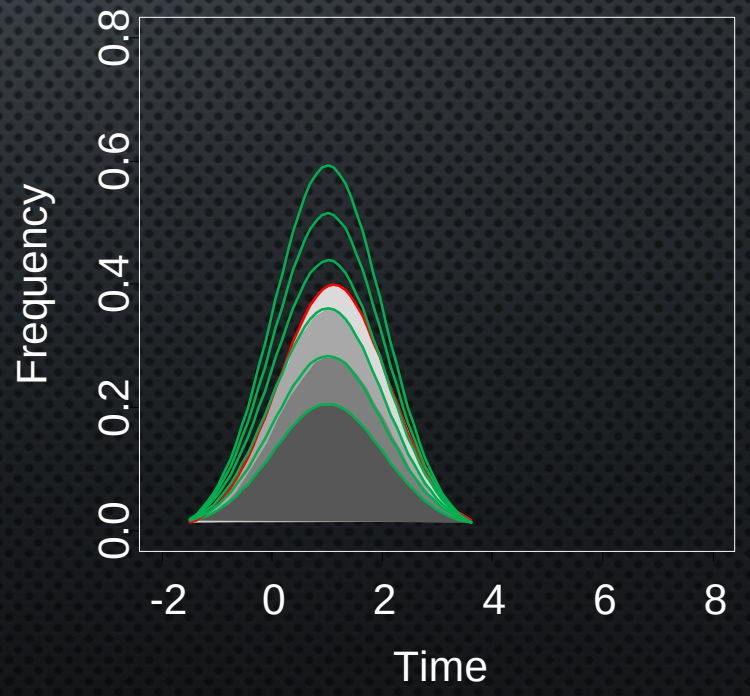


Change of the (a)synchrony

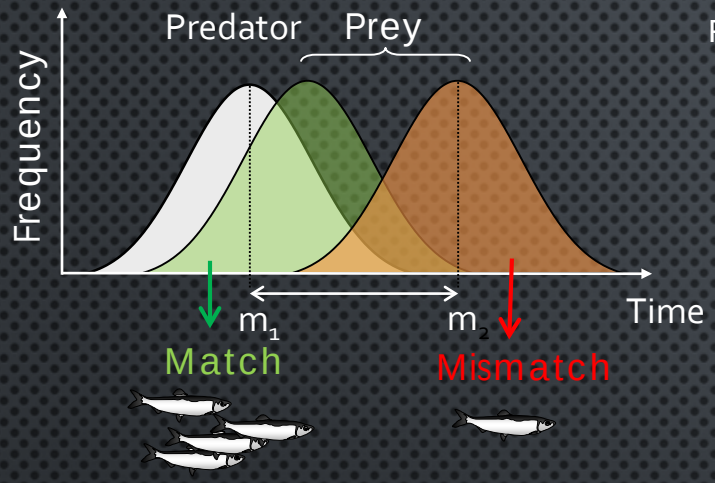
The importance to be *On Time*

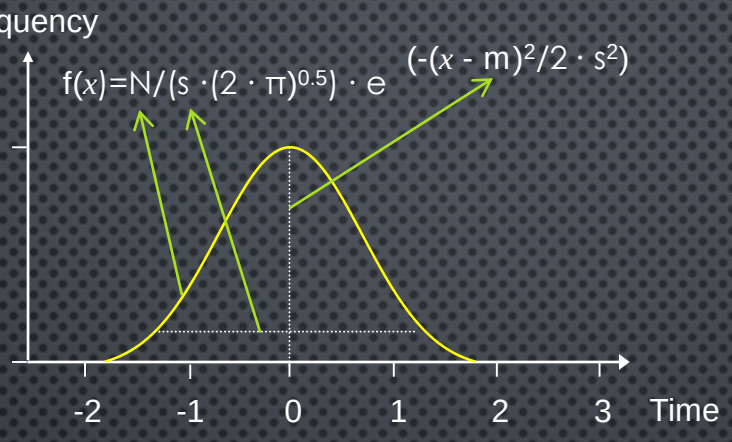
Increase of the prey abundance

The importance to have *Enough*

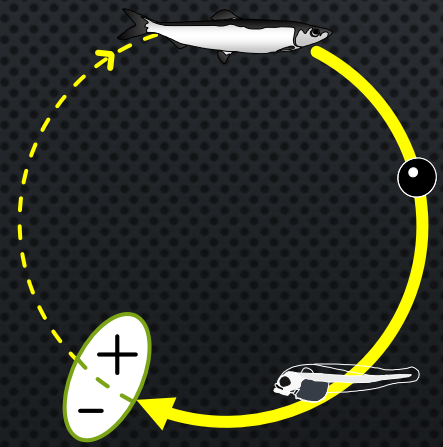


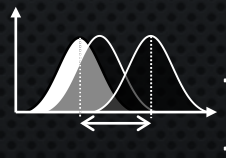
The Match Mismatch Hypothesis (MMH)



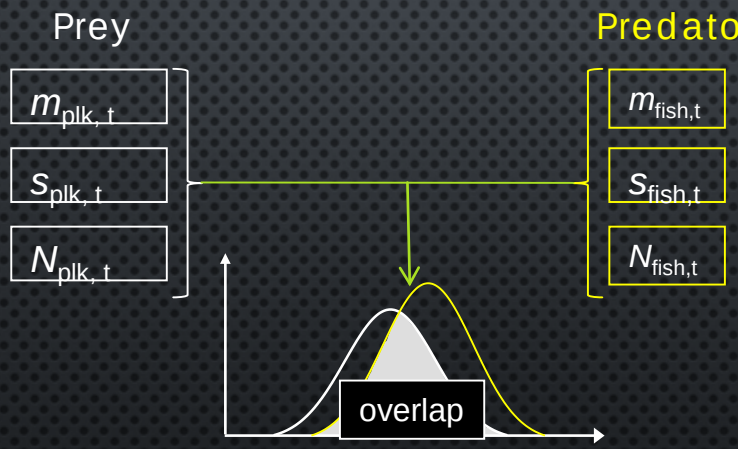


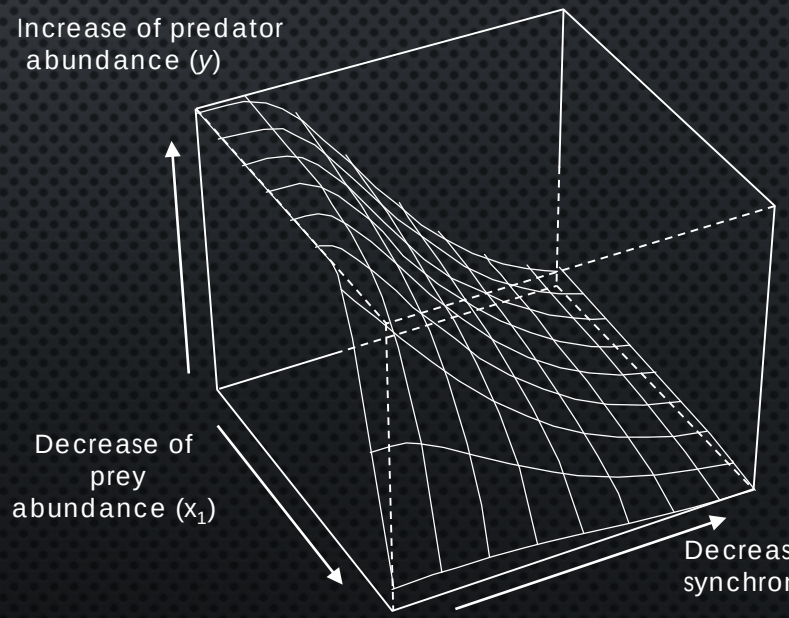
Cushing *et al.* 1969
Durant *et al.* 2007





Synchrony/Asynchrony





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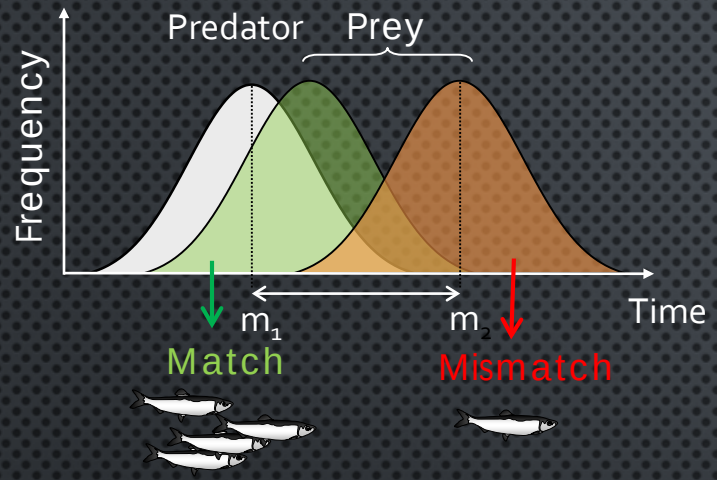
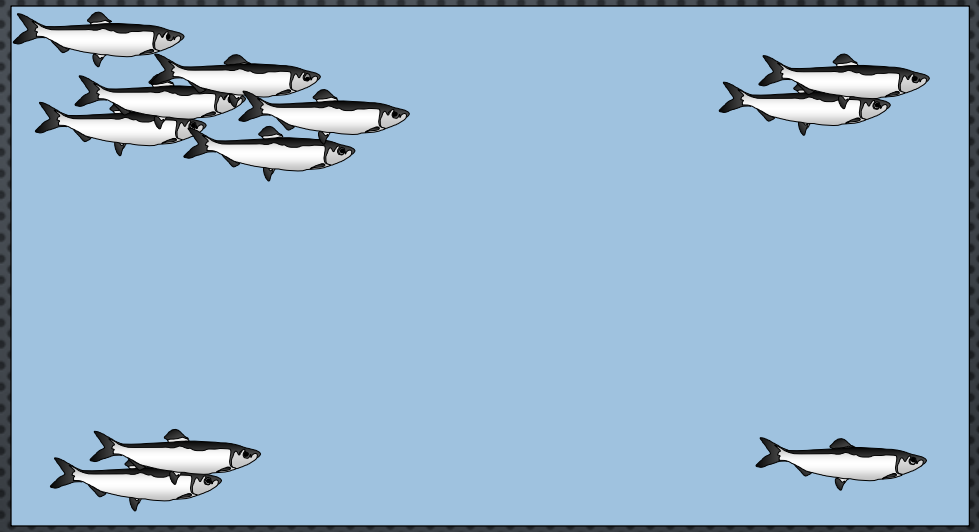
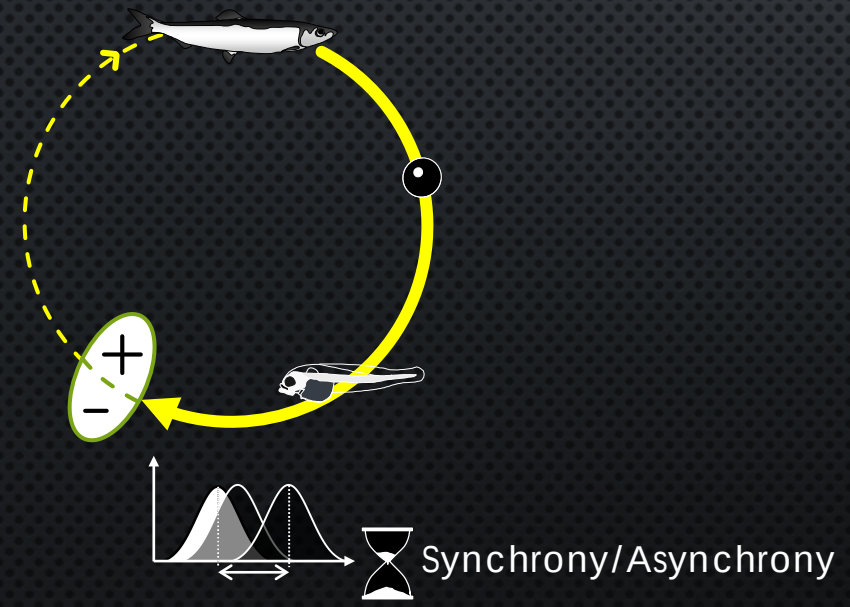
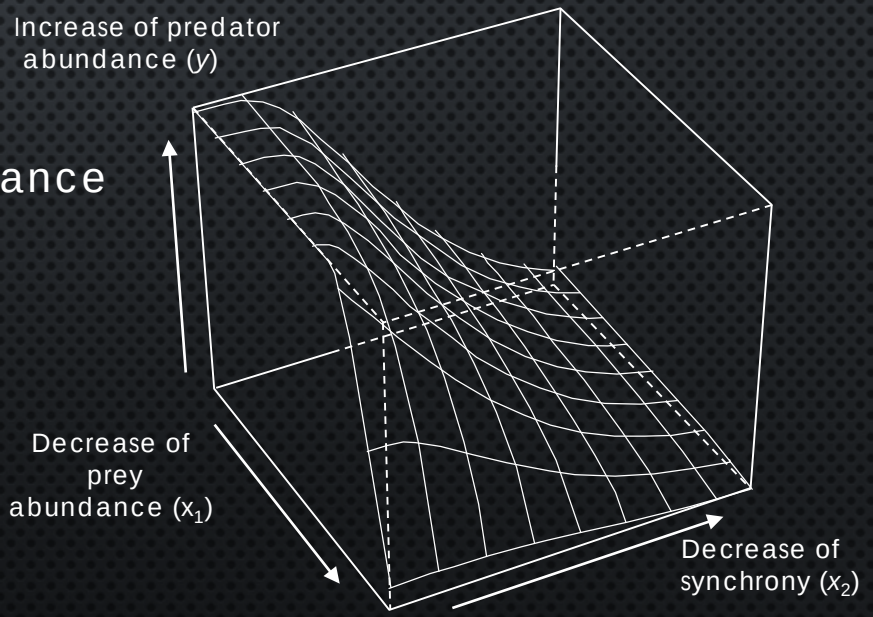


Cushing *et al.* 1969
Durant *et al.* 2007

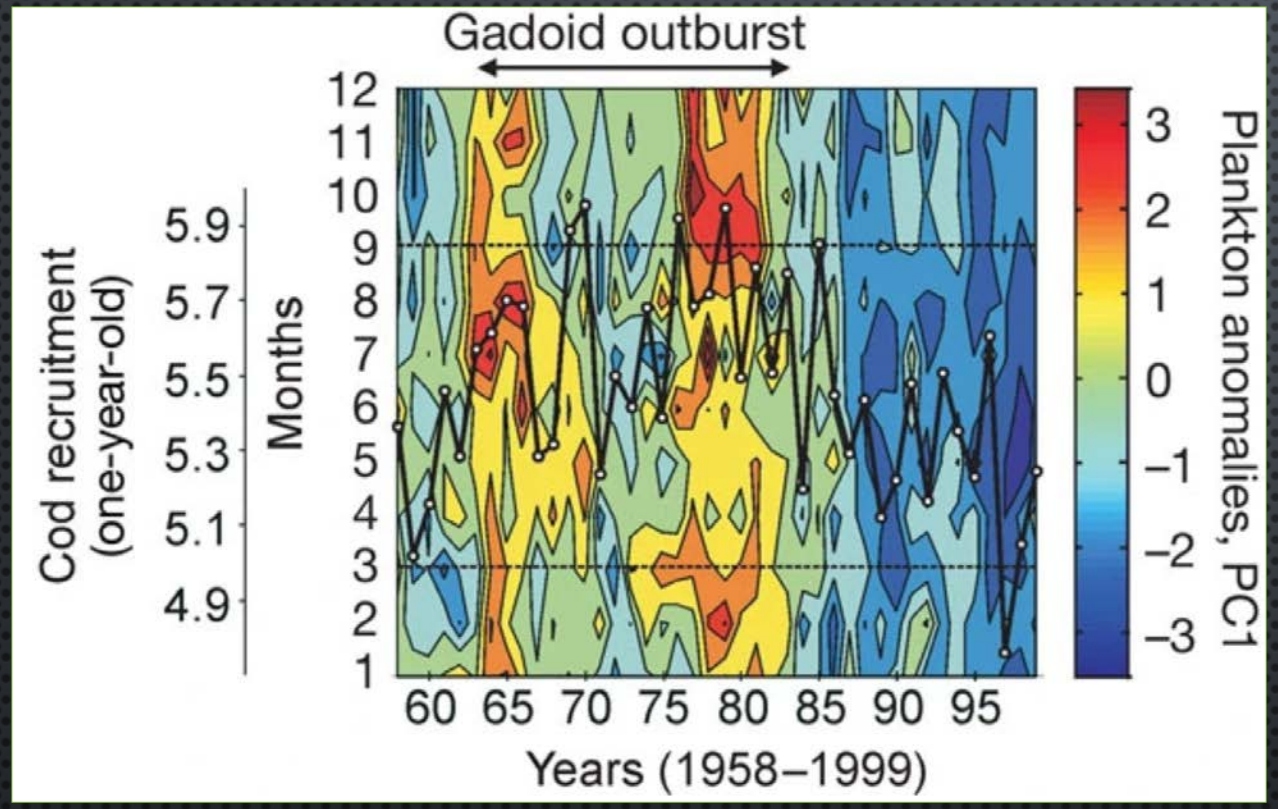




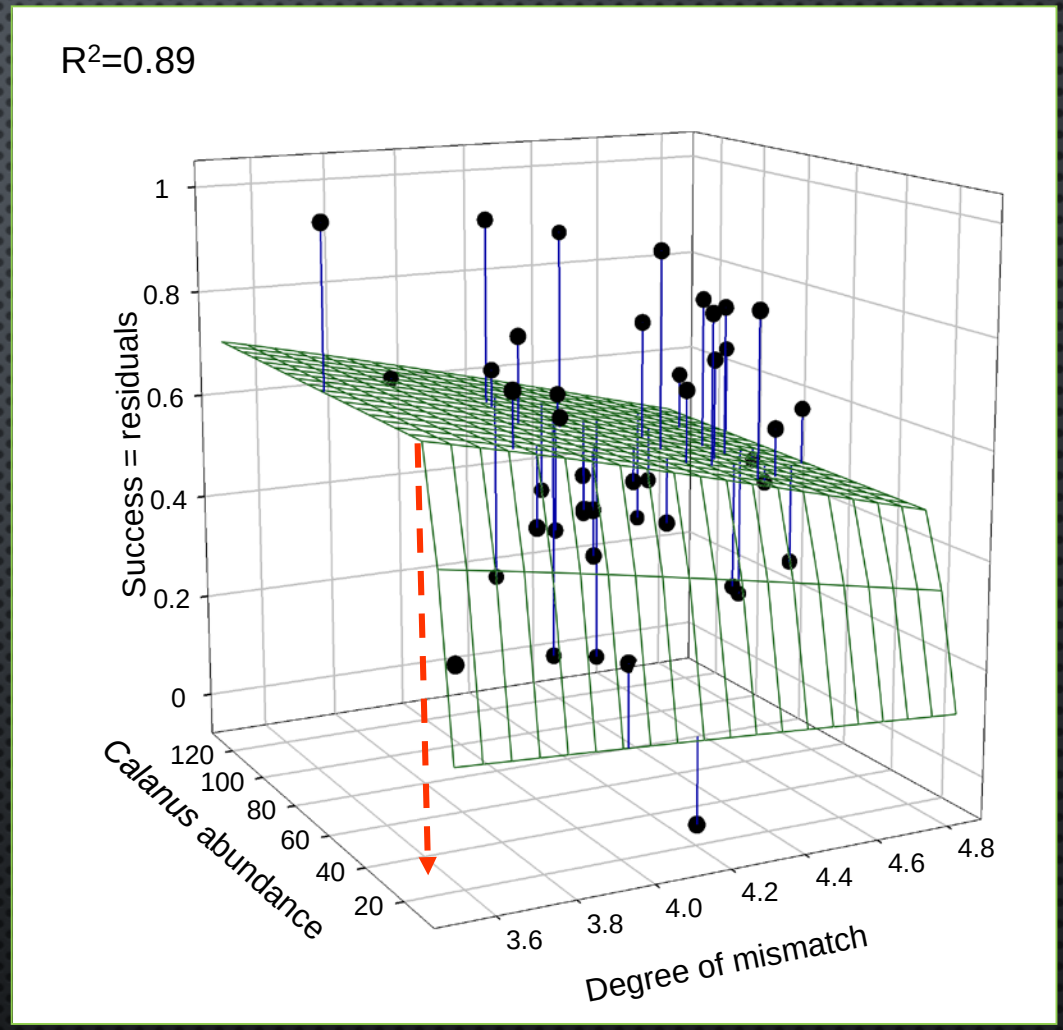
Durant *et al.* 2005
Showed the importance of considering the relative abundance of predator/prey



Cod and plankton in the North Sea



Beaugrand *et al*. 2003



Durant *et al*. 2005

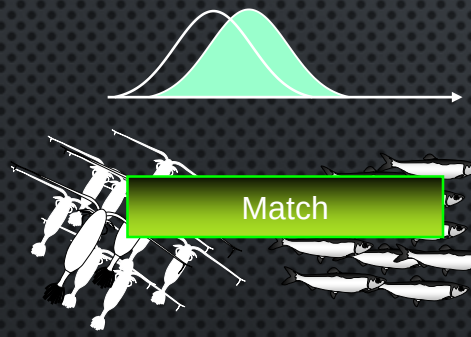
Where do we go from here?

How can we use the Match-Mismatch hypothesis ?

An ecosystem approach
Spatial mismatch
Projection

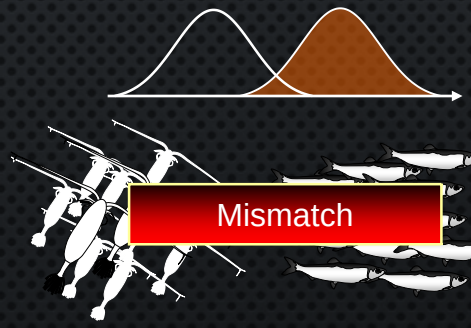
MMH and consequences for the ecosystem

Spawning area → Røst area



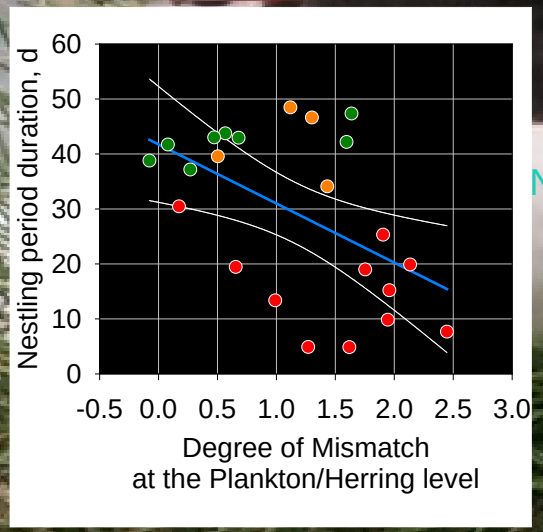
Good year

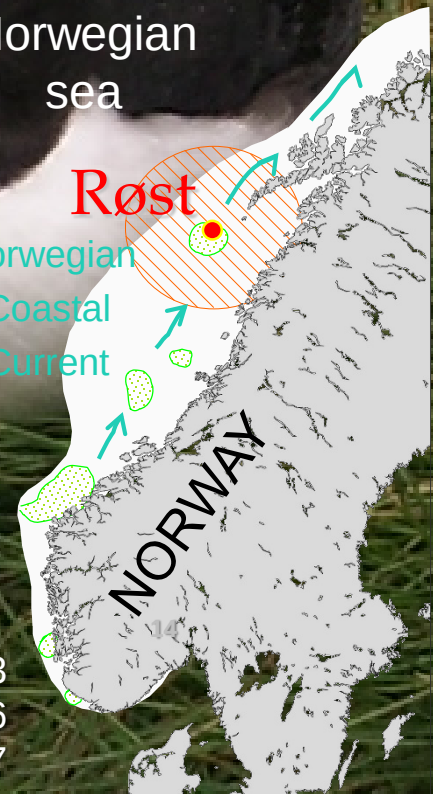
Many, large, schooling



Poor year

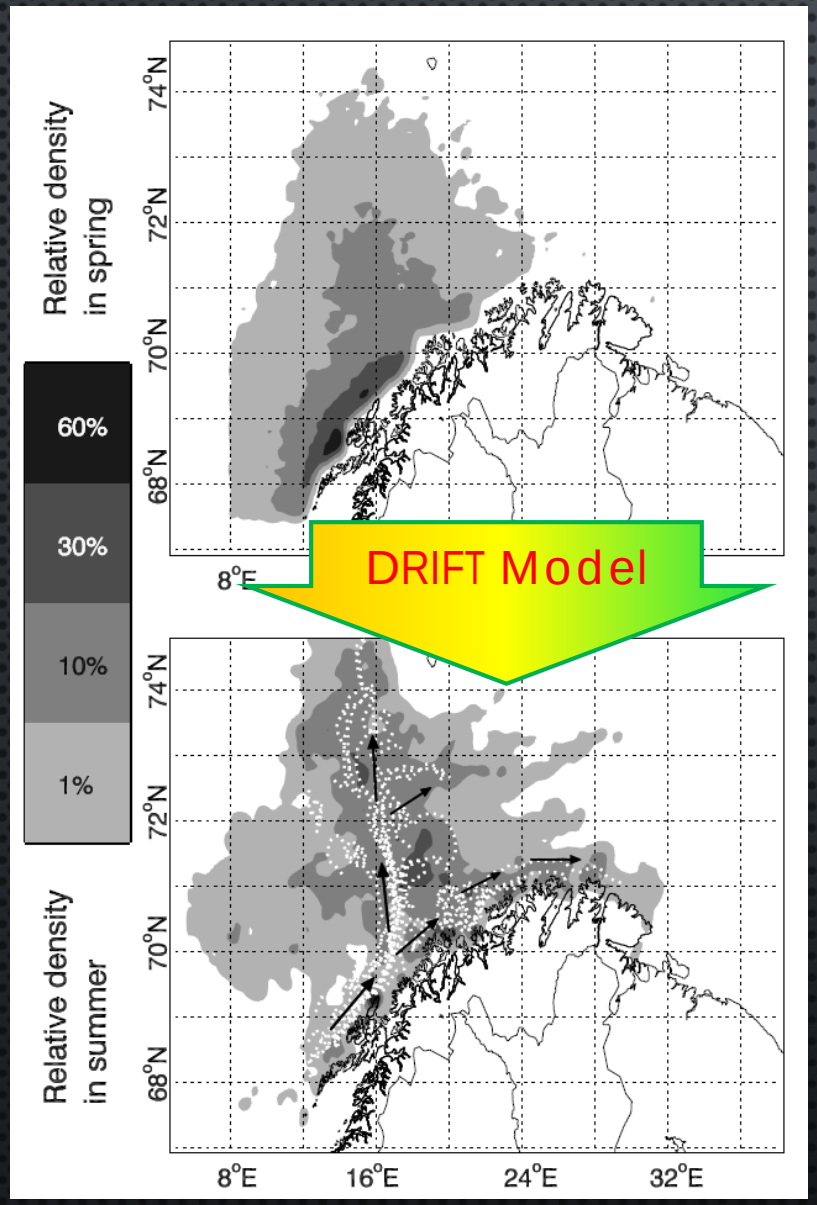
Few, small, dispersed





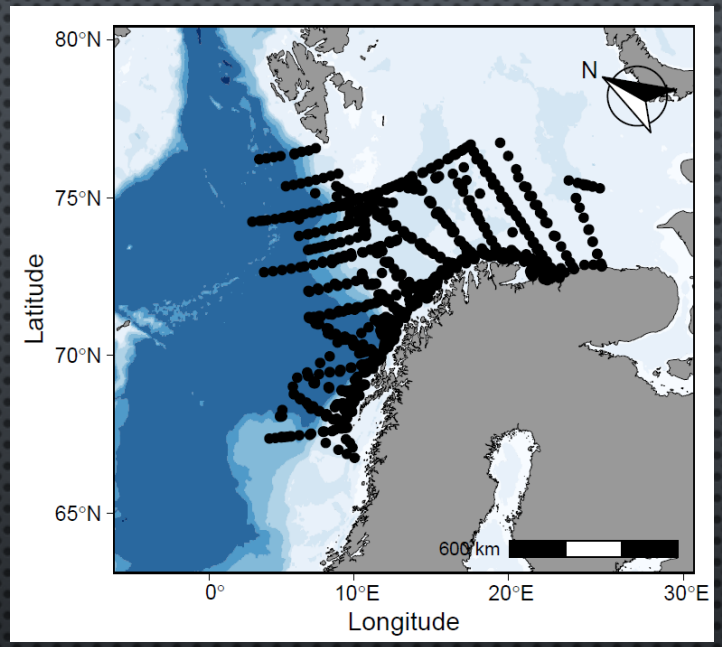
Durant *et al.* 2003
Durant *et al.* 2006
Durant *et al.* 2007

MMH & the spatial distribution



Langangen *et al.* 2014

Spatial distribution of zooplankton in the Norwegian-Barents Sea system



Consider the spatial distribution of both prey and predator
Ferreira *et al.* 2020

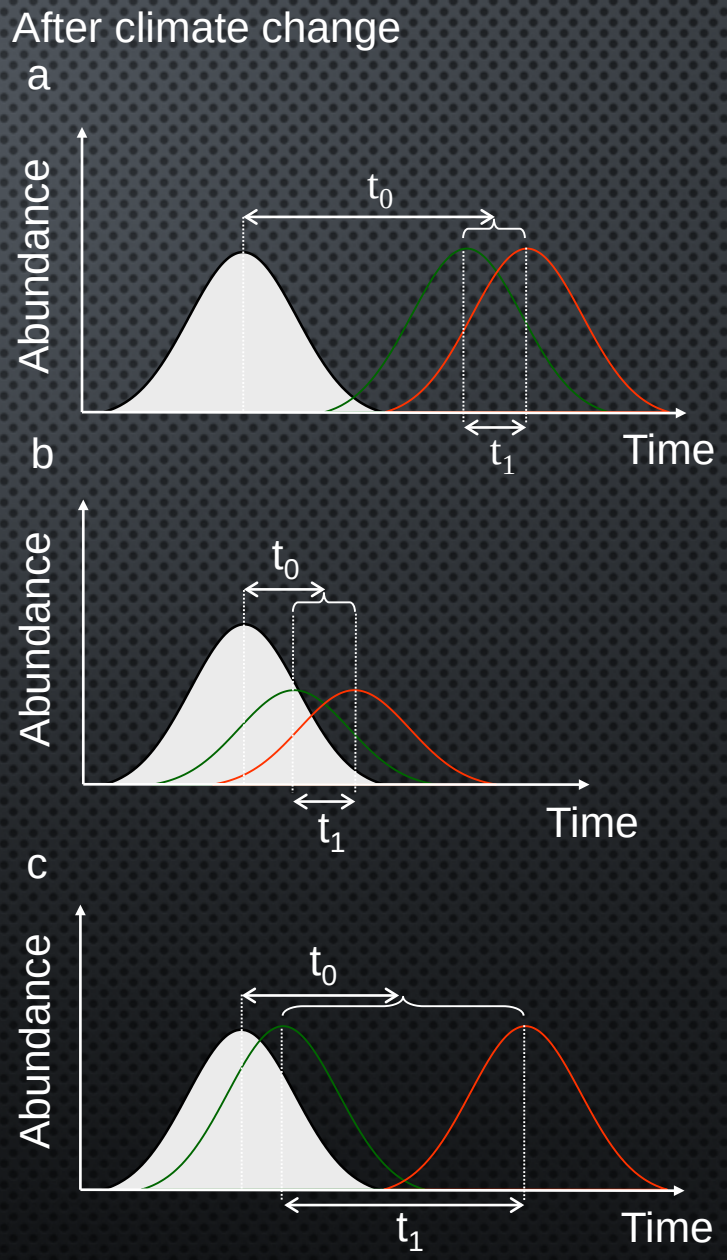
Explore the spatiotemporal overlap between the three species (cod, haddock, and capelin) on their survival at later stages.

Future and Match-Mismatch

Different time window creating a permanent "mismatch", e.g., Baltic tellin *Macoma balthica* (Philippart *et al*. 2003). If some overlap exists, there will be a a strong selection pressure on phenological extremes, hence on the phenotype.

Same time window but not enough prey for a successful predator reproduction, e.g. North Sea cod *Gadus morhua* L. (Beaugrand *et al*. 2004).

Extreme amplitude of inter-annual variation prey population creating an on-off pattern. This pattern may occur in regions where the inter-annual temperature variability is strongest (e.g., polar regions, Schär *et al*. 2004).



Cury *et al.* 2008

How to explore the Climate change consequences in the near future ?

Natural population

High variability
Poor data
Estimate
Environment dependent
Function not known
Weak relationships

Mathematical construction

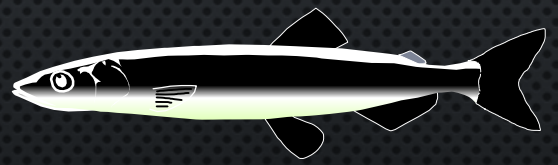
$$S(t) = \Pr(T > t)$$

$$l(t) = L_\infty (1 - e^{-K(t-t_0)})$$

$$R = \alpha S \, e^{-\beta S}$$

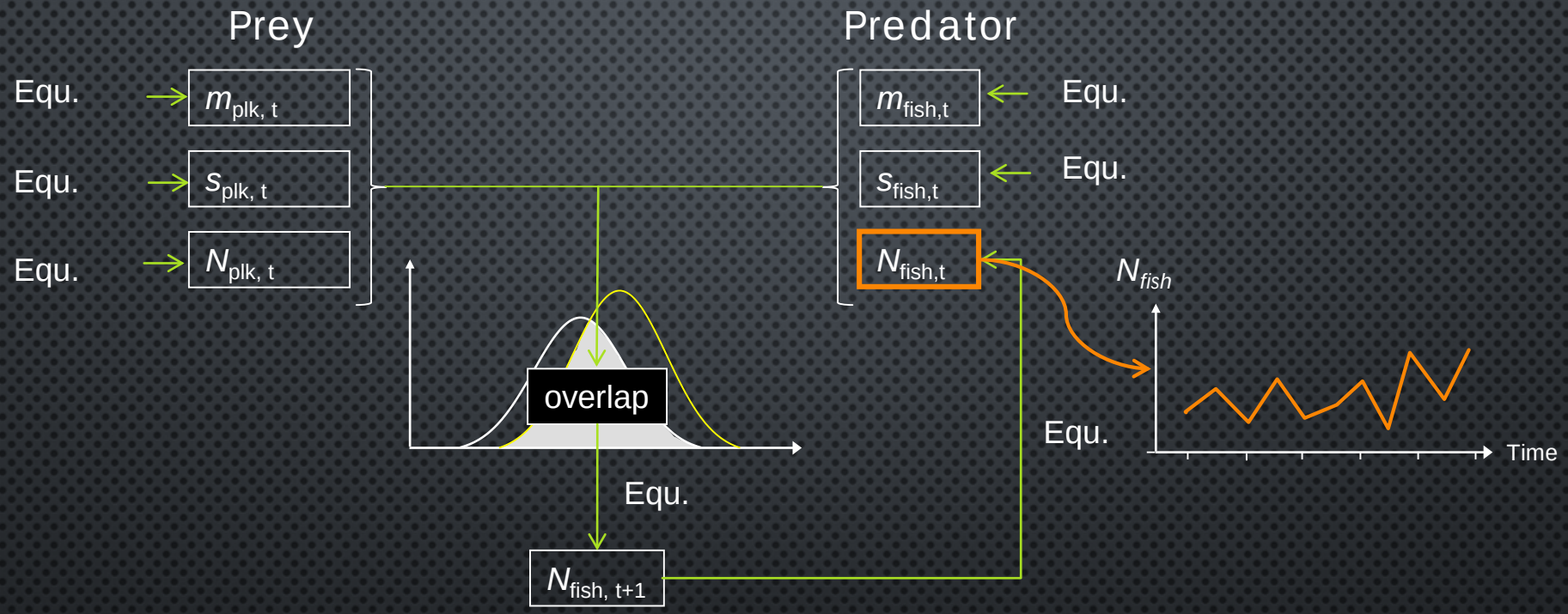
Unrealistic
Idealist
Predictable

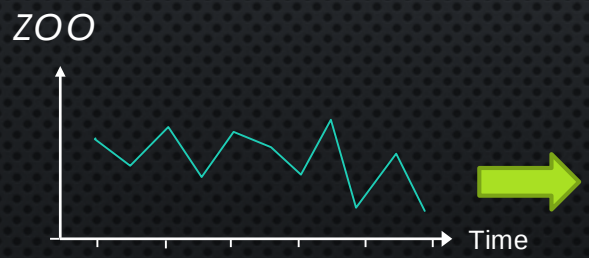
Modeled population



Mimicked real data
Environment dependent
Known relationships and function
Predictable

Development of a mechanistic model

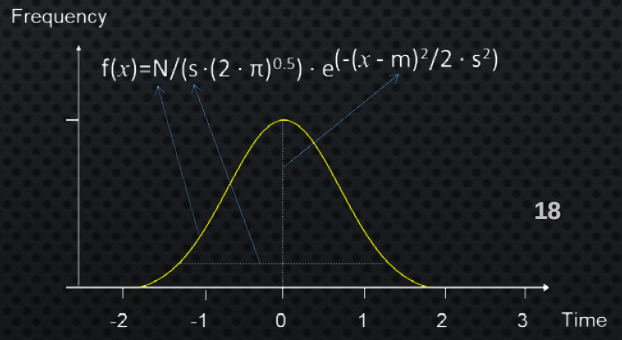




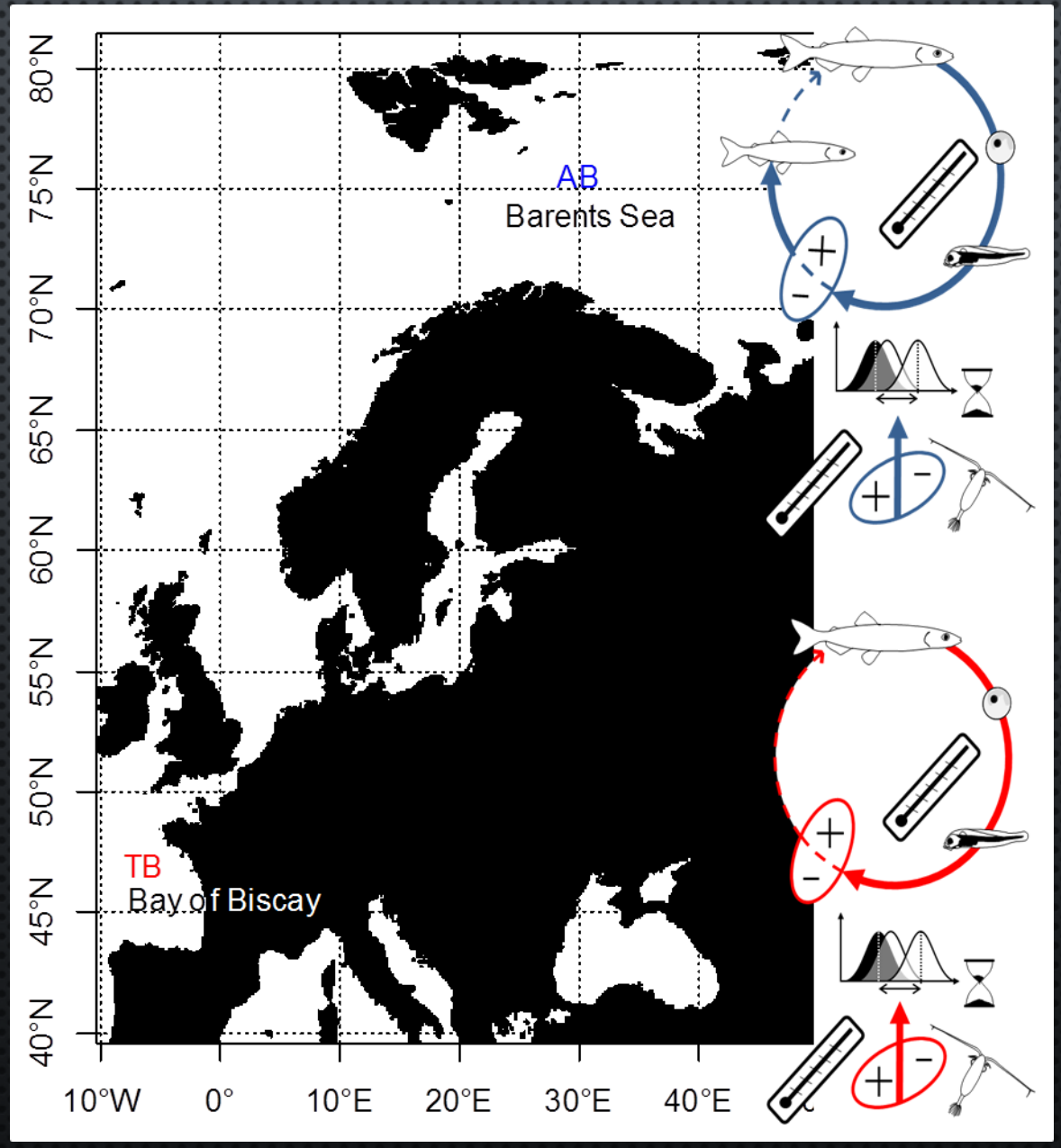
$$ZOO_{(T)} = 0.88 + 0.16 \cdot NAO_{(T)} + 0.51 \cdot TEMP_{(T)} - 0.42 \cdot ZOO_{(T-1)}$$

Stige *et al*. 2013

Normal distribution



Study area and schematic presentation of the life cycles used

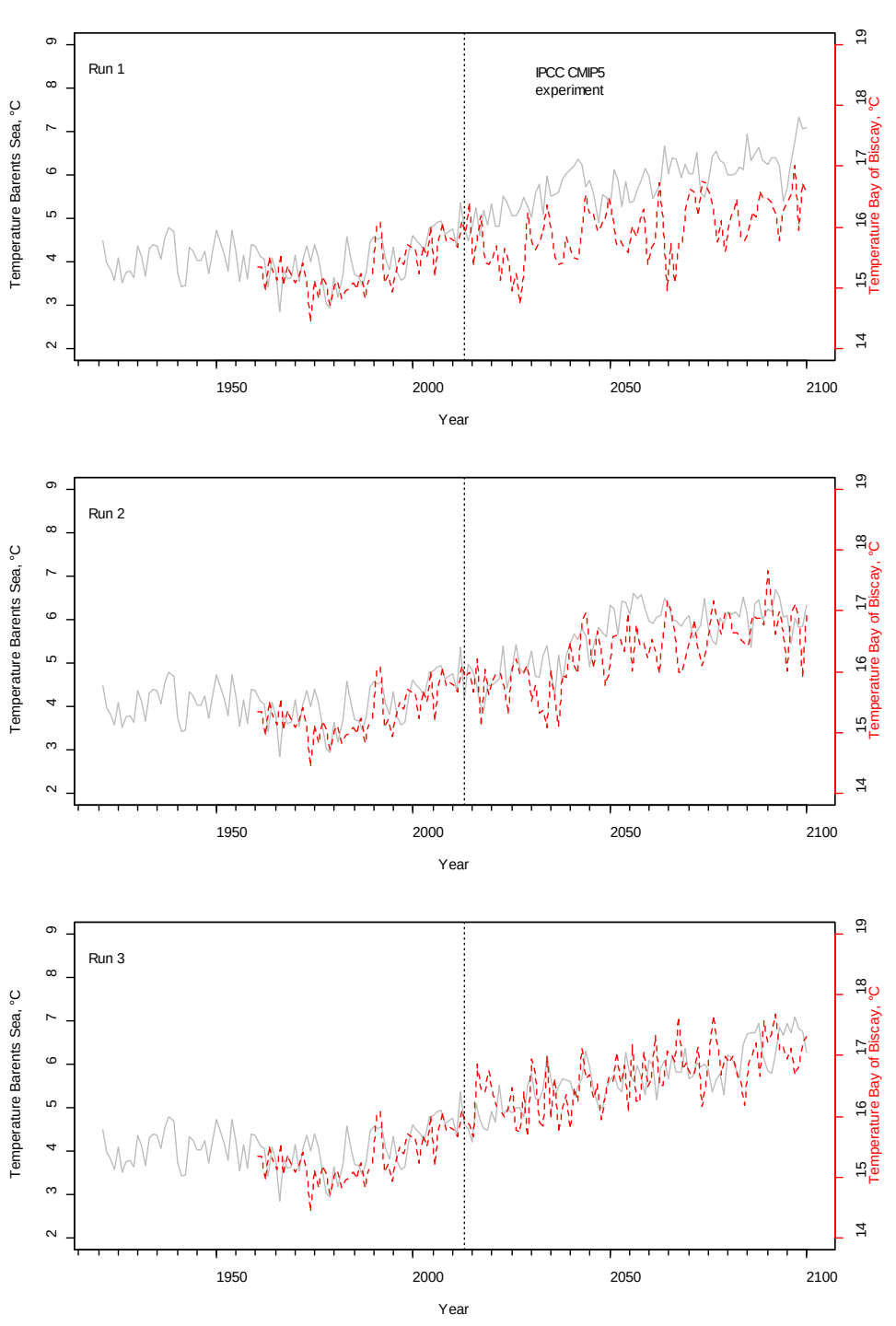


Durant *et al.* 2019

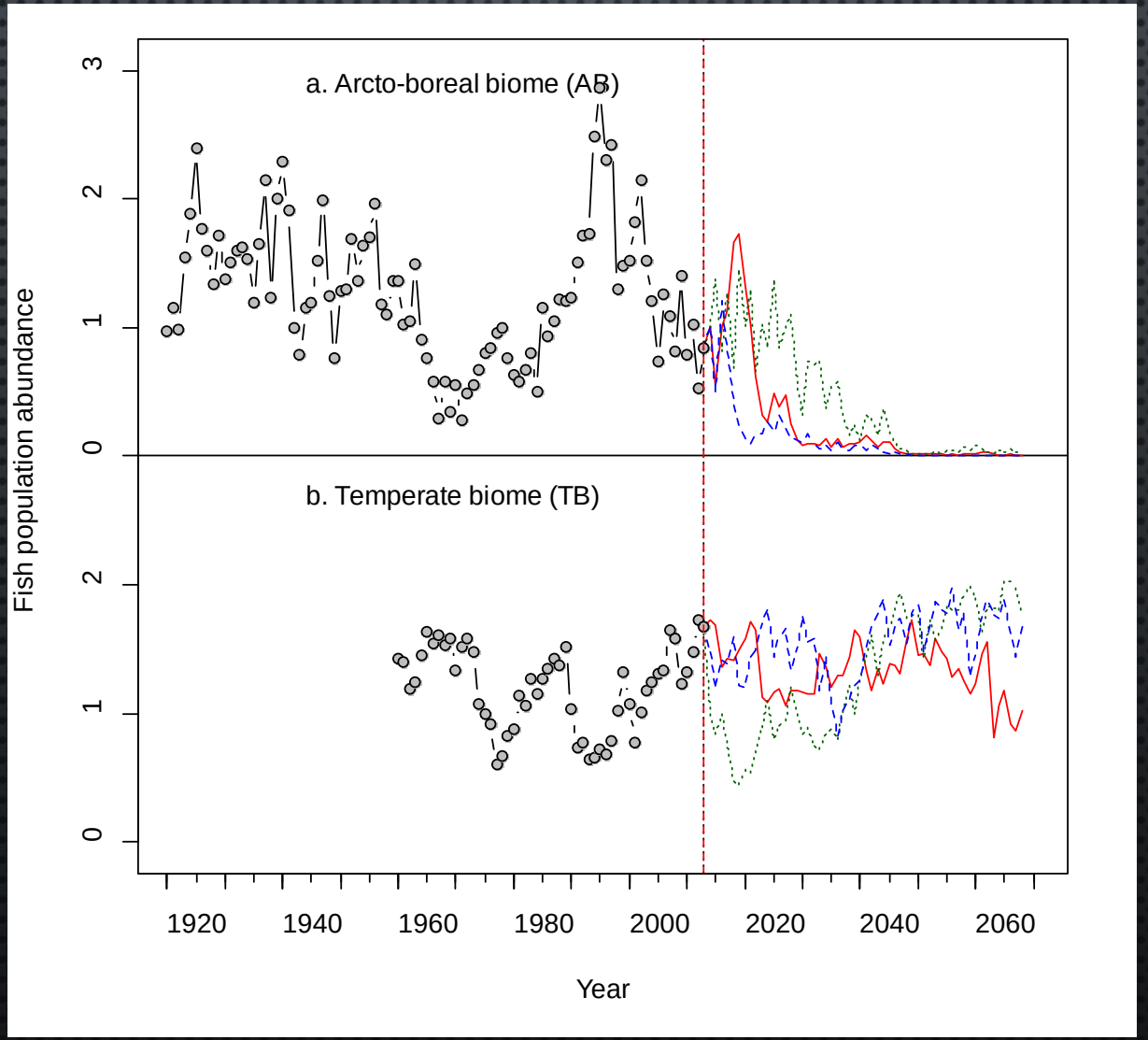
Historical and projected temperature change by a high emissions scenario

(RCP4.5, radiative forcing of 4.5 W m^{-2} at year 2100 relative to pre-industrial conditions)

Durant *et al.* 2019

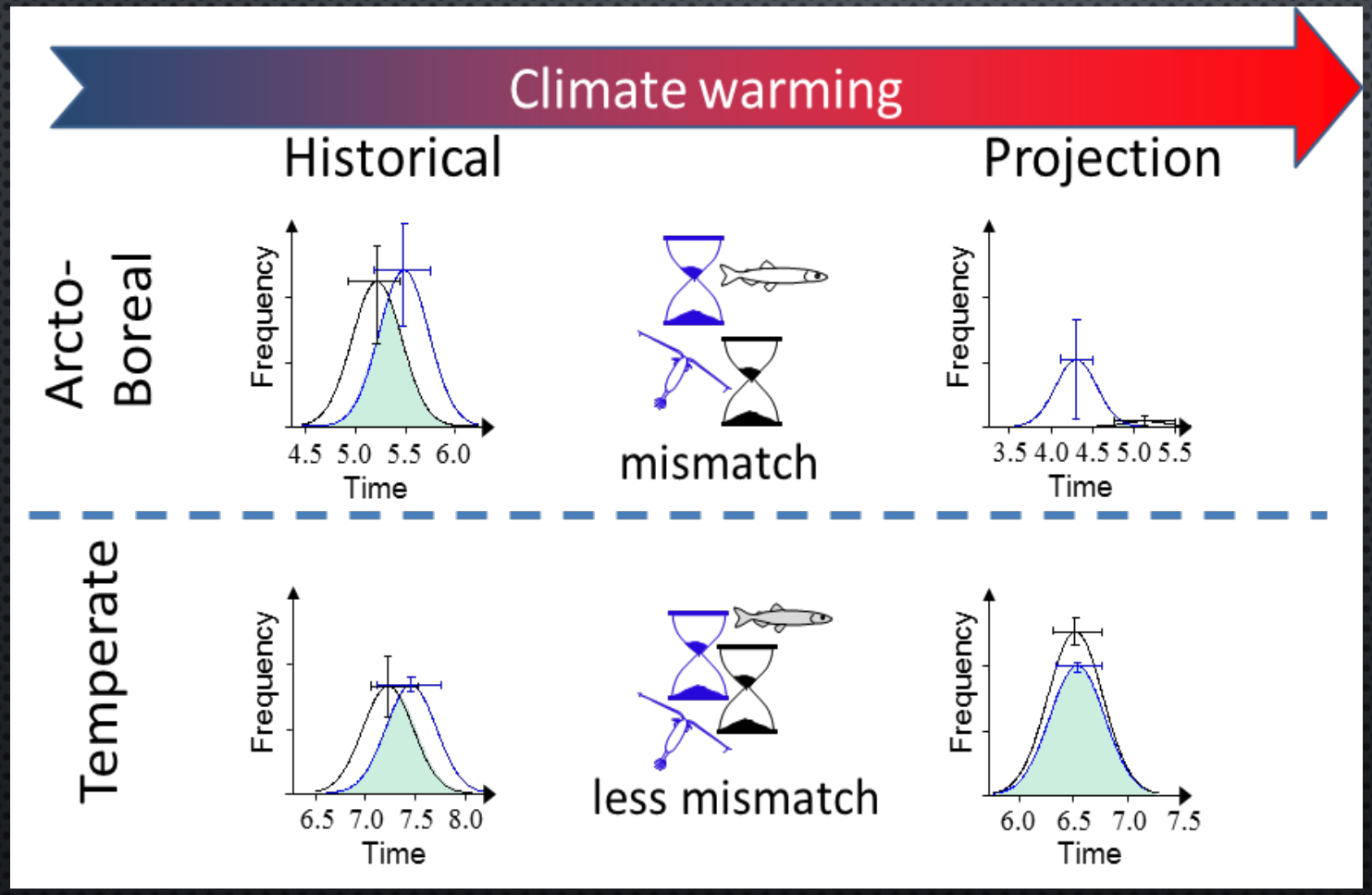


Temperature and match-mismatch effects on the fluctuations of the fish populations

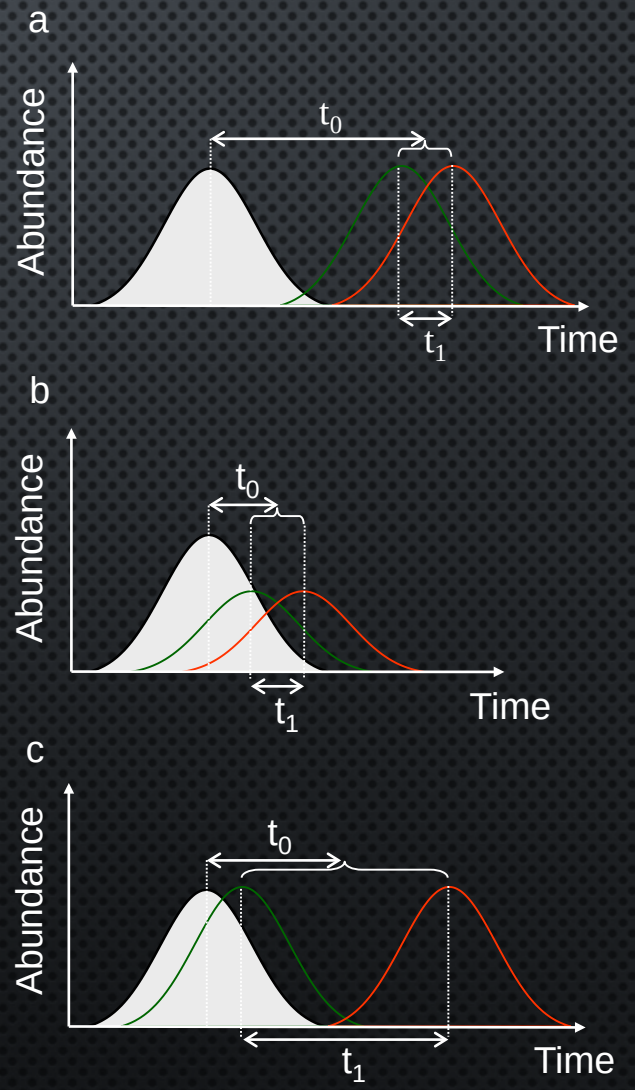


Durant *et al.* 2019

Effect of climate change on match-mismatch and population change in two different biomes



After climate change



Durant *et al.* 2019

Take home

- General importance of the food abundance for recruitment and mismatch analysis

An ecosystem approach

- A mismatch can propagate in the food chain
- Climate effect may be even stronger at this level

Spatial mismatch

- Similar to food abundance, the spatial distribution can disrupt the match between predators and prey

Using the match-mismatch for projections

- Due to climate change, we will have to get used to a world where our knowledge on ecosystem and trophic interactions is not anymore accurate or at least reliable
- To make projections, we need to use a mechanistic model.

Acknowledgements

I am grateful to all the people I collaborated with on the MMH
Particularly to:

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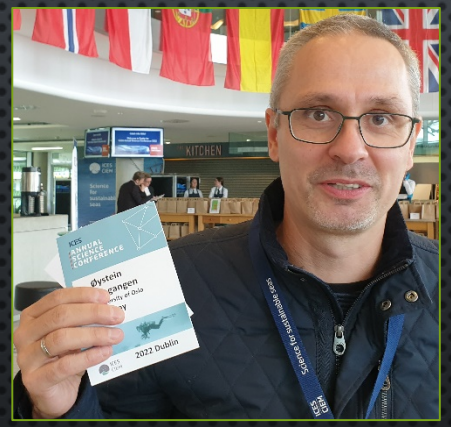
Ø. Langangen, AQUA, University of Oslo
N.C. Stenseth, CEES, University of Oslo



Convenors session 3:
Rebecca Asch
Matthew Baker
Jennifer Boldt
Patrick Polte

The Research Council of Norway