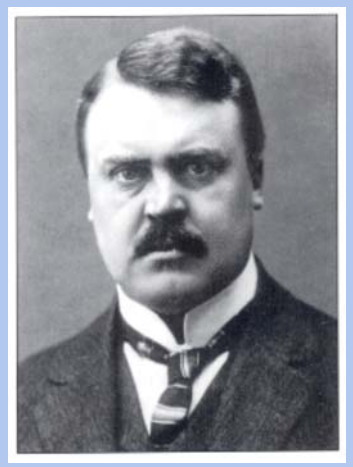
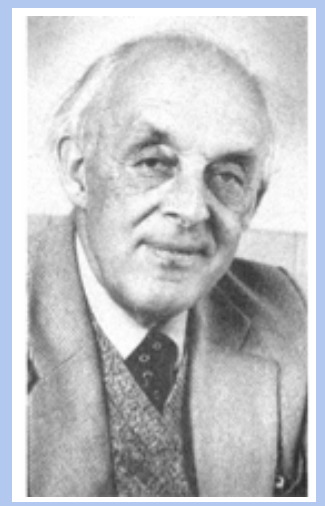
Match-Mismatch:

Trophic interactions and climate change





1914: Johan Hjort adopts the concept that understanding cod and other fishe s 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.

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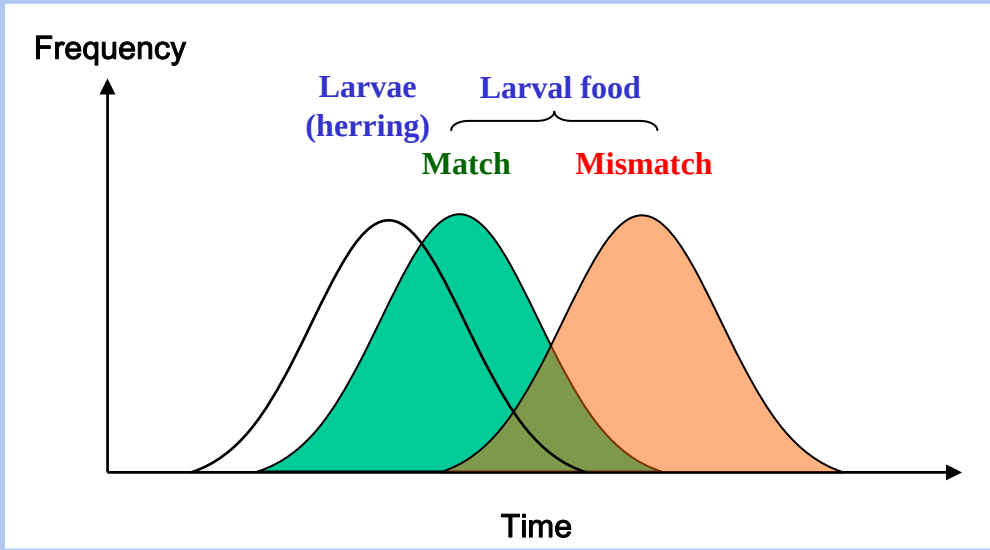
EcoClim NORDIC CENTRE OF EXCELLENCE PROGRAMME OSLO-HELSINKI-LUND

PICES XVI annual meeting, Victoria, BC. Nov.2, 2007

Match or Mismatch

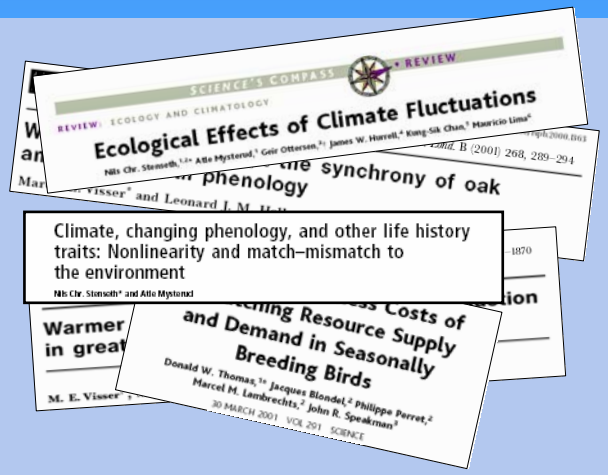
If recruitment-production at a given trophic level *matches* food availability, effective recruitment will be profound. If there is a *mismatch* between food requirement and food availability, effective recruitment will be low.

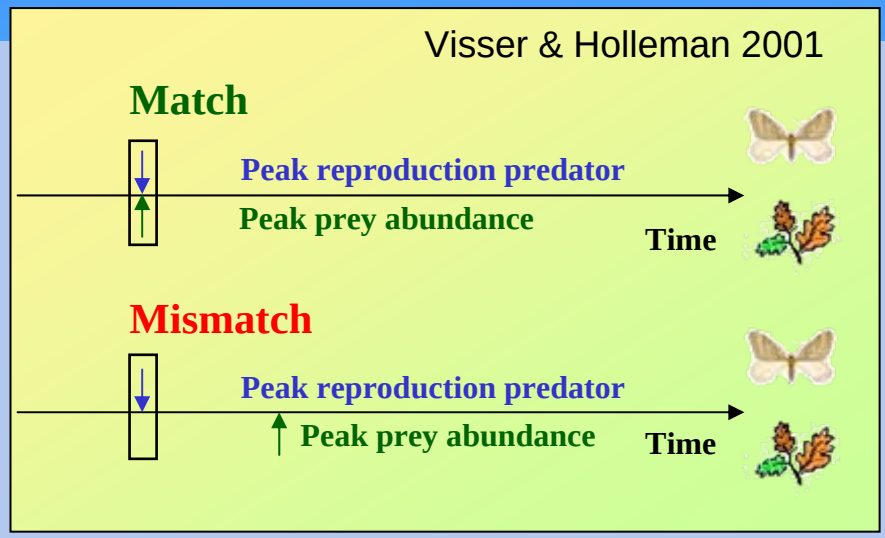


Cushing 1969 J Cons Int Explor Mer 33: 81-,
1990 Adv Mar Biol 26: 249-

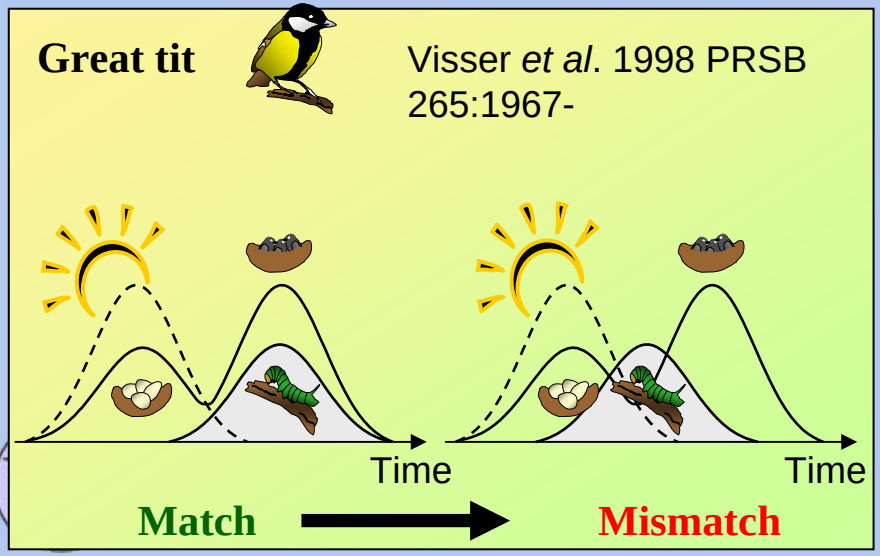
Match-mismatch in terrestrial systems

A climate perspective

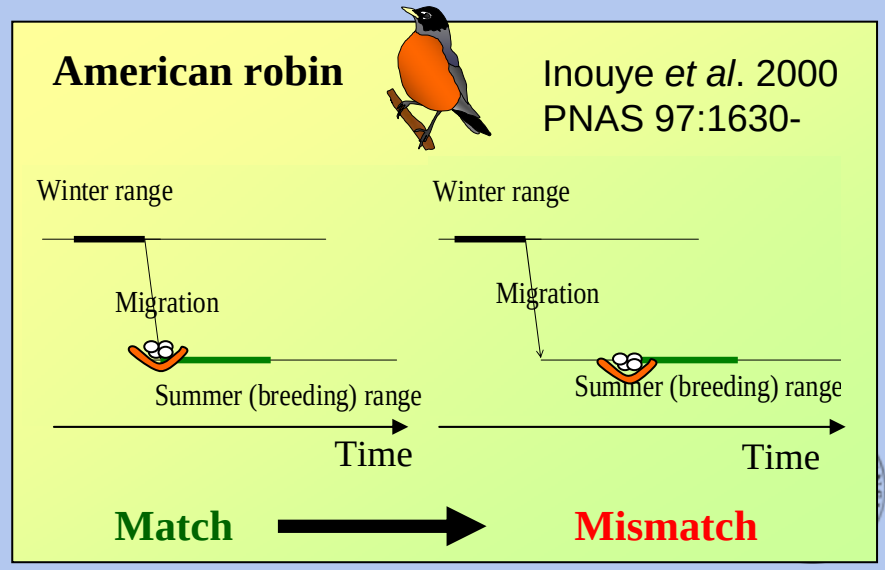




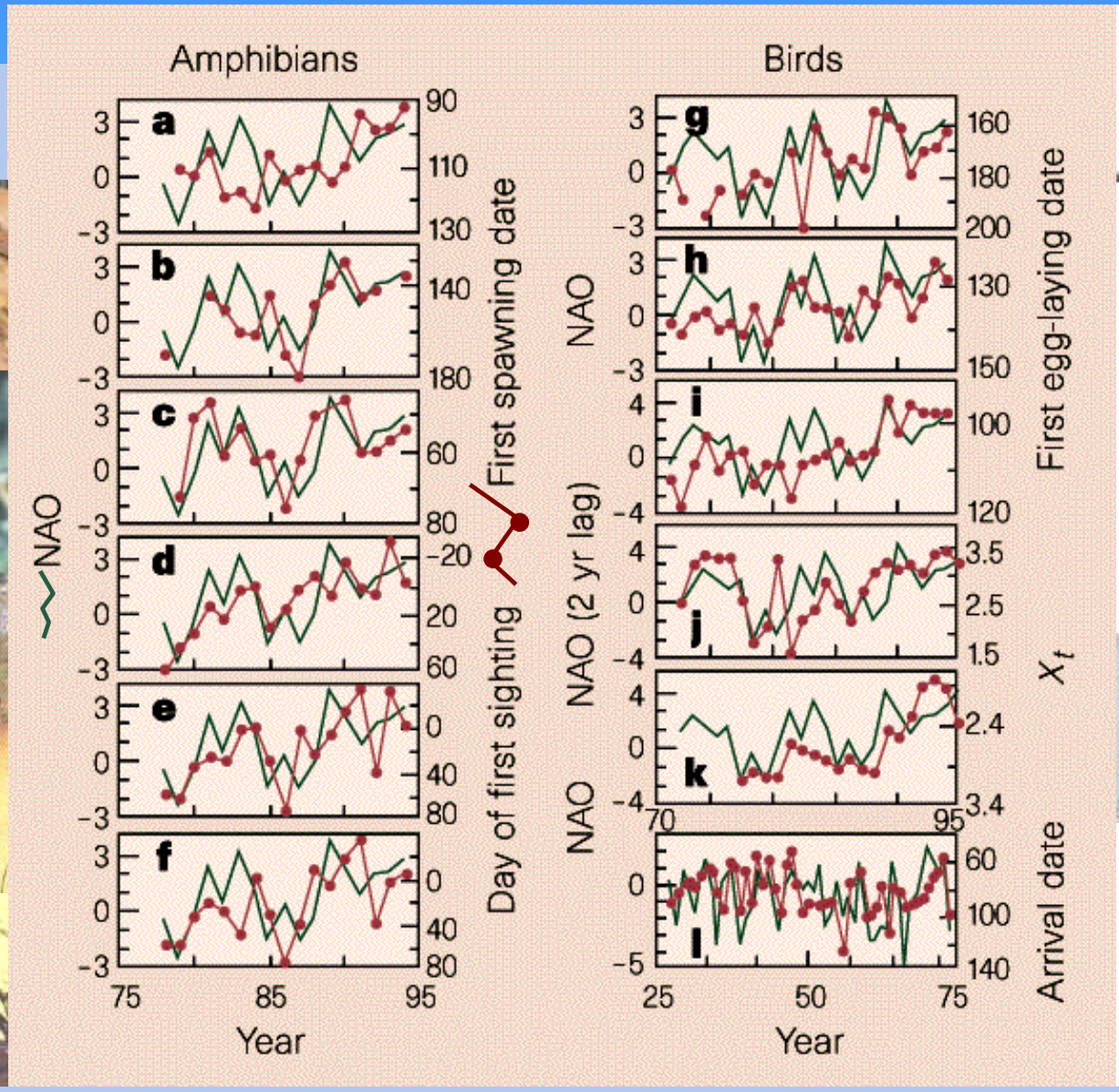
Climate effect on bird reproduction



On bird migration

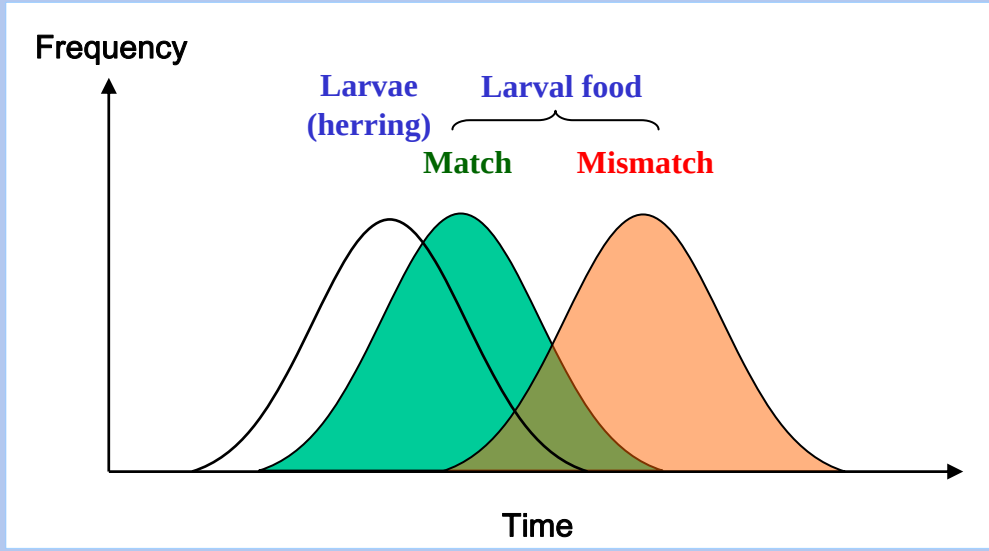


Climate and breeding phenology



Forchhammer et al. 1998 Nature 391:29-

What can we add to the discussion?



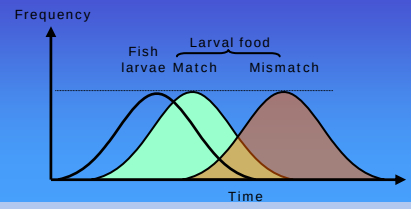
The time production of fish larvae should be matched or mismatched to that of their food

1. **If matched, recruitment would be high within the limits of variation of the primary production**
2. **If mismatched, recruitment will be low- more so if primary production is low, but less so if it is high.**

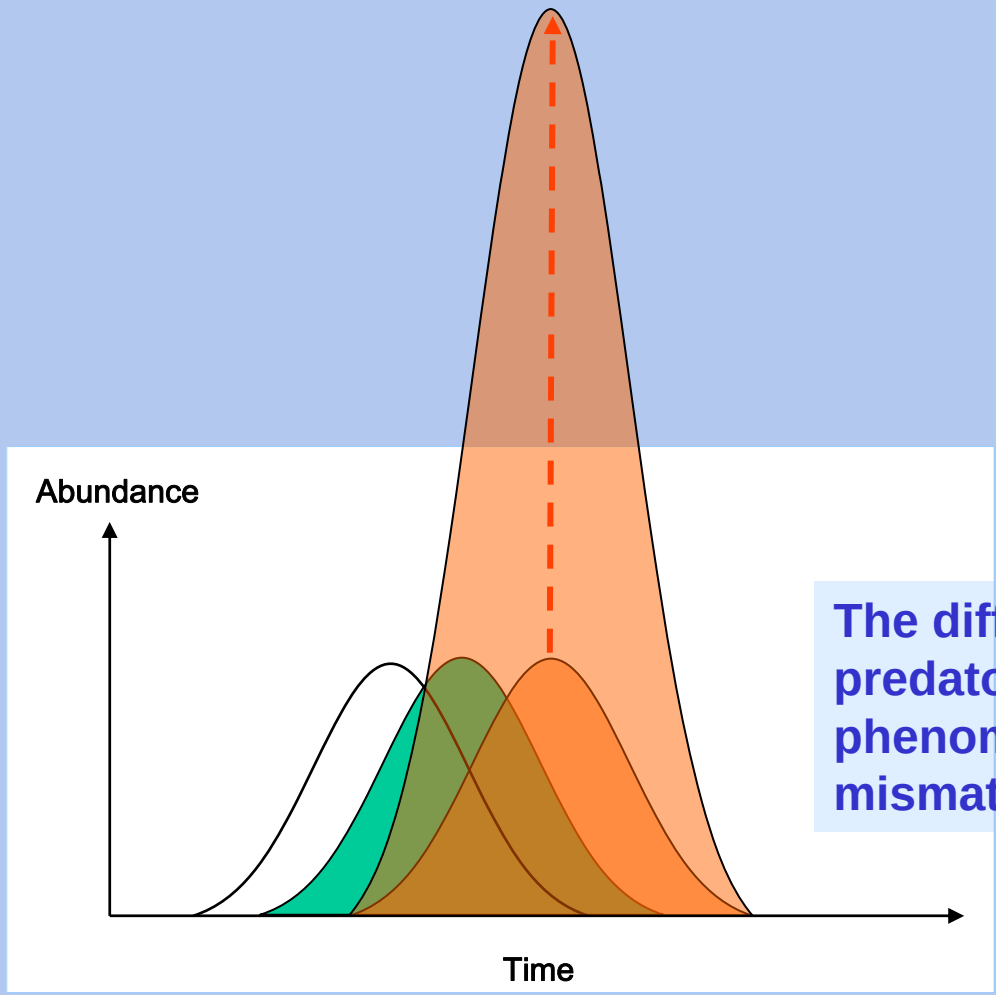
Cushing 1990 Adv Mar Biol 26: 249-

Match or mismatch:

The role of abundance



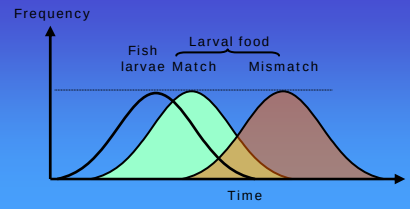
Match-Mismatch



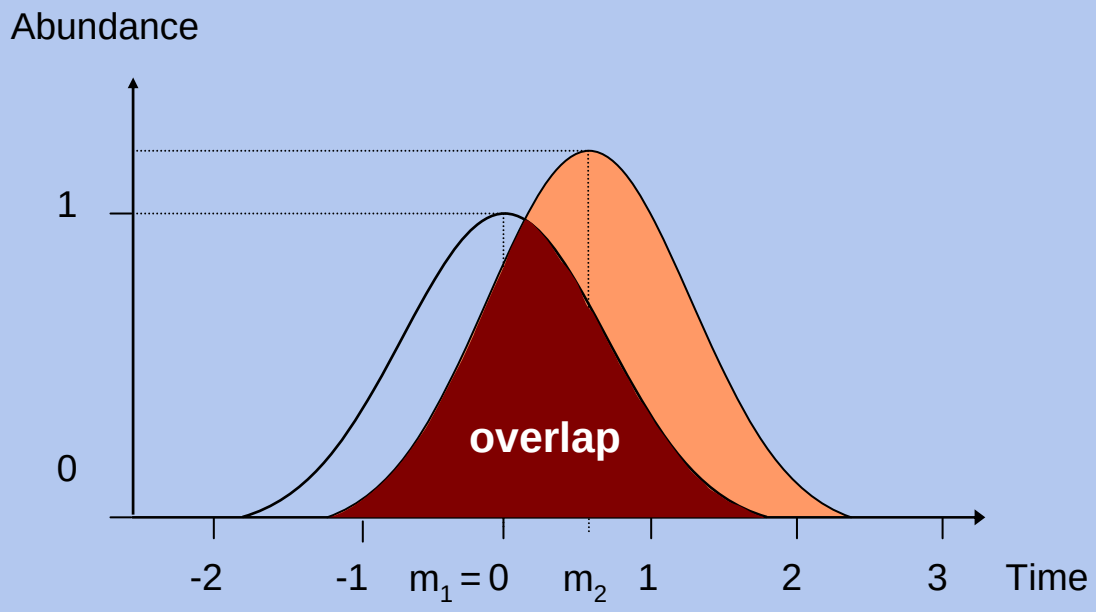
The difference in abundance of predator/prey can disrupt or amplify the phenomenon described by the match-mismatch hypothesis

Match or mismatch:

The role of abundance



Match-Mismatch



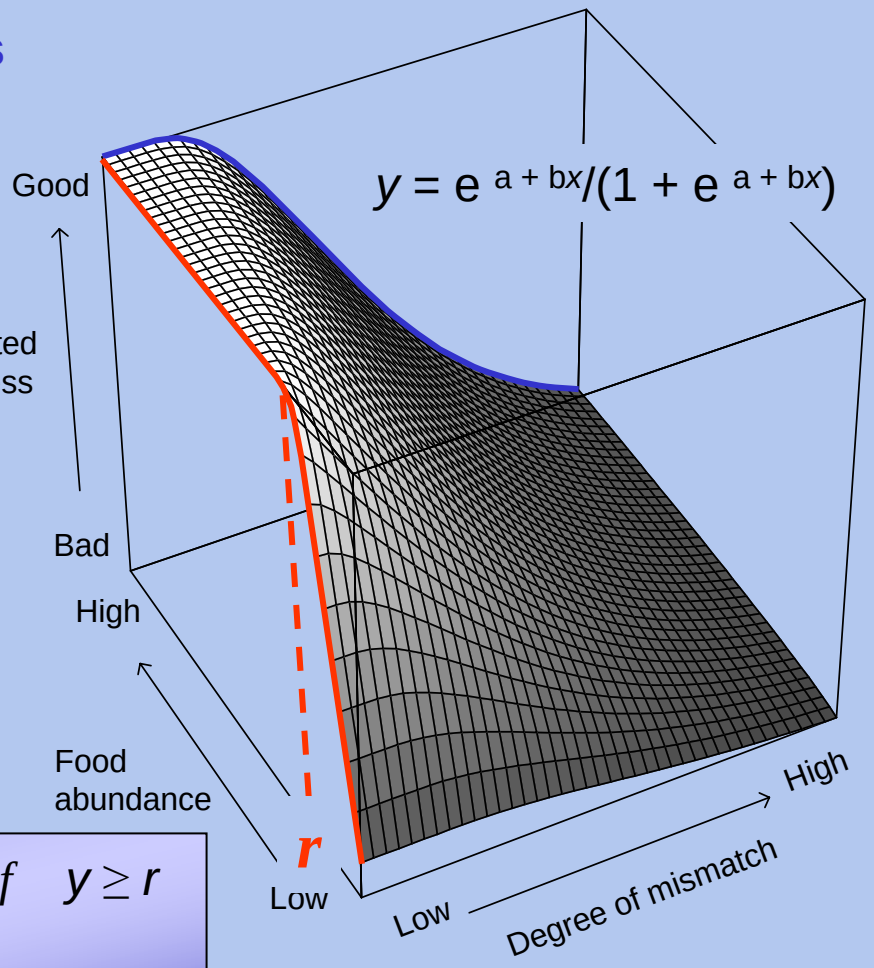
- We considered that the overlap of the curves is proportional to the reproductive success
- We calculated the overlaps resulting from the changes of mismatch degree (m_2-m_1) and Abundance

Effect of mismatch and food abundance on recruitment

Considering the overlap of the curves is proportional to the success.

$y = 1 \quad \geq r$

$y = c\,x + d < r$

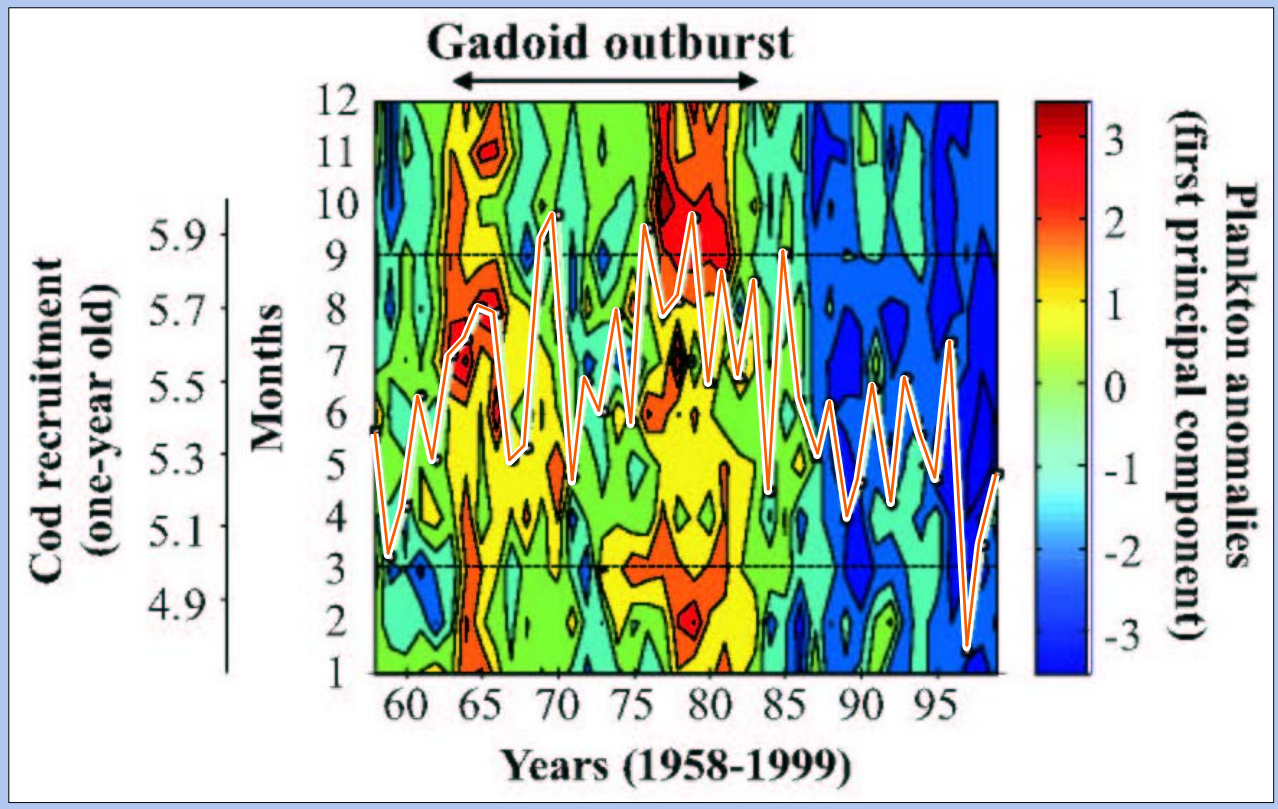


$$F(x, y) = \begin{cases} e^{a + bx}/(1 + e^{a + bx}) & \text{if} \quad y \geq r \\ [e^{a + bx}/(1 + e^{a + bx})][1 + c(y - r)] & \text{if} \quad y < r \end{cases}$$

With r = Food abundance

Durant *et al.* 2005 Ecol Lett 8:952

Cod and plankton in the North Sea

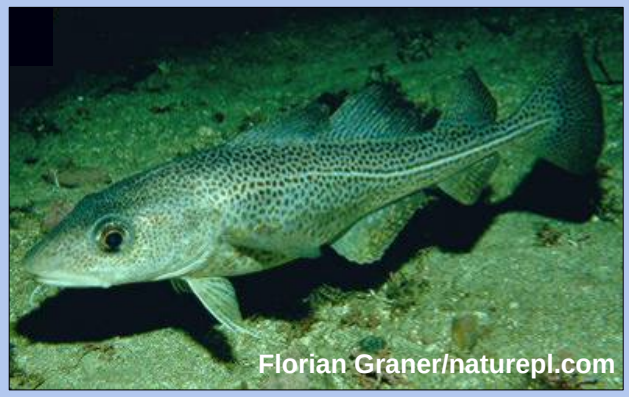


Beaugrand *et al.* 2003 Nature 426:661-

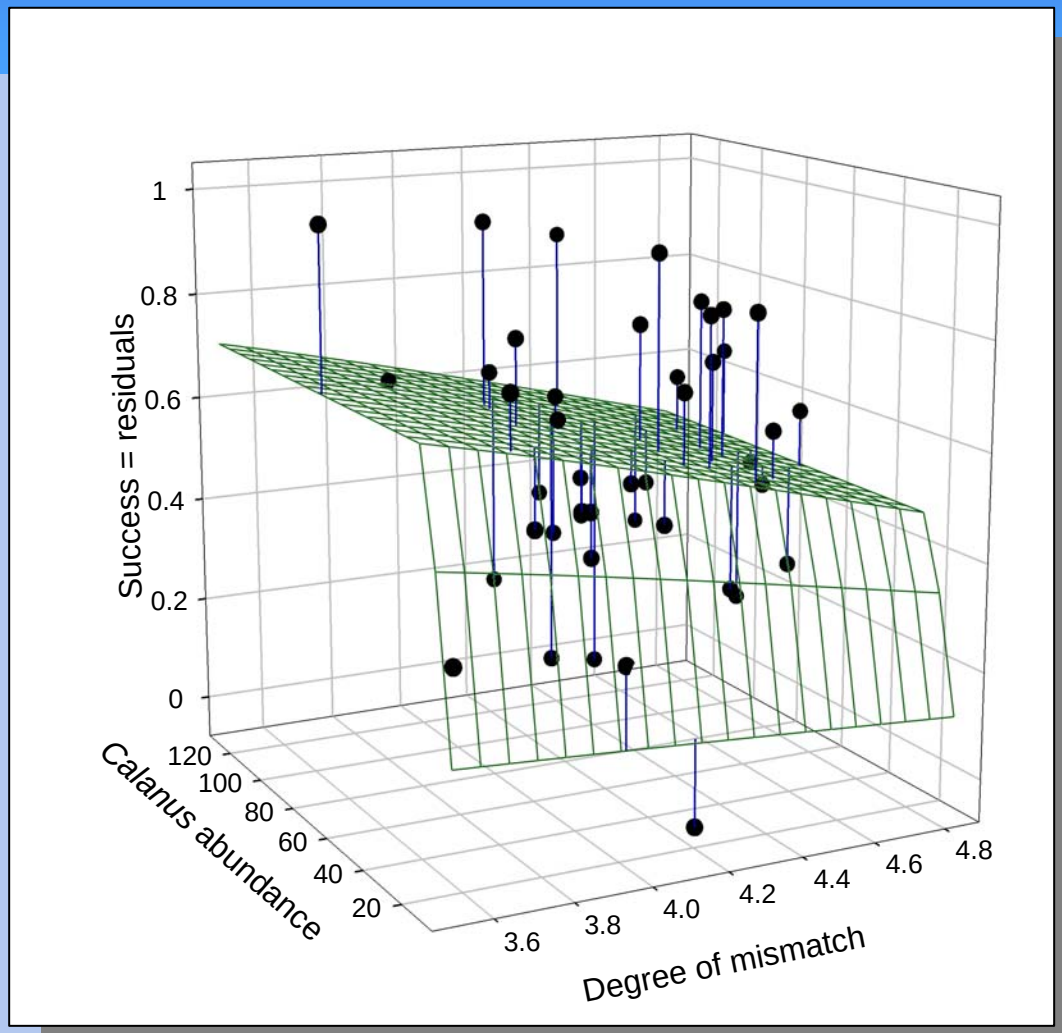
Data: Cod and plankton in the North Sea

Continuous Plankton Recorder (*CPR*) from Sir Alistair Hardy Foundation for Ocean Science
Virtual Population Analysis (*VPA*) from *ICES*

- Timing: centre of gravity of *Calanus* during the 5 first months (Colebrook & Robinson 1965) **CPR**
- Abundance: area under the graph of monthly means of *Calanus* during the 5 first months **CPR**
- Density: spawning stock biomass (SSB) **VPA**
- Success: VPA for cod age-1 corrected by density **VPA**



Model on cod data



Durant *et al.* 2005 Ecol Lett 8:952

System	2.5 %	Estimate	97.5%	p-value
Cod/zooplankton				
Mismatch	-1.511	-0.724	0.094	**0.037**
Food	0	0.039	0.084	**0.038**

Summary 1: Match-Mismatch and food abundance

- General importance of the food abundance for recruitment and Match-Mismatch analysis

How can we use the Match-Mismatch hypothesis ?

An ecosystem approach
Spatial mismatch
Evolution

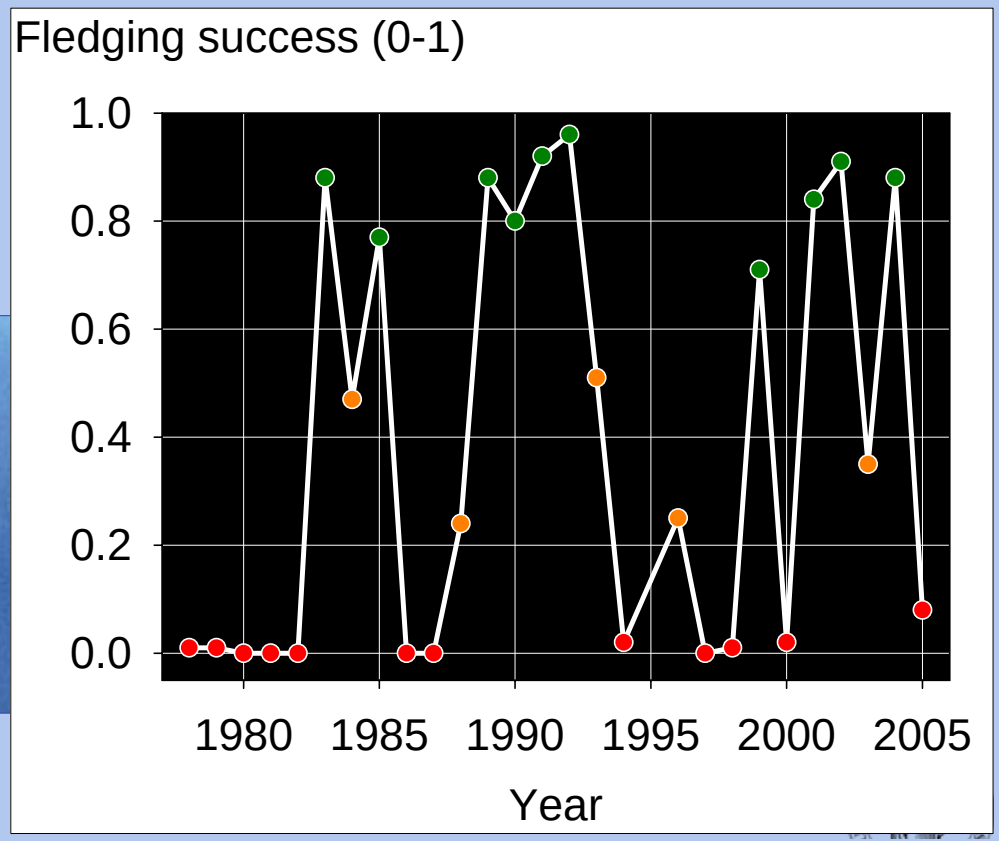
Motives


Google Earth

The Atlantic puffins fledging success is showing huge inter annual variations at their breeding site (Røst, Lofoten, Norway)

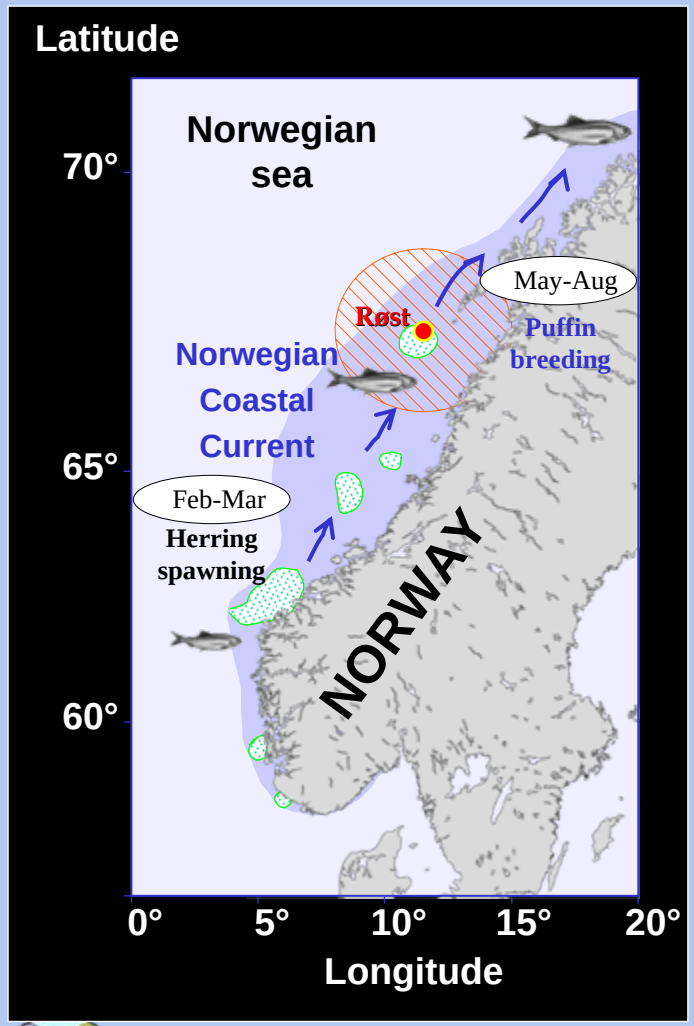
- good reproduction
- very bad reproduction

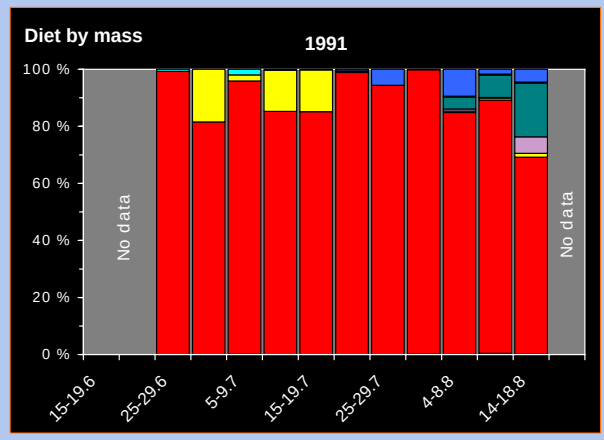

T Anker-Nilssen



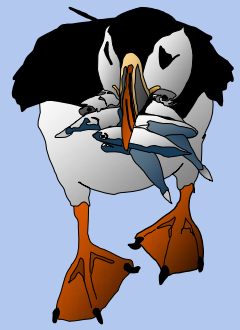
Durant *et al.* 2003 PRSB 27:1461-, 2006 Biol Lett 2: 628-

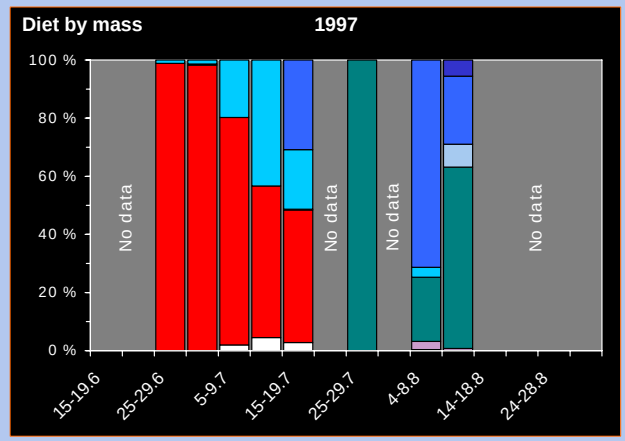
Relationship with Norwegian spring spawning herring





Fledging success = 92%



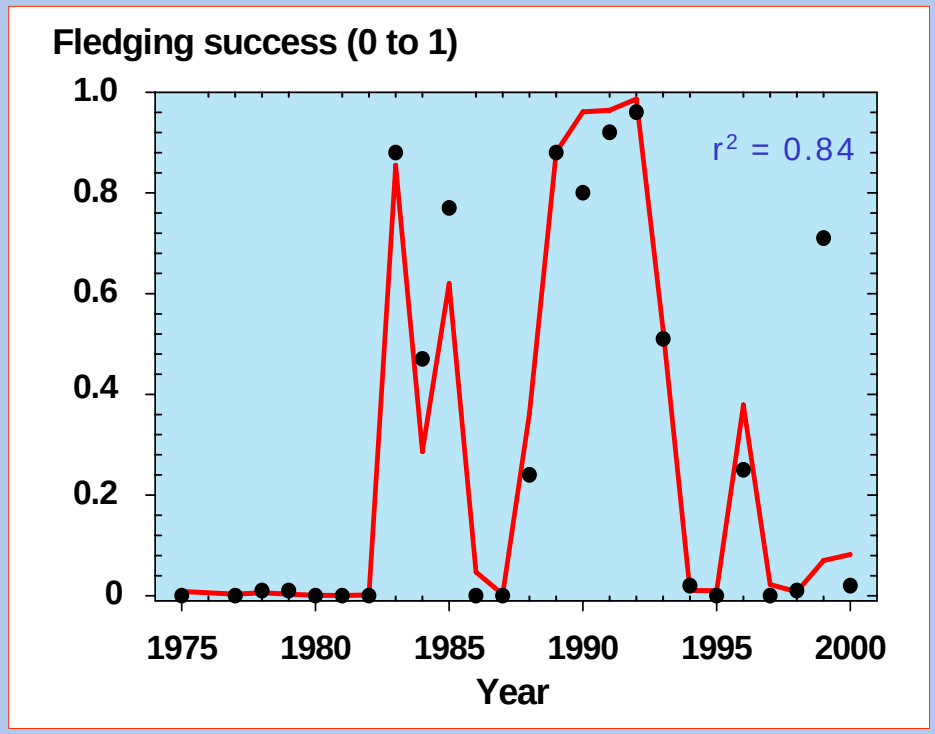


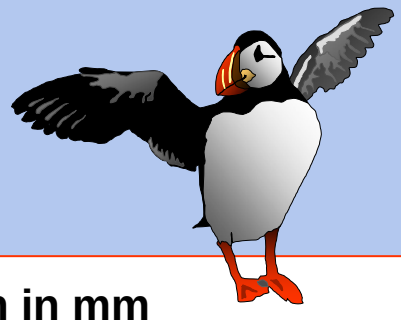
Fledging success = 0%

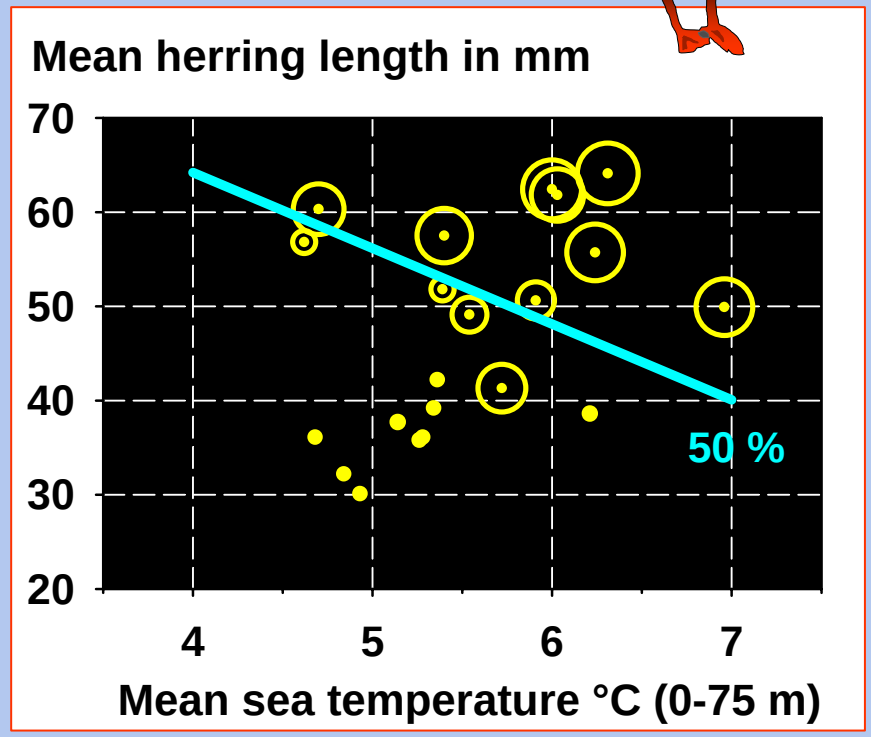
Sætre *et al*. 2002 J Mar Sci 59: 725-
Durant *et al*. 2003 PRSB 27:1461-

Anker-Nilssen & Øyan 1995 NINA report
Anker-Nilssen & Aarvak 2002 NINA report

Puffin breeding success, climate and trophic interactions



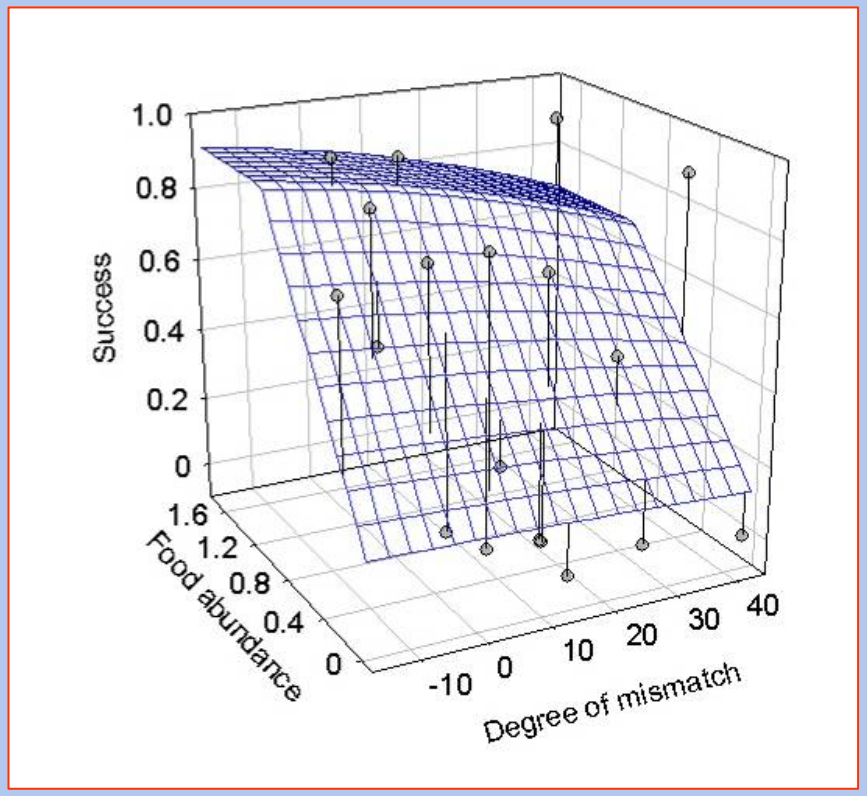


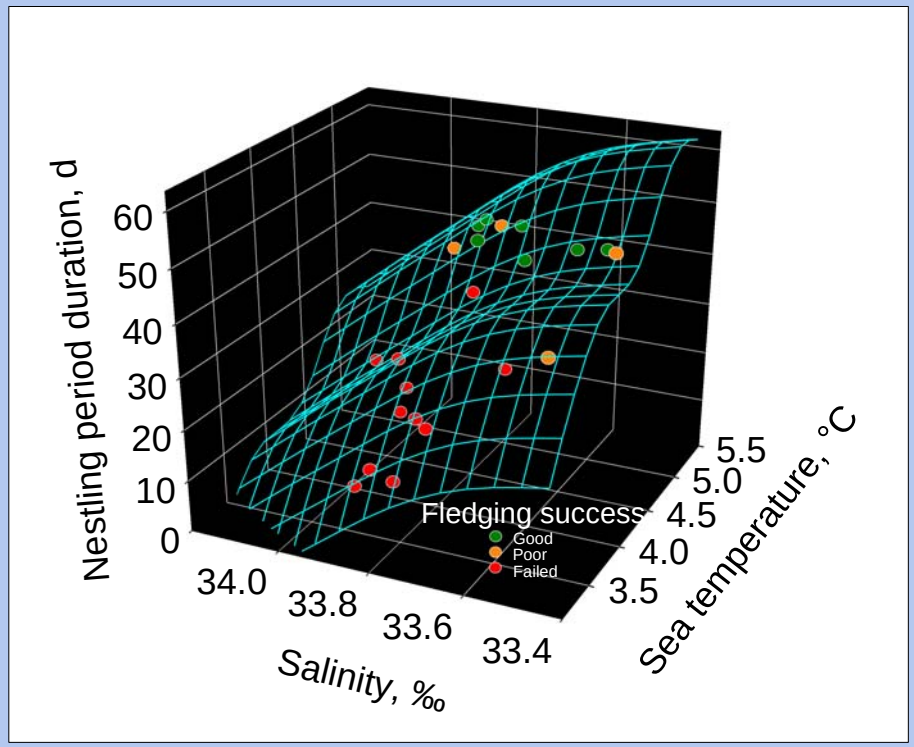


Puffin fledging success can be explain by *Sea temperature* and *Herring length*

Durant *et al.* 2003 PRSB 27:1461-

Match-Mismatch or not?

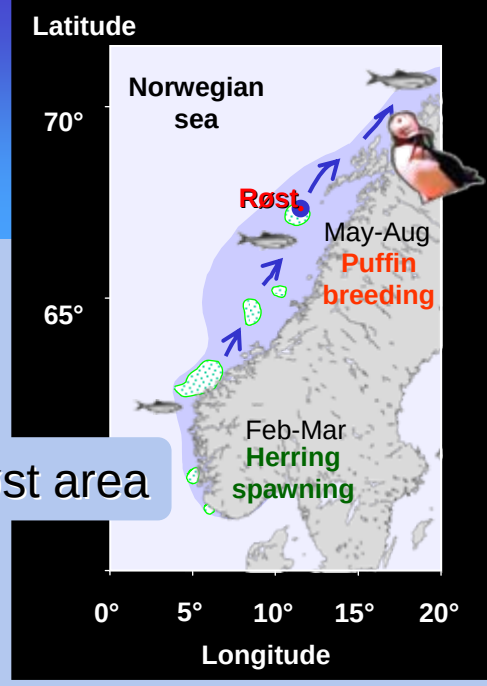




System	R^2=0.31	2.5 %	Estimate	97.5 %	p-value
Atlantic puffin/Norwegian spring spawning herring					
Mismatch		-0.148	-0.027	0.028	0.190
Food		0.131	0.800	7.615	**0.013**

Durant *et al.* 2003 PRSB 27:1461-, 2006 Biol Lett 2: 628-

An ecosystem approach



Spawning area → Røst area

Match → Good year → Many, large, schooling

Delayed hatching
High mortality
Slow growth

CLIMATE VARIABILITY

Mismatch → Poor year → Few, small, dispersed

Durant *et al.* 2007 Clim Res 33:271-

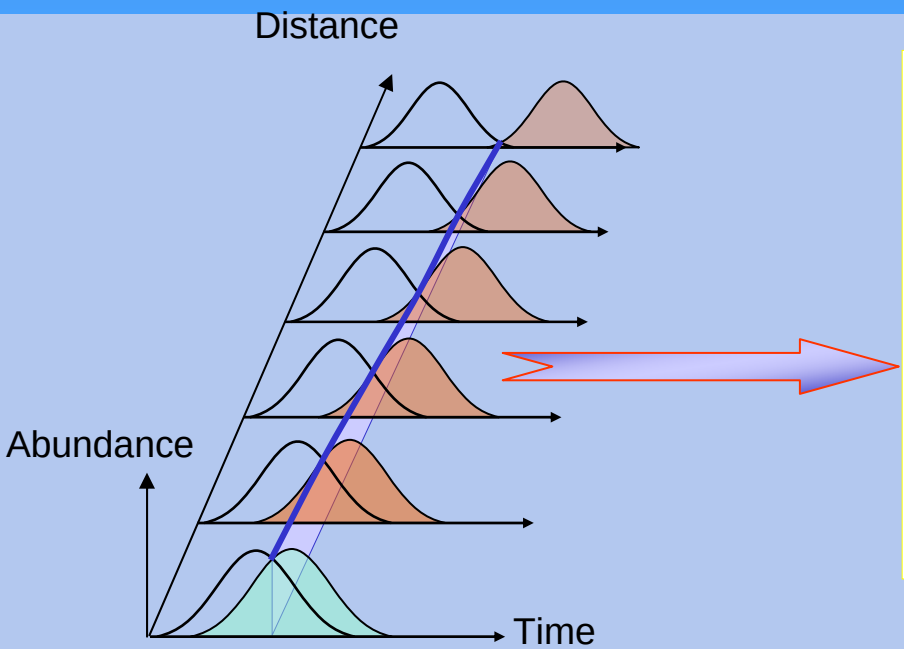
Summary 2: Ecosystem approach

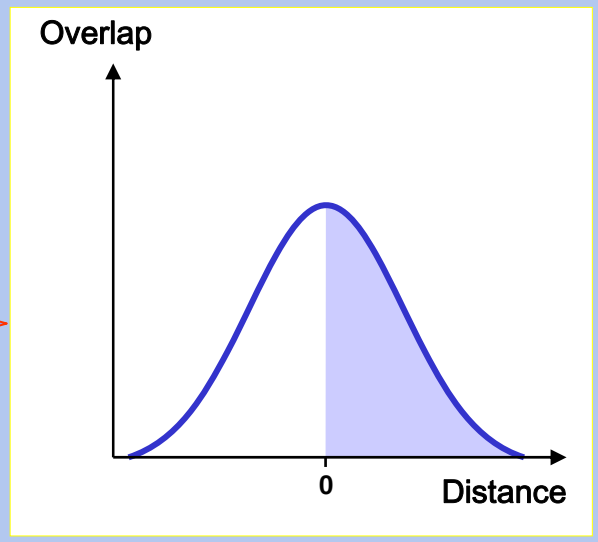
- General importance of the food abundance for recruitment and Match-Mismatch analysis

An ecosystem approach

- **A mismatch can hide another one**
- **Climate effect may be even stronger at this level**

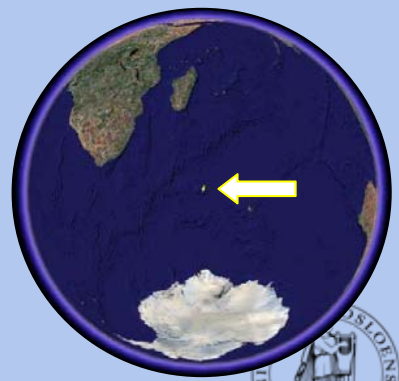
A spatial mismatch?





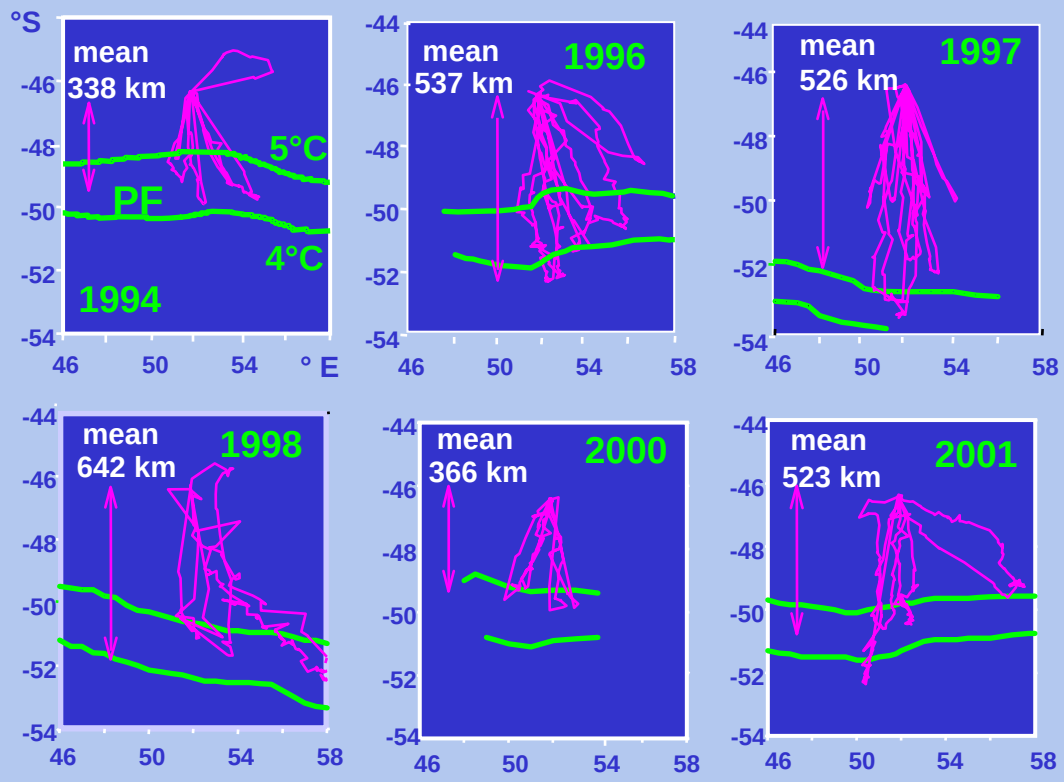
Distance match **Distance mismatch**

e.g. the King penguin

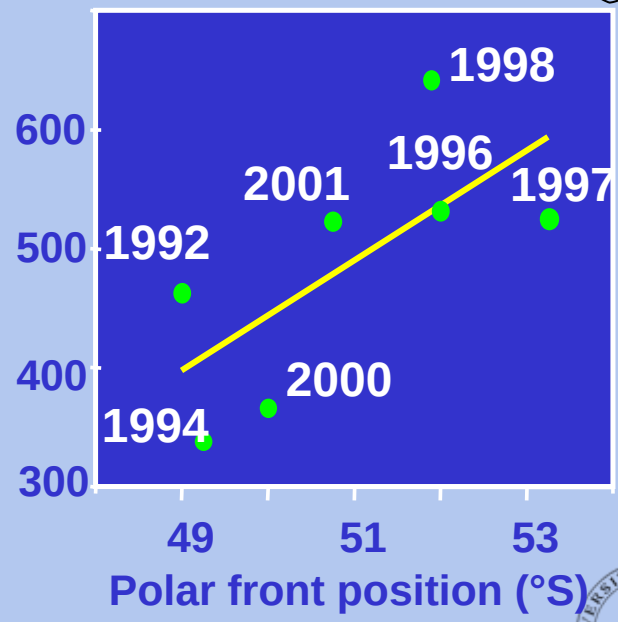


Google Earth

Variation of the polar front and foraging range of king penguins



Foraging range (mean, Km)



Bost et al. 2001

Breeding success of king penguins from Crozet Islands

Birds status	Explanatory variables X1	Explanatory variables X2	ΔAIC	Fix effect *P*-value	Random effect *P*-value	ANOVA *P*-value
Early breeders	**SOI_t**	**Val. $[Chla]_{Cro\ t}$**	**0**	**<0.001**	**1.000**	**<0.001**
	SOI_t	Date $[Chla]_{Cro\ t}$	19.30	<0.001	1.000	<0.001
	SOI_t	Date $SST_{Cro\ t\text{-}2}$	26.50	<0.001	1.000	0.001
	SOI_t	-	32.38	<0.001	0.011	
Late breeders	SOI_t	Val. $SST_{Cro\ t}$	0	<0.001	0.001	0.01
	SOI_t	Lat.$SST_{iso4°C\ t}$	0.40	<0.001	0.001	0.05
	SOI_t	-	**1.82**	**<0.001**	**0.000**	

location of the 4°C isotherm

Le Bohec *et al*. 2008 PNAS in press

Summary 3: Spatial Match-Mismatch

- General importance of the food abundance for recruitment and Match-Mismatch analysis

An ecosystem approach

- A mismatch can hide another one
- 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**

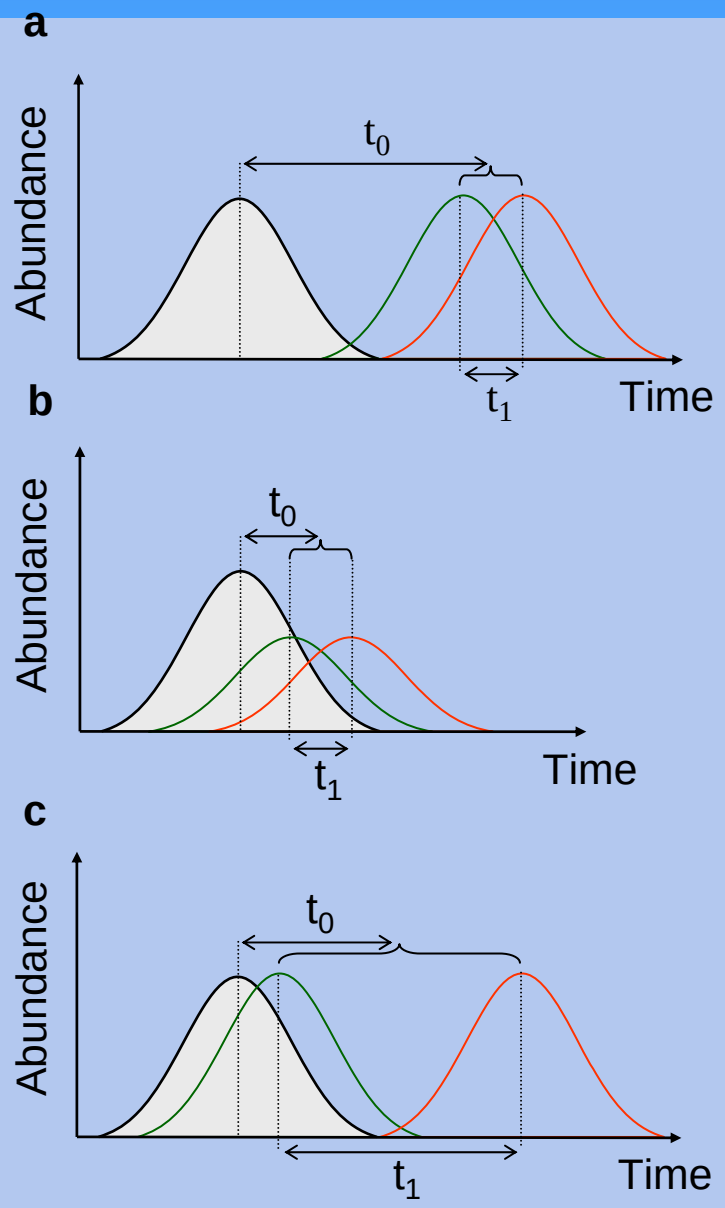
Evolution and Match-Mismatch

Different time window creating a permanent "mismatch", e.g. Baltic tellin *Macoma balthica* (Philippart *et al*. 2003 Limnol Oceanogr 48: 2171-). If some overlap exists, there will be a a strong selection pressure on phenological extremes, hence on the phenotype.

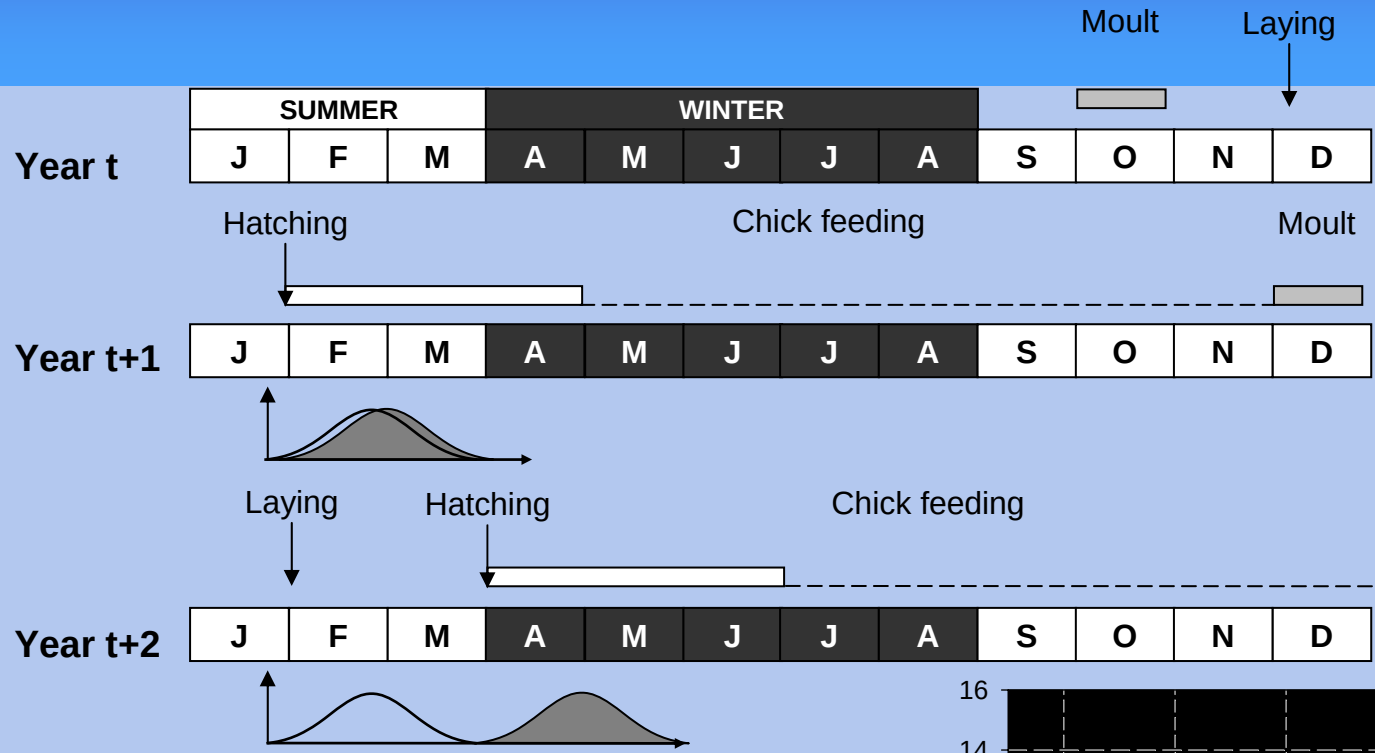
Same time window but not enough prey for a successful predator reproduction, e.g. North Sea cod *Gadus morhua* L. (Beaugrand *et al*. 2003 Nature 426: 661-).

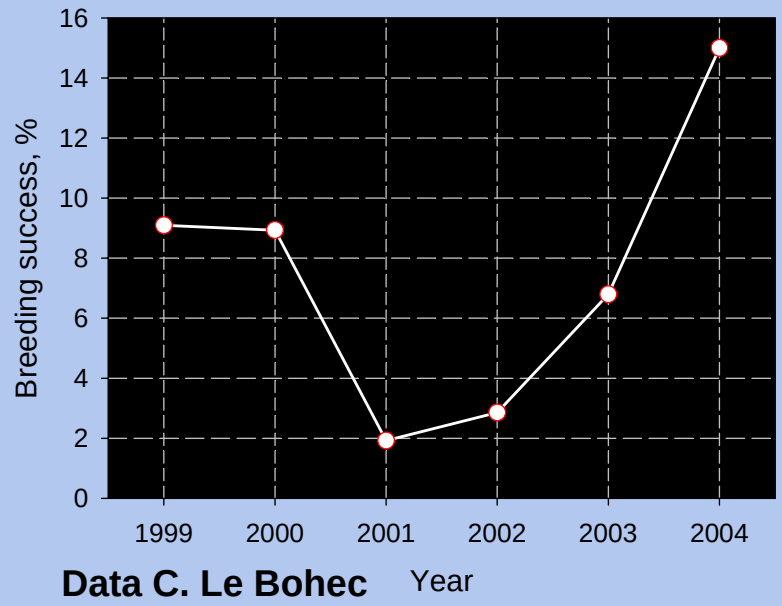
Extreme amplitude of inter-annual variation prey population creating an on-off pattern. This pattern may occur in regions where the inter-annual temperature variability is strongest (e.g. polar regions, Schär *et al*. 2004 Nature 427: 332-).

After climate change



Evolution driven mismatch





Data C. Le Bohec

Summary 4: Evolution and Match-Mismatch

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

An ecosystem approach

- A mismatch can hide another one
- Climate effect may be even stronger at this level

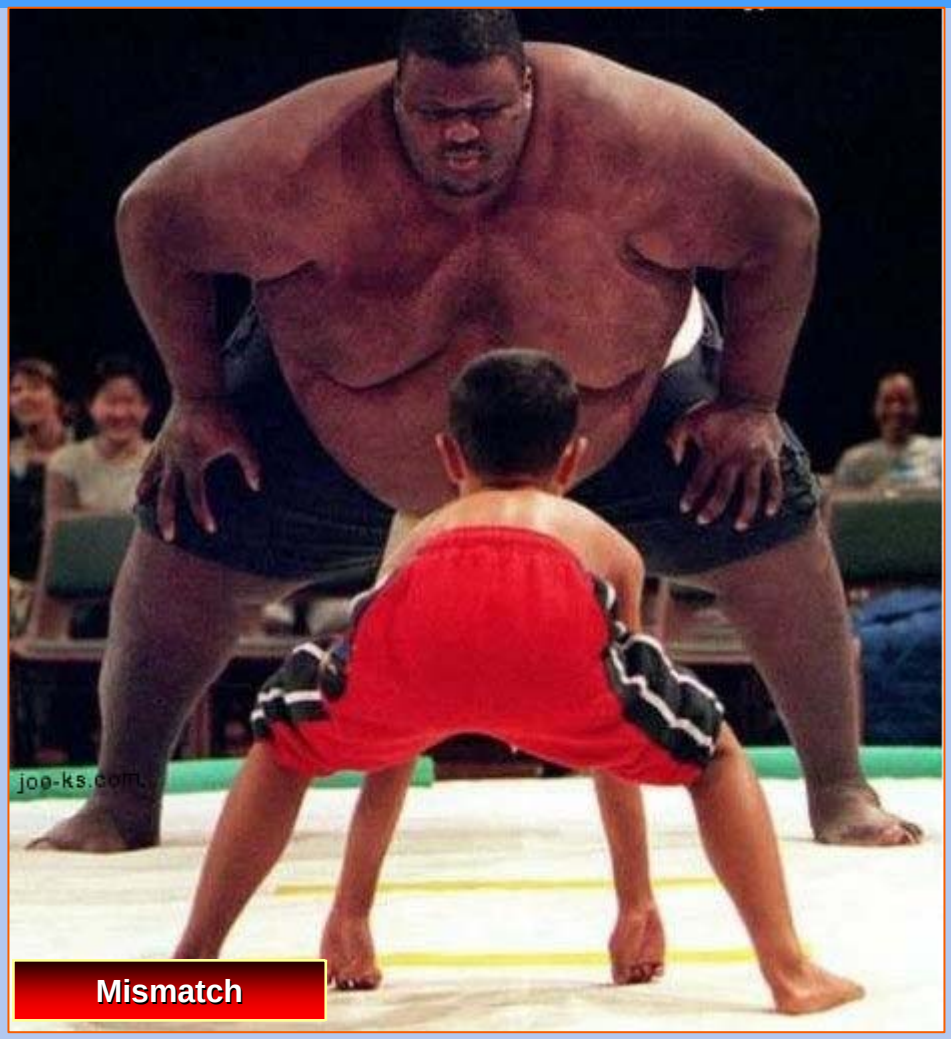
Spatial mismatch

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

Evolution

- **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**

Conclusion: Further considerations



A question of perspective

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G. Ottersen, IMR, Norway
G. Beaugrand, CNRS Lille, France
A. Mysterud, CEES, Oslo, Norway
N. Pettorelli, ZSL, London, UK
…

W. Sydeman and PICES organization

Front cover: ”Cinq siècles de pêche à la morue : Terre-Neuvas et Islandais”