Marine habitat dynamics & Climate: an inconvenient truth

1) What does habitat mean?

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2) Simulated effects of changes in temperature on habitat dynamics & population dynamics for a structure oriented site attached fish

1) What does habitat mean?

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3) Drivers of habitat dynamics in the MAB shelf break ecosystem

1) What does habitat mean?

2) Simulated effects of changes in temperature on habitat dynamics & population dynamics for a structure oriented site attached fish

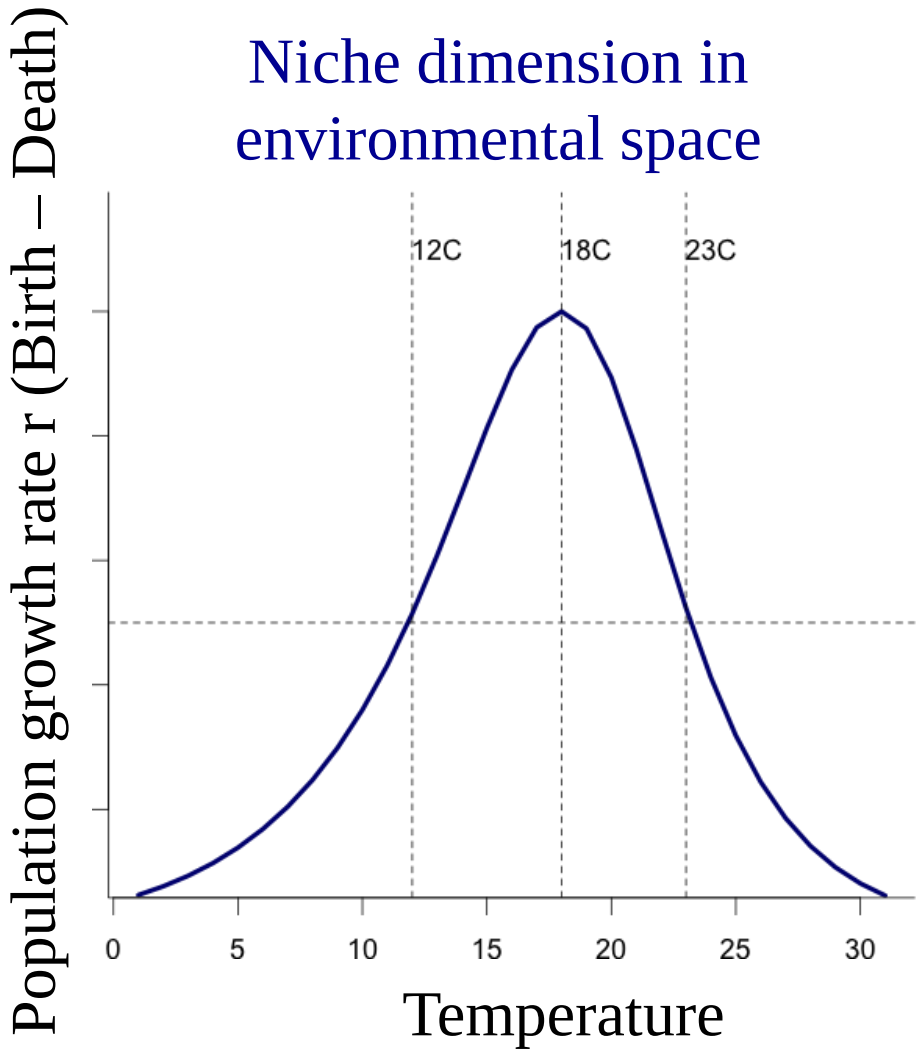
3) Drivers of habitat dynamics in the MAB shelf break ecosystem

4) With all that complexity can you make something useful

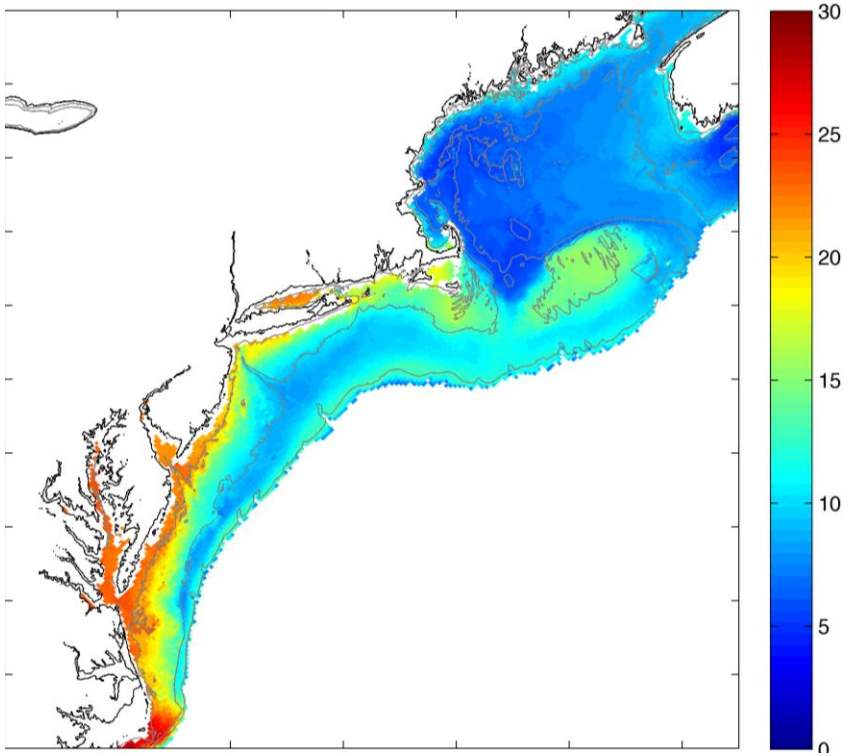
1) What does habitat mean?

Niche theory: Hutchinson, G. E. 1957. Concluding Remarks. Cold Spring Harbor Symposia on Quantitative Biology 22:415-442.

Niche dimension in environmental space



Environmental feature in space



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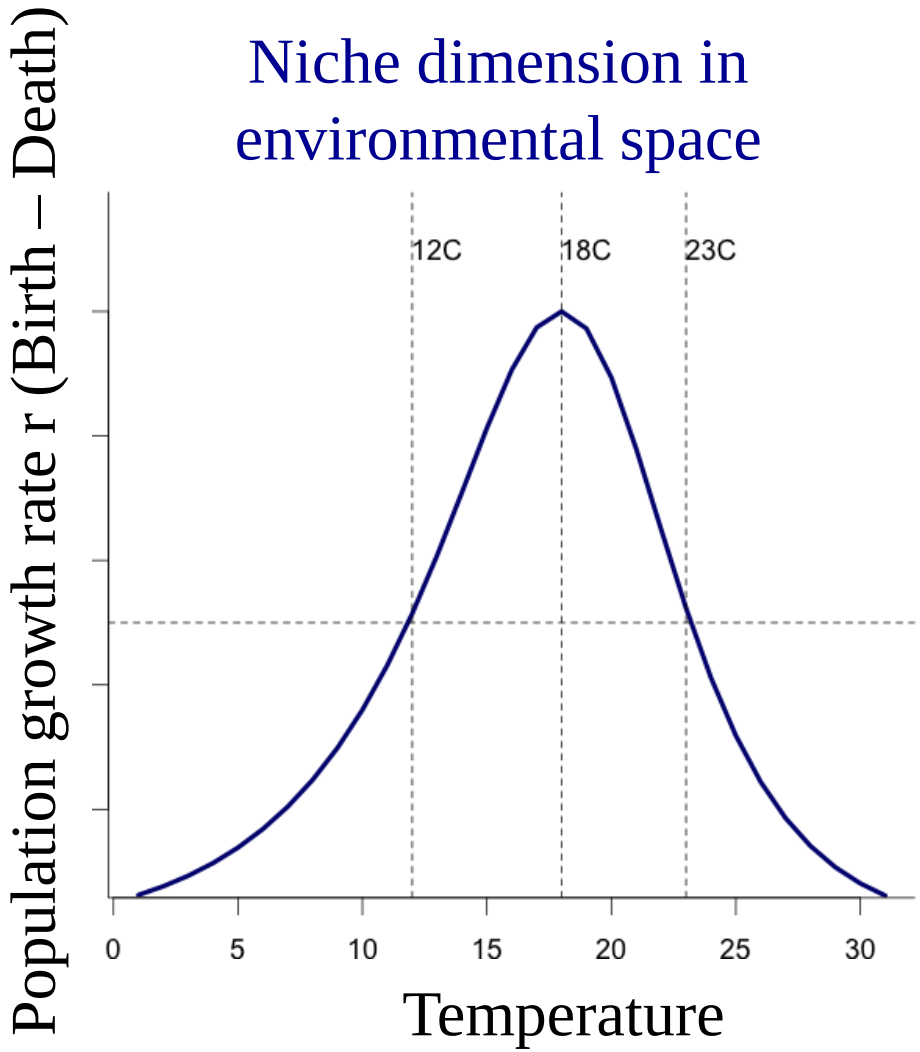
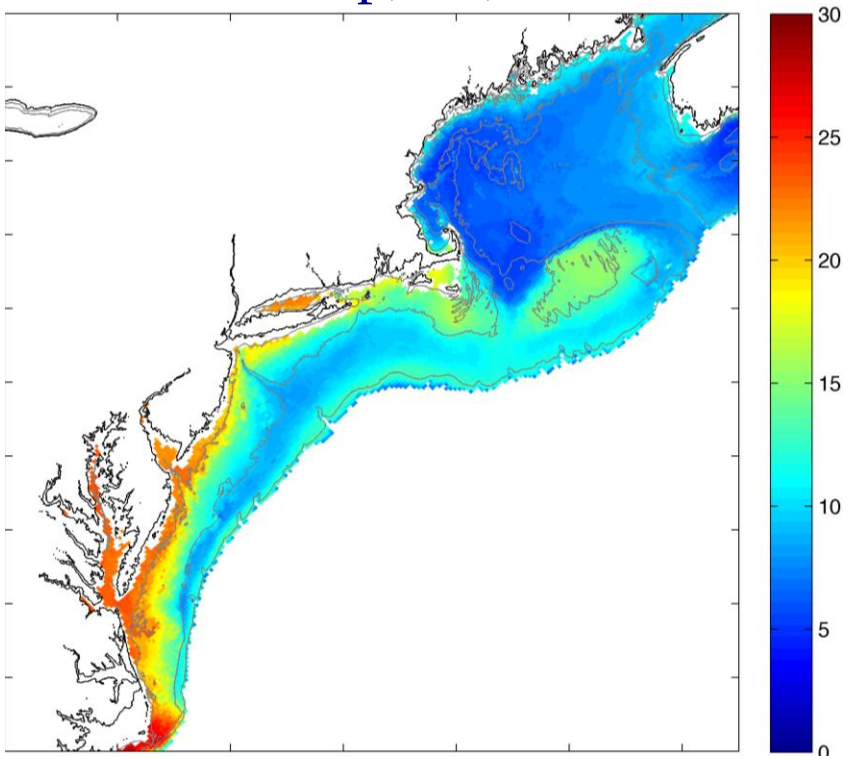


Environmental feature in space on Sep, 22, 2001



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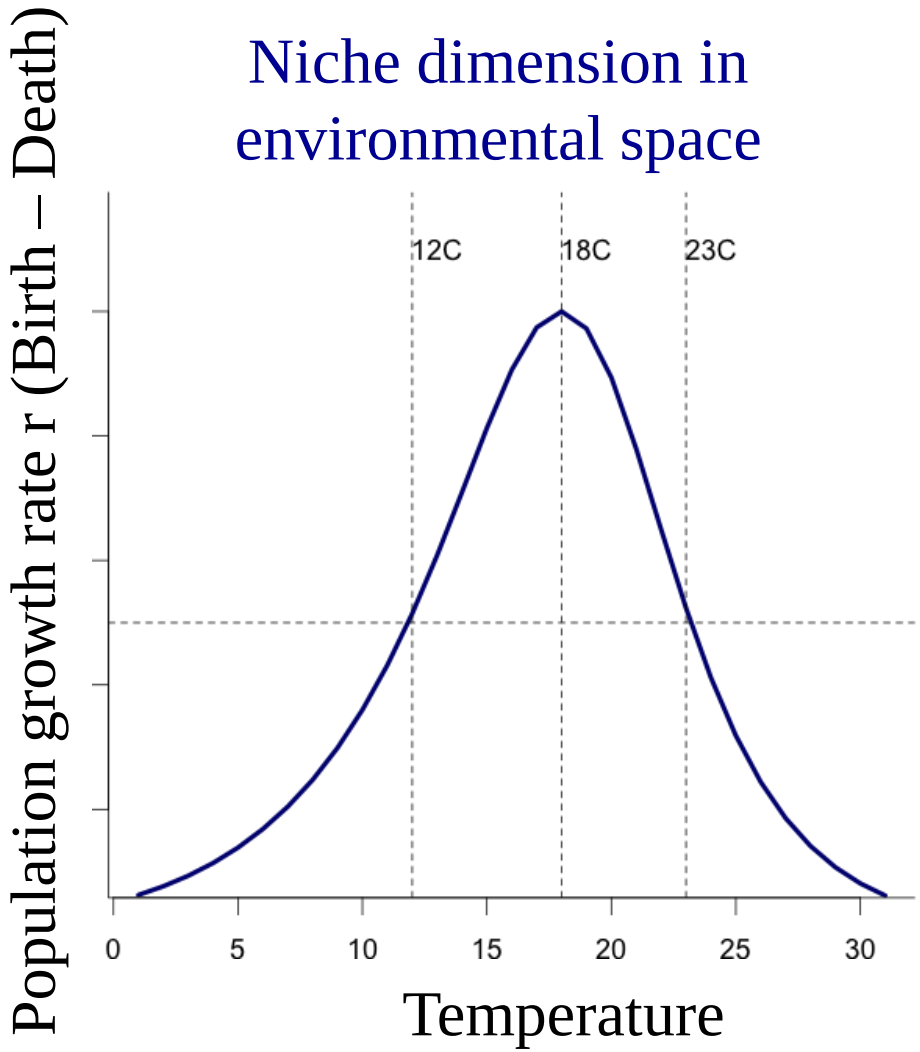
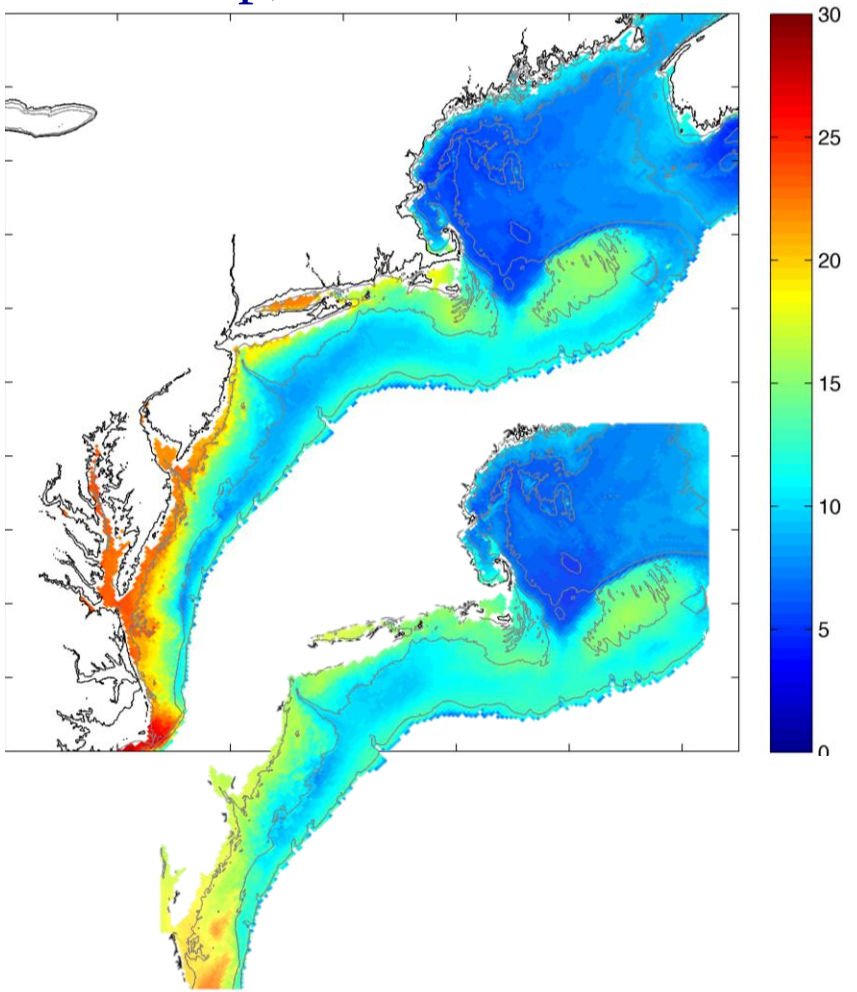
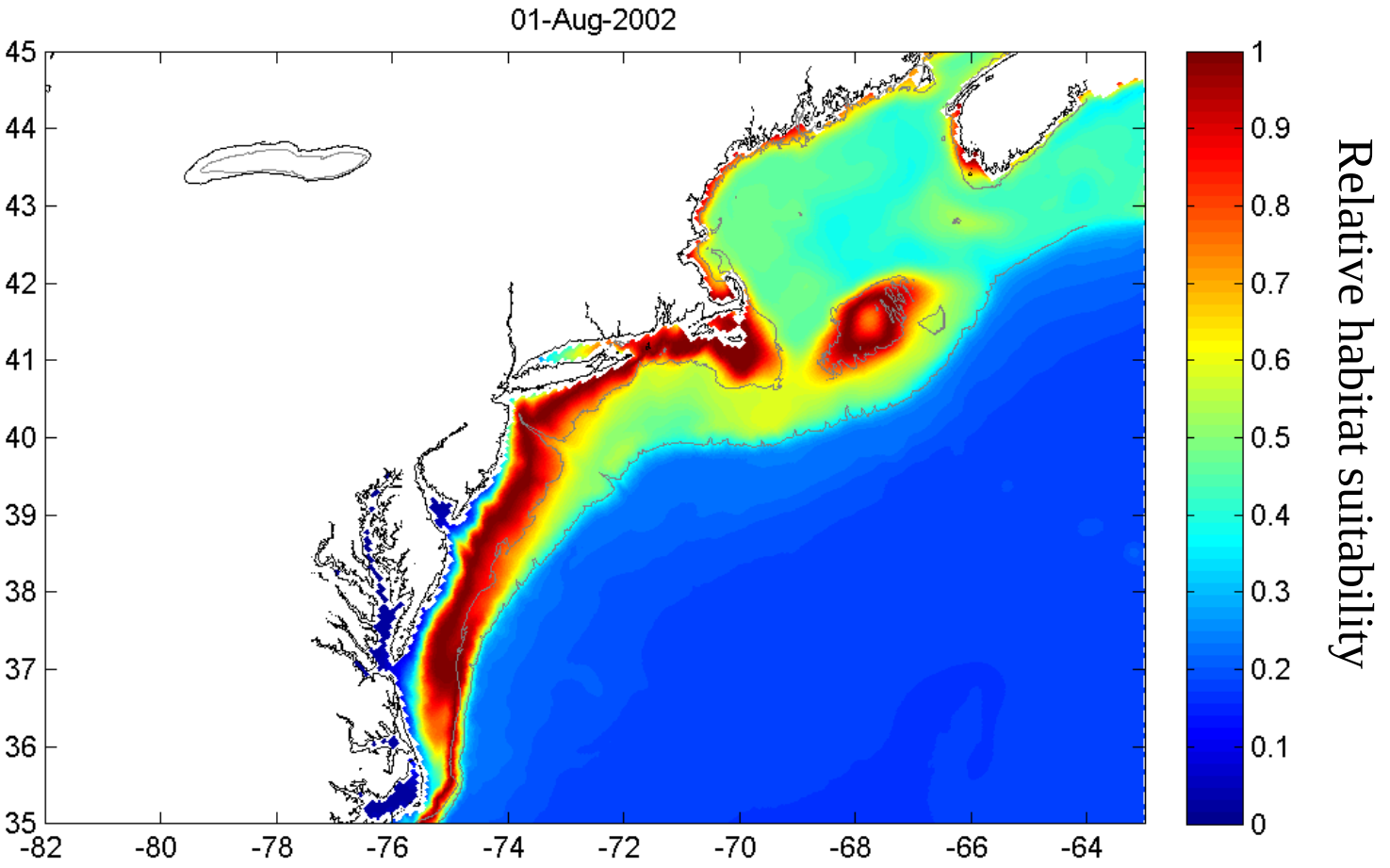


Environmental feature in space on Sep, 22 & Oct 21 2001

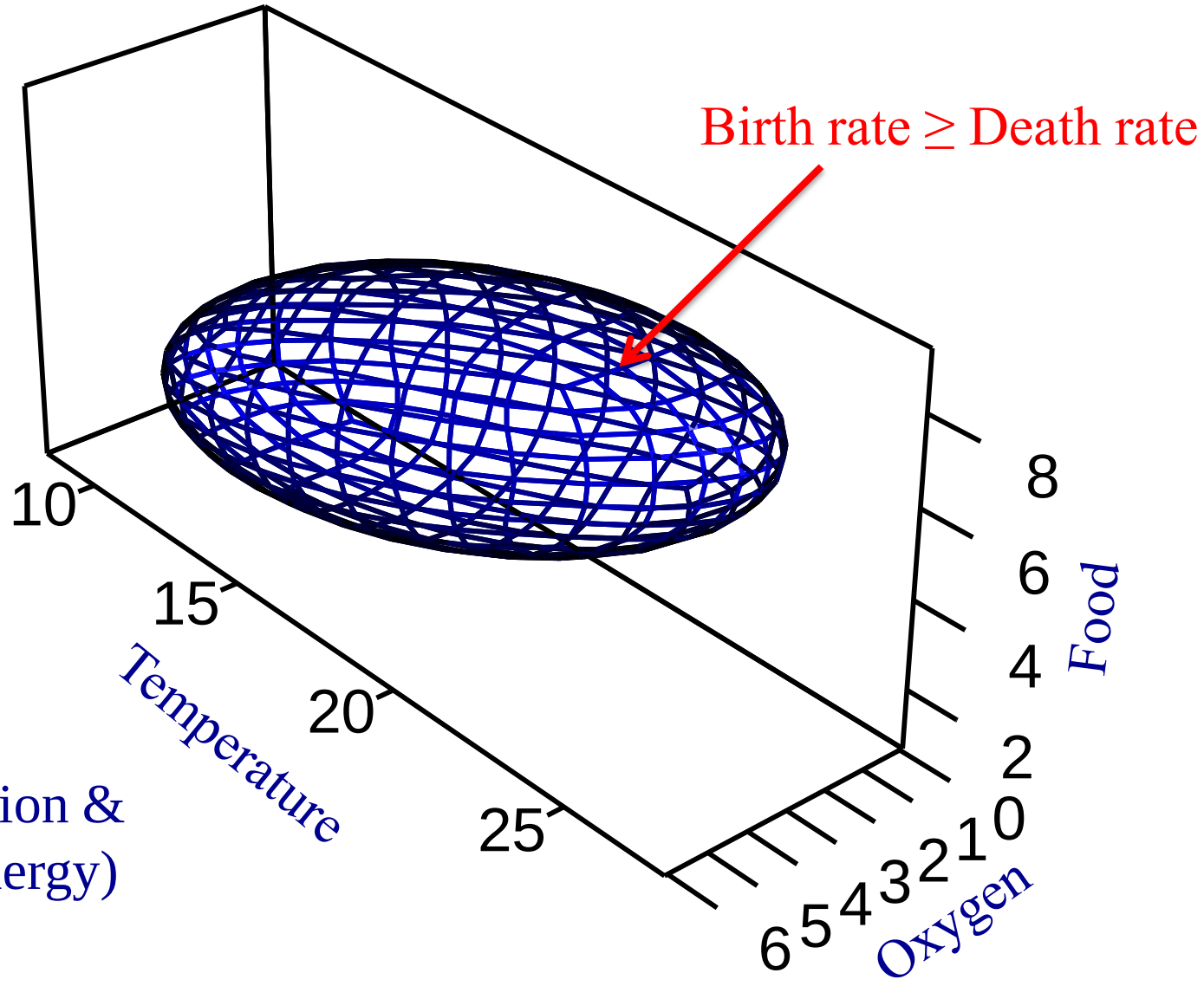


Habitat distribution => niche projected onto environmental variation in space & time



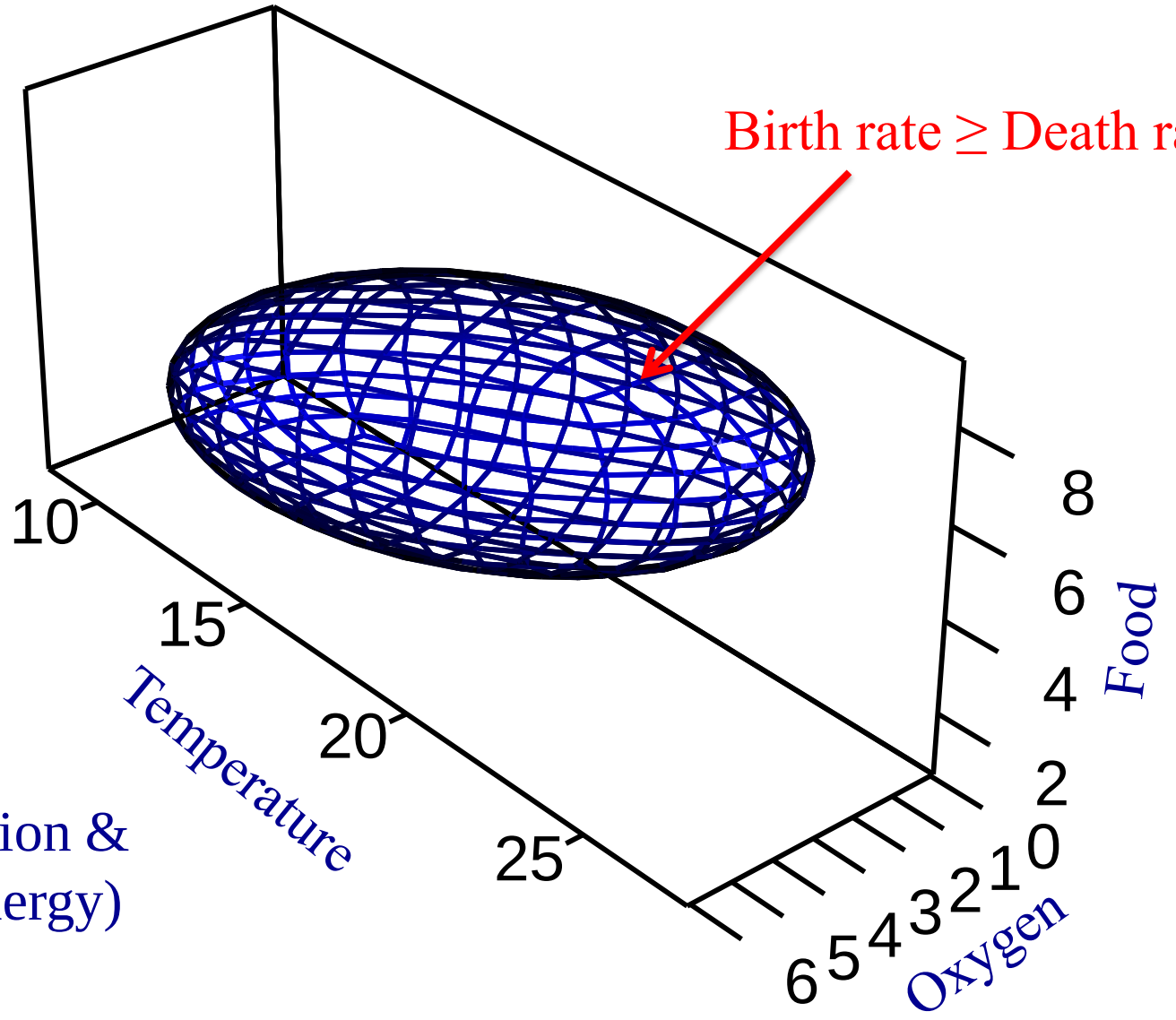
Species distributions reflect birth, death & movement process through filter of dynamic habitat distributions

Niches are multi-dimensional



Add refuge:
- from predation &
- drag (i.e. energy)

Niches are multi-dimensional



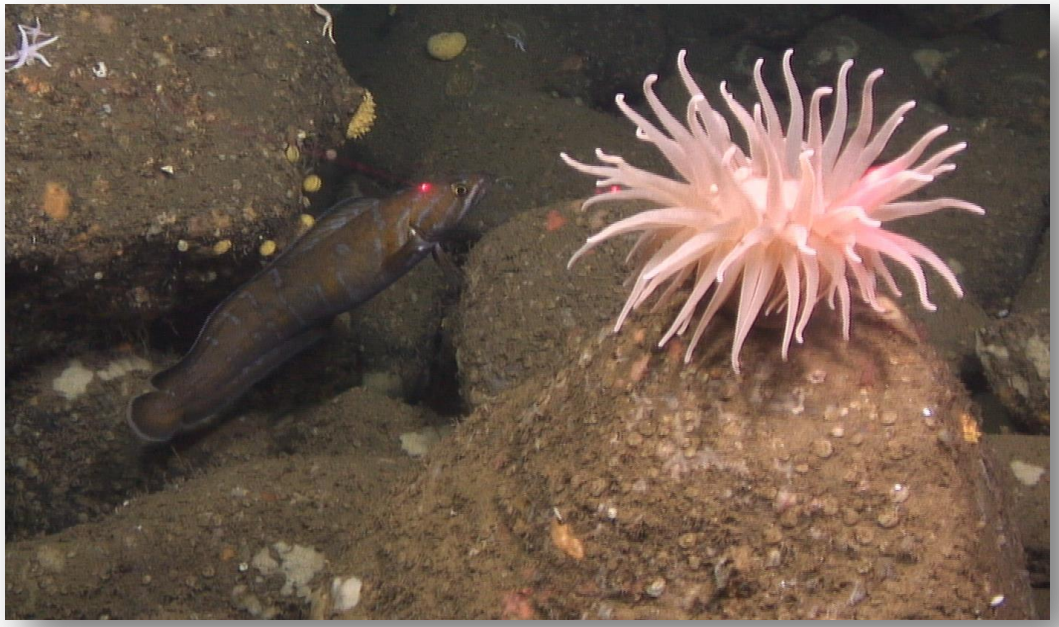
Add refuge:
from predation &
drag (i.e. energy)

Defined by environmental features affecting birth & death

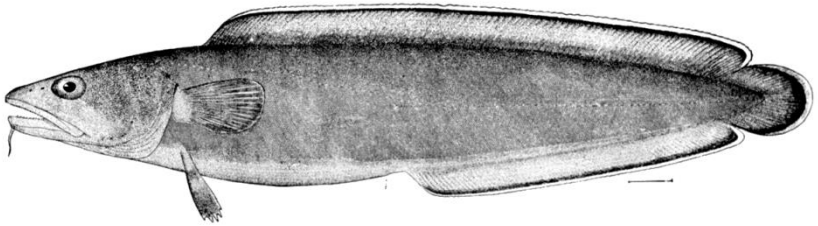
In sea most niche/habitat dimensions directly/indirectly related to fluid

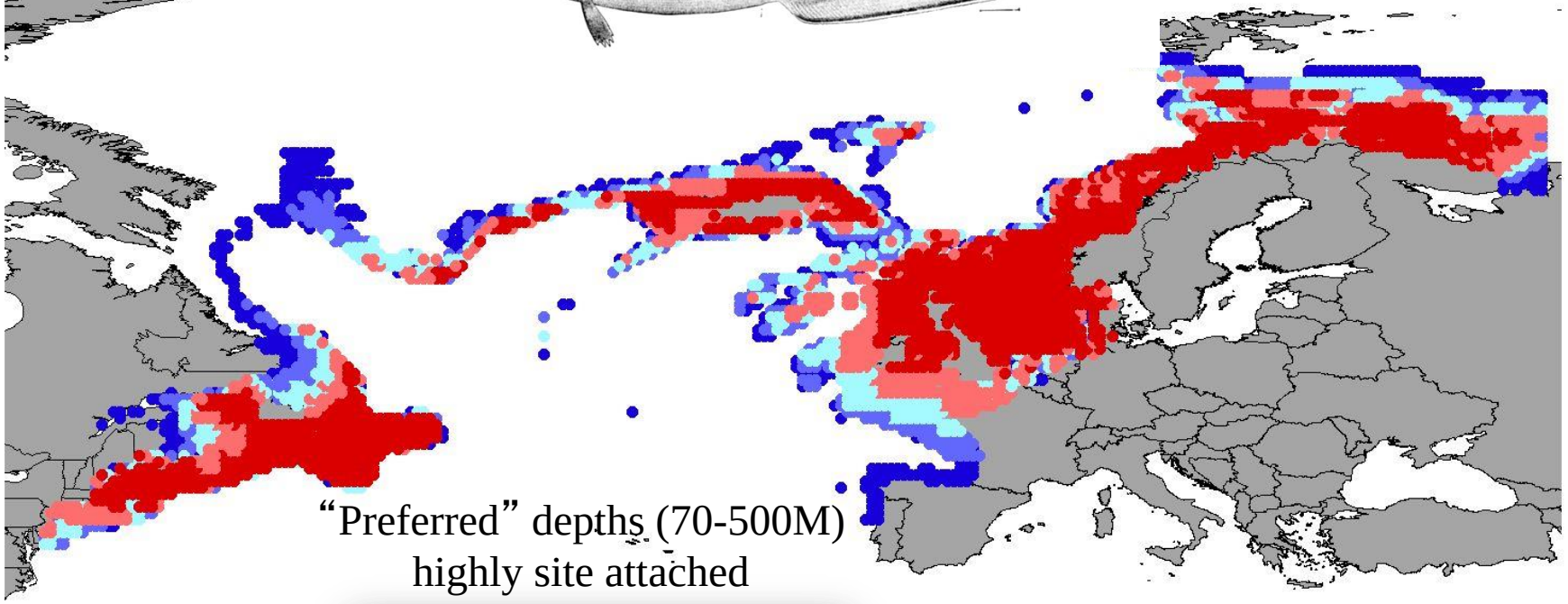
1) What does habitat mean?

2) Simulated effects of changes in temperature on habitat dynamics & population dynamics for a structure oriented site attached fish

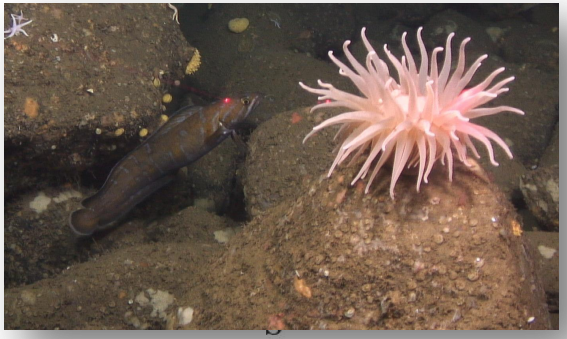


Climate impacts on habitat for cusk





"Preferred" depths (70-500M)
highly site attached



Probability of occurrance

- 0.01 - 0.19
- 0.19 - 0.41
- 0.41 - 0.64
- 0.64 - 0.87
- 0.87 - 1

Cusk/Tusk
Brosme brosme

2000 0 2000 4000 Miles

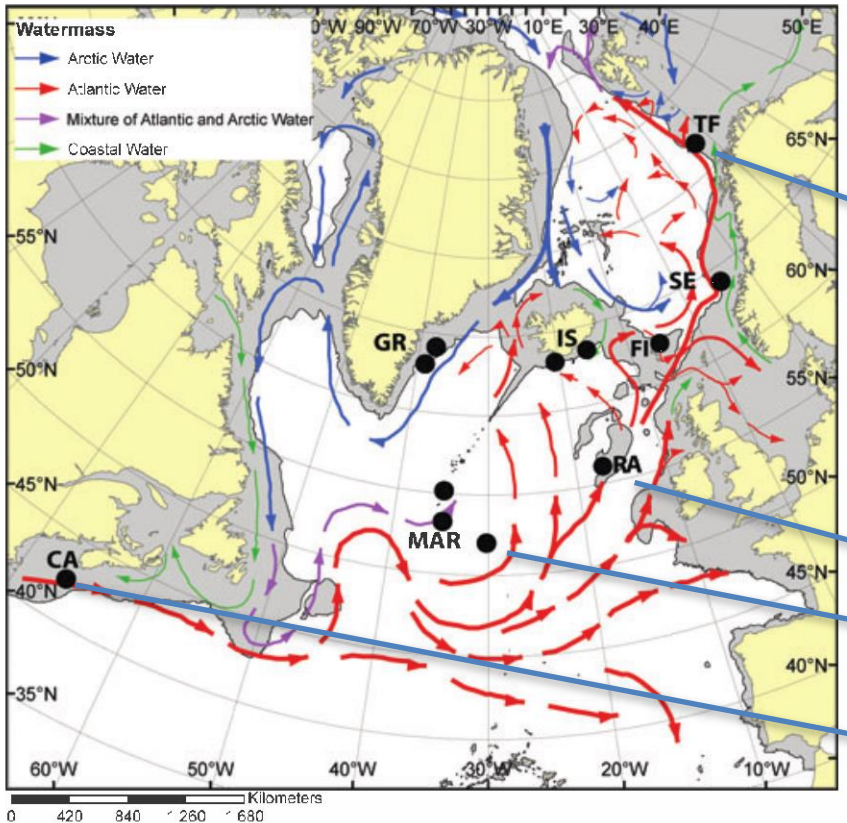
At Atlantic basin scale

Cusk have spatially subdivided-metapopulation structure

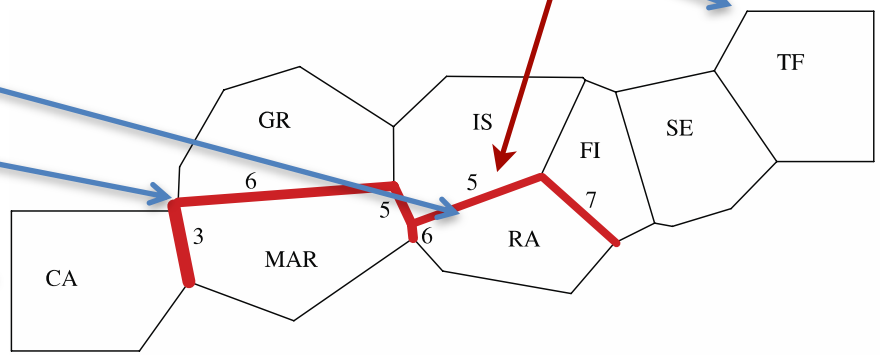
Portfolio effect & potential subpopulation rescue

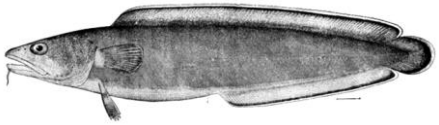
Bathymetric Barriers Promoting Genetic Structure in the Deepwater Demersal Fish Tusk (*Brosme Brosme*)

HALVOR KNUTSEN,* PER ERIK JORDE,† HANNE SANNÆS,* A. RUS HOELZEL,‡ ODD AKSEL BERGSTAD,* SERGIO STEFANNI,§ TORILD JOHANSEN– and NILS CHR. STENSETH*†

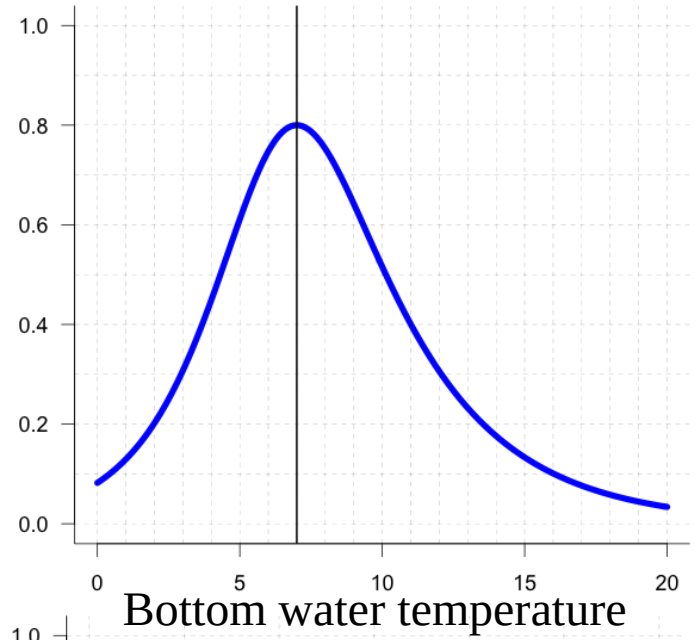


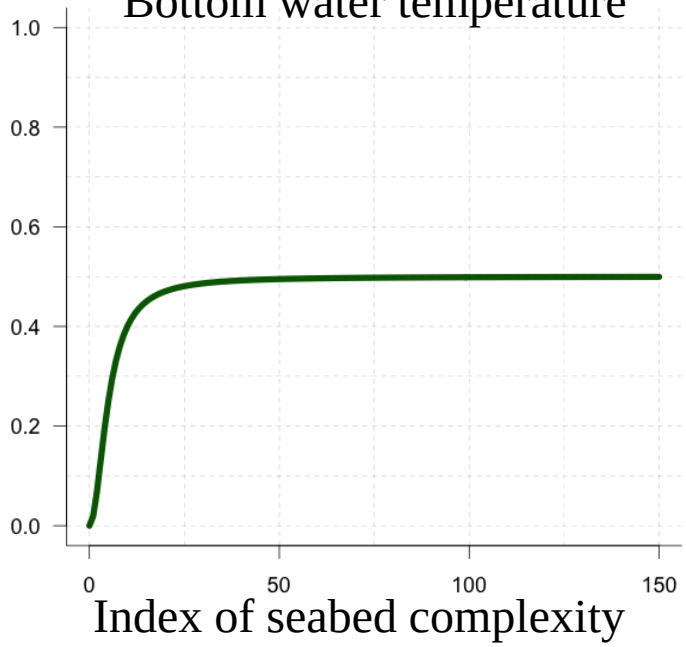
Number of alleles different & contributing to barrier

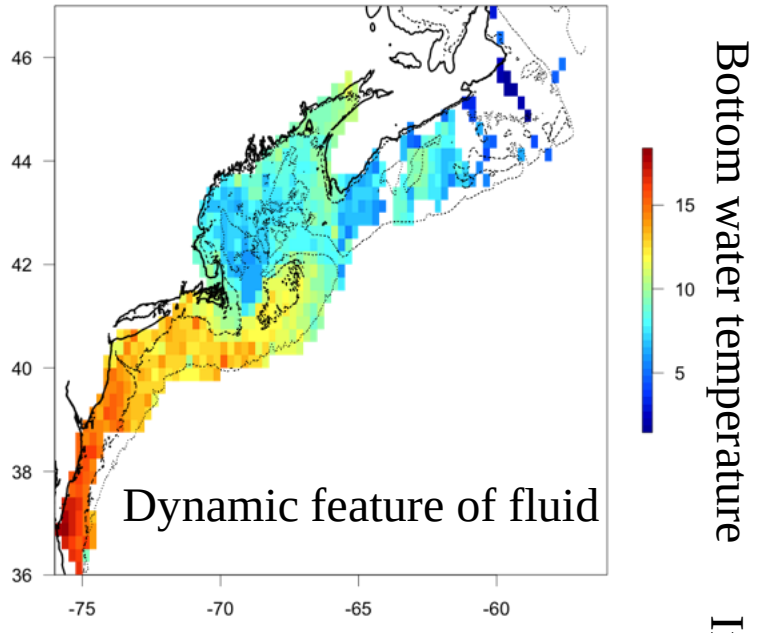


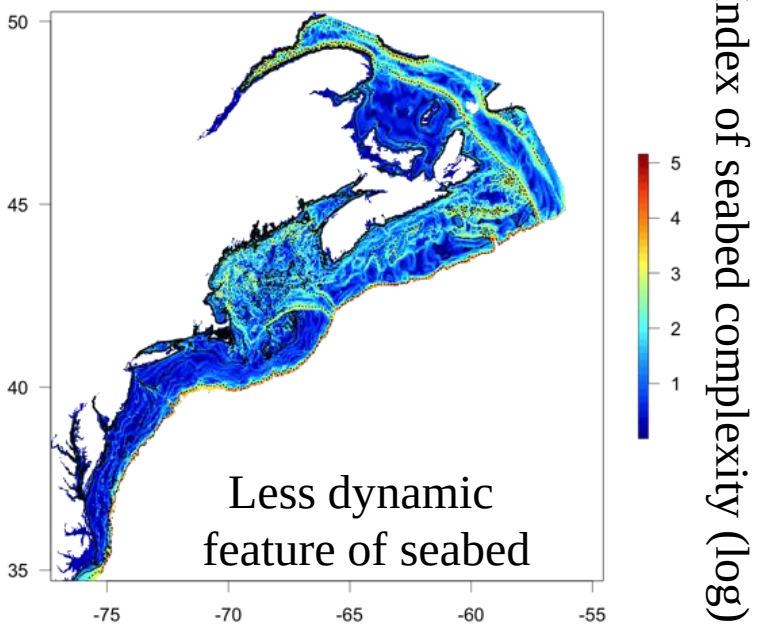


Simplified idealized niche model

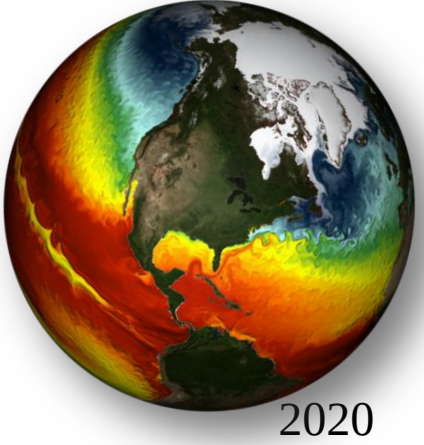








Global Climate Model Based Projections downscaled temperatures

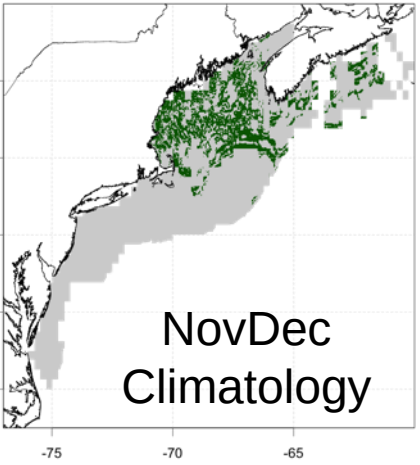


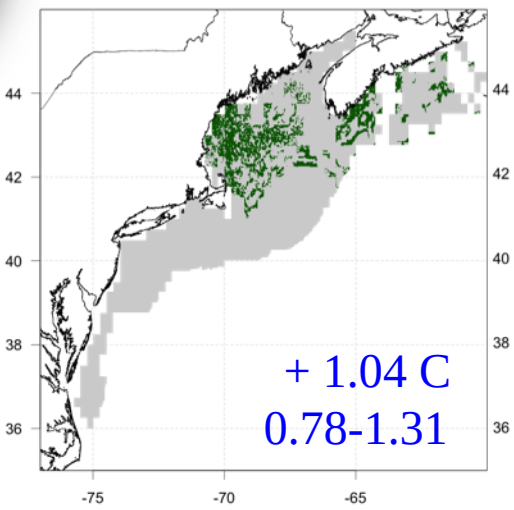
B1: +550 ppm

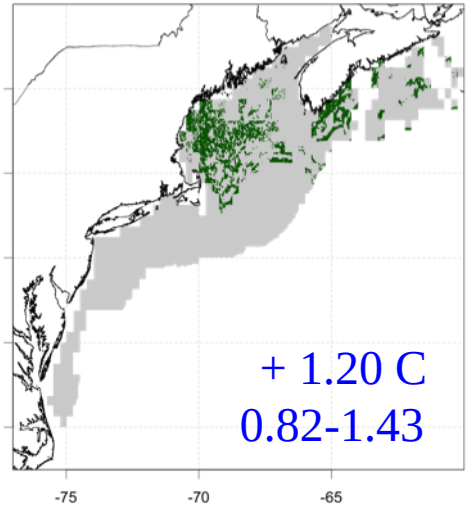
A1B: +720 ppm

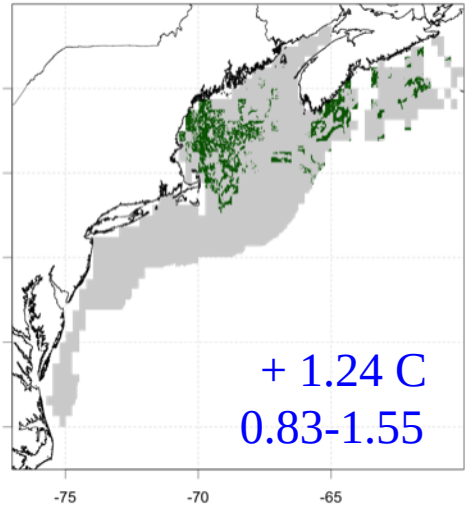
A2: +800 ppm

2020 -2060

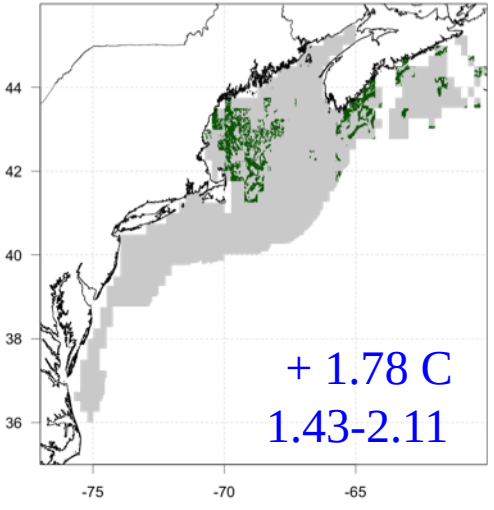


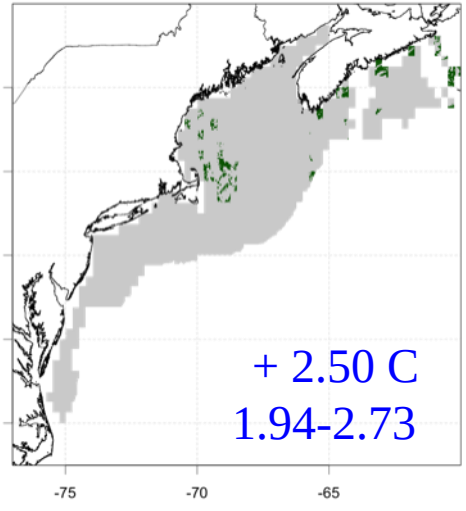


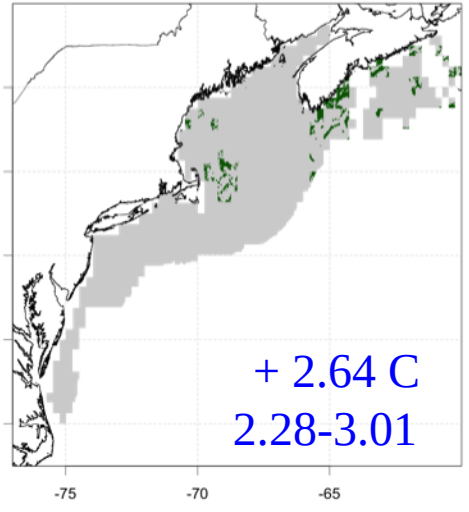




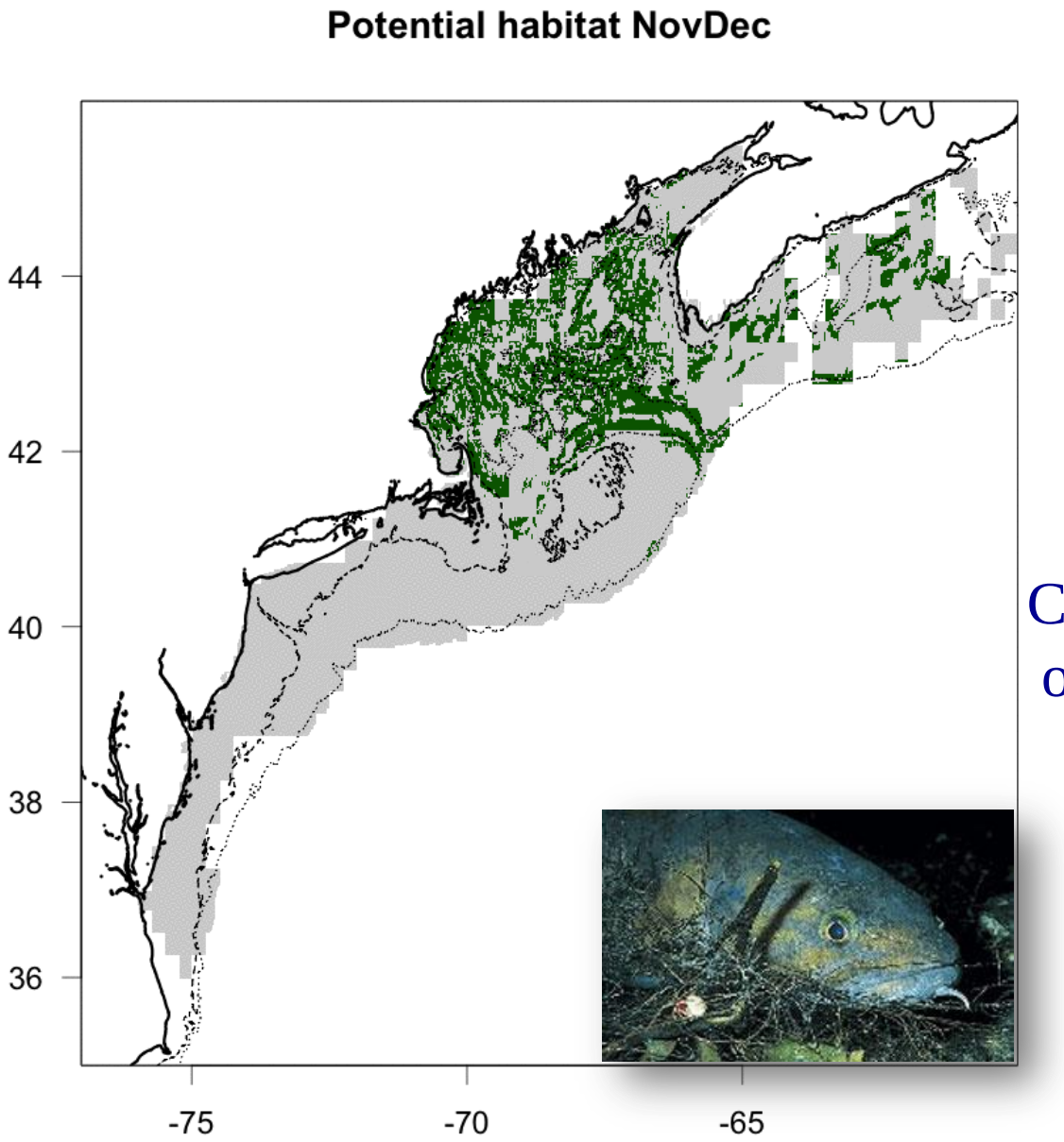
2060 -2100





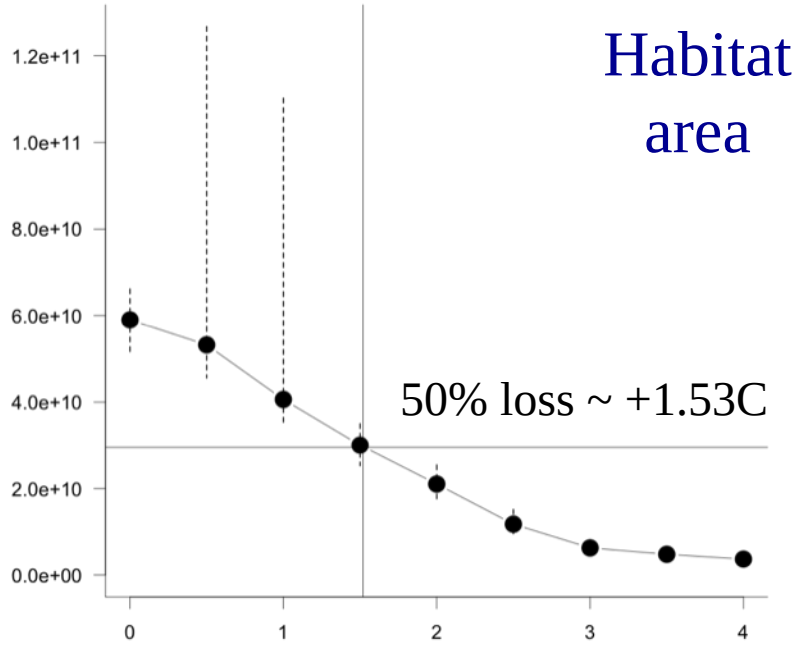


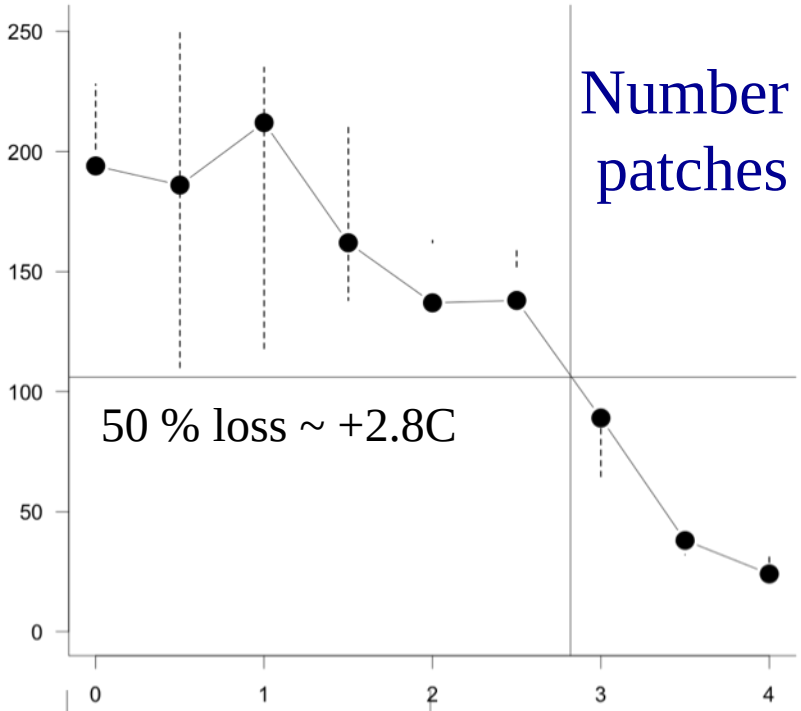
Simple dynamic habitat model for Cusk:
Simulate effects of temperature change on habitat distributions

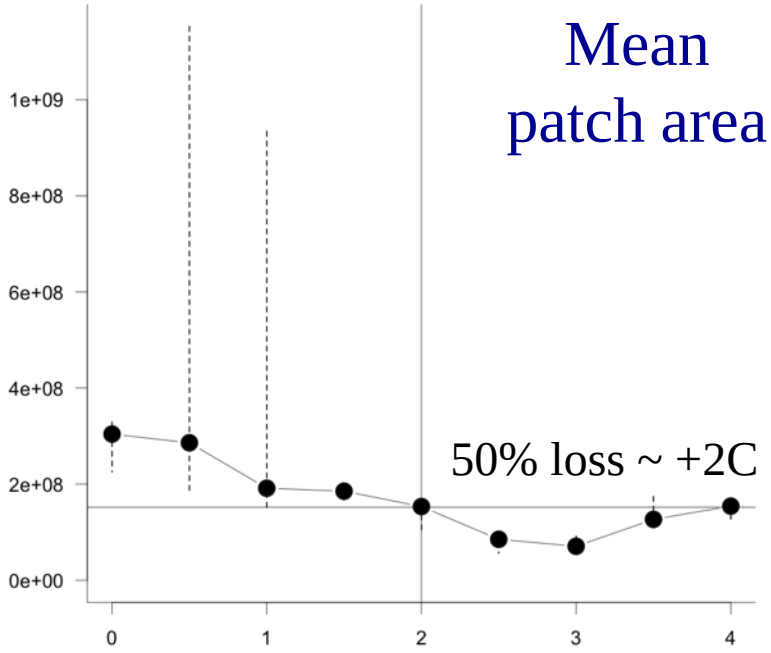


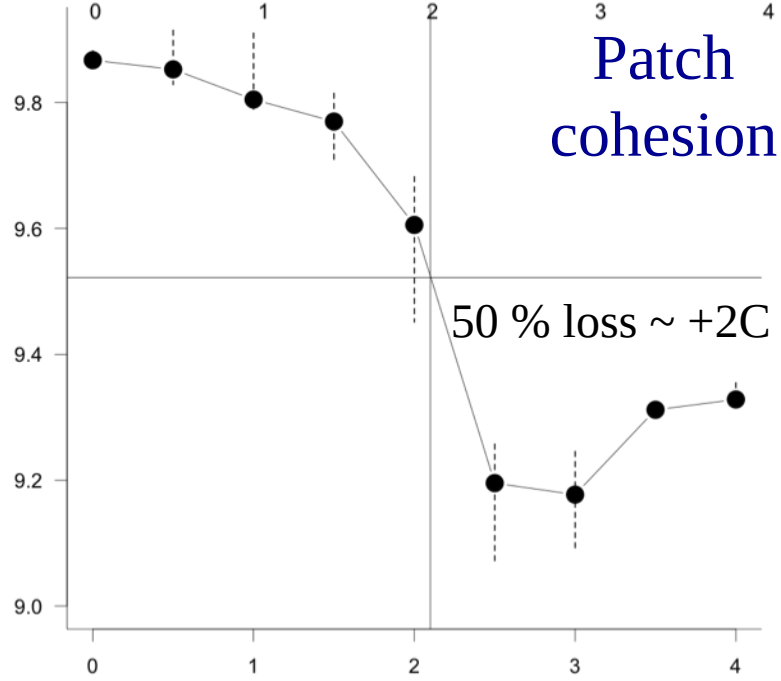
Complex dynamics & habitat velocities:

Changing co-distribution of optimal temperatures & rocks

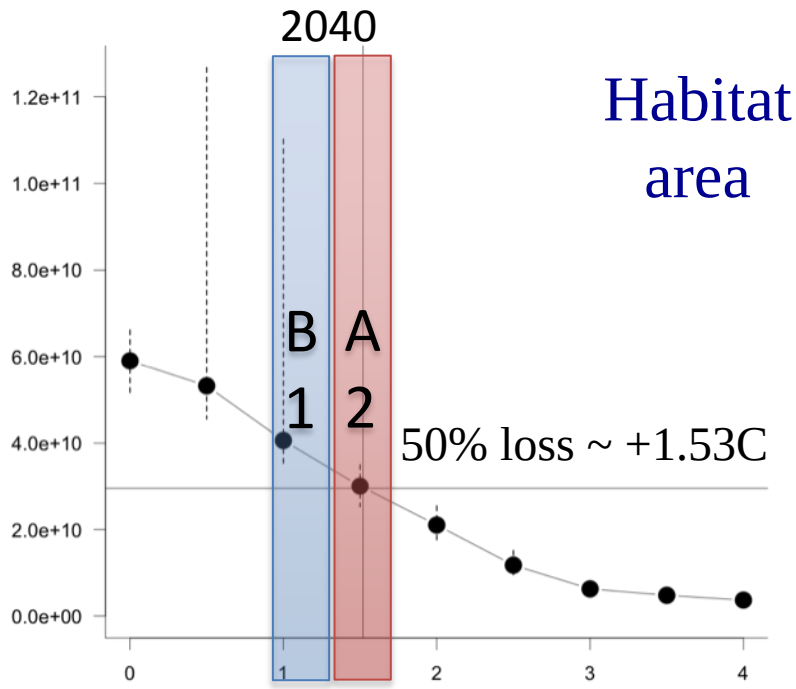


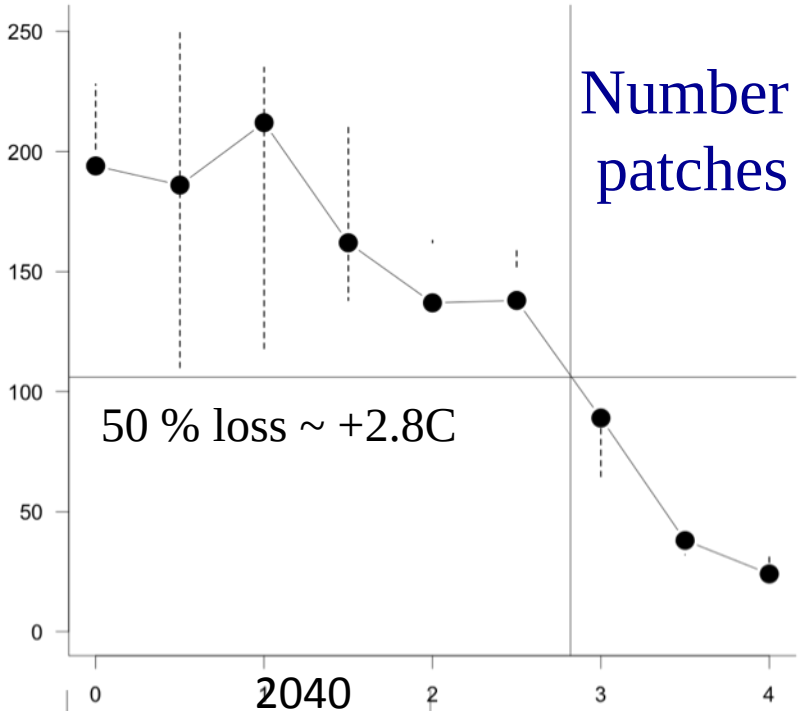


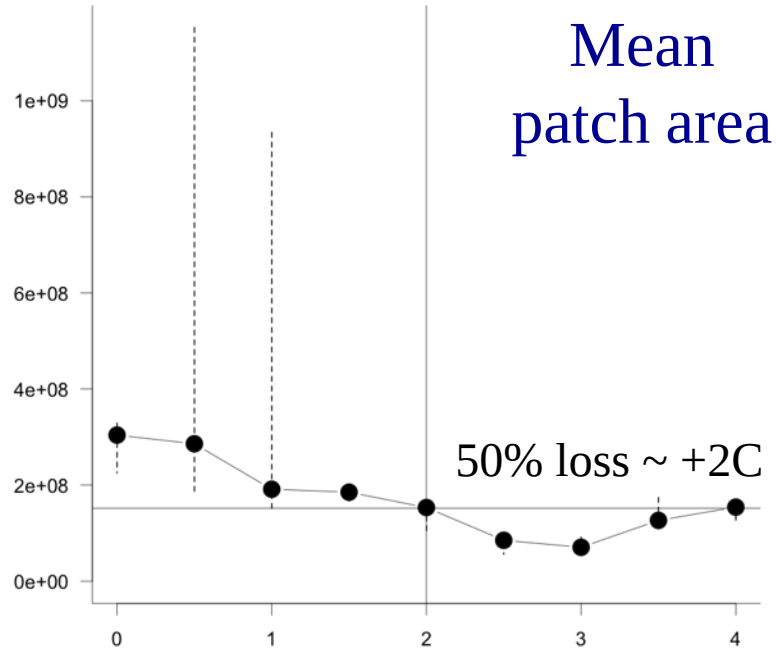


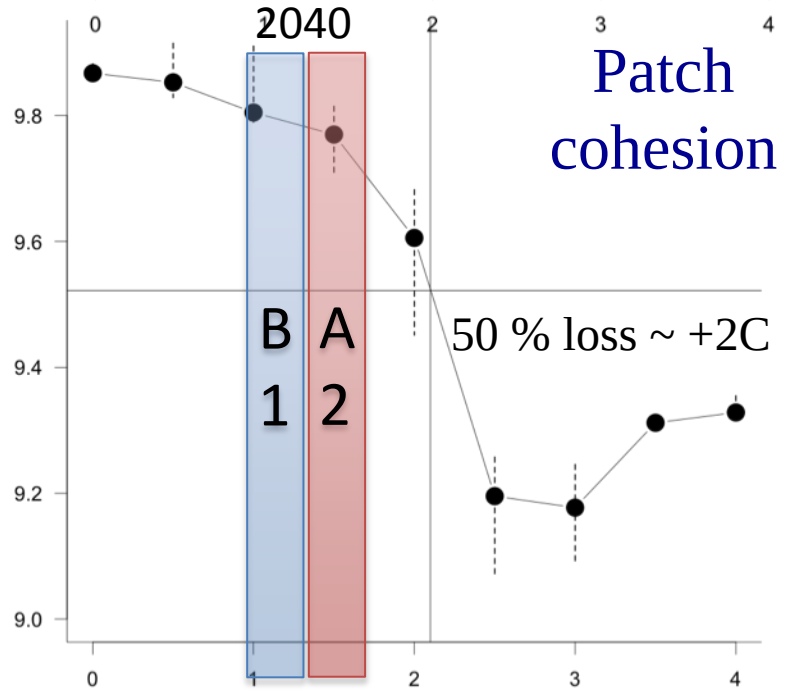


^{o}C above NovDec bottom temperature climatology









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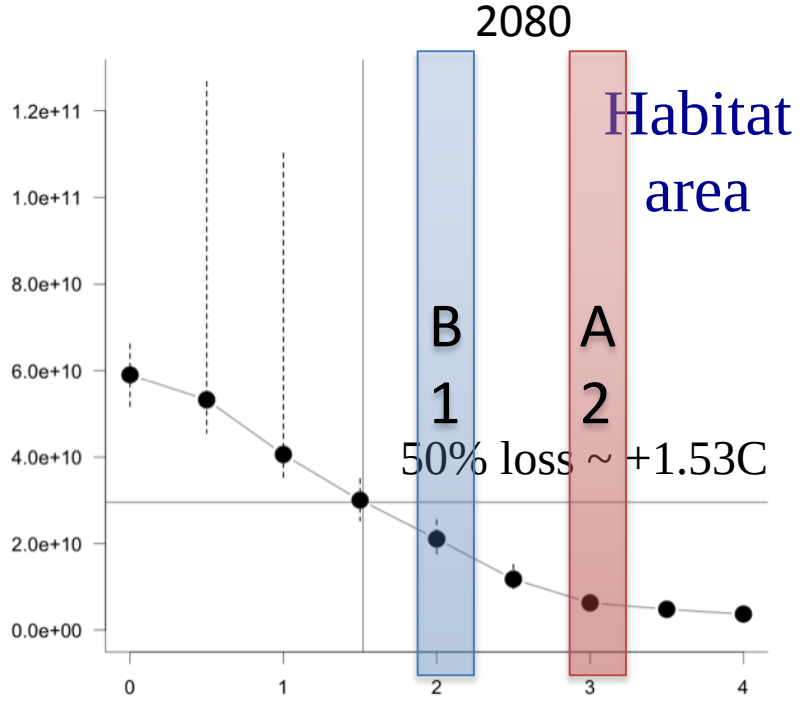
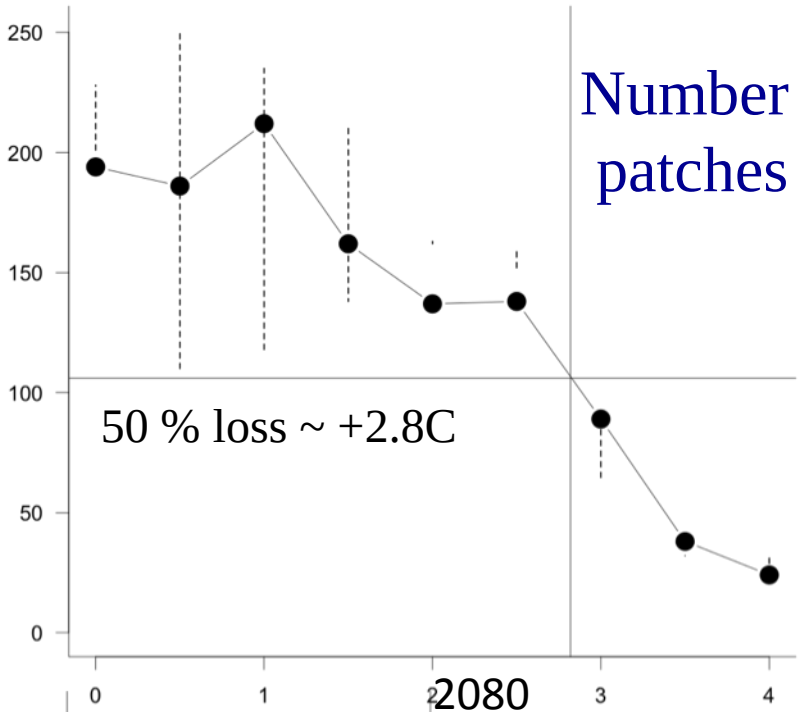
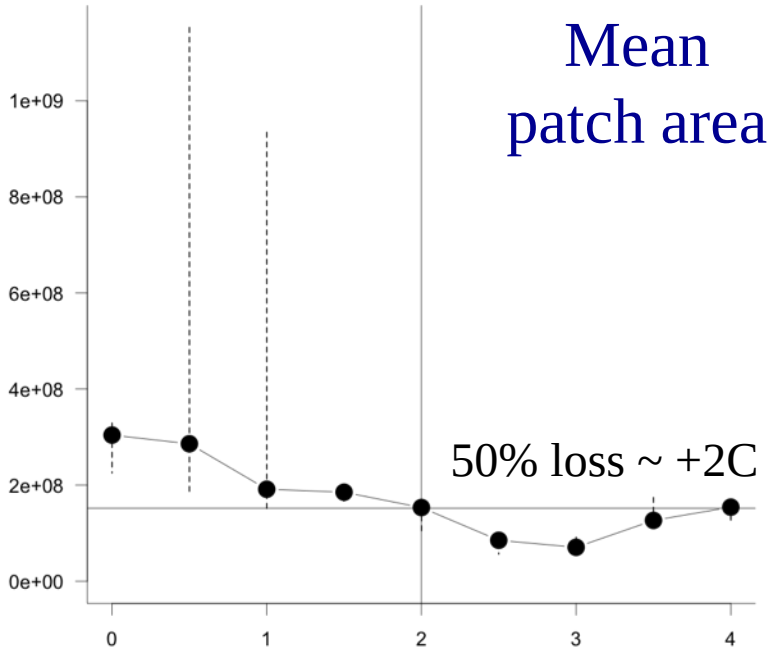
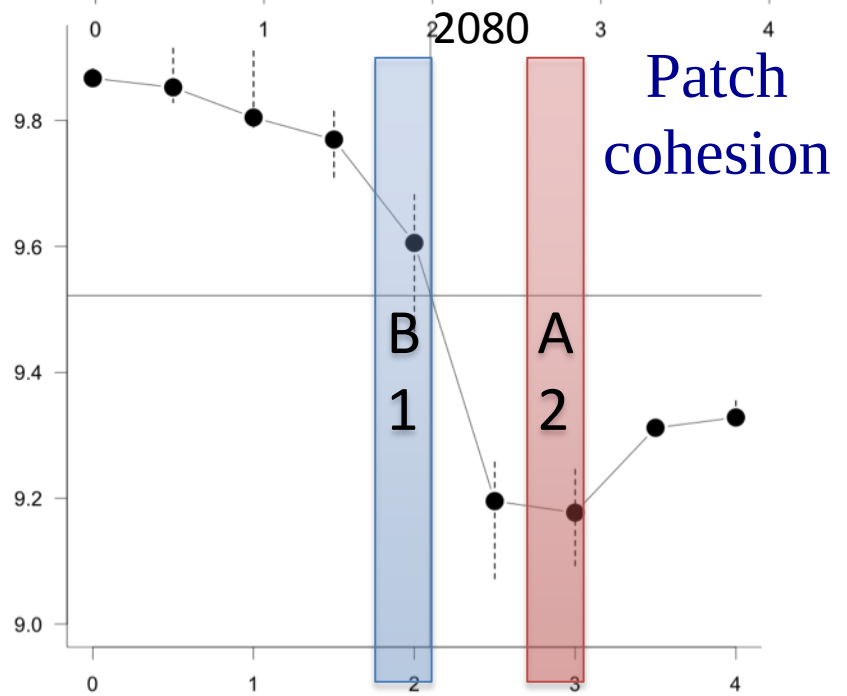




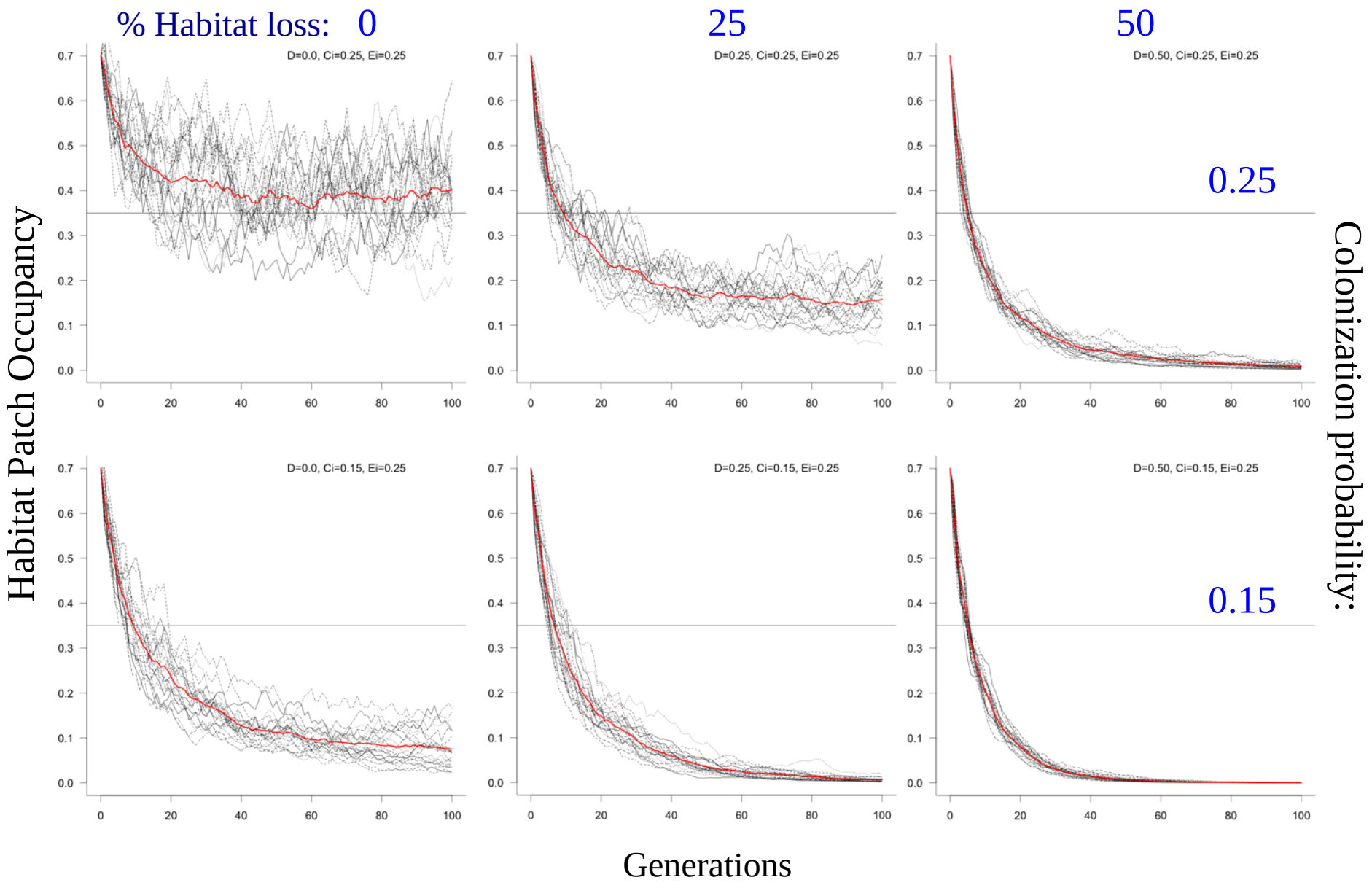




°C above NovDec bottom temperature climatology

So what? Emergent effects of habitat loss & fragmentation on population

Lande metapopulation model- portfolio effects + subpopulation rescue

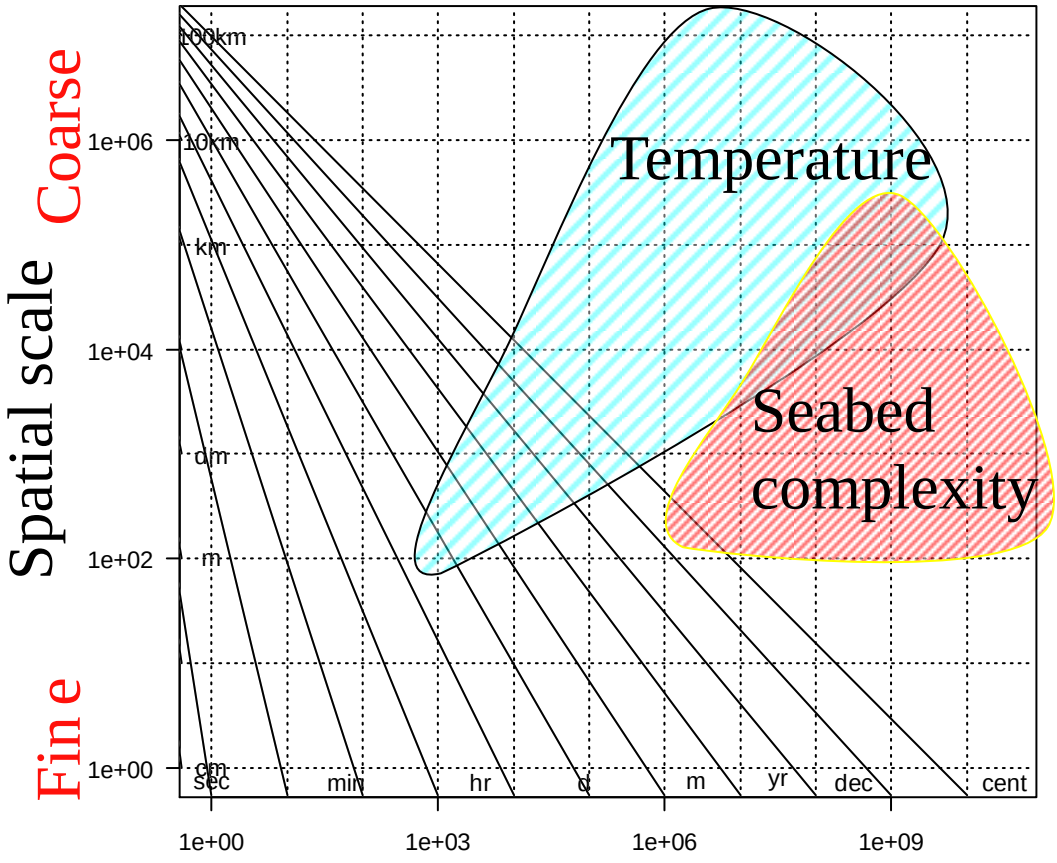


Ecophysiology + Environmental variability = Habitat dynamics

Growth, survival, reproduction, dispersal

Regulate Metabolism T,S,DO

Find prey
Find refuge: predation & energetic



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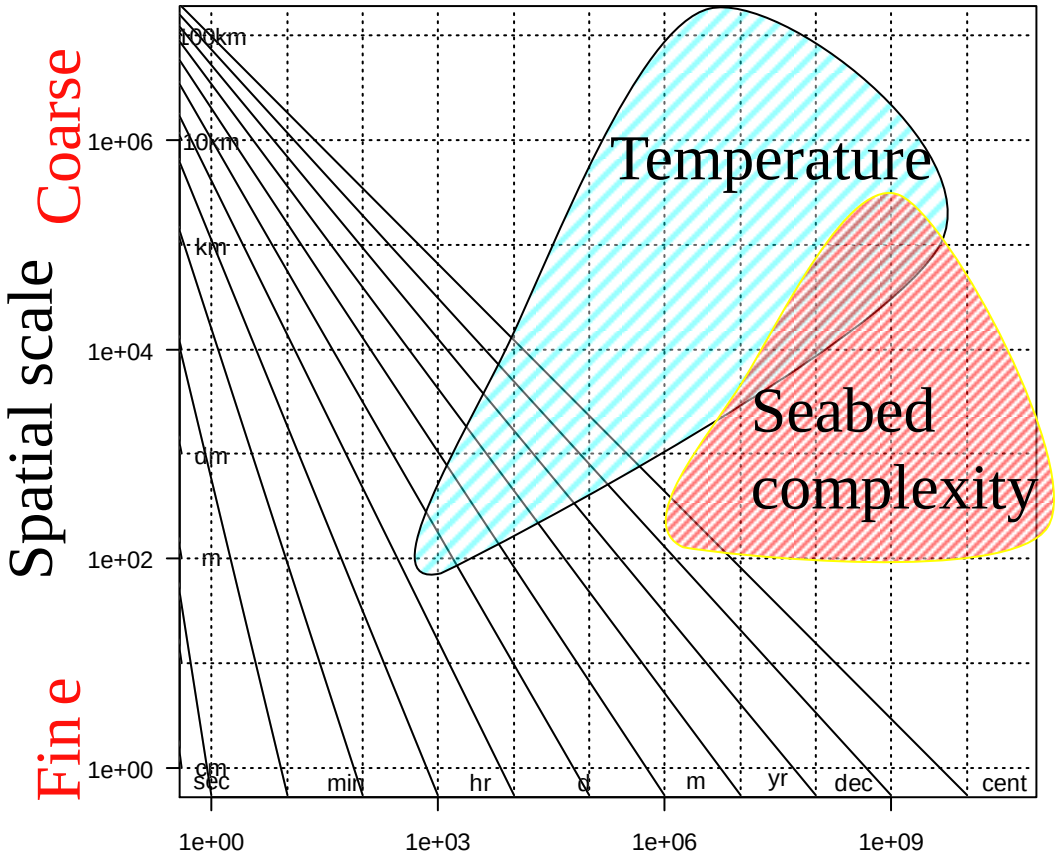

⇒ Fluid properties/processes regulate habitat dynamics: motion & rates of evolution

Ecophysiology + Environmental variability = Habitat dynamics

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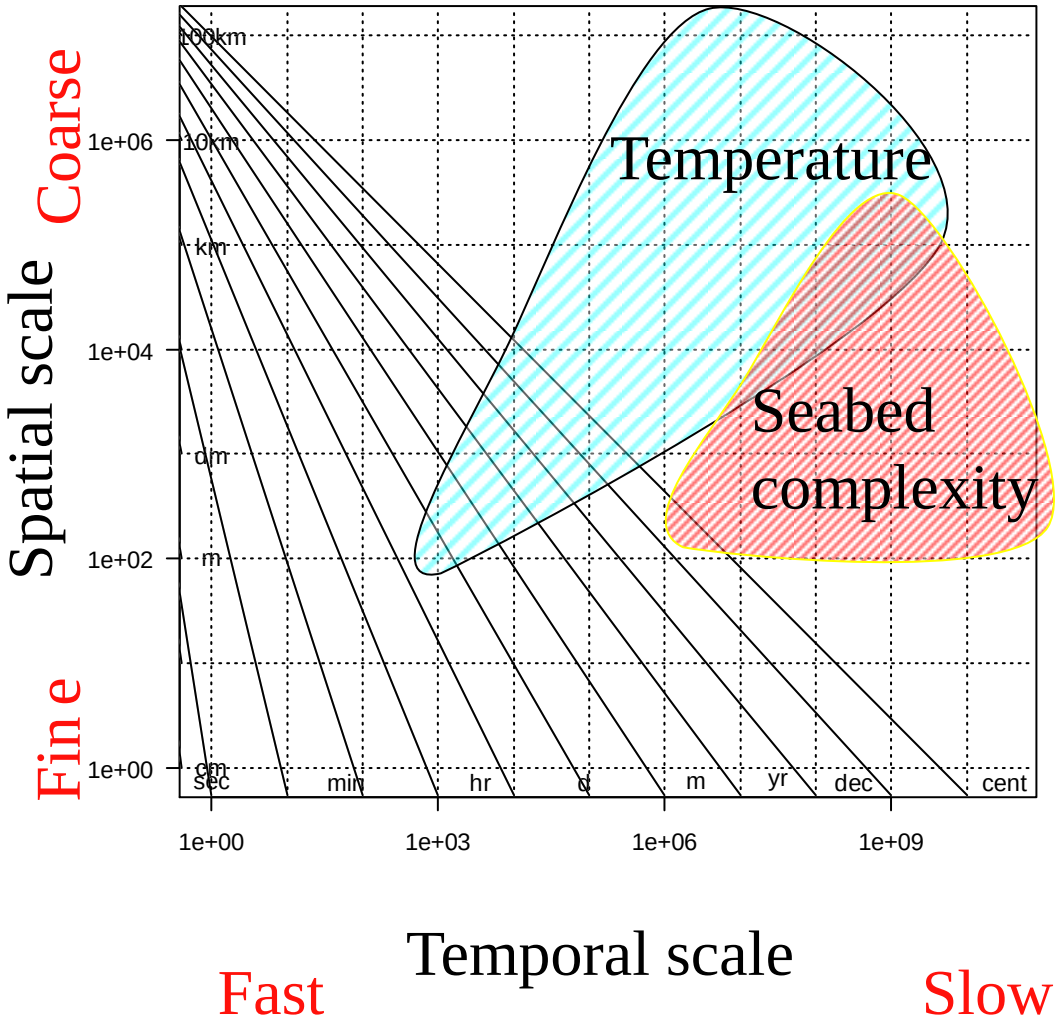

⇒ Fluid properties regulate habitat dynamics: rates motion & evolution

⇒ "velocities" of different habitat dimensions produce complex nonlinear habitat dynamics & emergent spatial population dynamics

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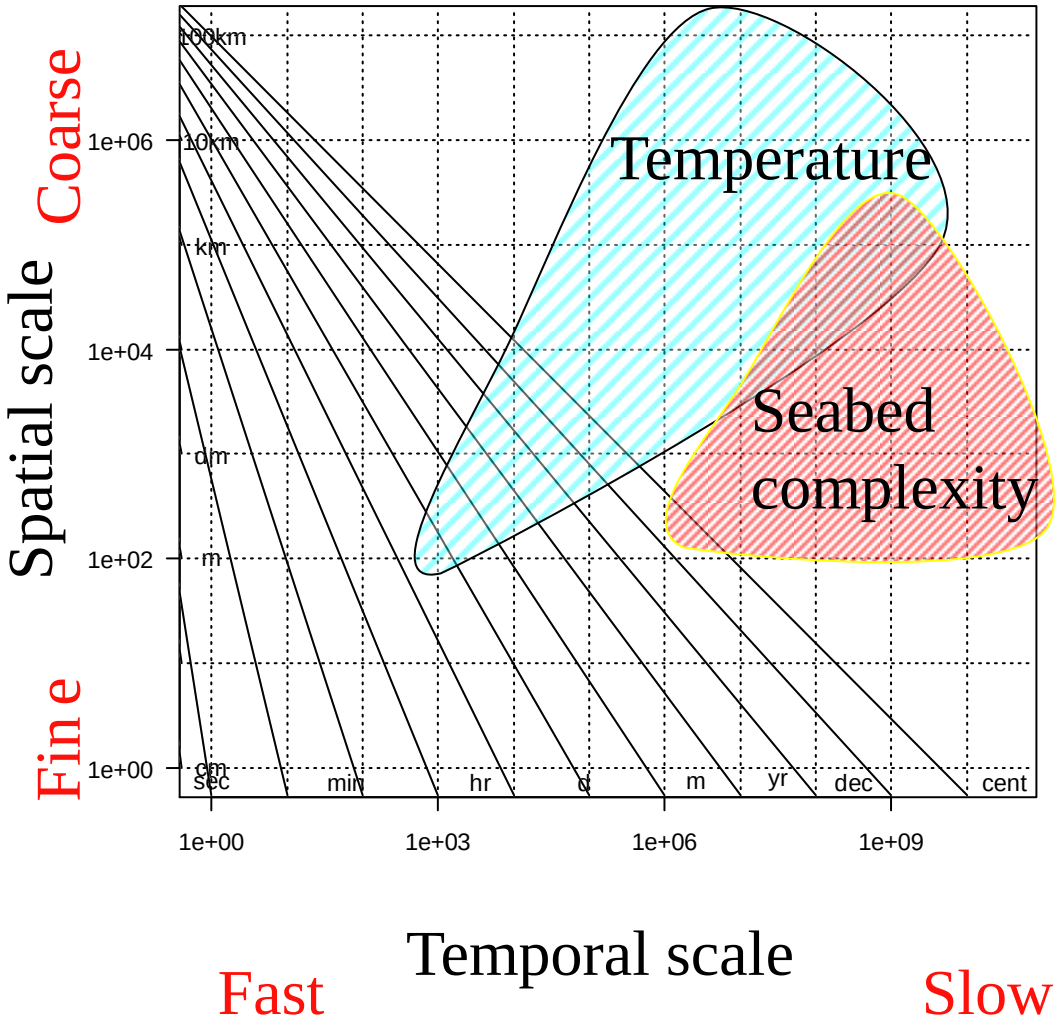


⇒ Fluid properties regulate habitat dynamics: rates of motion & devolution

⇒ differences "velocities" of habitat dimensions produce nonlinearities & complex spatial habitat & emergent population dynamics

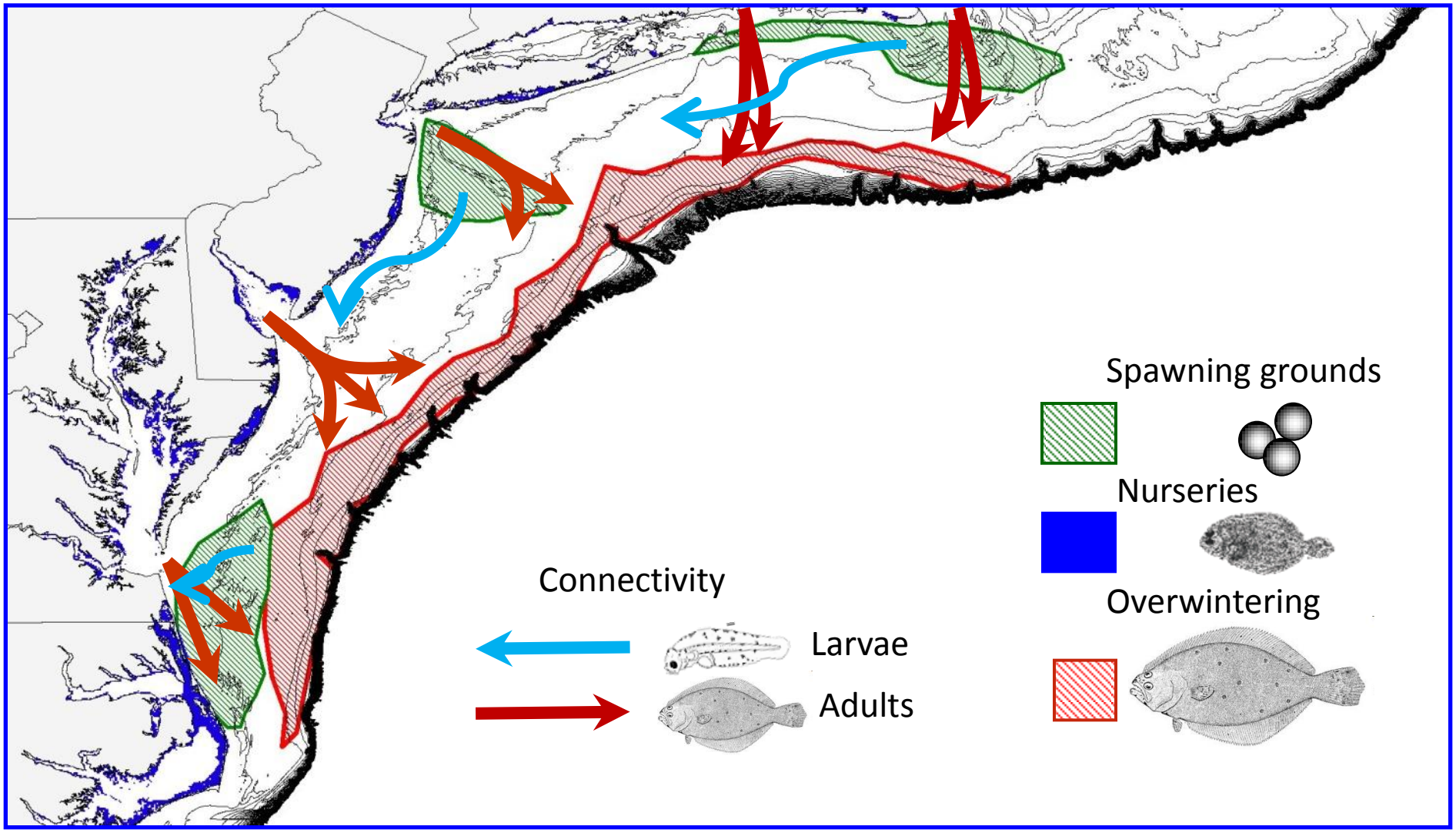
⇒ Marine habitat dynamics strongly coupled to atmospheric forcing & climate because ocean dynamics largely controlled by atmospheric forcing

1) What does habitat mean?

2) Simple simulation of possible climate impacts on habitat dynamics & population dynamics of a highly structure oriented benthic fish

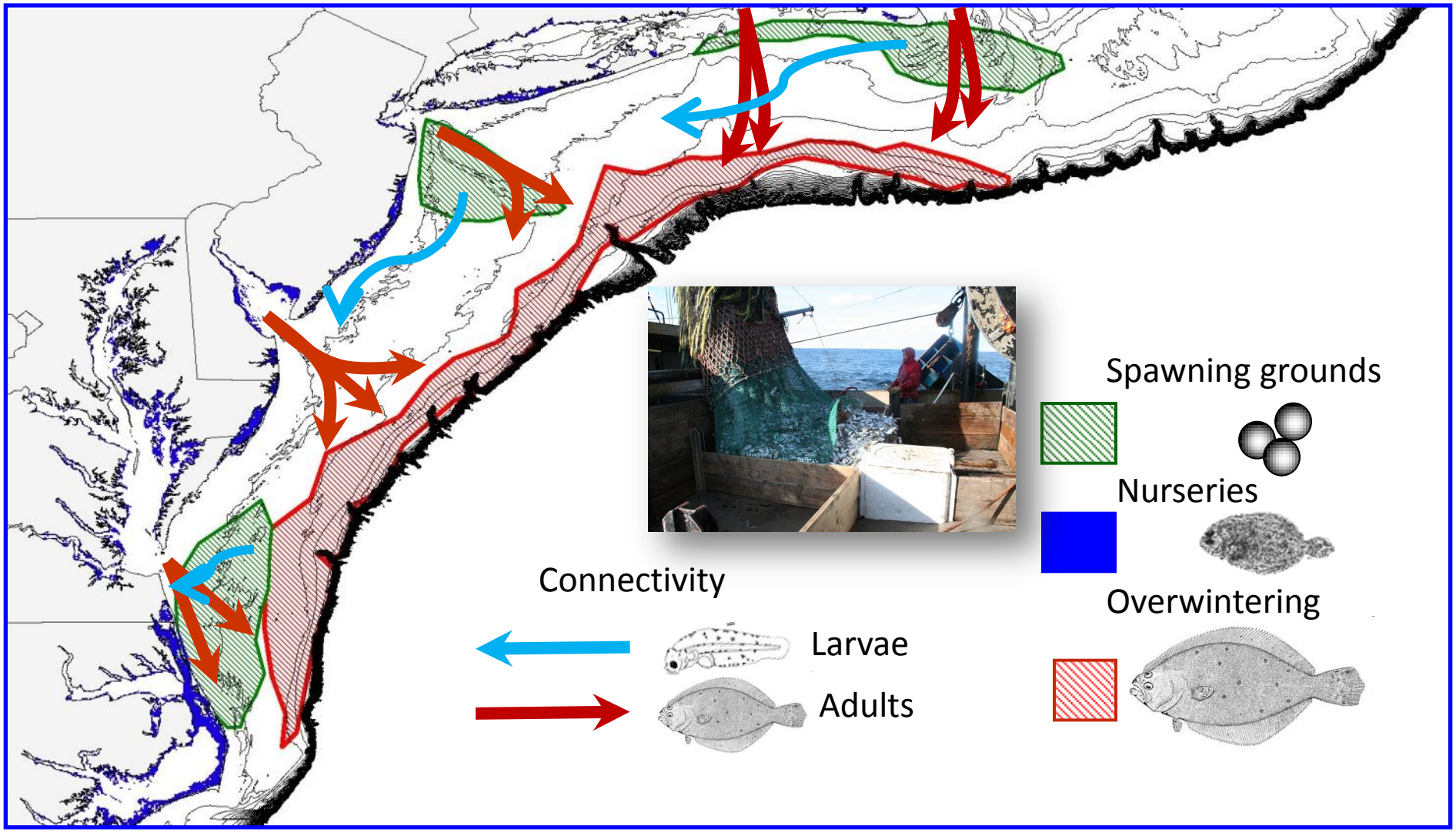
3) Potential climate drivers of habitat dynamics in the MAB shelf break ecosystem

Take ecosystem/habitat centric view



MAB shelf break: Overwintering habitat. Longfin squid, Butterfish, Mackerel, Scup, Bluefish, Fluke, Black seabass, Dogfish, Silver Hake, Spotted Hake, Red Hake, White Hake.....
Swordfish, Tuna's, Marine mammals, Birds..... Year round residents: John Dory, Tilefish, Lobster

Take ecosystem/habitat centric view



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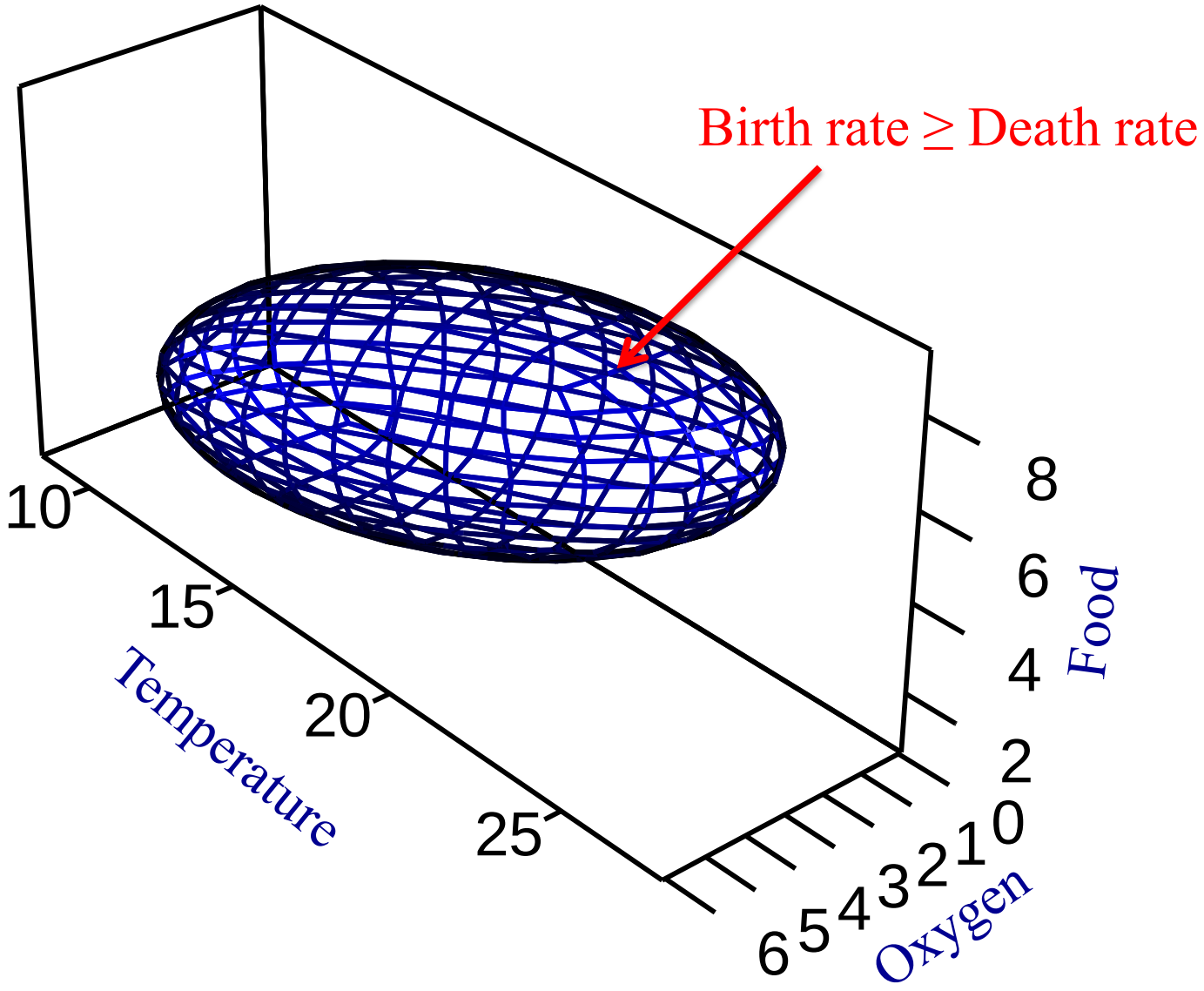
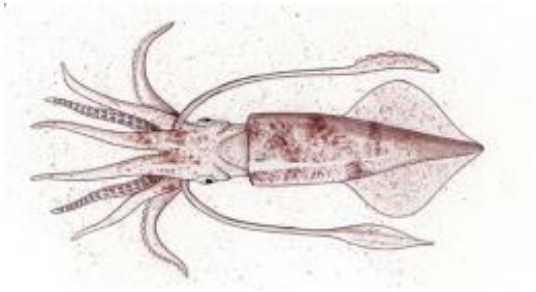




Many animals share thermal envelope with temperature peaks ~ 14C

Large scale forcing:

Atmospheric & Oceanographic

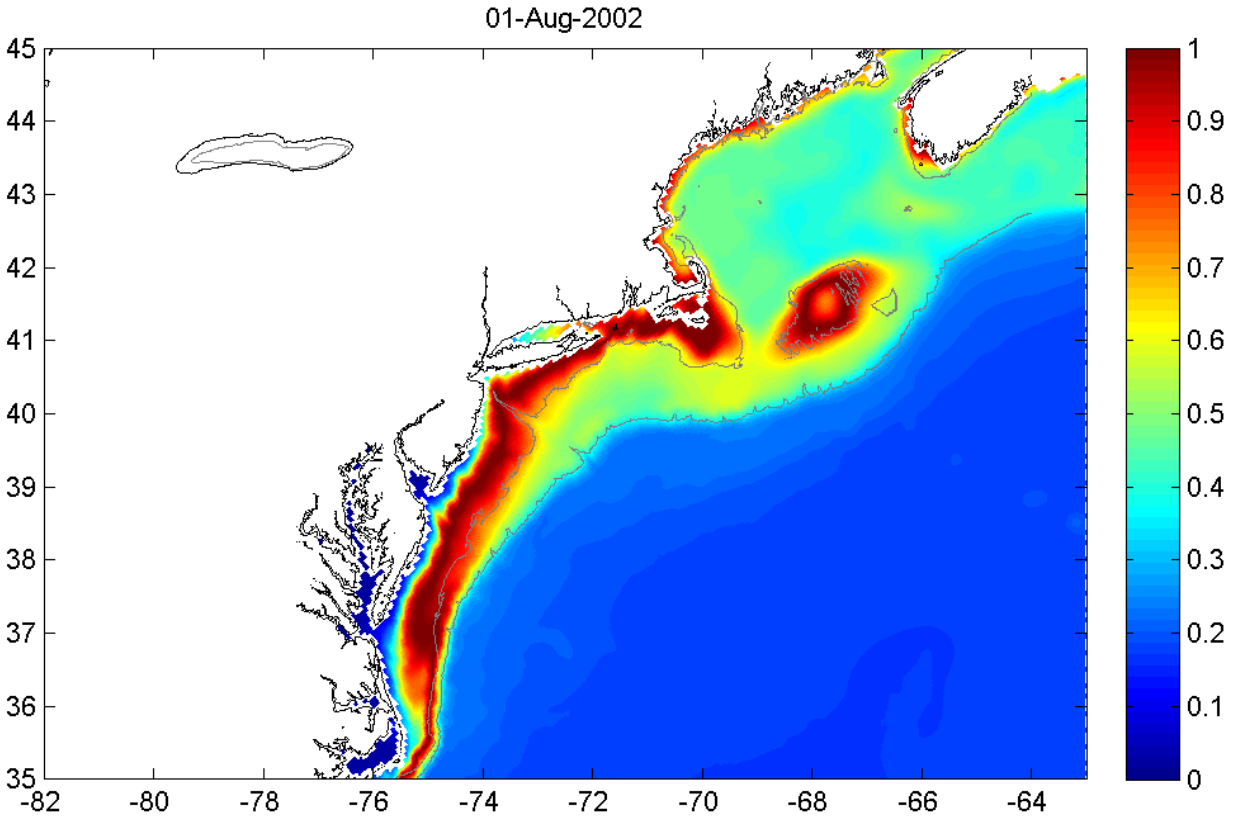
Atmosphere: jet stream

Ocean: regional sea scale flows

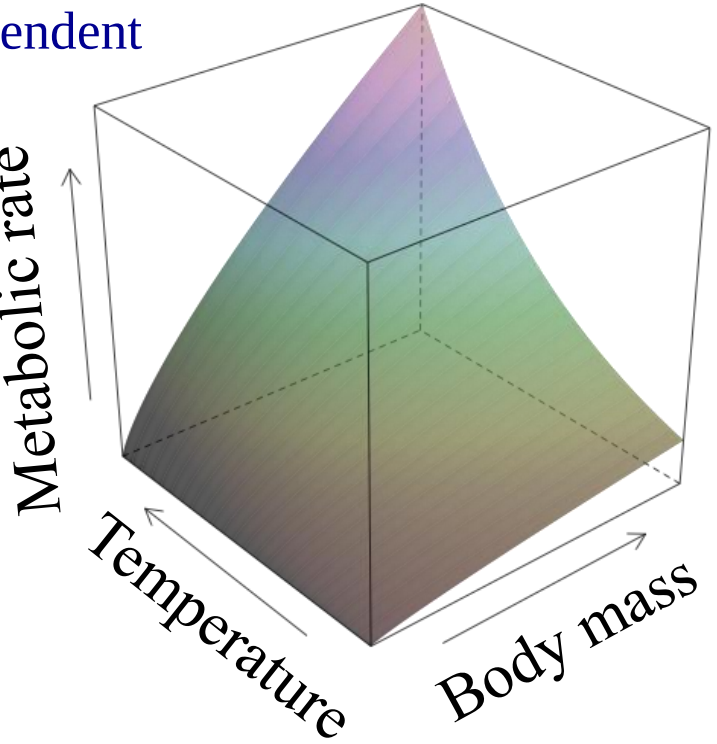
Fine scale forcing:

frontal passages & winds

Tides & internal waves



Where can I meet my temperature dependent metabolic demand without meeting somebody else's?



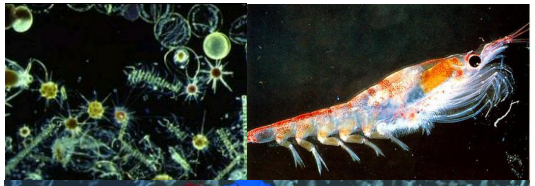
Feeding & Growth

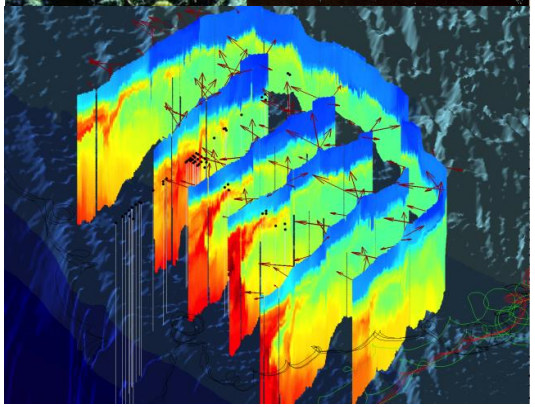
Concentration

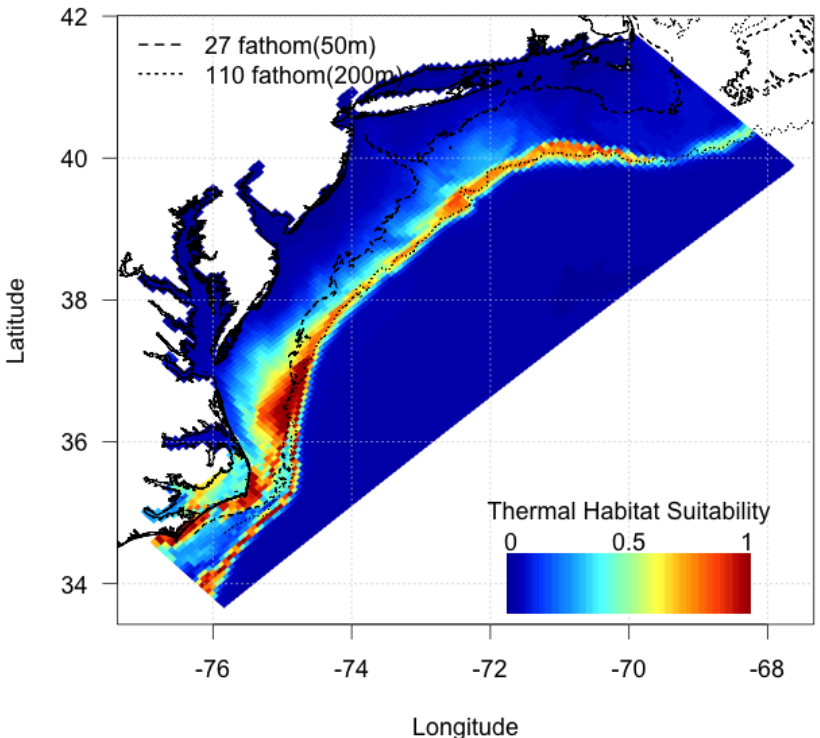
Productivity

Nutrient enrichment

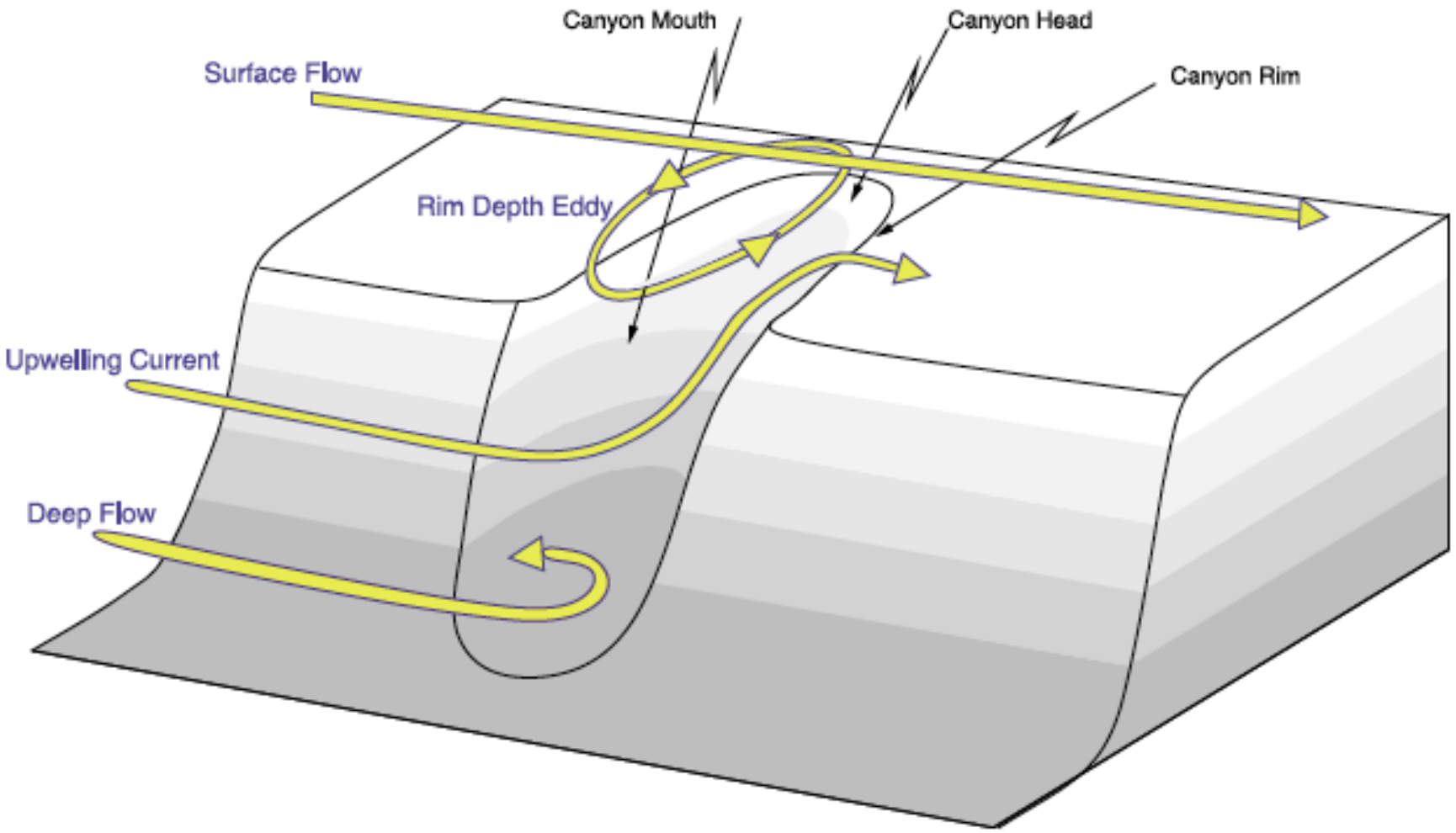
Physical mixing

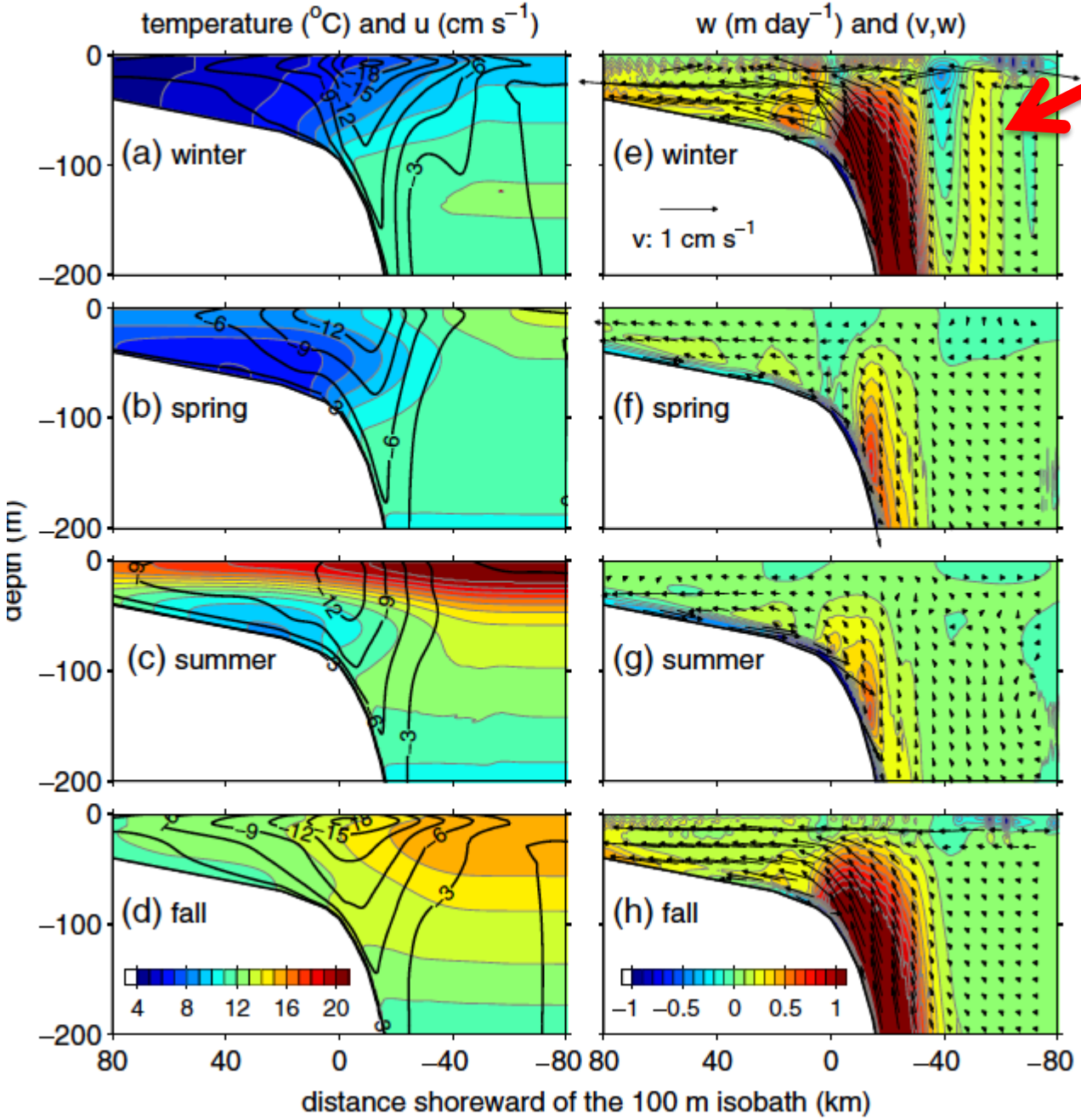






Complex physical dynamics around canyons





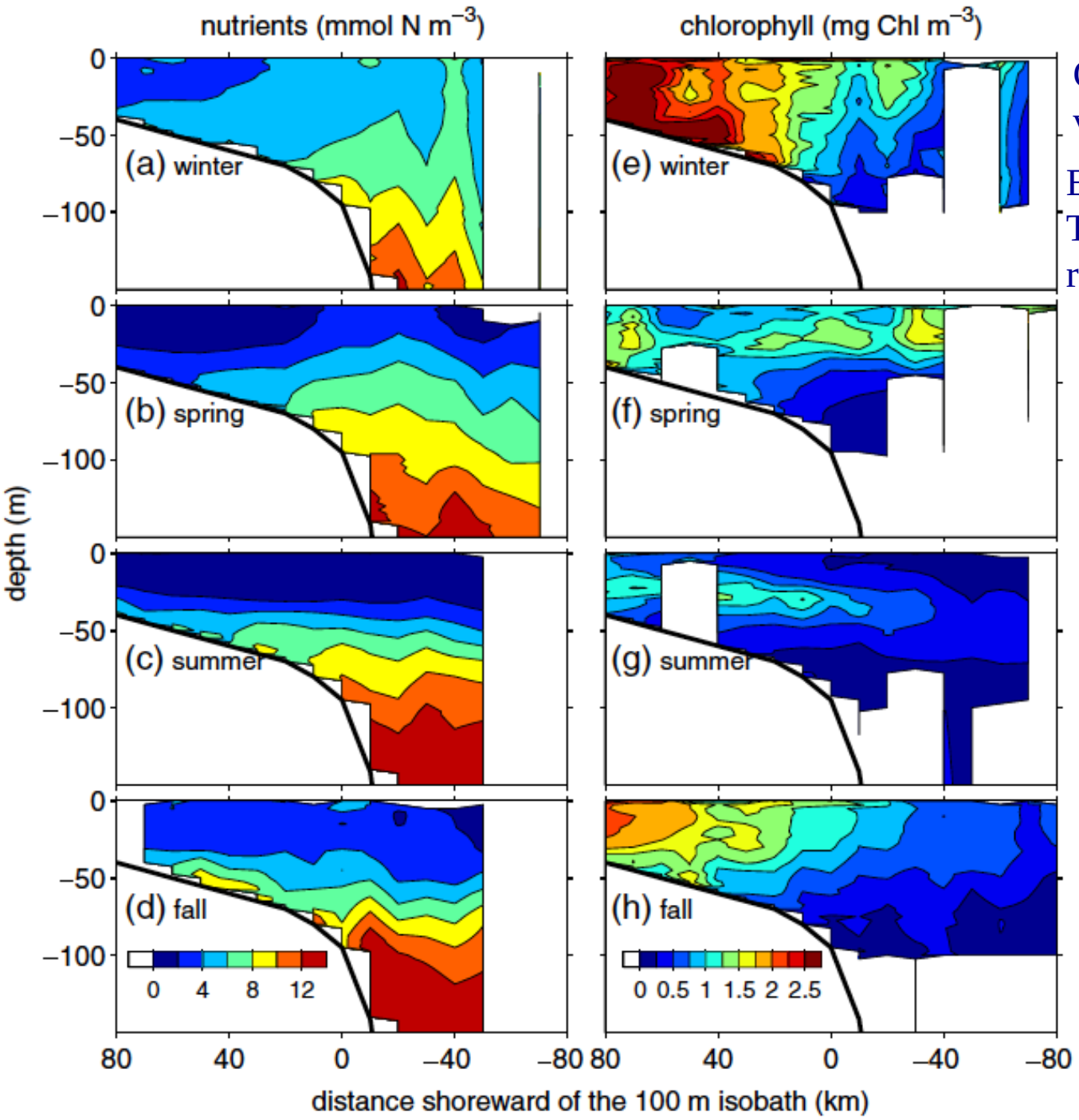
Upwelling

Forcing:
density differences
shelf & slope water

gulfstream eddies
& meanders,

passages of atmospheric
fronts & wind
internal waves

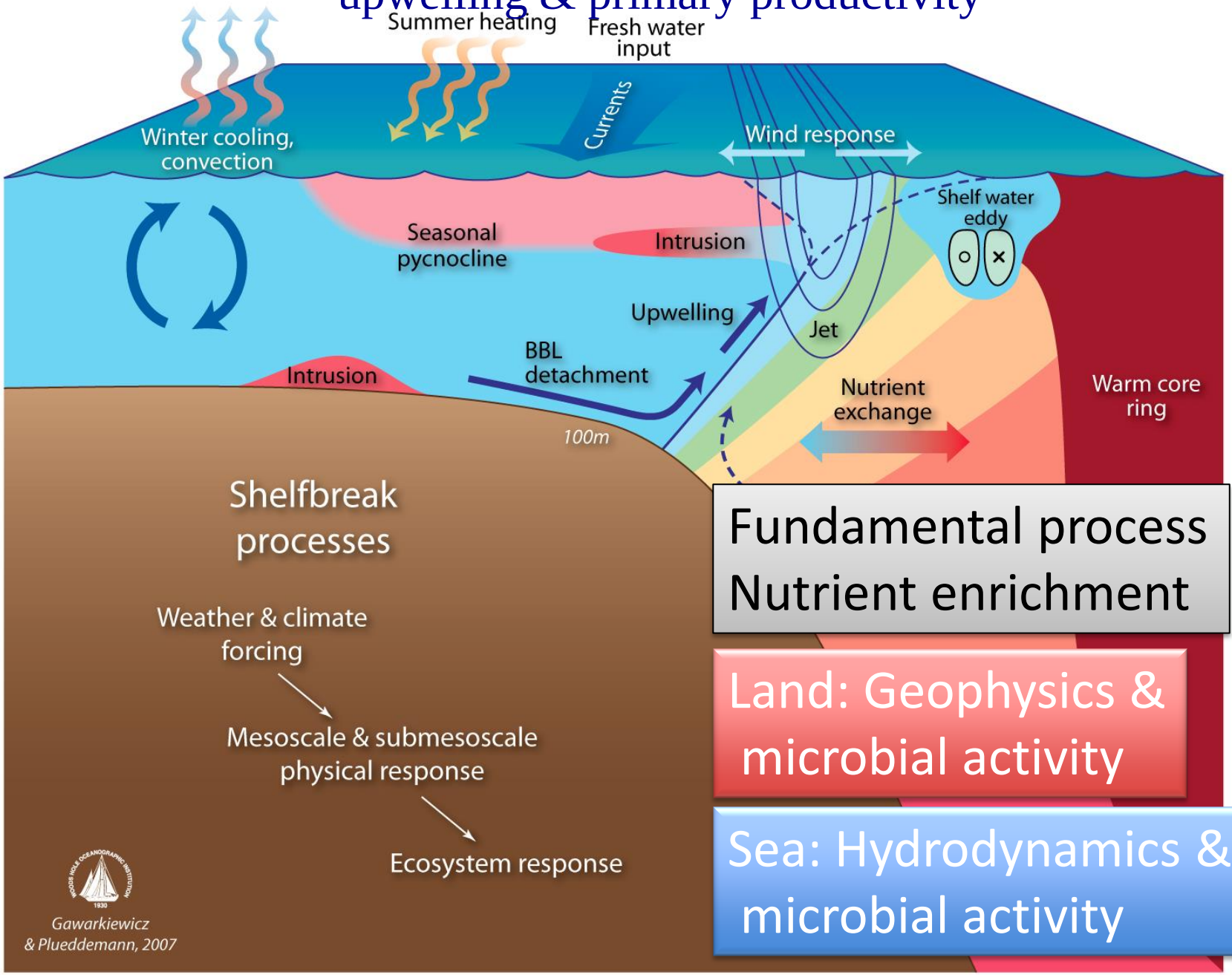
Upwelling strongly seasonal
but within seasons
Episodic & transient dynamics



Chlorophyll
variability higher than mean

Episodic &
Transient dynamics
related to upwelling dynamics

Complex hydrodynamic processes driving thermal regime, upwelling & primary productivity

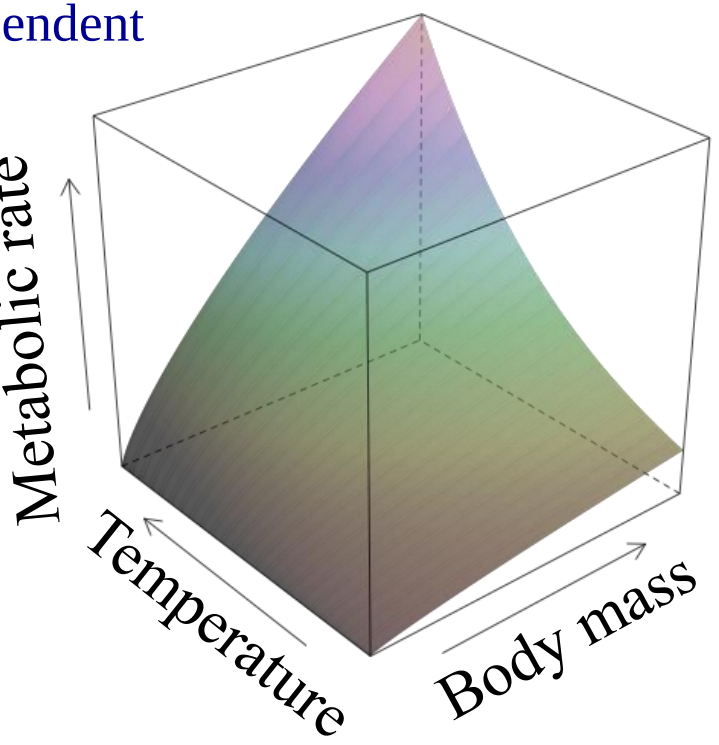


Fundamental process
Nutrient enrichment

Land: Geophysics & microbial activity

Sea: Hydrodynamics & microbial activity

Where can I meet my temperature dependent metabolic demand without meeting somebody else's?



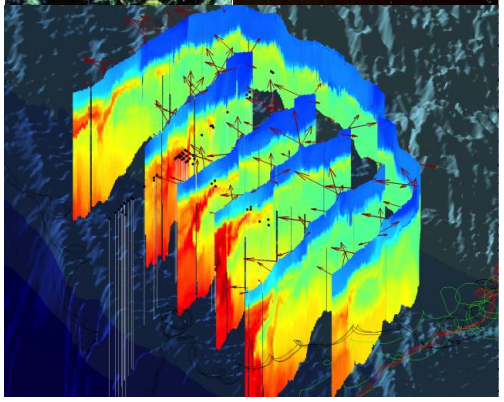
Feeding & Growth

Concentration

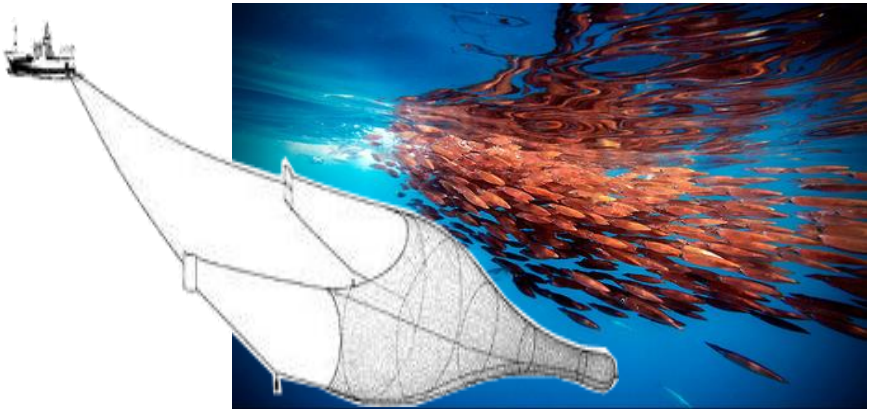
Productivity

Nutrient enrichment

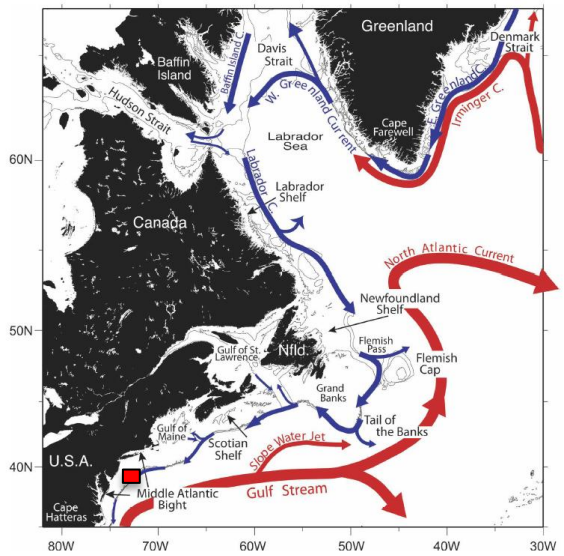
Physical mixing



Predation mortality

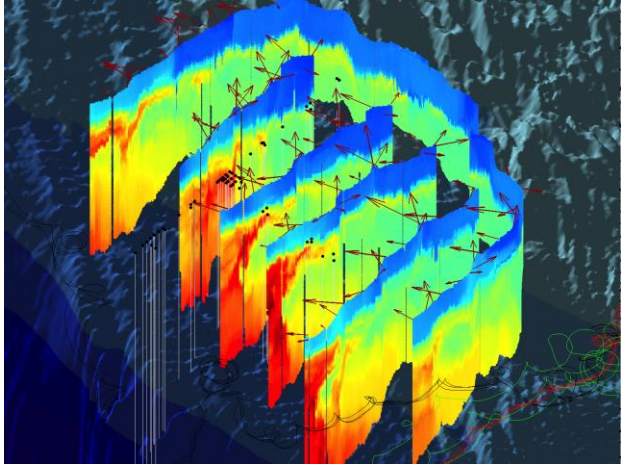


Structure of seabed & water column.
Spatial & temporal habitat partitioning



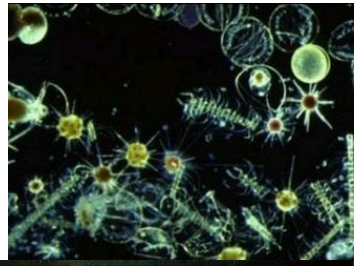
Fratantoni and Pickart. (2007)

Ocean & Atmosphere Physical Drivers Shelf break dynamics



Regional habitat dynamics
(Thermal habitat & metabolic demand)

Local habitat processes (upwelling, fronts, etc.)
Phytoplankton & food web dynamics



Rates of growth, development, survival

Intrinsic population growth of
forage species & other species

Coupled human ecological system (including socio-economic drivers)

The inconvenient truth:
Vital rates of marine organisms & therefor their habitats are coupled to ocean fluid
more than organisms & habitats on land are to the atmospheric fluid)

A Journal of Macroecology

Global Ecology and Biogeography, (Global Ecol. Biogeogr.) (2010) 19, 303–316

META-ANALYSIS

Marine range shifts and species introductions: comparative spread rates and community impacts

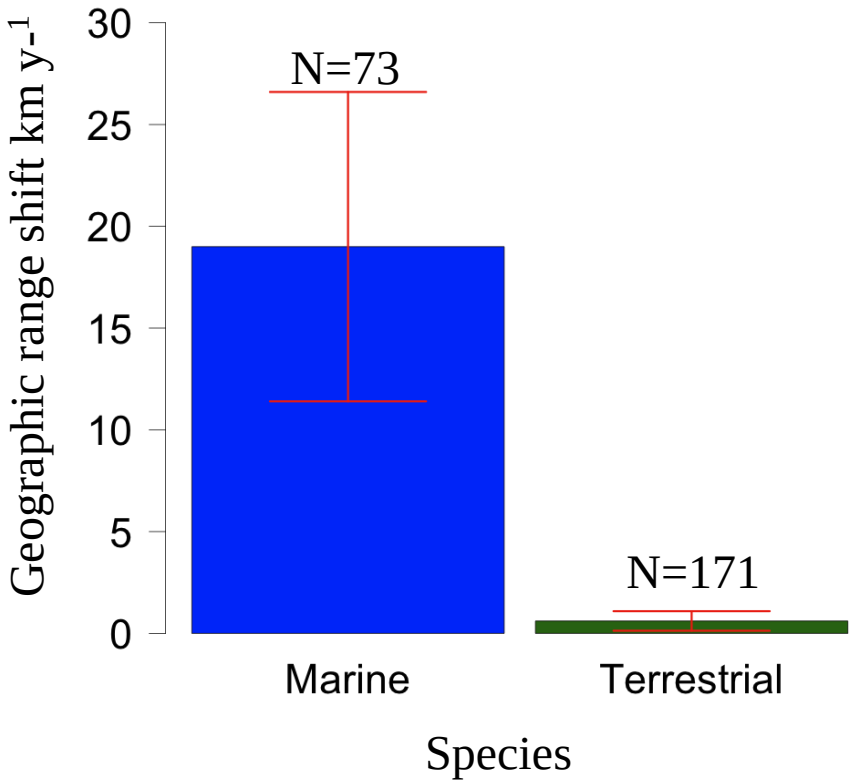
Cascade J. B. Sorte[1]*, Susan L. Williams[1] and James T. Carlton[2]

[1]Bodega Marine Laboratory and Department of Evolution and Ecology, University of California at Davis, PO Box 247, Bodega Bay, CA 94923-0247, and [2]Maritime Studies Program, Williams College – Mystic Seaport, Mystic, CT 06355, USA

ABSTRACT

Aim Shifts in species ranges are a predicted and realized effect of global climate change; however, few studies have addressed the rates and consequence of such shifts, particularly in marine systems. Given ecological similarities between shifting and introduced species, we examined how our understanding of range shifts may be informed by the more established study of non-native species introductions.

Sorte et al 2010: 129 marine species (plants to birds) show range shifts
75% shifts poleward



- Population & ecosystem dynamics emerge from interactions between species life history traits & constraints and habitat processes & dynamics

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- To forecast future you have to understand mechanistic effects of habitat process & dynamics on birth & death rates

- Population & ecosystem dynamics emerge from interactions between species life history traits & constraints and habitat processes & dynamics

- To forecast future you have to understand mechanistic effects of habitat process & dynamics on birth & death rates

- Fish live in the water & most important processes underlying habitat dynamics are hydrodynamic & not stationary & forced by atmospheric & planetary forcing

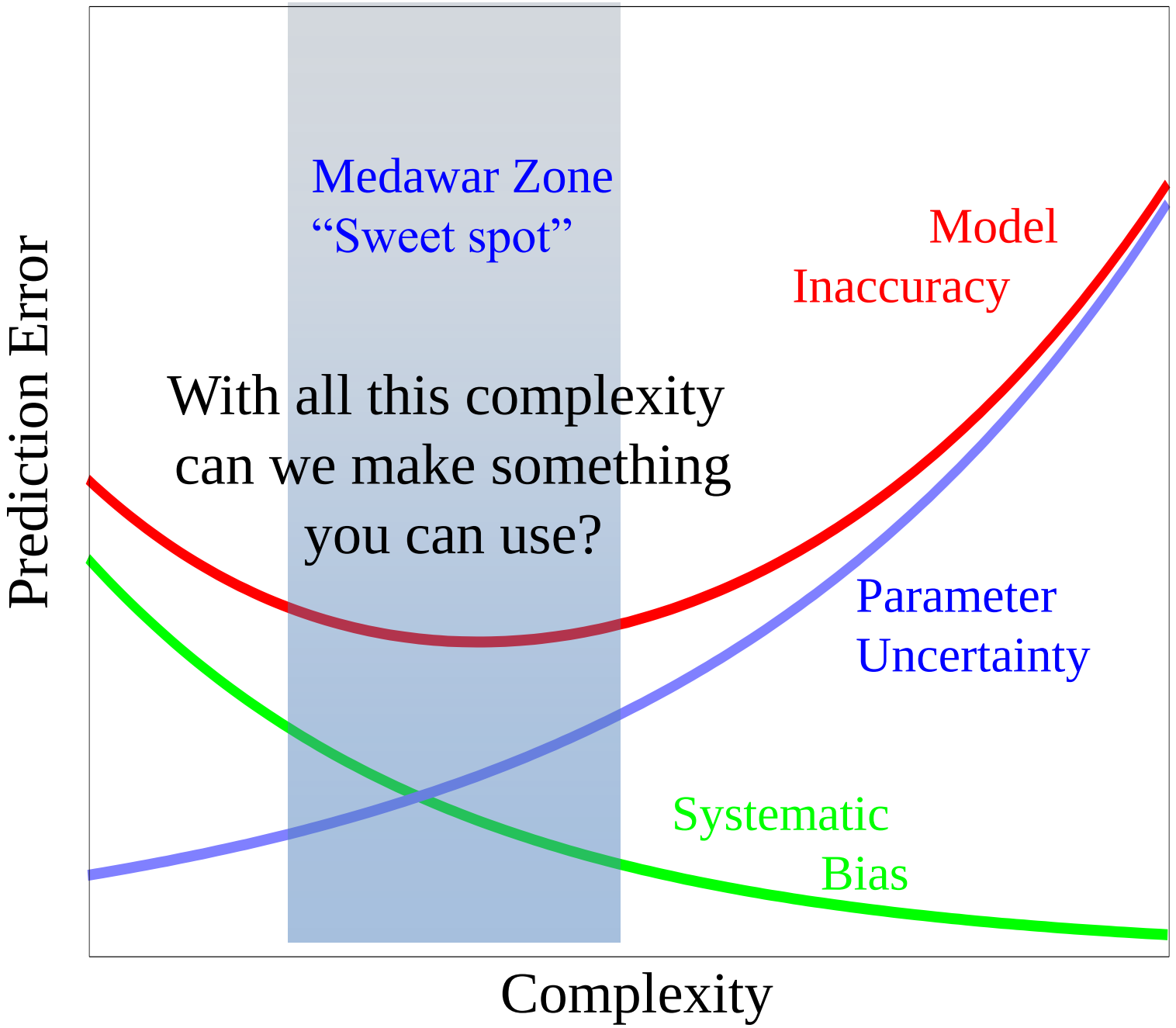
1) What does habitat mean?

2) Simulated effects of changes in temperature on habitat & population dynamics for a structure oriented site attached fish

3) Drivers of habitat dynamics in the MAB shelf break ecosystem

4) With all that complexity can you make something useful

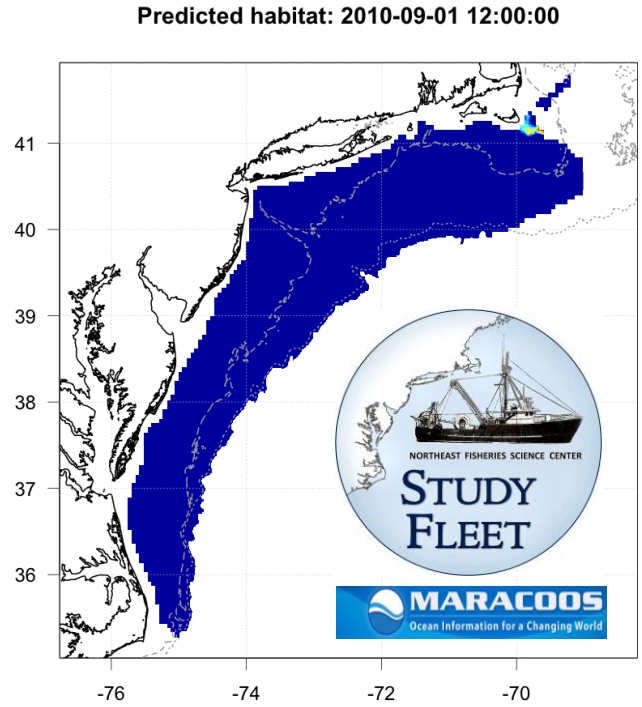
Models & the problem of complexity



Cooperative Research

Combine fishermen & scientists' knowledge in Operational Ocean Observing System :

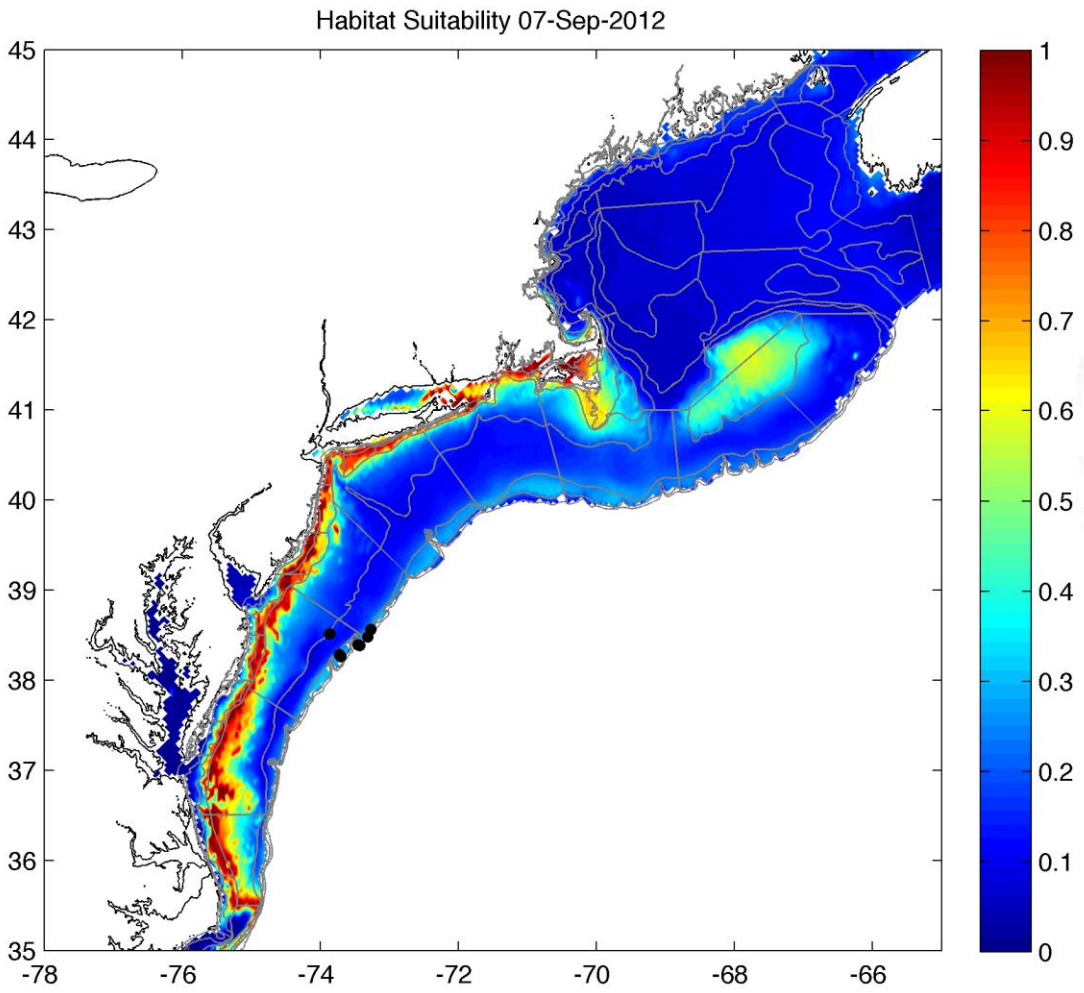
Develop products capturing ecosystem dynamics & key driving processes at space-time scales of the natural system



Fisherman: Operate at habitat scales
See climate impacts firsthand first

Can we actually make a useful product?

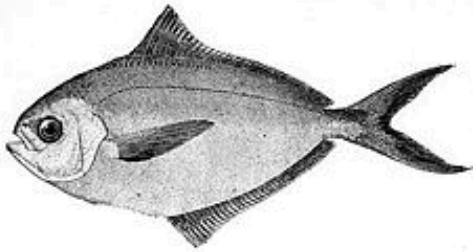
Model to calculate how much habitat stock assessment surveys actually sampled dynamically



Habitat Suitability Index

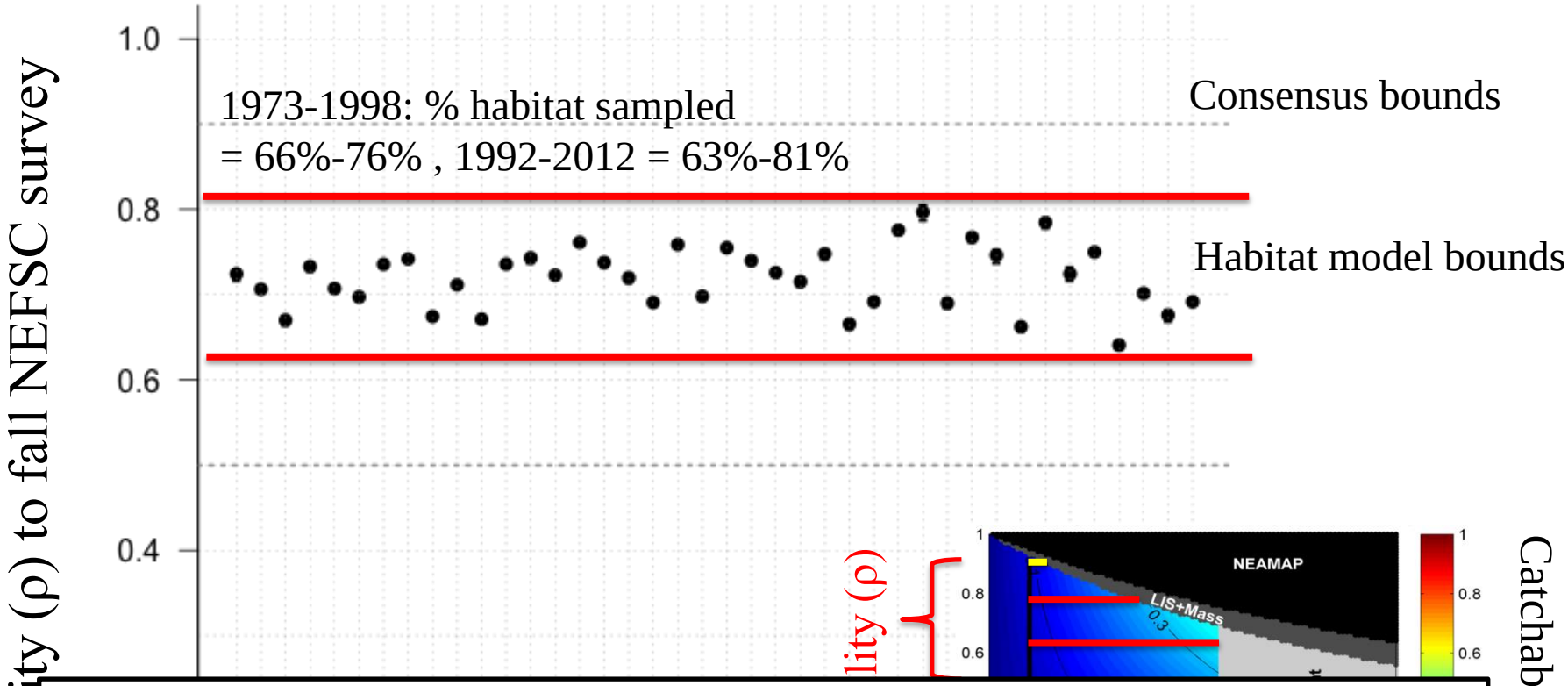
HSI

Good habitat



Poor habitat

Habitat model based estimate of availability (ρ) of butterfish to fall NEFSC survey



Estimates changes in availability (ρ) over time.

Thermal habitat based ρ accounts for shifts in species distributions associated with climate impacts on ocean temperatures

“Comparison of marine & terrestrial dynamics has more than theoretical interest. ..imposition of terrestrial standards for marine problems may produce too strict or too lax criteria -- or most likely quite inappropriate ones”

Steele JH (1991) Can ecological theory cross the land-sea boundary? Journal of Theoretical Biology 153:425-436

Particularly true with climate change since habitat dynamics in sea primarily defined by fluid properties & processes with strong atmospheric/climate forcing