Optimization and evolution of traits in models of fish

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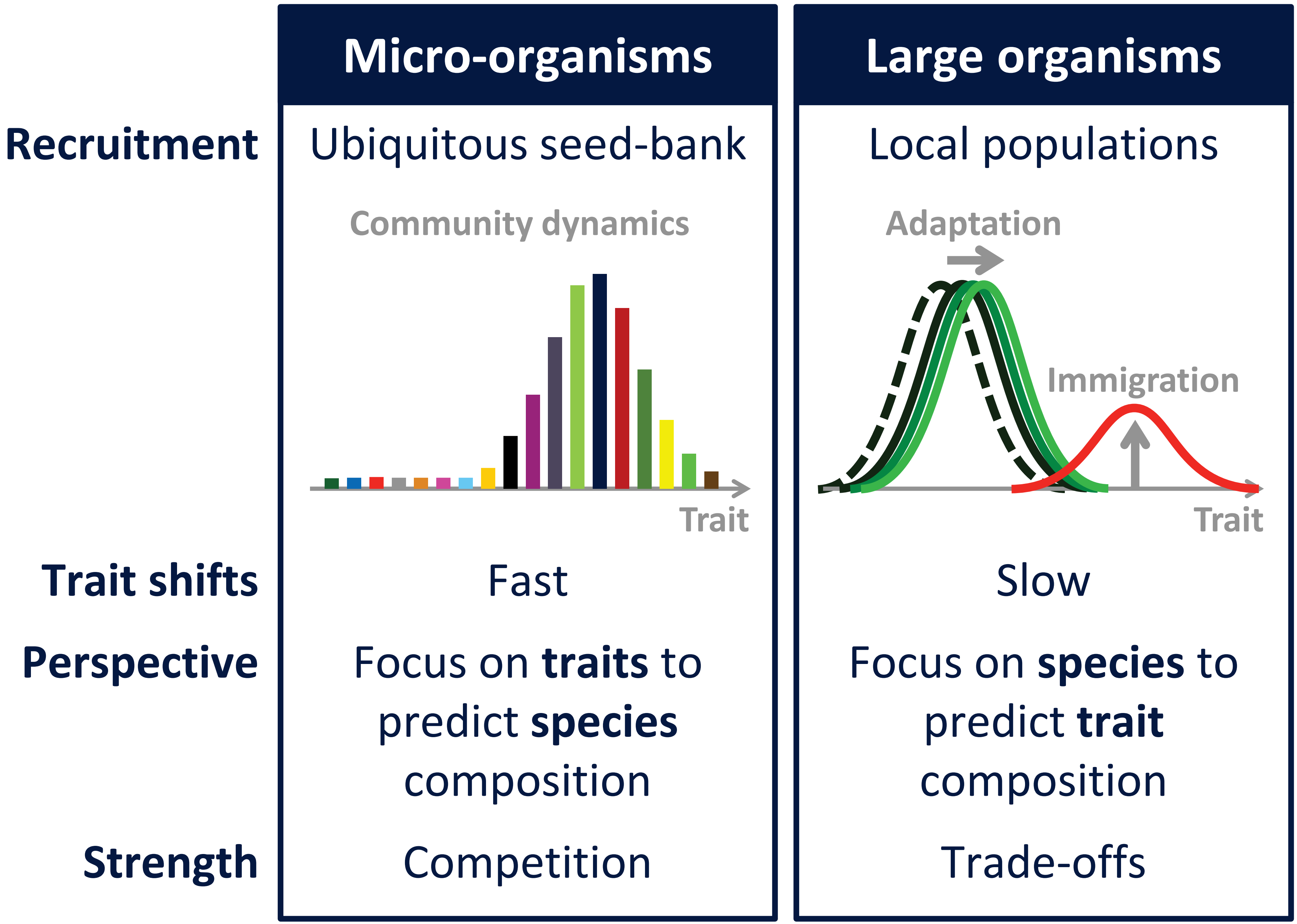
Micro-organisms
Large organisms
Recruitment
Ubiquitous seed-bank
Local populations
Community dynamics
Trait
Adaptation
Immigration
Trait
Trait shifts
Fast
Slow
Perspective
Focus on traits to predict species composition
Focus on species to predict trait composition
Strength
Competition
Trade-offs


Iceland
Faroe Islands
Denmark
Poland
Slovakia
Czech Republic
Hungary
Germany
Austria
Serbia
Netherlands
Croatia
Slovenia
Belgium
Isle of Man
United Kingdom
Liechtenstein
Switzerland
San Marino
Ireland
Italy
Holy See (Vatican)
Guernsey
France
Monaco
Andorra
Data SIO, NOAA, U.S. Navy, NGA, GEBCO
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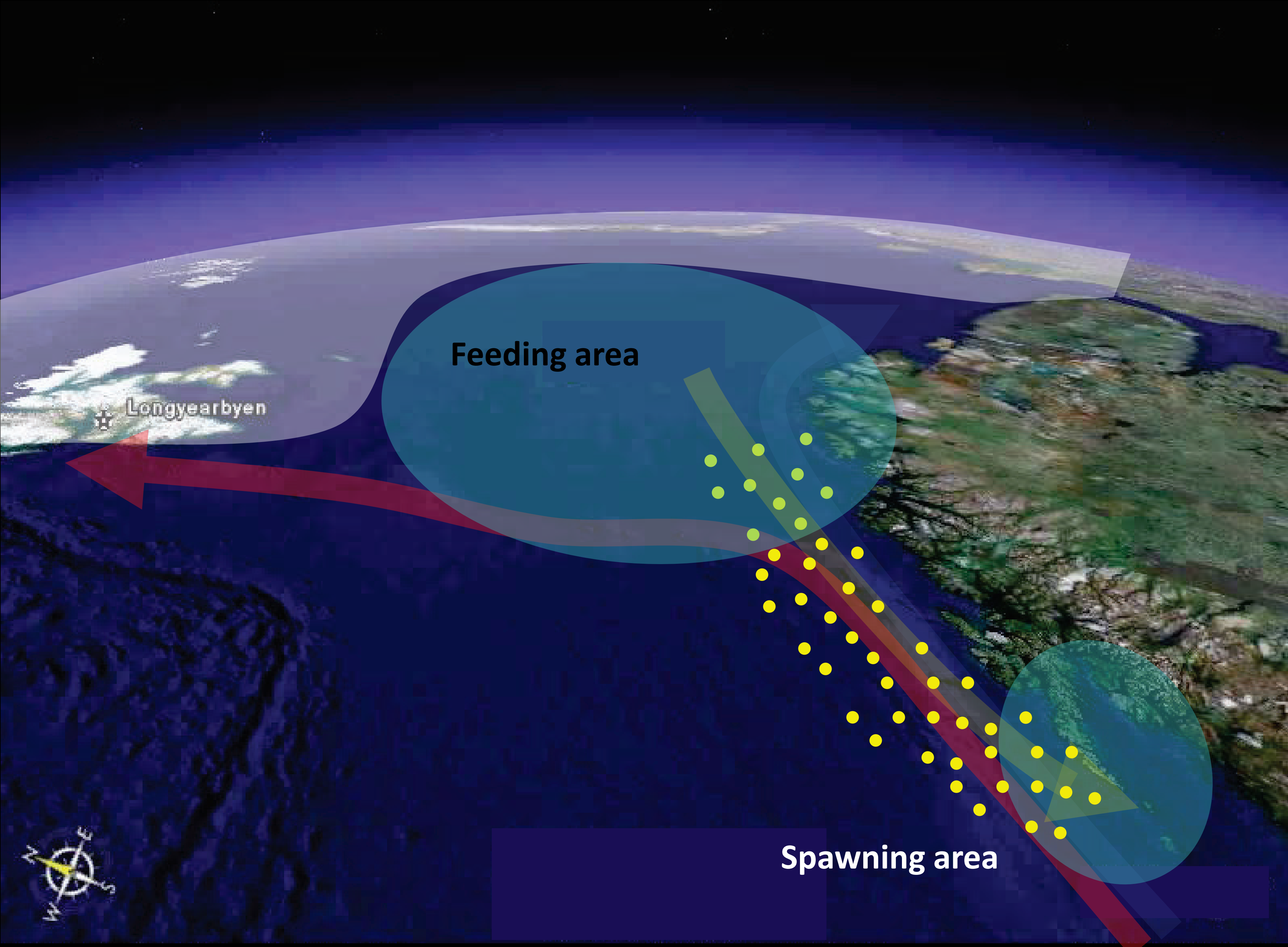
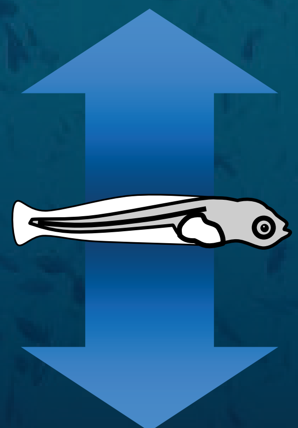
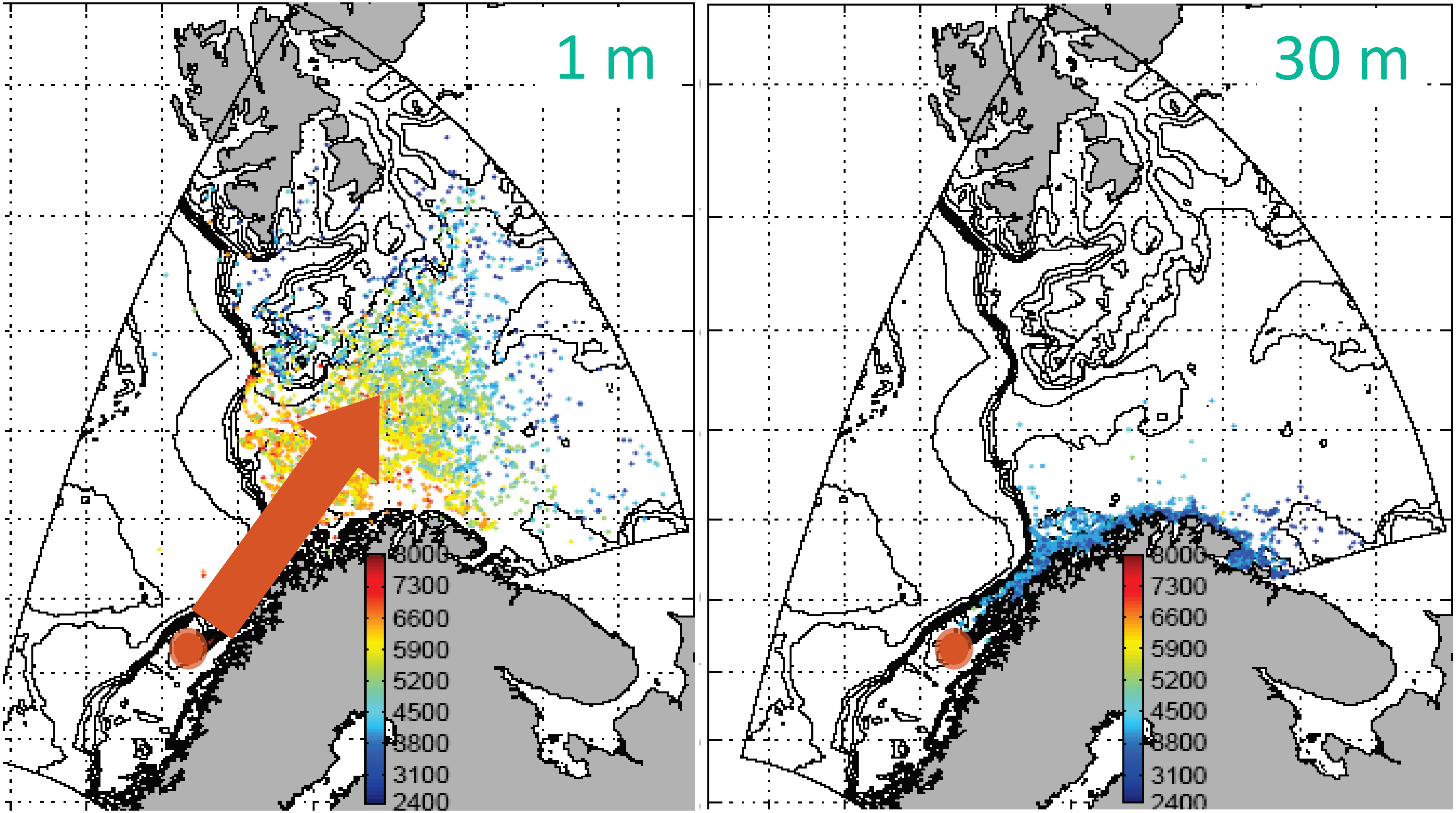


Feeding area
Longyearbyen
Spawning area

Life for a cod larva…

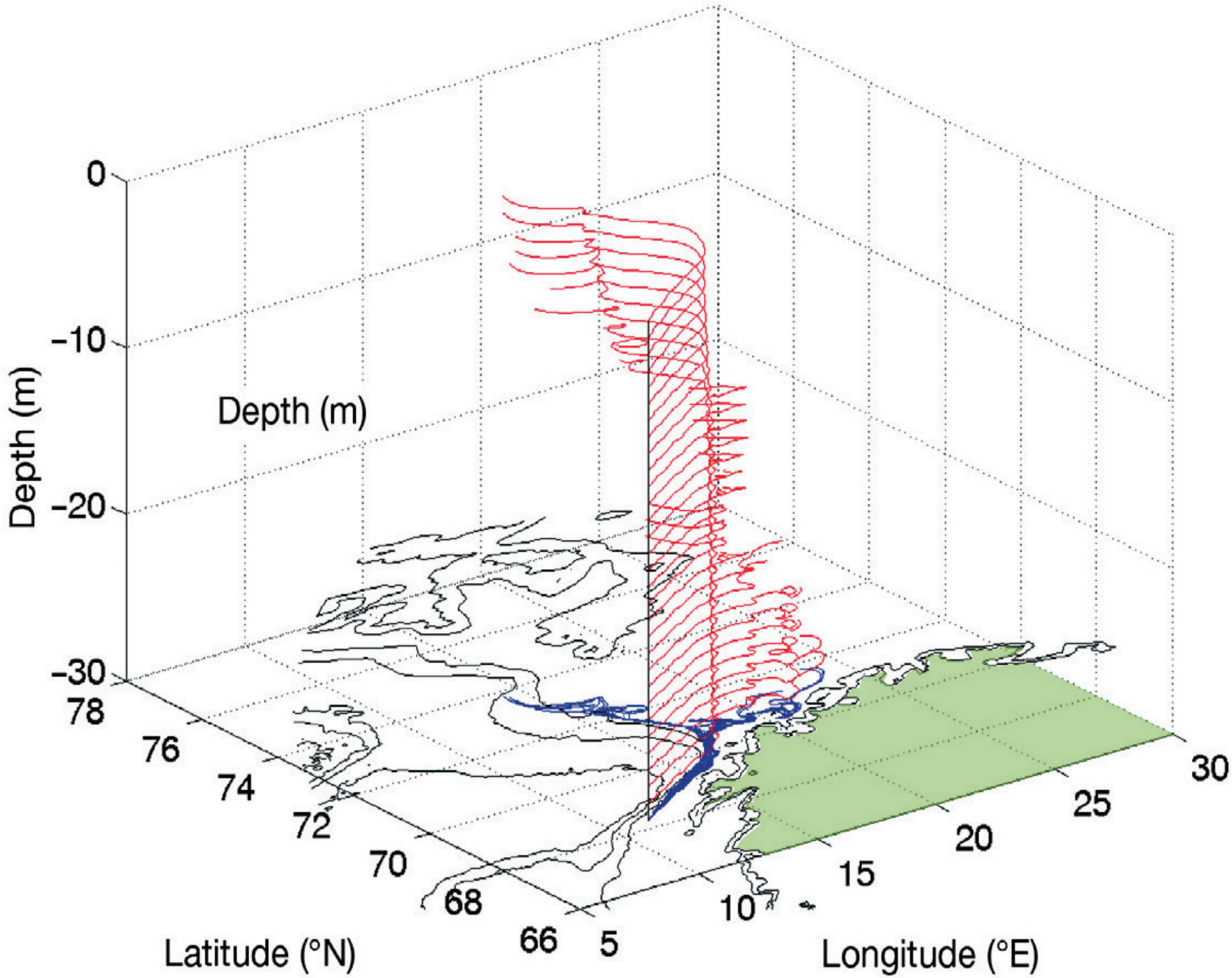


Drifting particles, but at which depth?



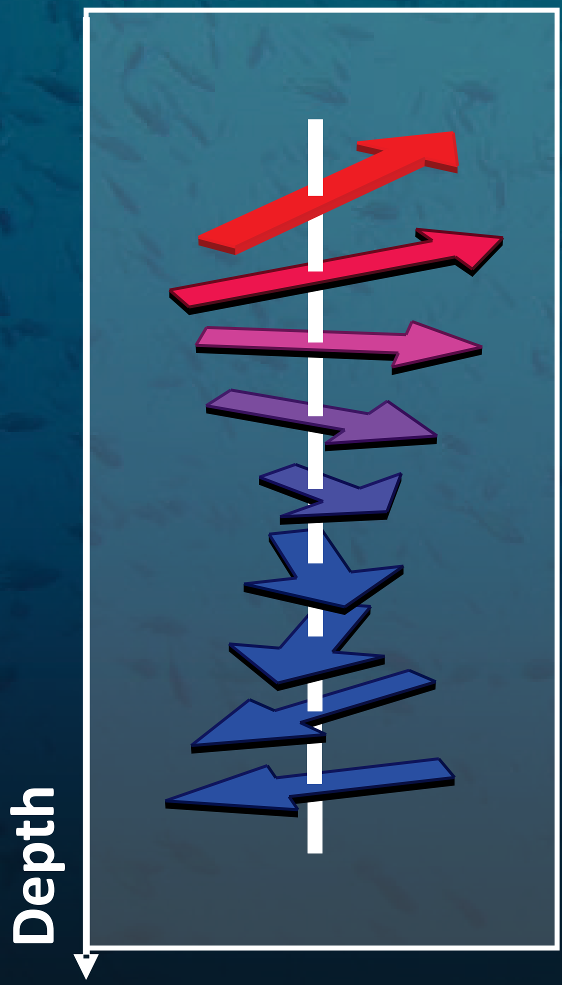
Vikebø F, Sundby S, Ådlandsvik B, and Fiksen Ø. 2005. *ICES J Mar Sci* **62**: 1375-1386.

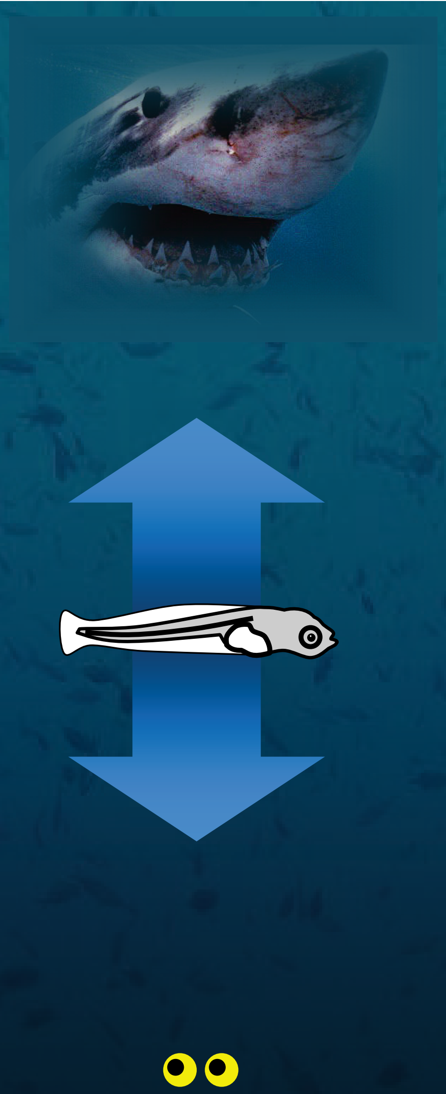
A highway intersection in the deep



Fiksen Ø, Jørgensen C, Kristiansen T, Vikebø F, Huse G. 2007. *Mar. Ecol. Progr. Ser.*, **347**: 195-205.

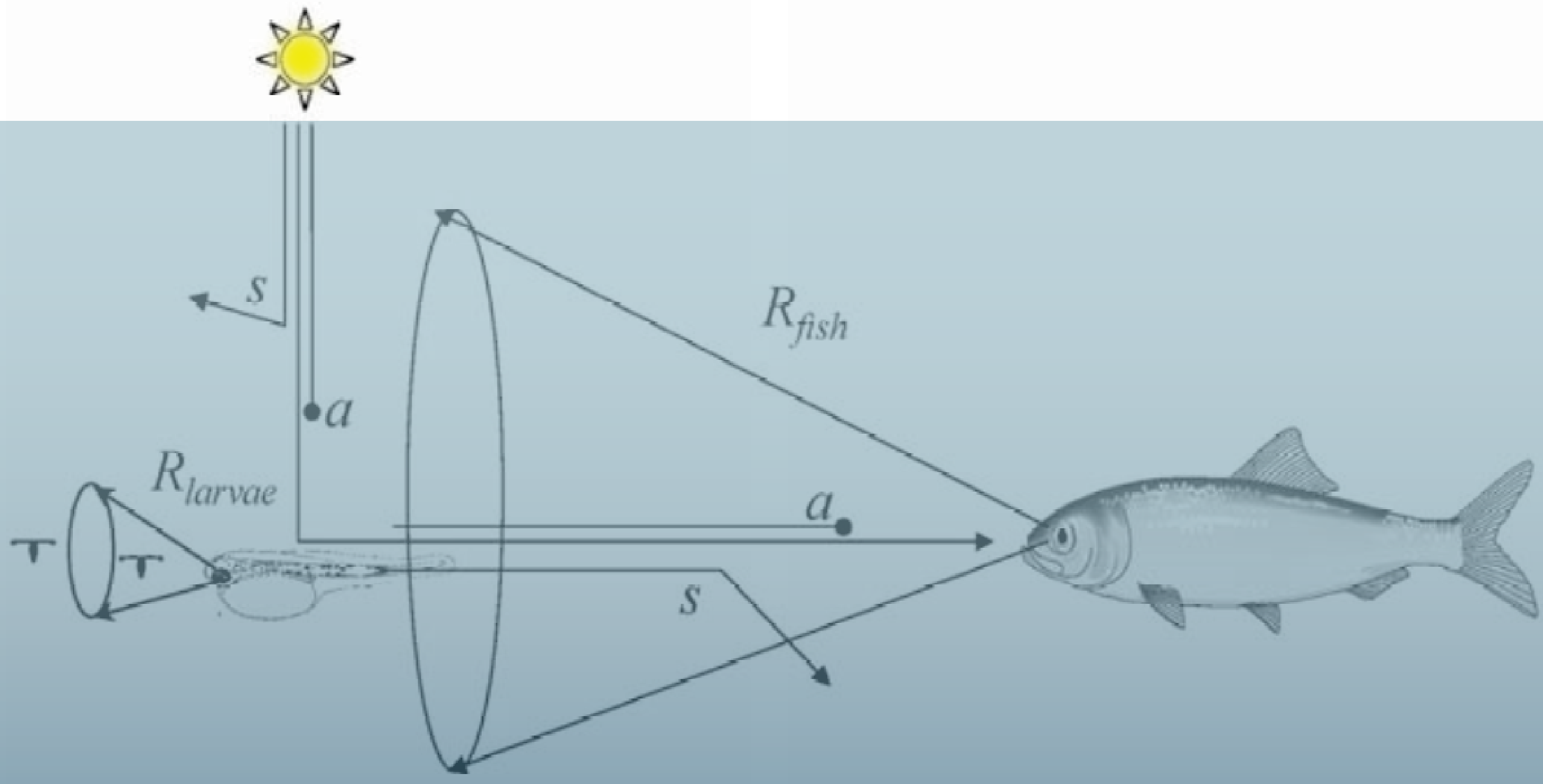
Life for a cod larva…





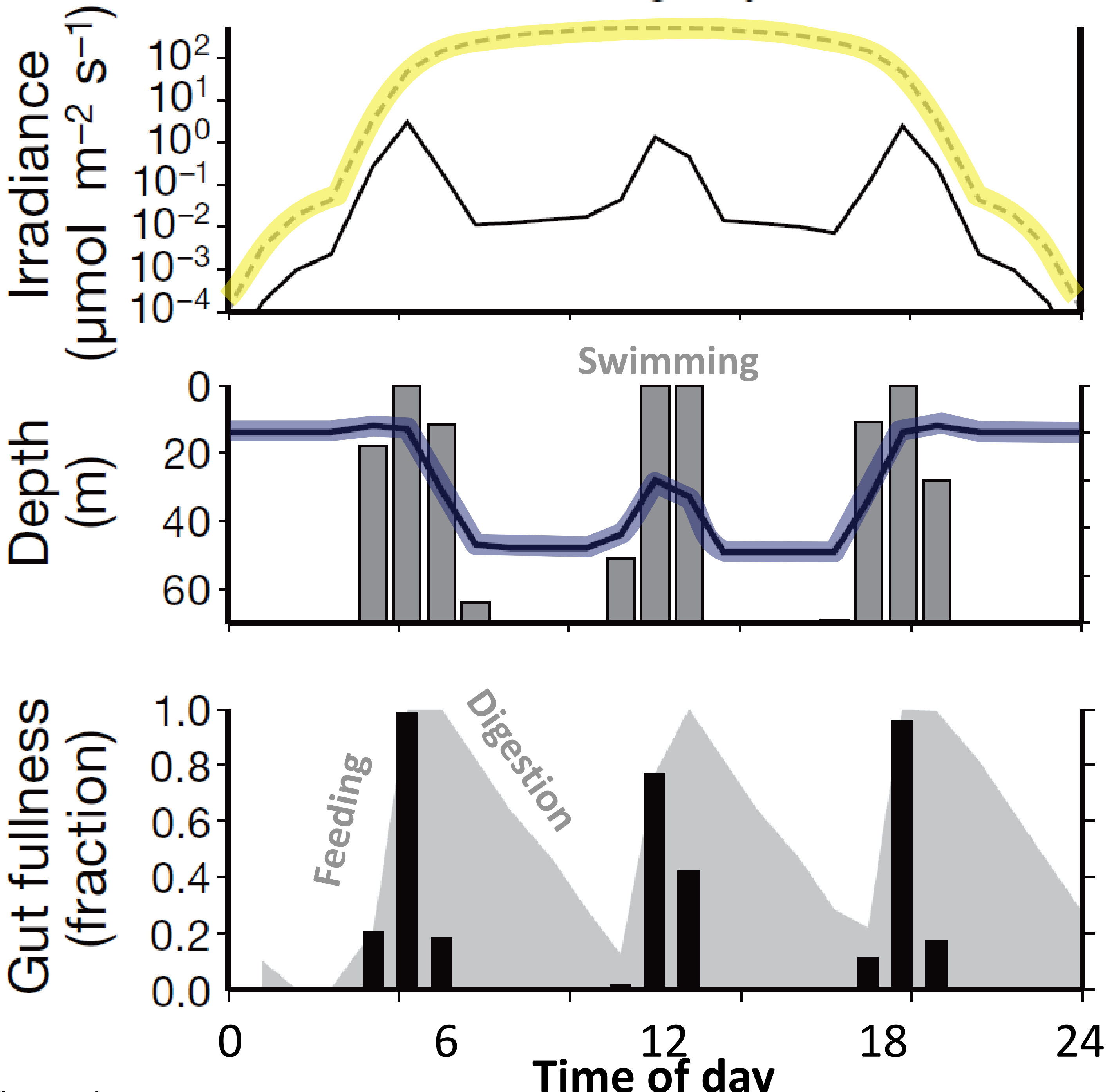
Vikebø F, Sundby S, Ådlandsvik B, and Fiksen Ø. 2005. *ICES J Mar Sci* **62**: 1375-1386.

Light, vision, encounters, and predation



Fiksen, Ø., Aksnes, D.L., Flyum, M.H., and Giske, J. 2002. *Hydrobiologia*, **484**: 49-59.

Optimal daily vertical migrations



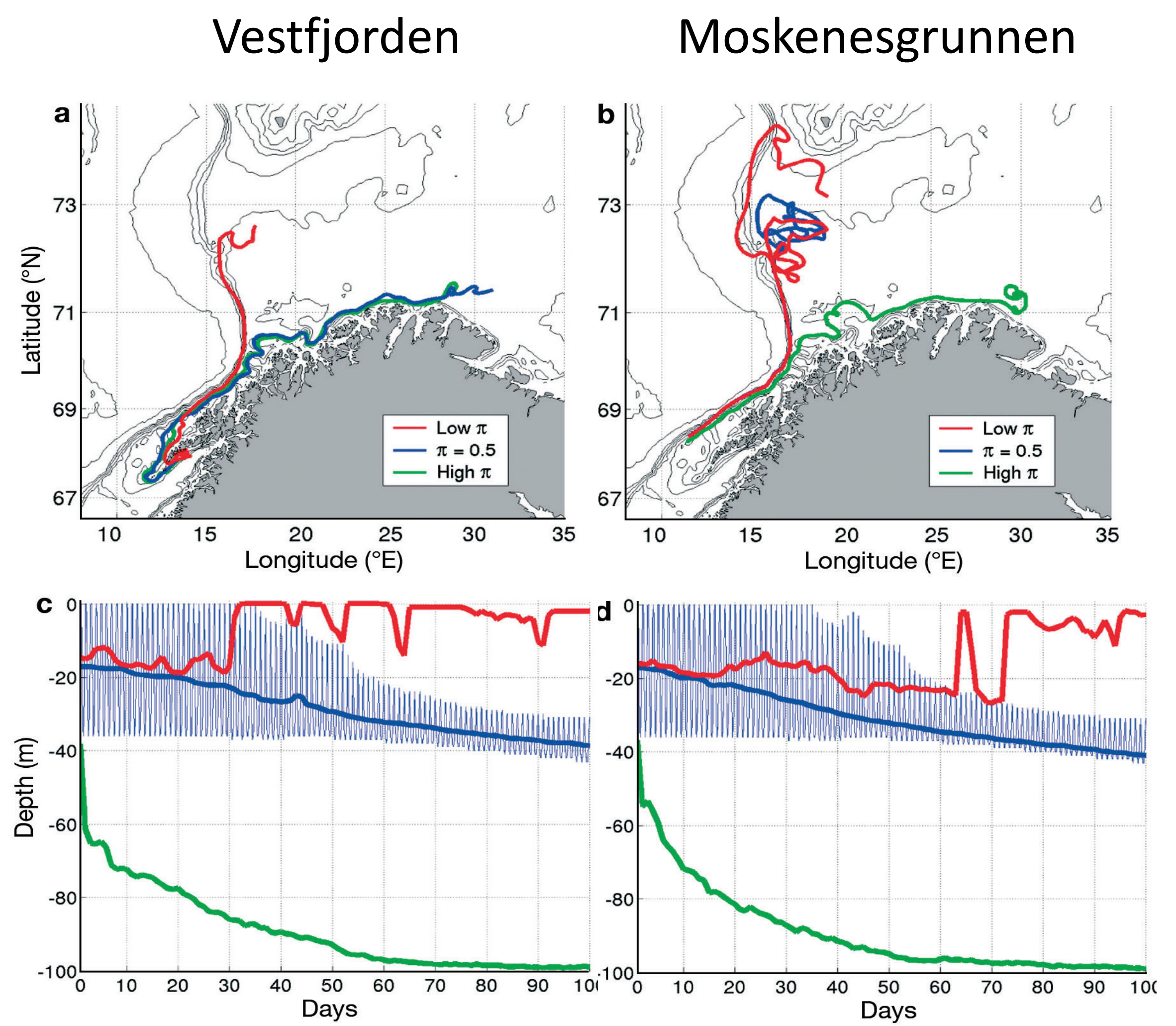
Fiksen Ø, Jørgensen C (2011) *MEPS* **432**:207-219

Behavior in ROMS

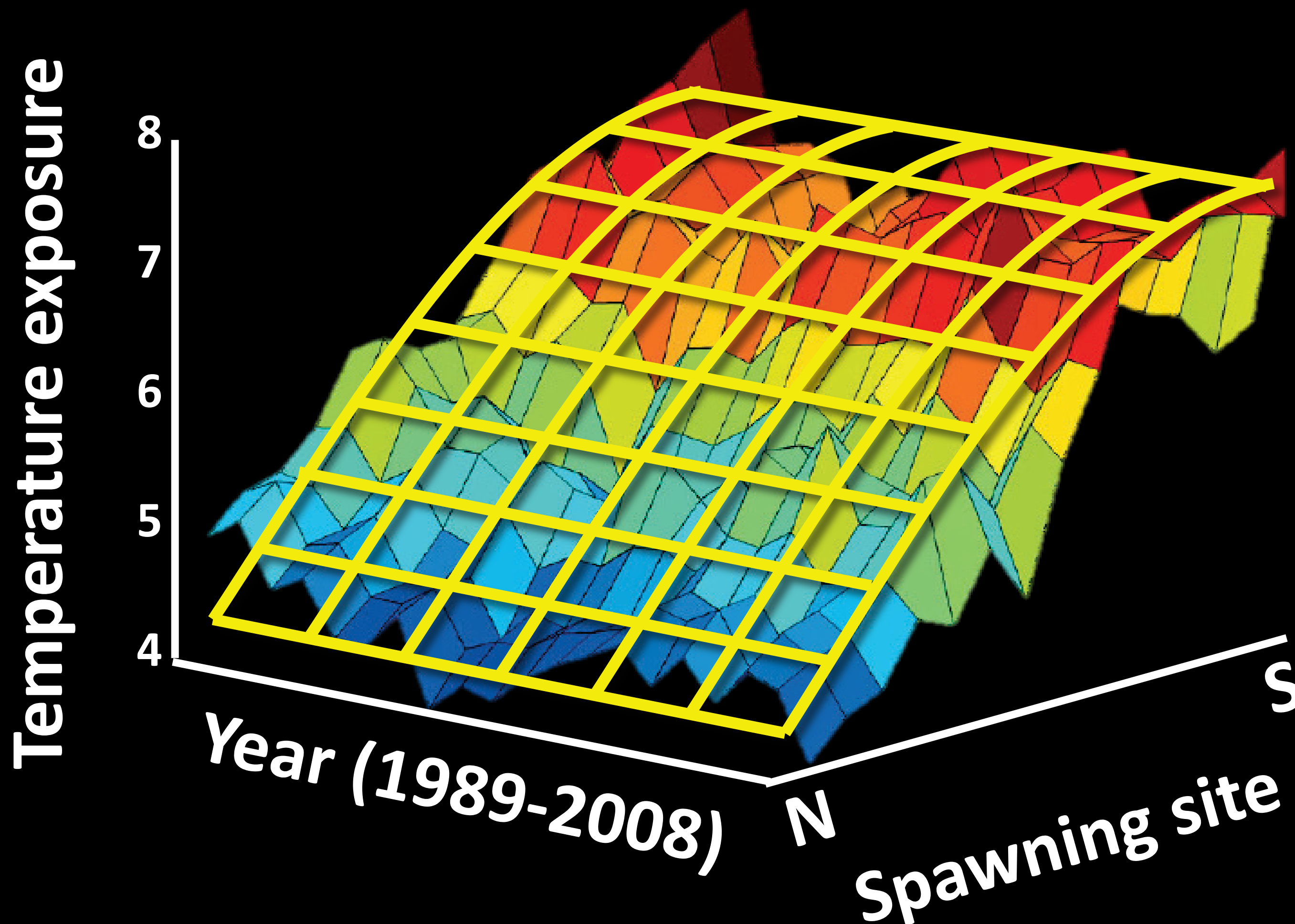
- Growth model *g*
  - -Size, temperature
  - -Light-dependent encounters with prey
- Survival model *m*
  - -Light-dependent encounters with visual predators
  - -Tactile predators

$$z_i^{\star}(t) \;=\; \max_{z}[(1-\pi_i)g_z - \pi_i m_z]$$

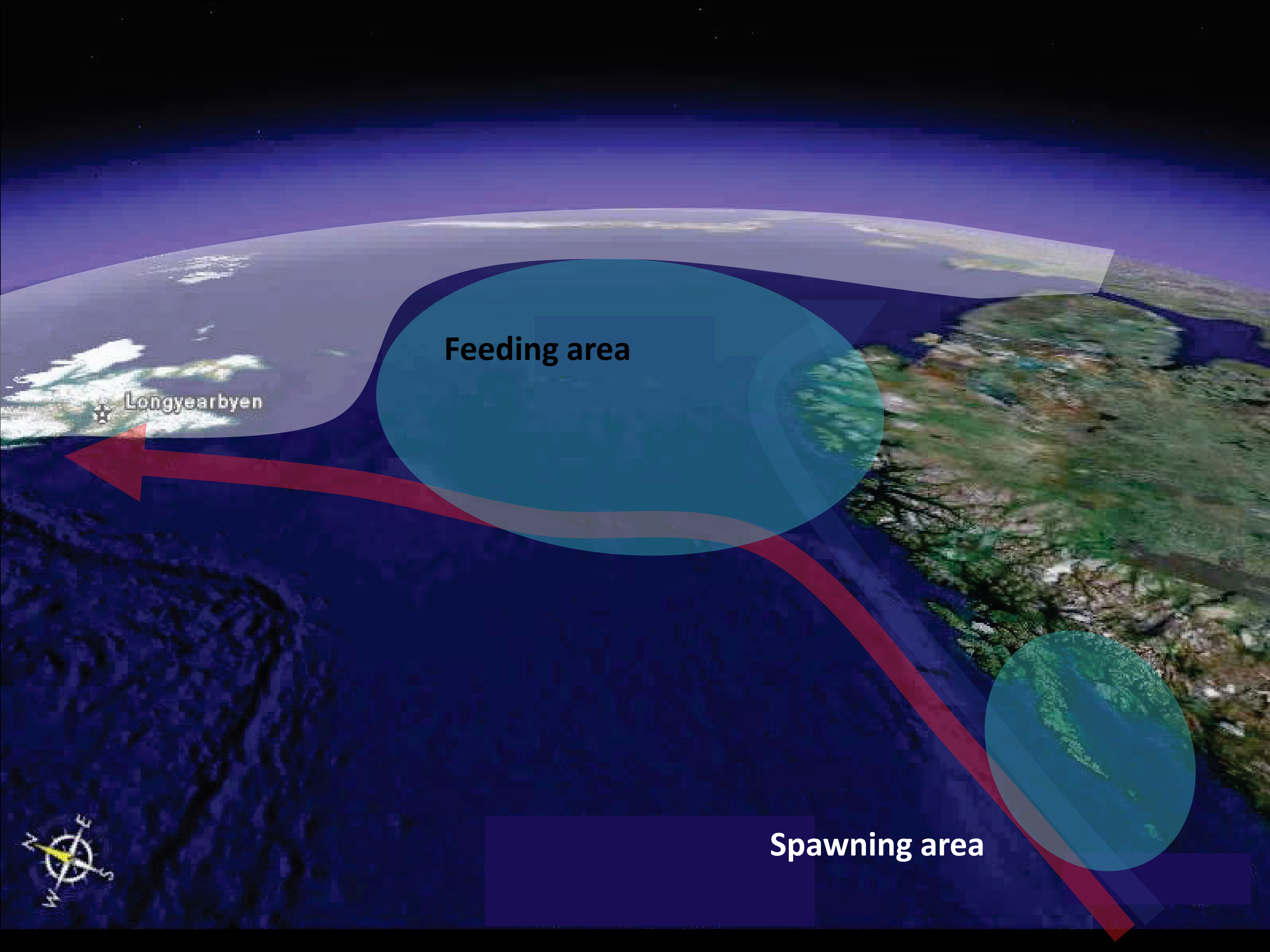
- Fearfulness π
  - -High π – risk averse
  - -Low π – seeking risk



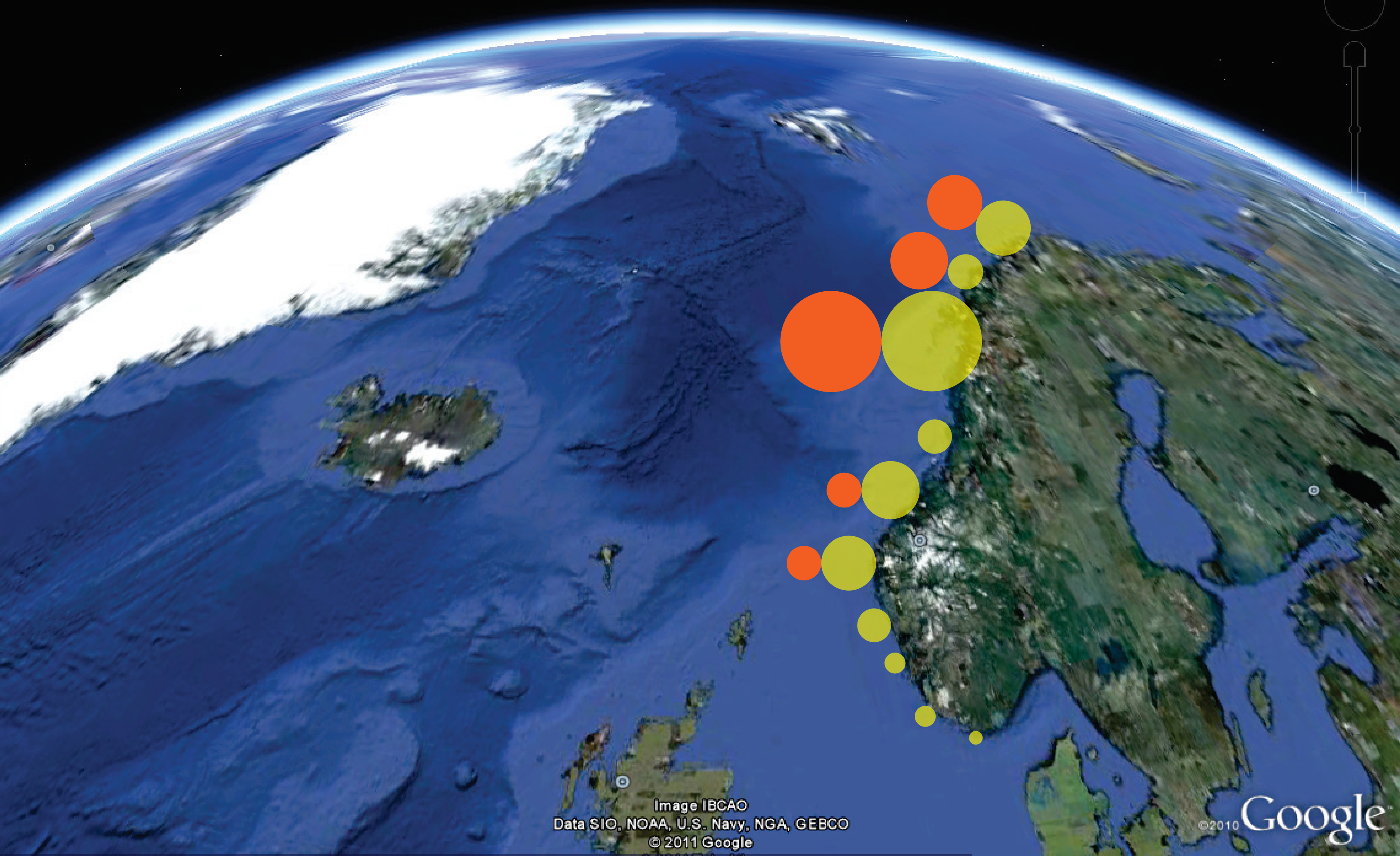
Vikebø F, Jørgensen C, Kristiansen T, Fiksen Ø (2007) *MEPS* **347**:207-219



Opdal AF, Vikebø FB, Fiksen Ø. 2011. *MEPS* **439:**255-262.

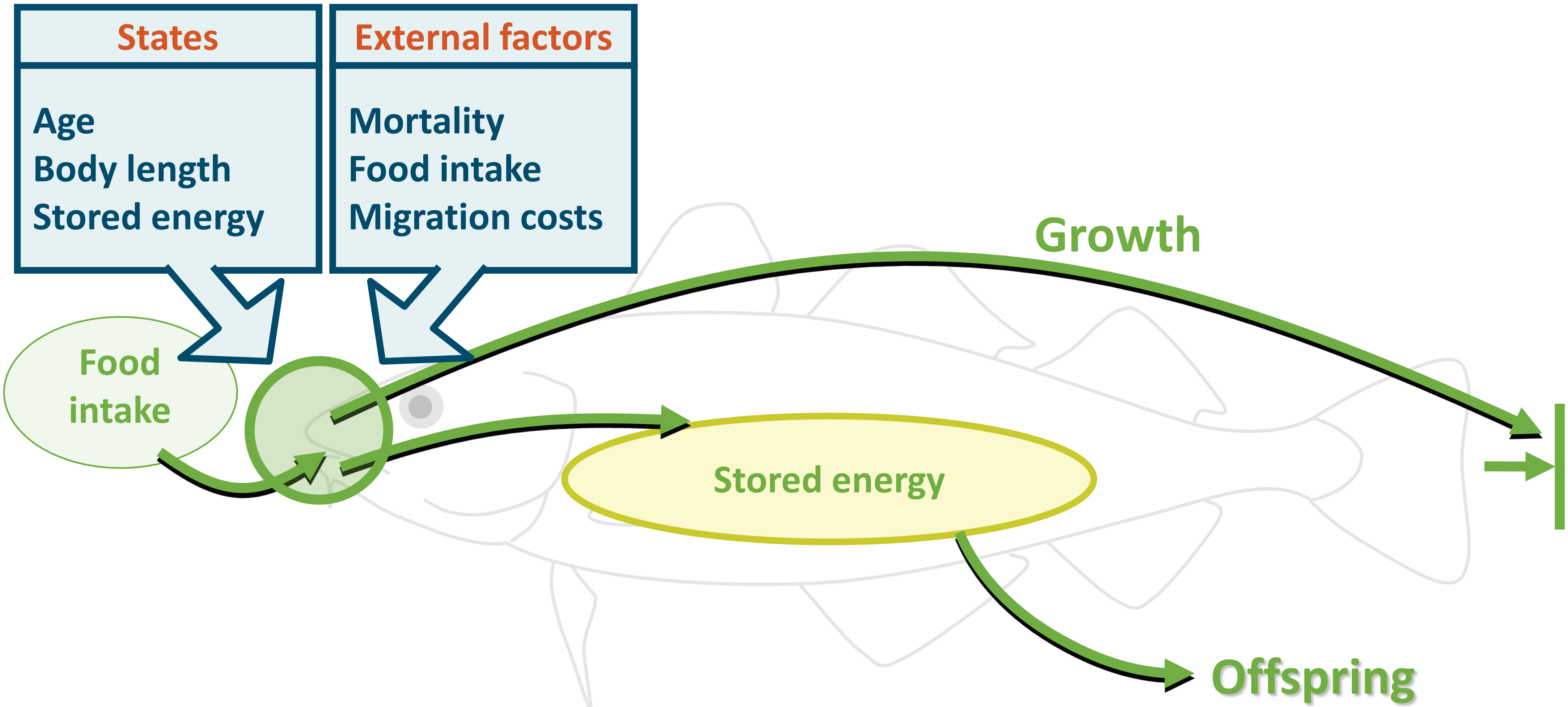

Feeding area
Longyearbyen
Spawning area

Spawning distribution 1910 and 1948



Jørgensen C, Dunlop ES, Opdal AF & Fiksen Ø (2008) *Ecology* **89**:3436-3448

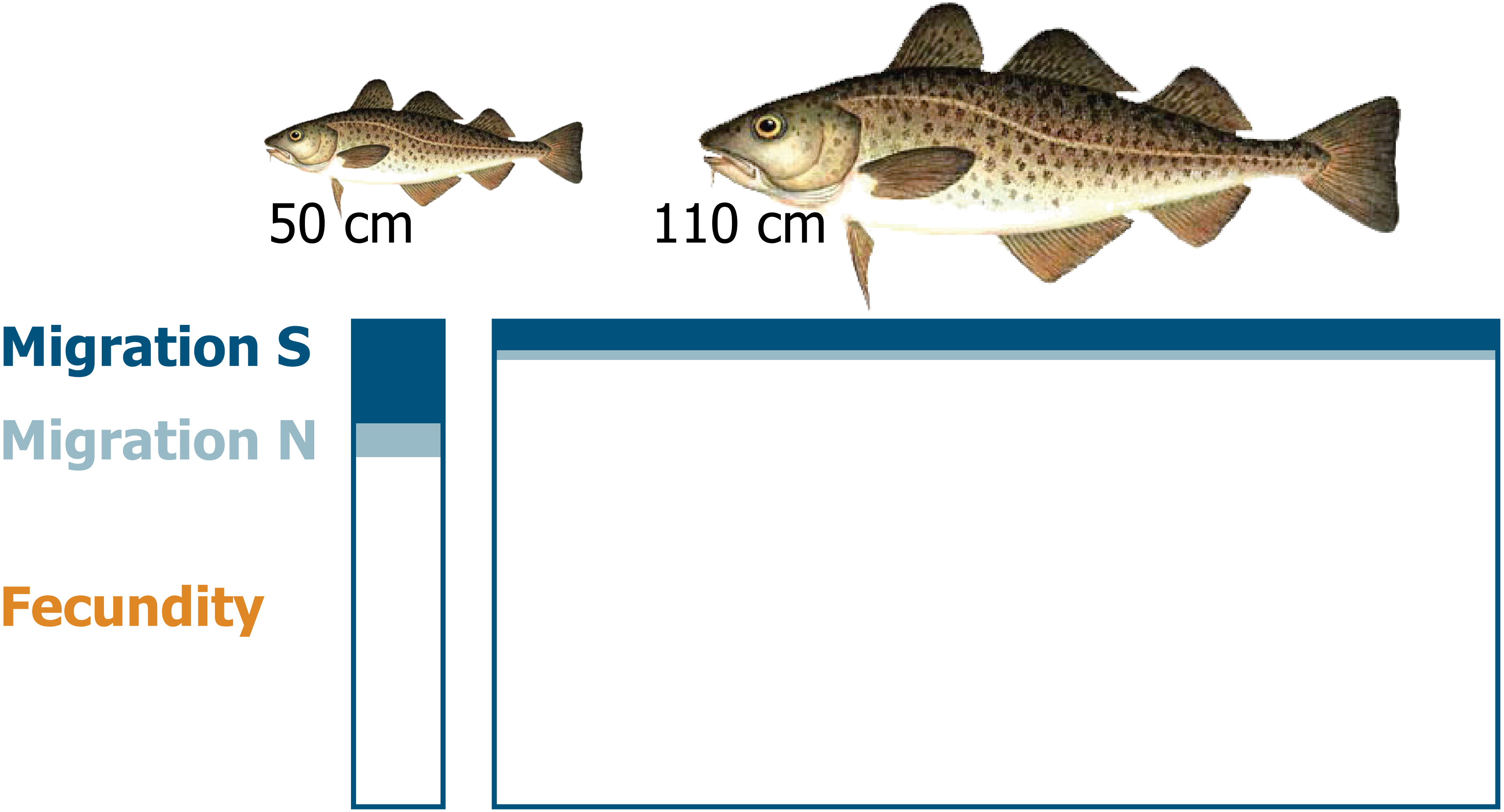
Mechanism: Energy allocation



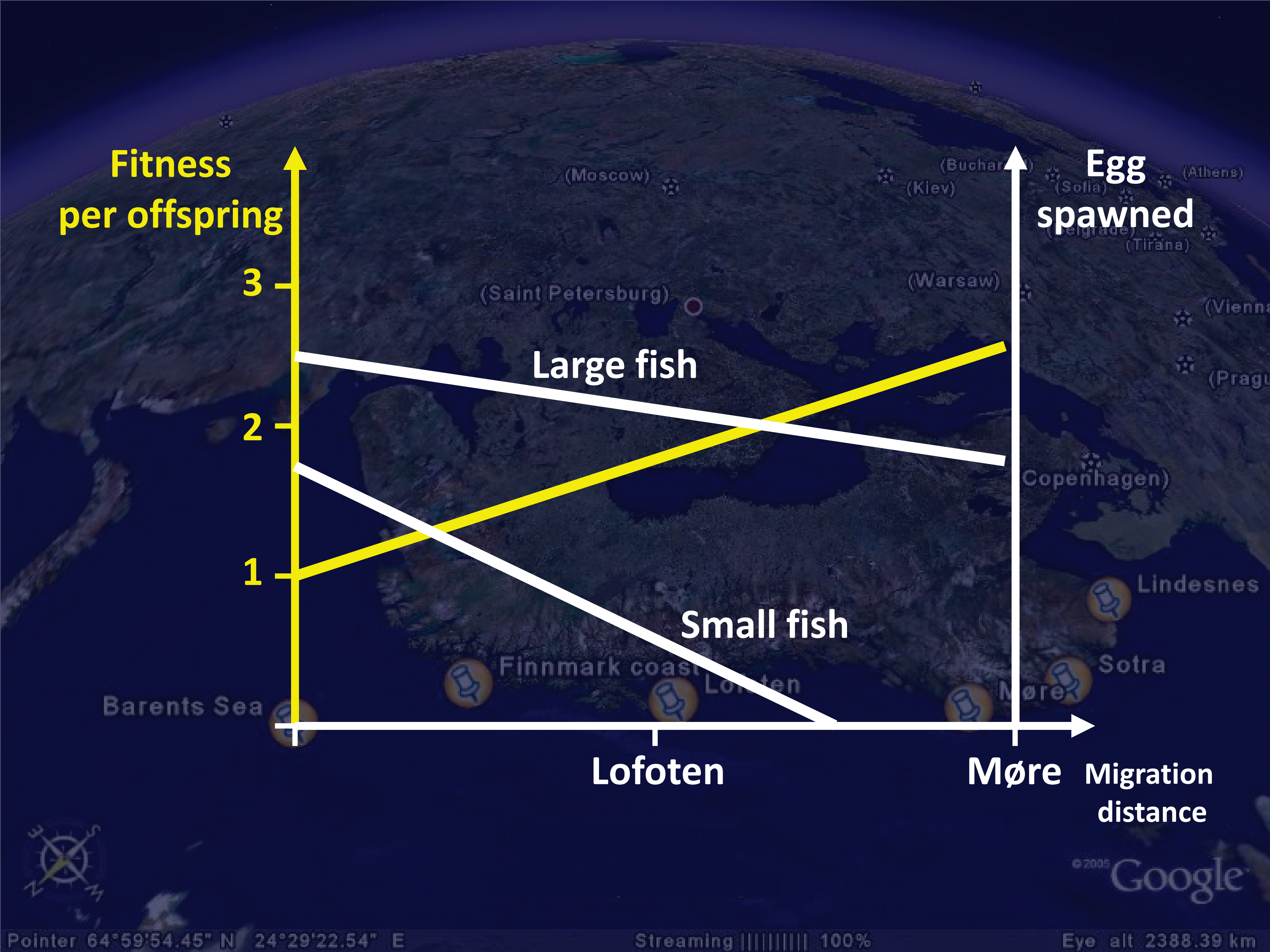
$$V(A,L,E,F) = \max_{\alpha}\left[B(E) + S\sum_{F'} P(F' \mid F)\cdot V(A+1, L', E', F') \right]$$

Jørgensen C, Fiksen Ø. 2006. *Can J Fish Aquat Sci.* **63**:186-199

Migration costs versus body size

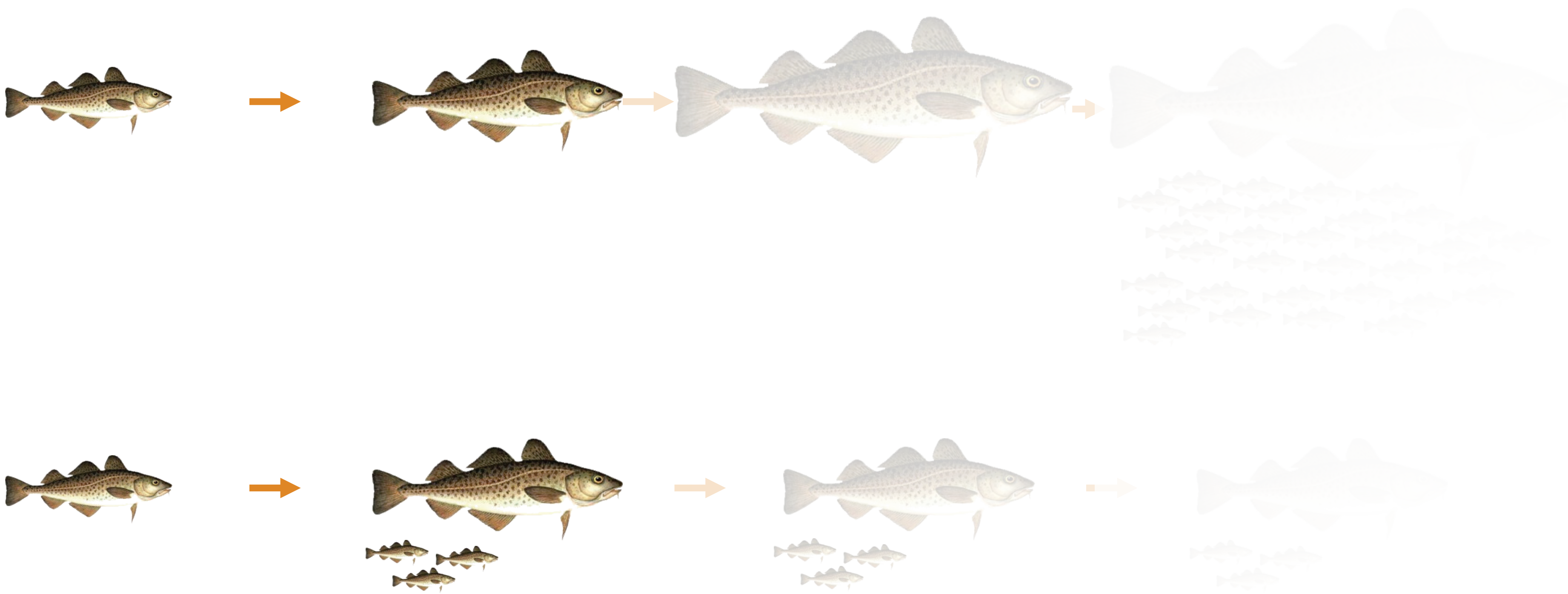


Jørgensen C, Dunlop ES, Opdal AF, Fiksen Ø. 2008. *Ecology* **89**:3436-3448.



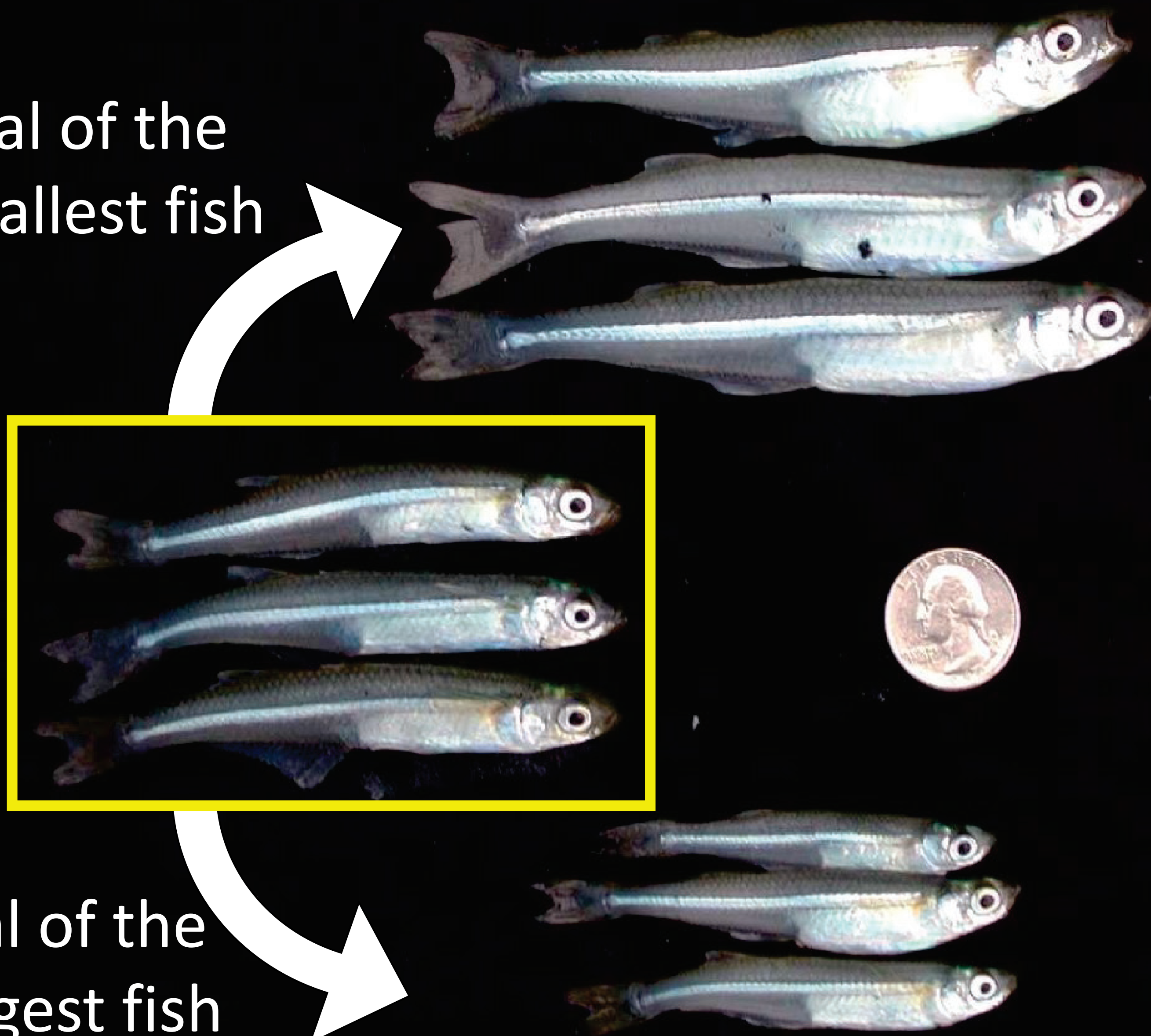
Fitness per offspring
3
2
1
Egg spawned
Large fish
Small fish
Lofoten
Møre
Migration distance
(Moscow)
(Kiev)
(Saint Petersburg)
(Warsaw)
(Tirana)
(Athens)
Copenhagen)
Lindesnes
Sotra
Finnmark coast
Barents Sea
Google
Pointer 64°59'54.45" N 24°29'22.54" E
Streaming 100%
Eye alt 2388.39 km

Evolution driven by mortality



Heritable changes after 4 generations of harvesting

Removal of the
90% smallest fish

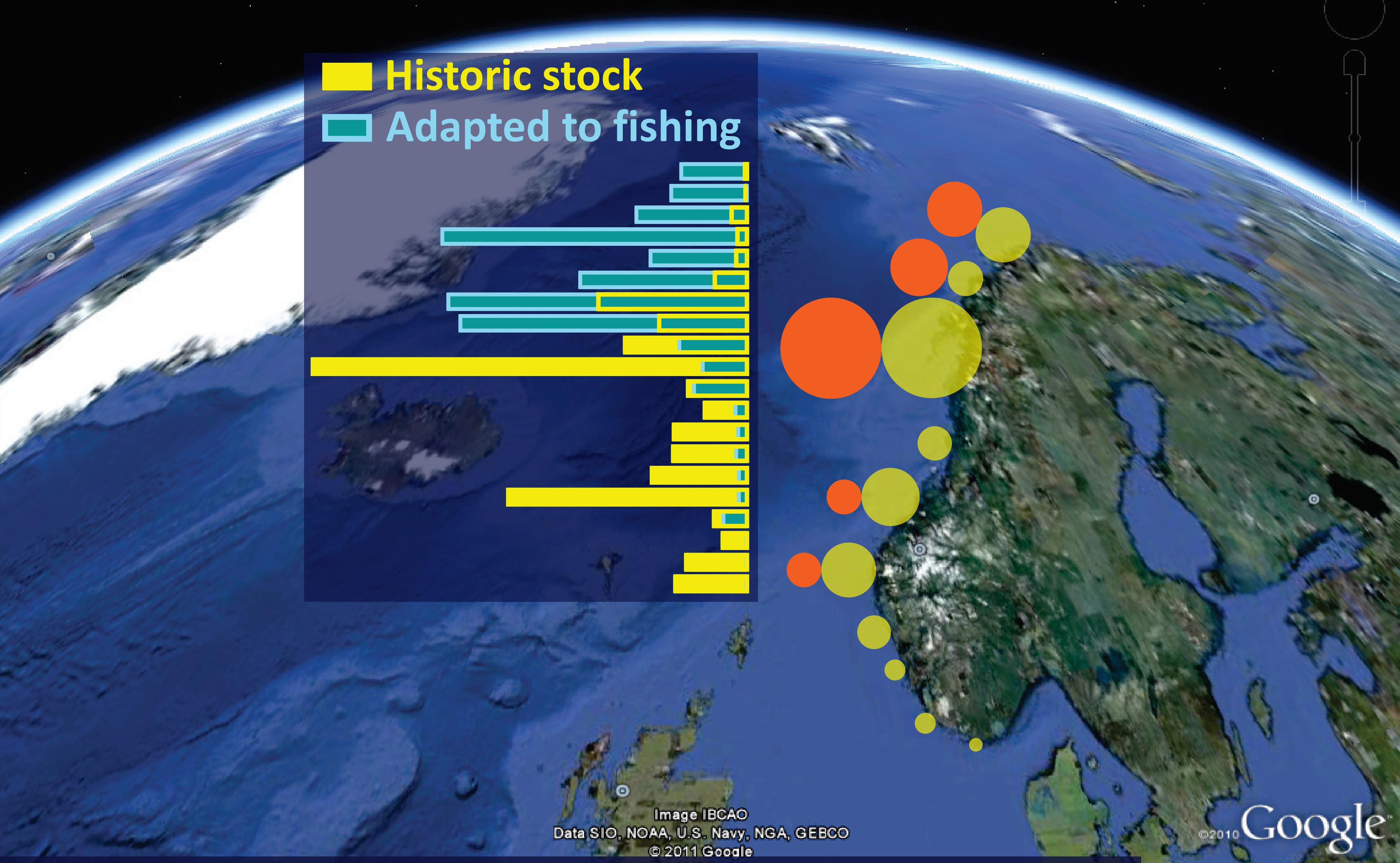


Removal of the
90% largest fish

Picture courtesy of David Conover

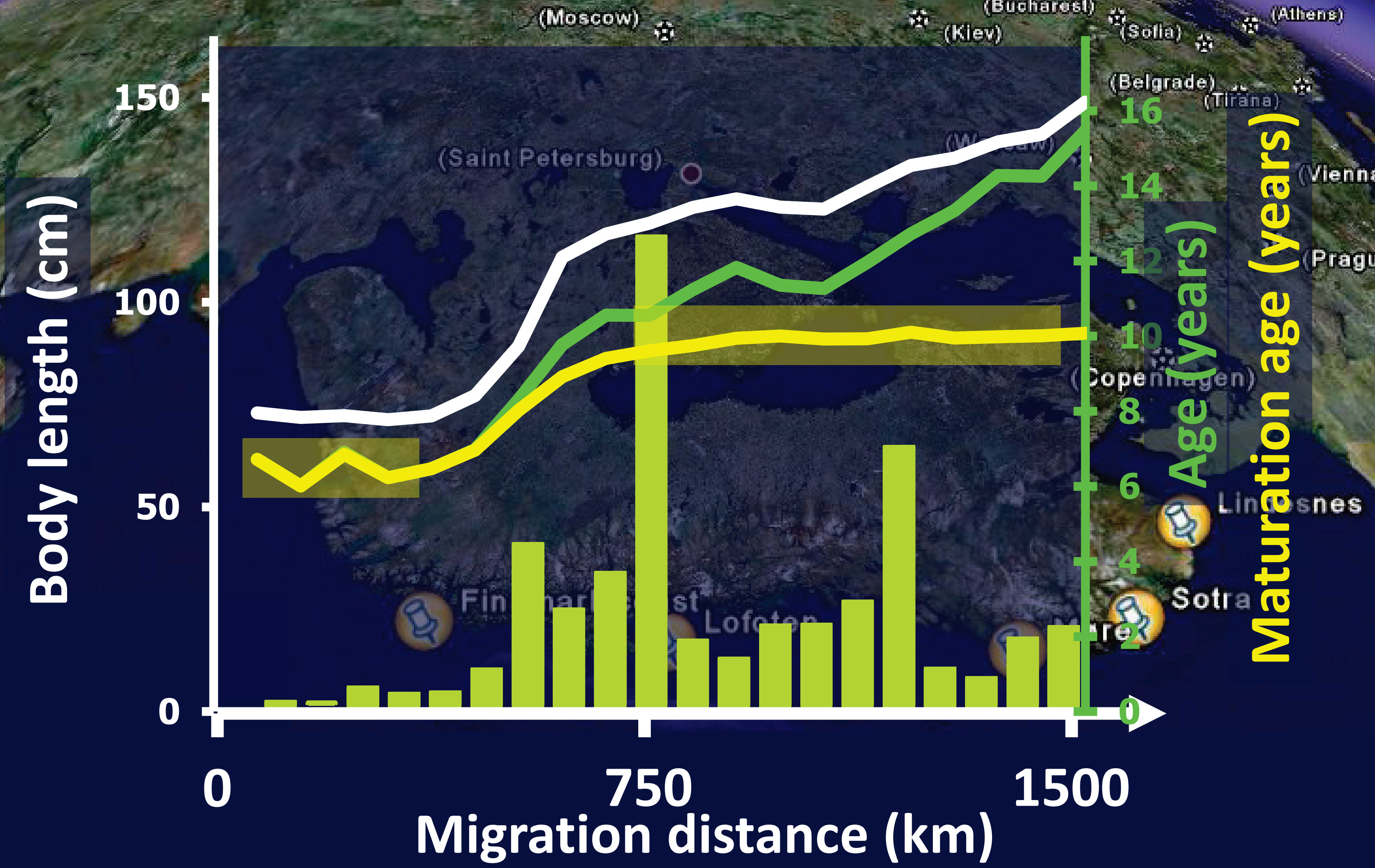
Conover DO, Munch SB. 2002. *Science* **297**: 94-96.

Spawning distribution 1910 and 1948



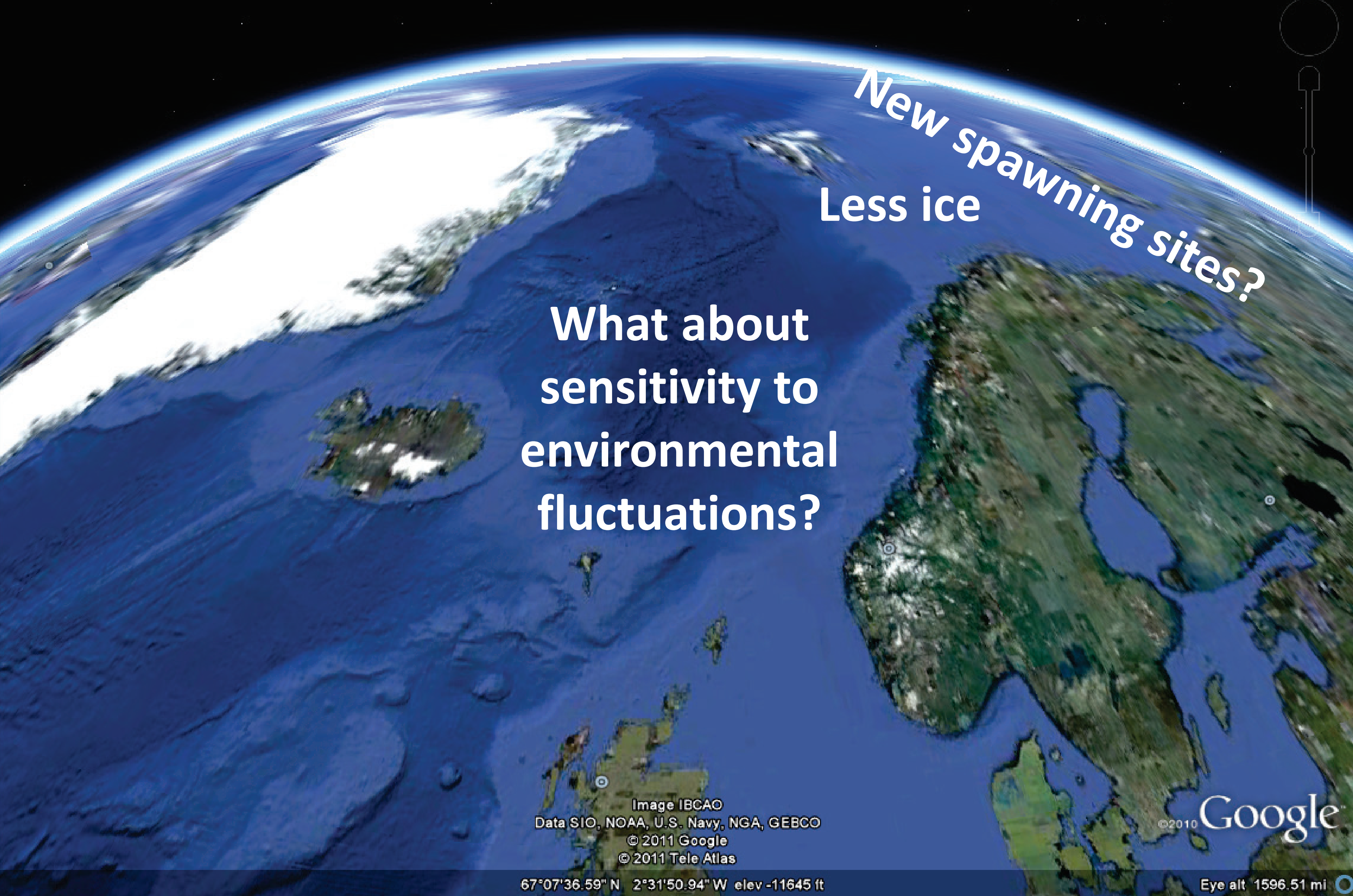
Jørgensen C, Dunlop ES, Opdal AF and Fiksen Ø. 2008. *Ecology* **89**:3436-3448

Which fish migrate longest?

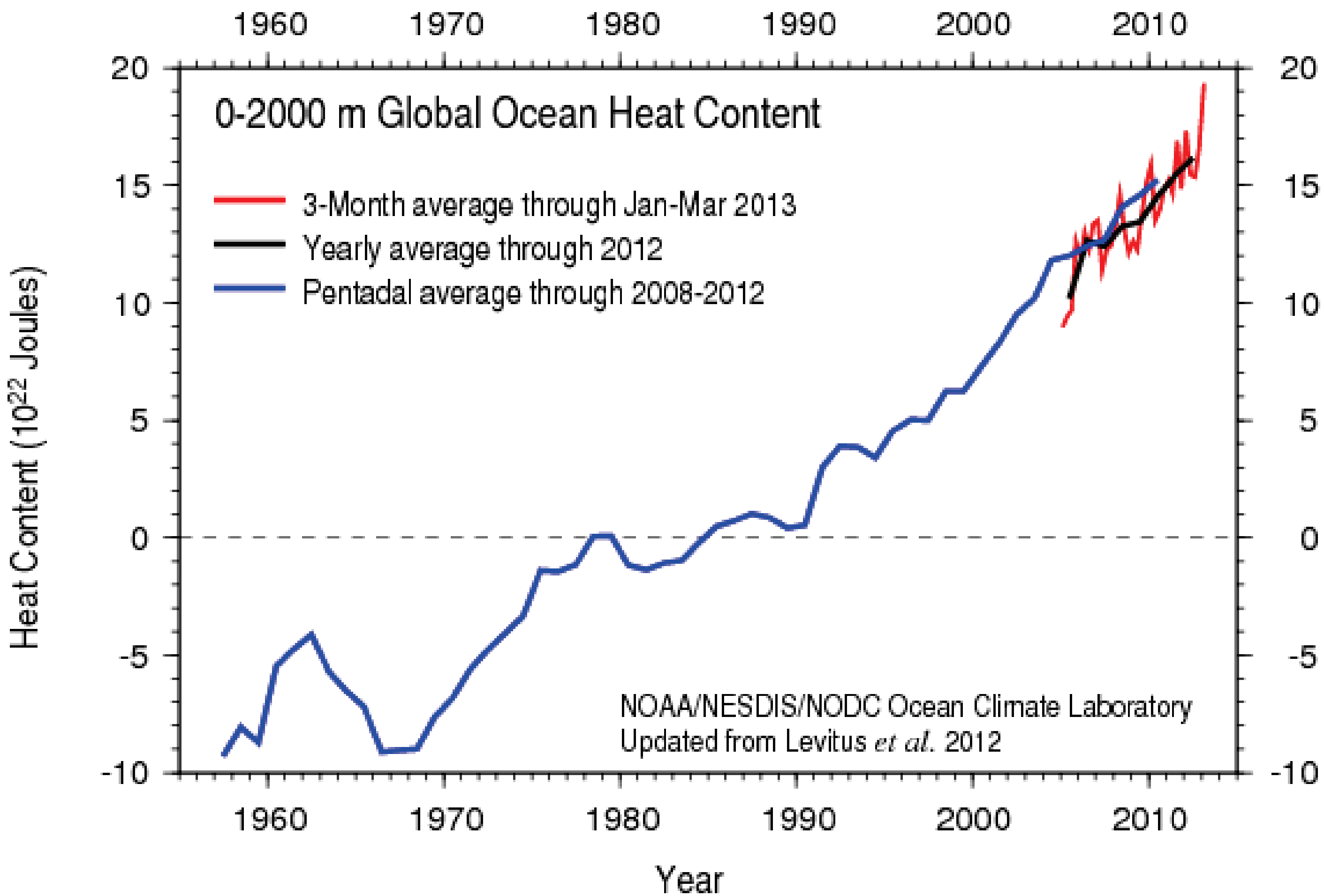


Jørgensen C, Dunlop ES, Opdal AF & Fiksen Ø (2008) *Ecology* **89**:3436-3448

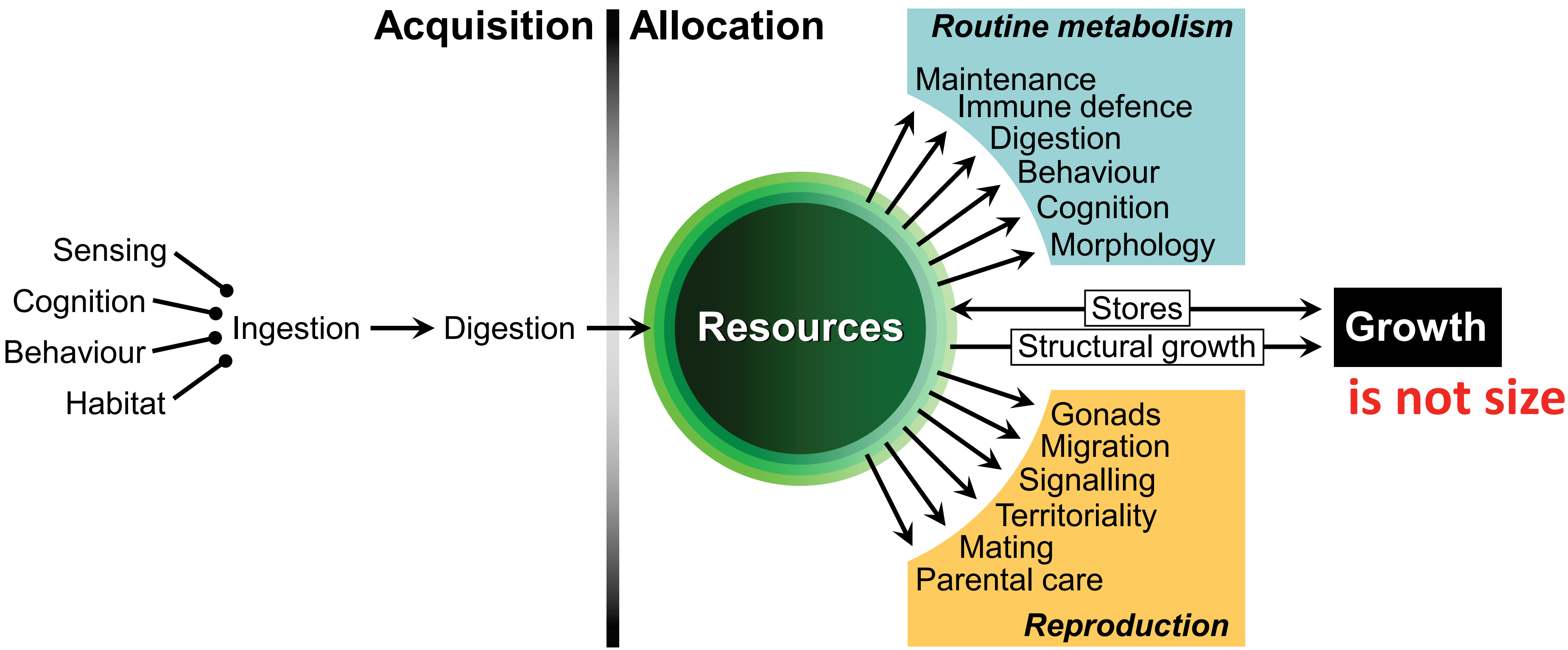
Long-term consequences



Climate warming



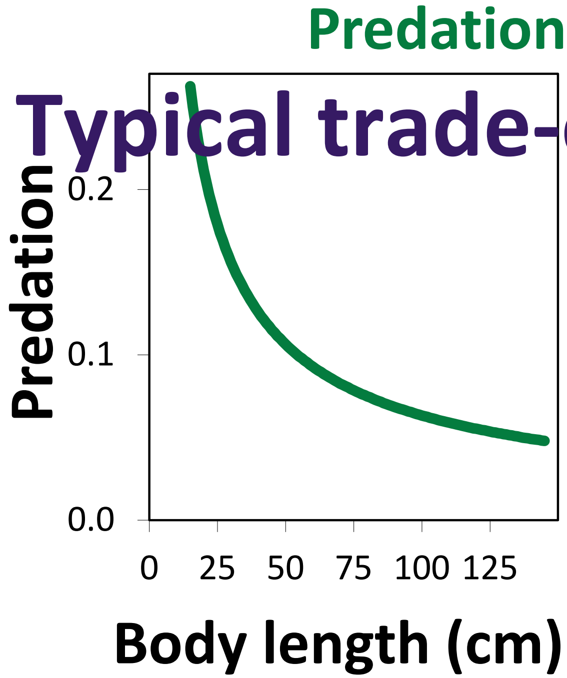
A potential problem for thermal conformers



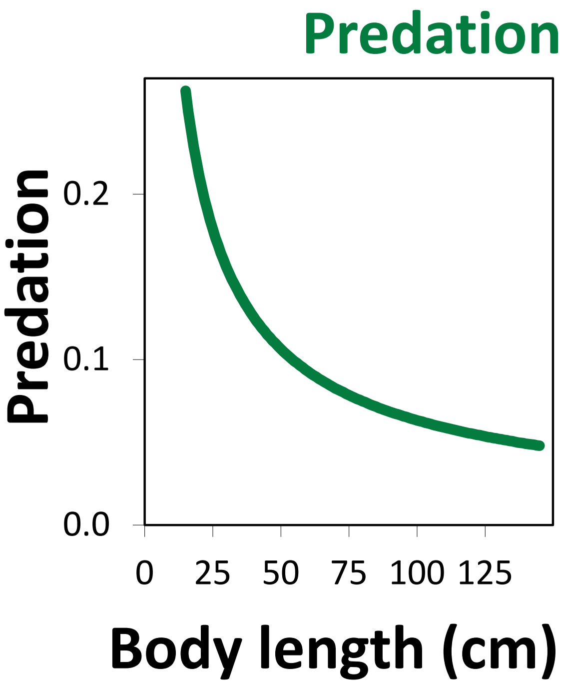
Many of these components and processes are in trade-offs with survival

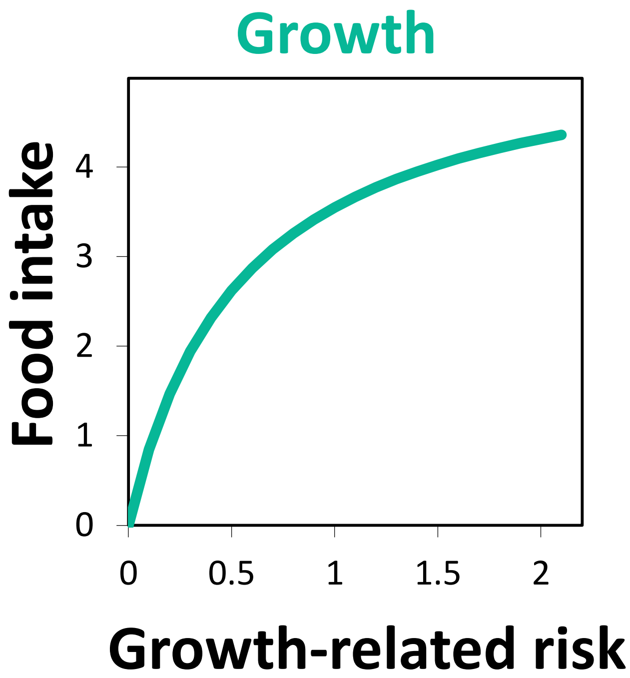
Enberg K, Jørgensen C, Dunlop ES, Varpe Ø, Boukal DS, Baulier L, Eliassen S, Heino M. 2012. Fishing-induced evolution of growth: concepts, mechanisms and the empirical evidence. *Marine Ecology* **33**:1-25.

Typical trade-offs



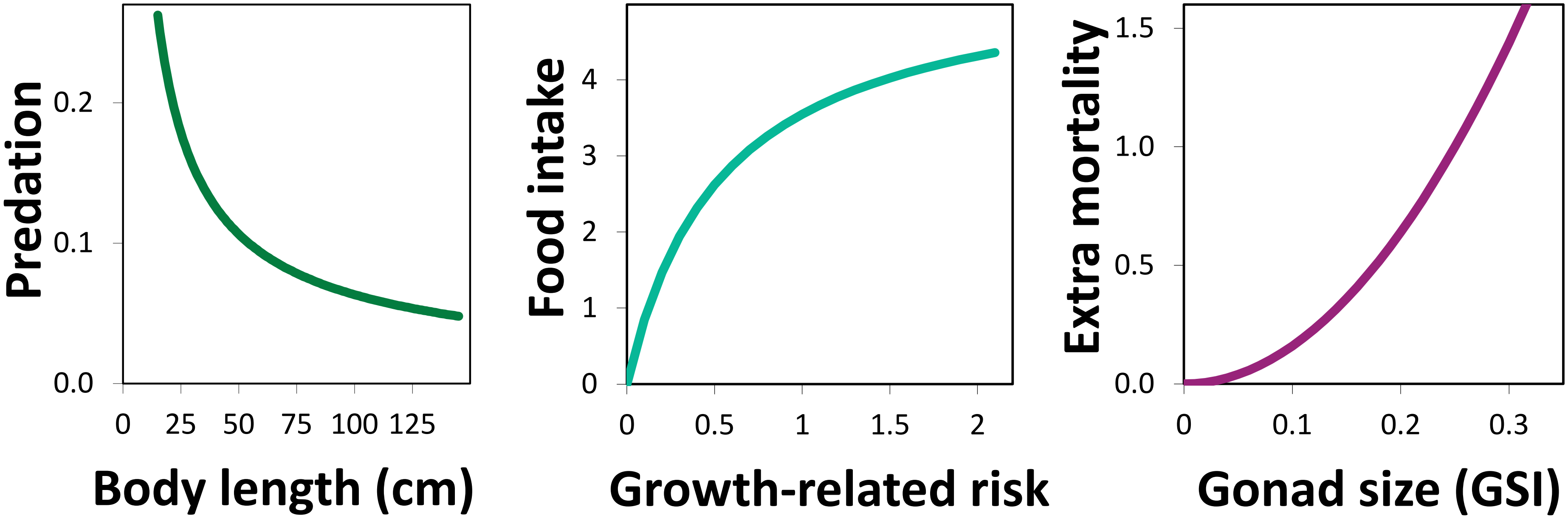
Small fish more often encounter a mouth large enough to engulf them





Foraging is risky

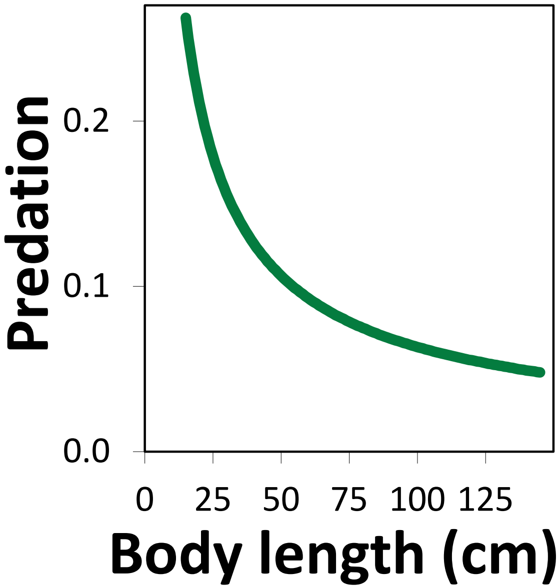
Mortality: Predation **Growth** **Reproduction**

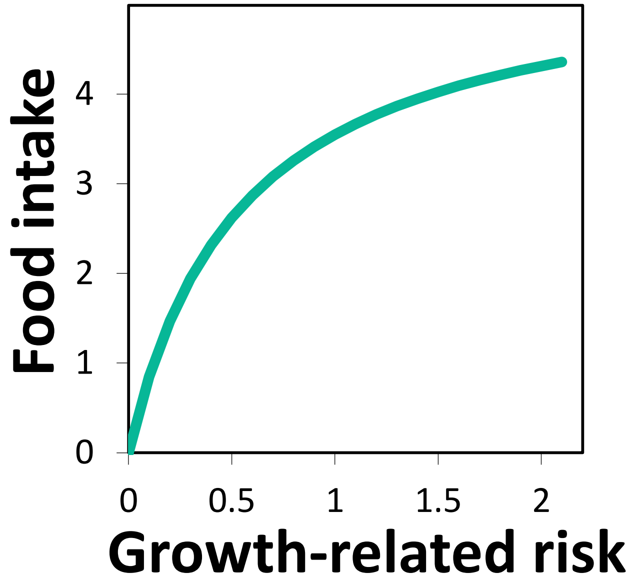


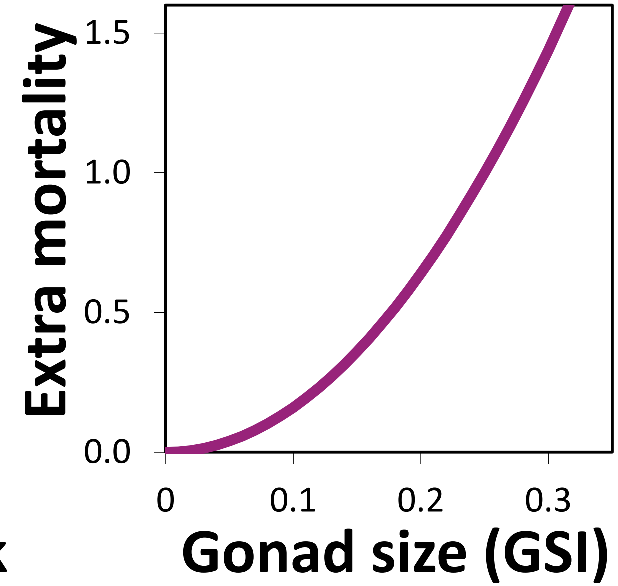
Reproduction is risky

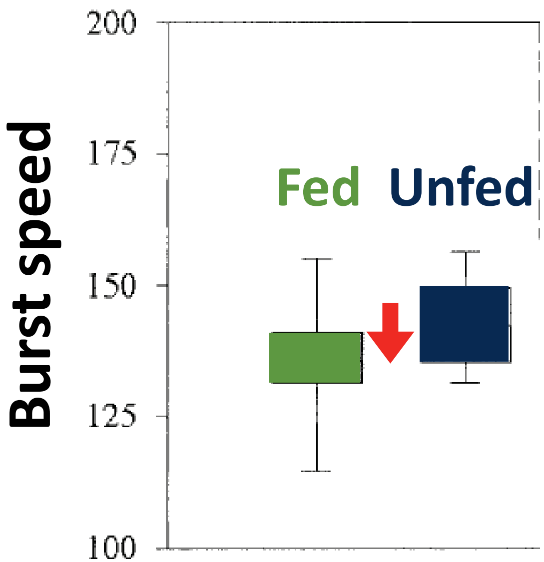
- Stout body shape impedes **swimming performance**.
- **Finding mates** takes time and involves exposure to predators.

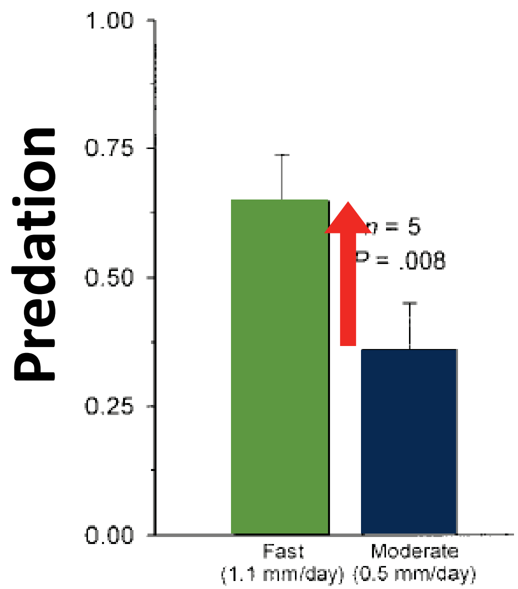
Mortality: Predation **Growth** **Reproduction**

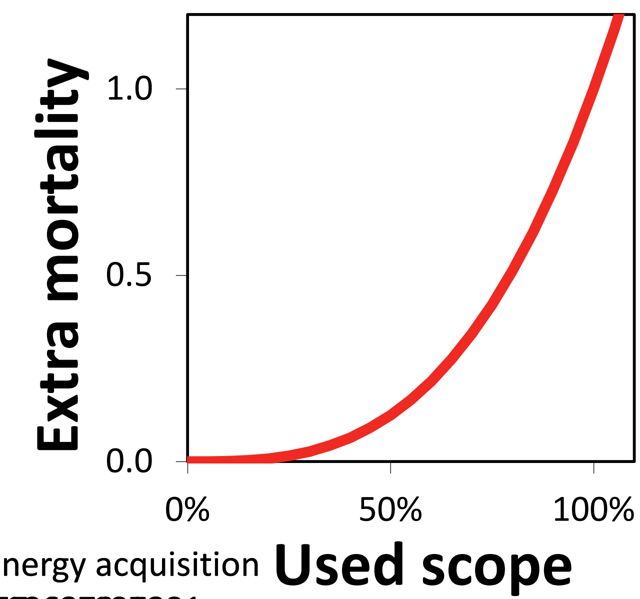








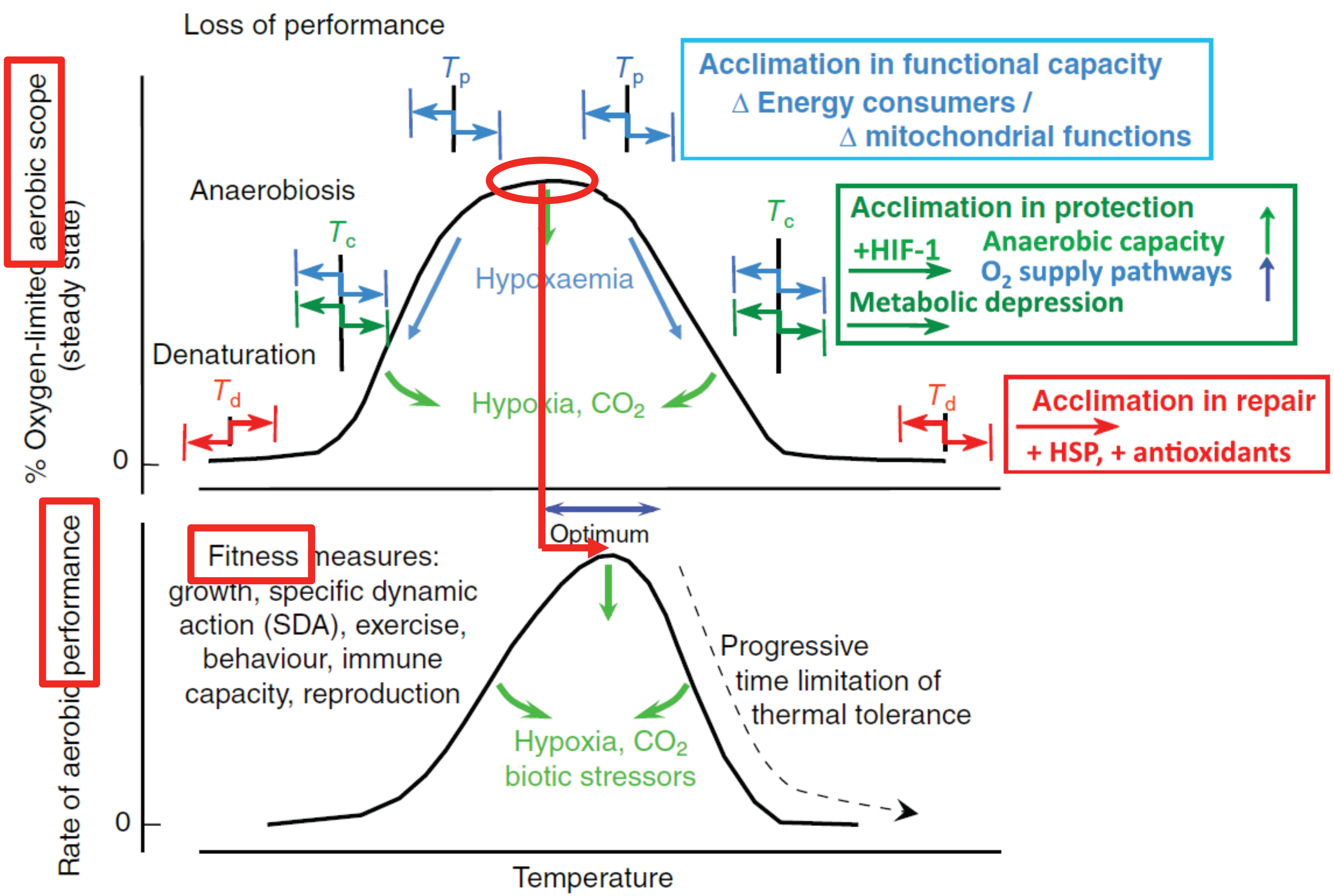




Billerbeck JM, Lankford TE, Conover DO. 2001. Evolution of intrinsic growth and energy acquisition rates. I. Trade-offs with swimming performance in *Menidia menidia*. *Evolution* 55:1863-1872.

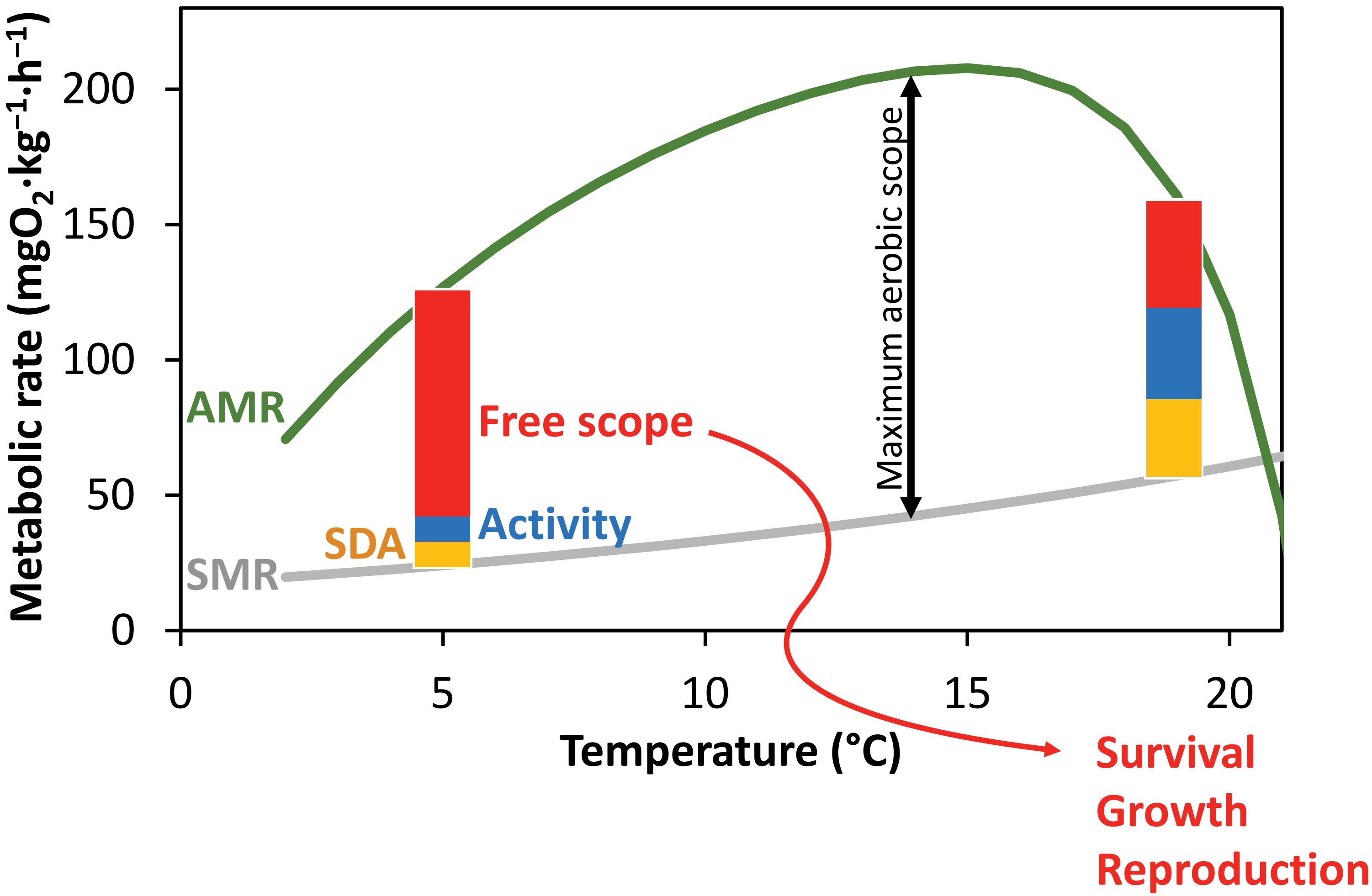
Lankford TE, Billerbeck JM, Conover DO. 2001. Evolution of intrinsic growth and energy acquisition rates. II. Trade-offs with vulnerability to predation in *Menidia menidia*. *Evolution* 55:1873-1881.

Oxygen- and capacity-limited thermal tolerance

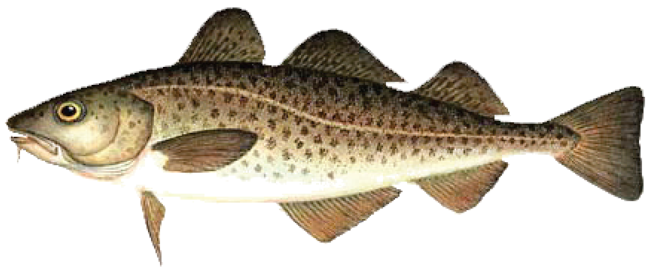


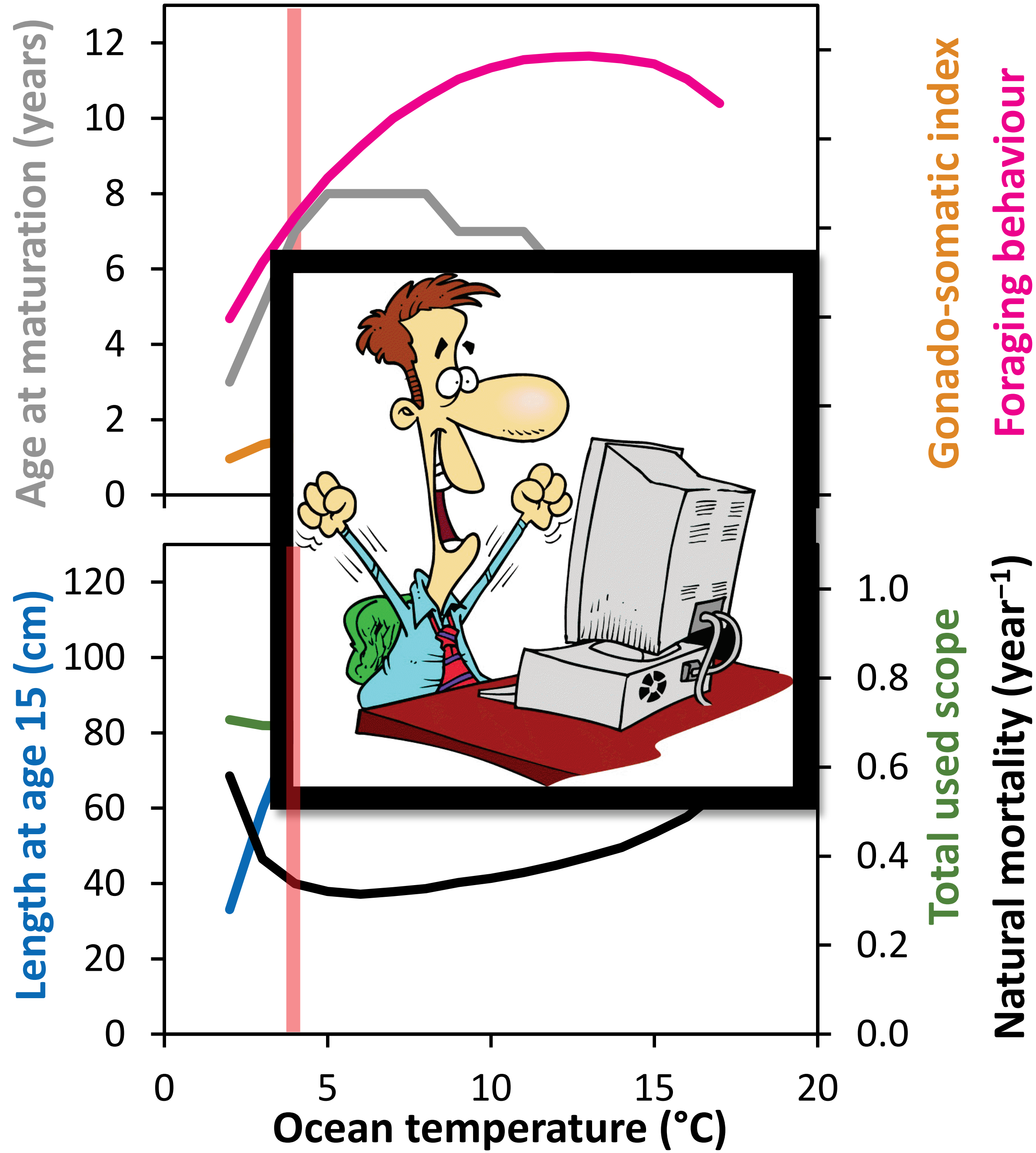
Pörtner HO. 2010. Oxygen- and capacity-limitation of thermal tolerance: a matrix for integrating climate-related stressor effects in marine ecosystems. *J Exp Biol* **213**: 881-893

Bioenergetics budgets – with overhead costs



What the model says

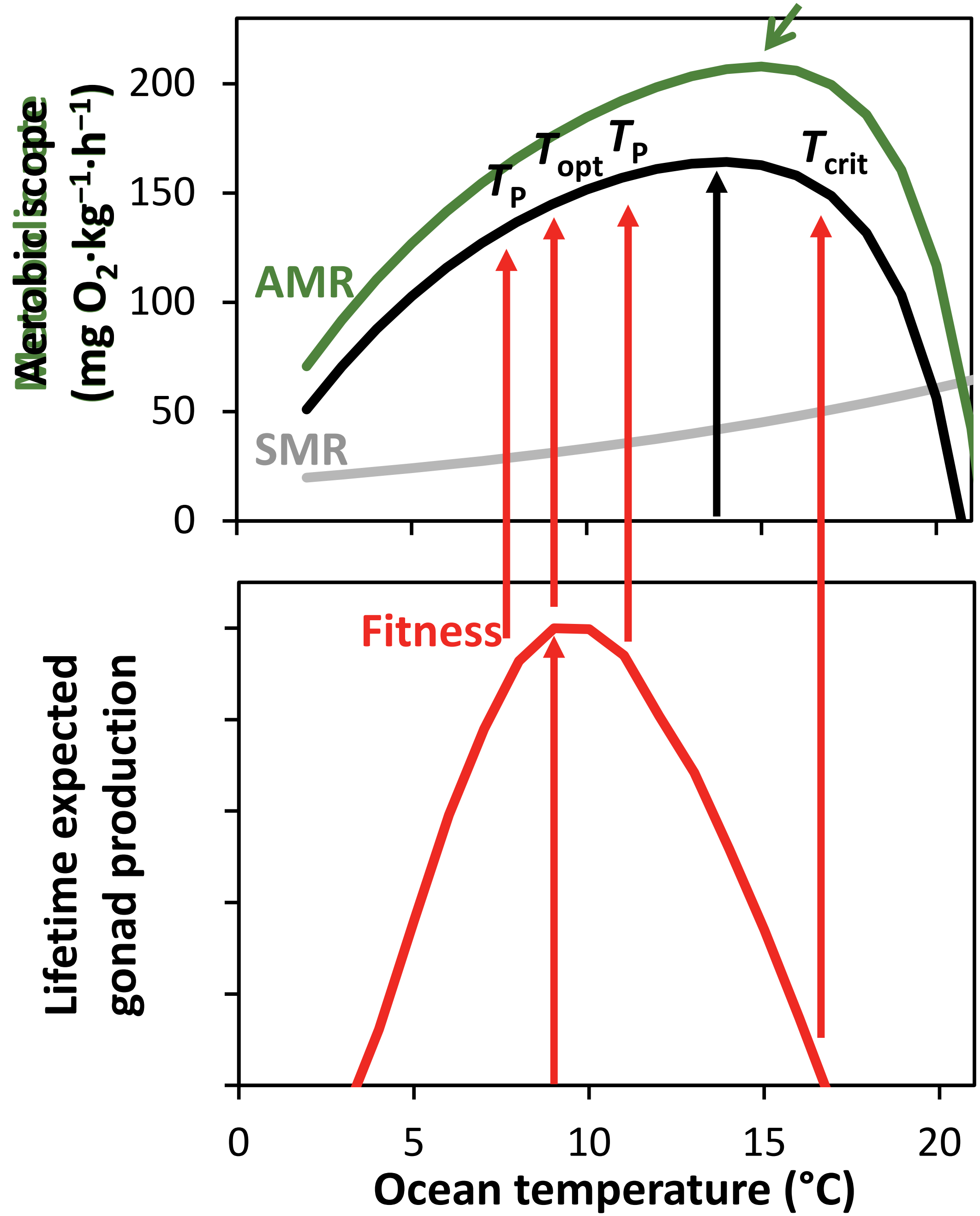




Constant temperature throughout life.

No temperature effects on **spawning** or early life stages.

Find **optimal** strategies and their consequences.

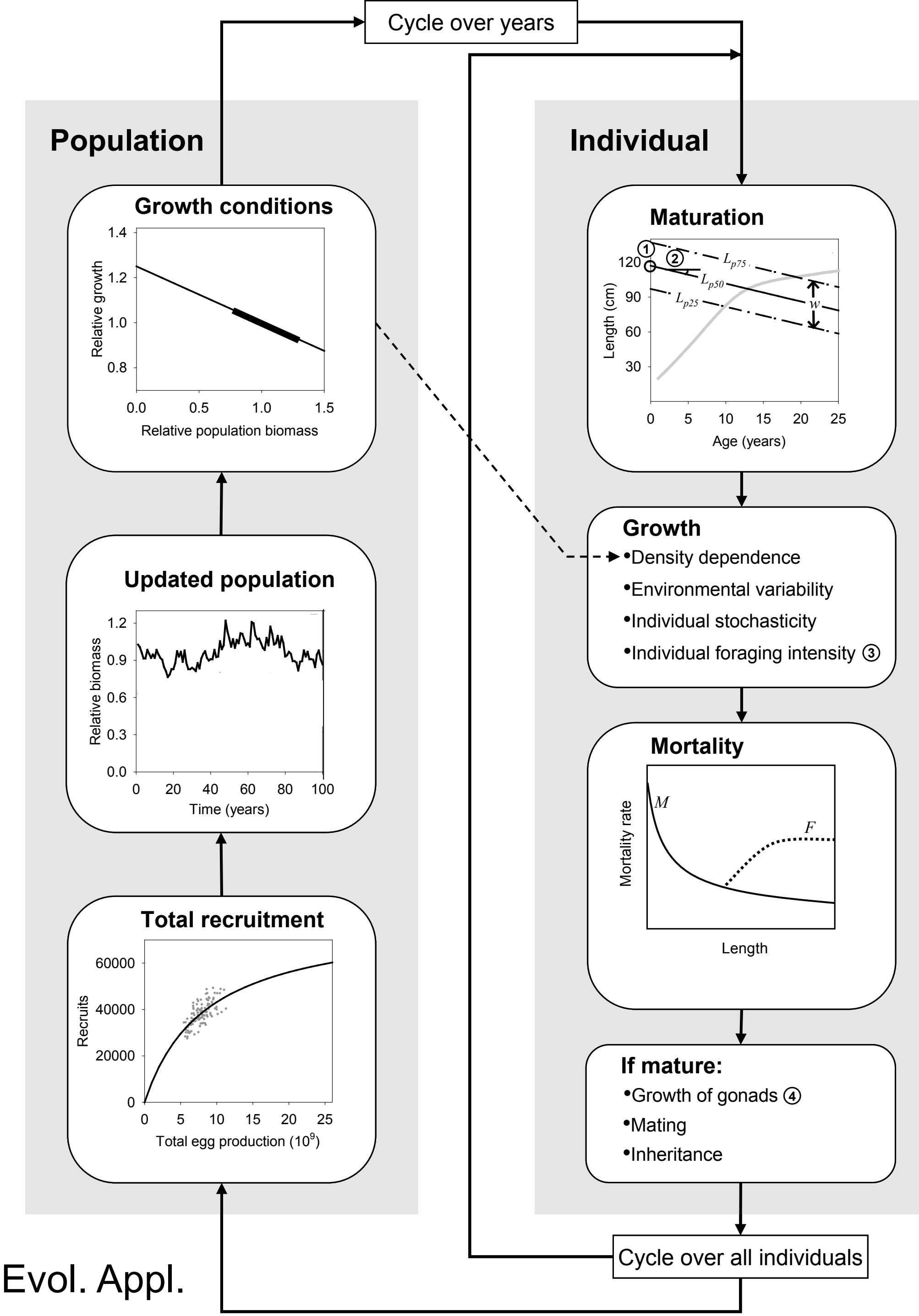


Max AMR: 15 °C

Max Aerobic Scope: 14 °C

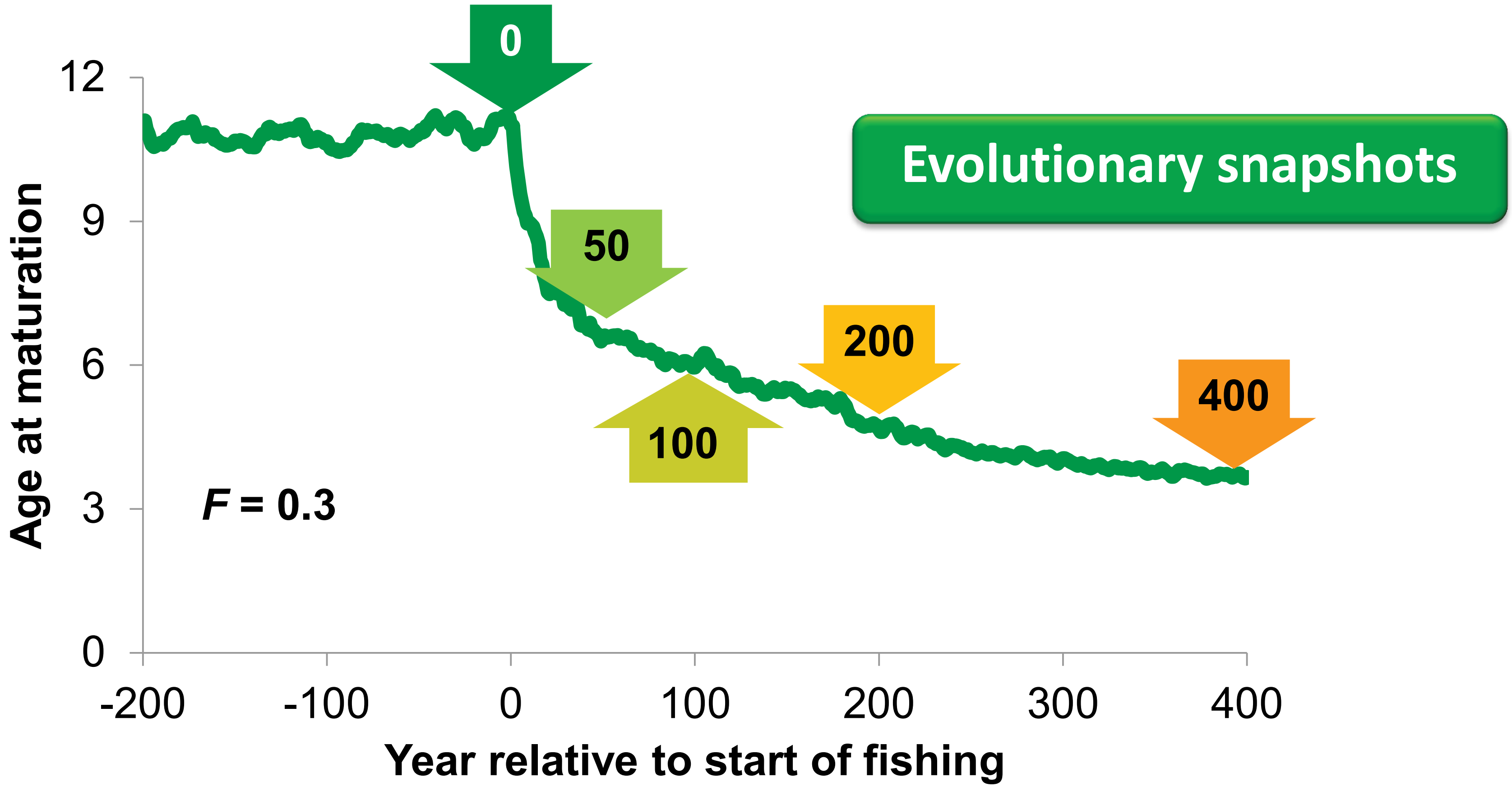
Max Fitness: 9 °C

Adding behavioural and life history perspectives **modifies predictions** based on physiology alone.



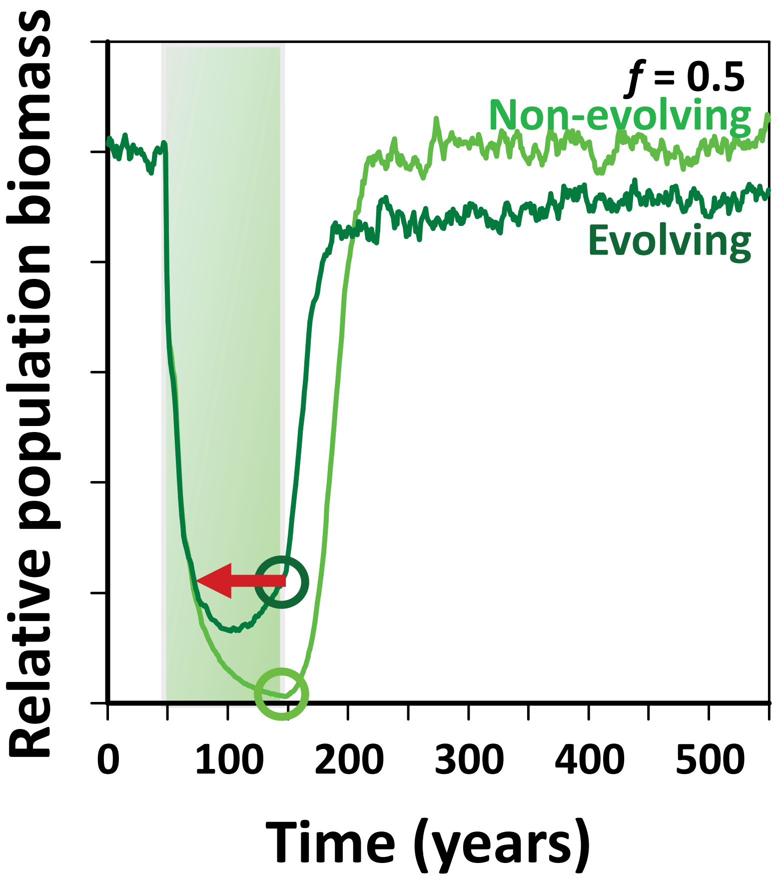
Enberg *et al.* 2009 Evol. Appl.

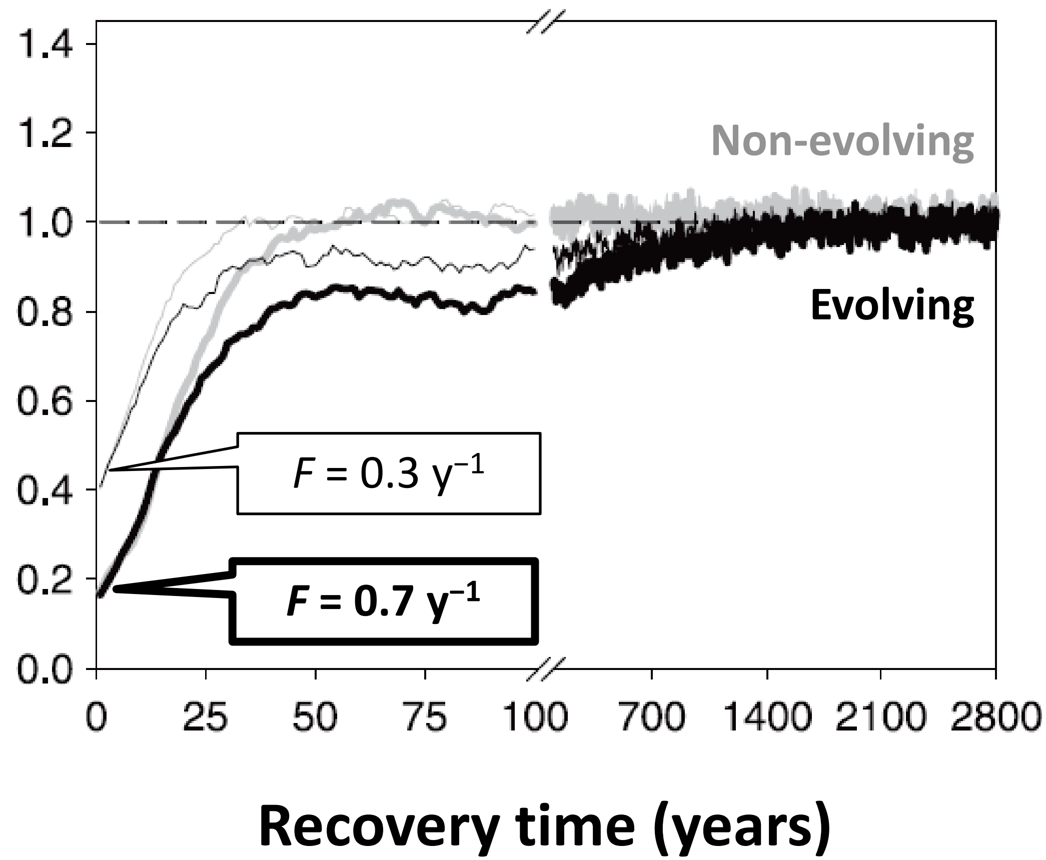
The model as a virtual laboratory

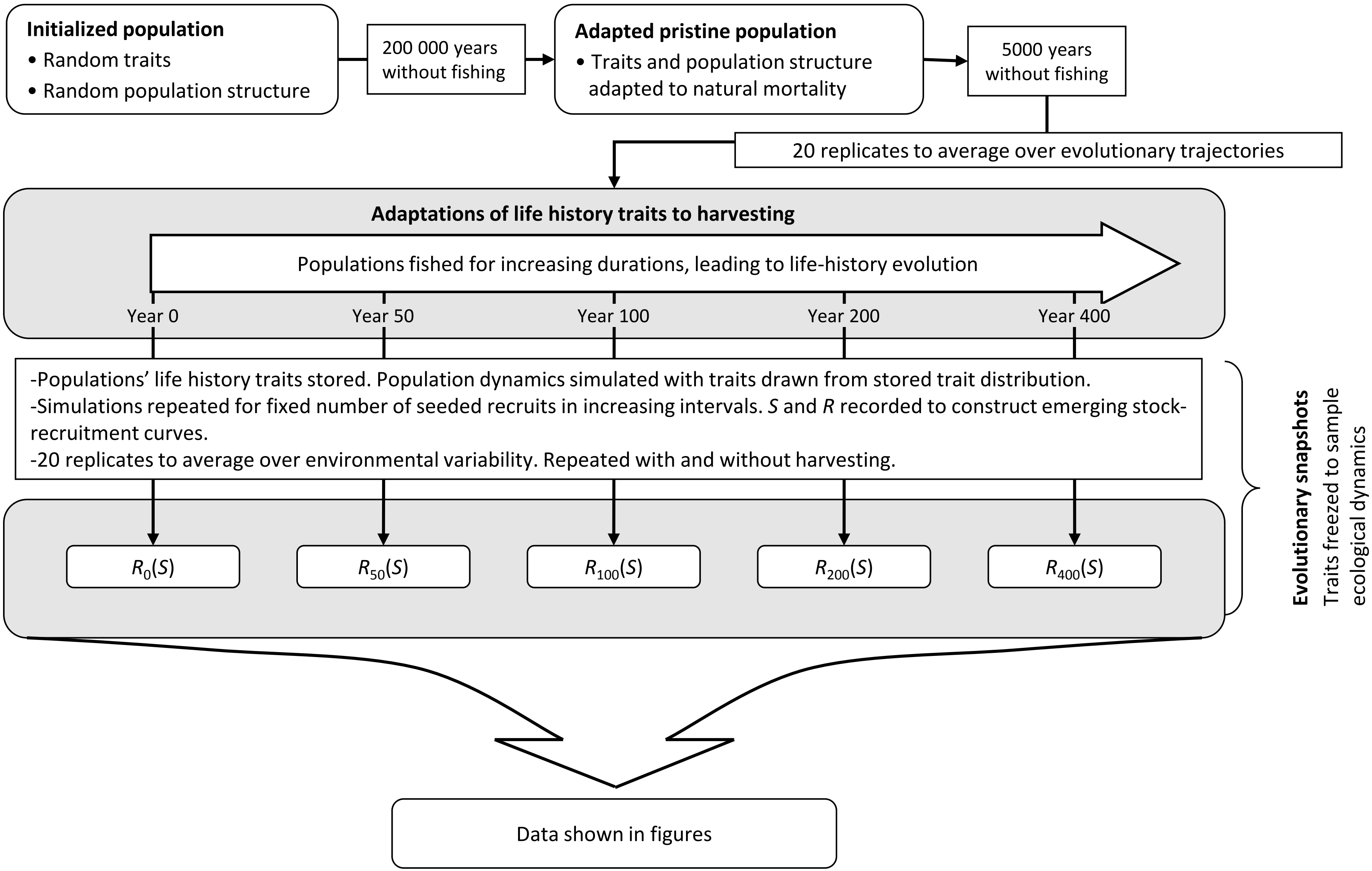


Manipulating and comparing

100 years of harvesting







Initialized population
• Random traits
• Random population structure
200 000 years without fishing
Adapted pristine population
• Traits and population structure adapted to natural mortality
5000 years without fishing
20 replicates to average over evolutionary trajectories
Adaptations of life history traits to harvesting
Populations fished for increasing durations, leading to life-history evolution
Year 0
Year 50
Year 100
Year 200
Year 400
-Populations' life history traits stored. Population dynamics simulated with traits drawn from stored trait distribution.
-Simulations repeated for fixed number of seeded recruits in increasing intervals. S and R recorded to construct emerging stock-recruitment curves.
-20 replicates to average over environmental variability. Repeated with and without harvesting.
$R_0(S)$
$R_{50}(S)$
$R_{100}(S)$
$R_{200}(S)$
$R_{400}(S)$
Evolutionary snapshots
Traits freezed to sample ecological dynamics
Data shown in figures

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Frode Vikebø
Anders F. Opdal

Cod and climate: Rebecca E. Holt

Evolving IBMs: Katja Enberg

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