Jarl Giske

Geir Huse IMR

Individual Based Models
Evolutionary IBMs

Øyvind Fiksen

Department of Biology

University of Bergen, Norway

Katja Enberg IMR

Christian Jørgensen

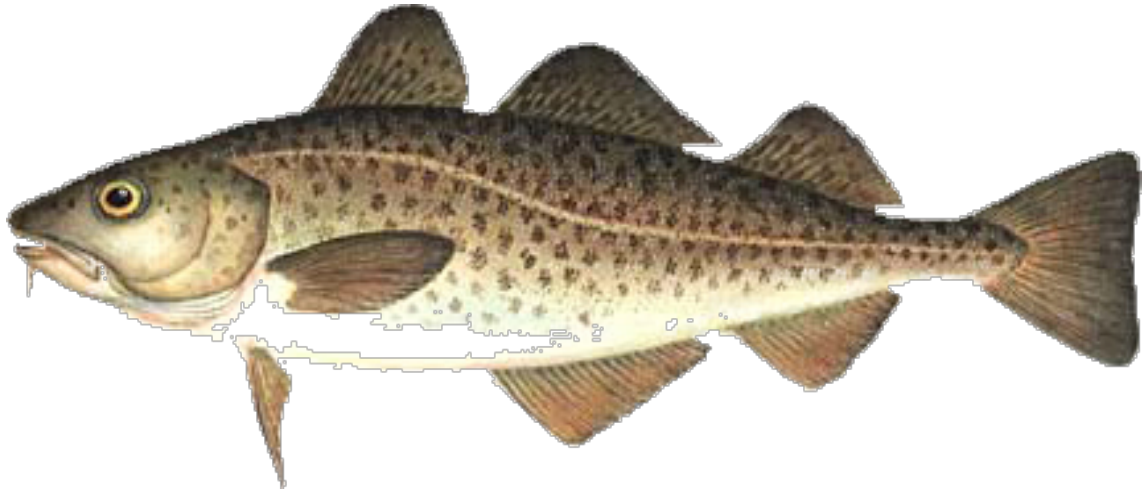
Frode
Vikebø IMR

Øystein
Varpe

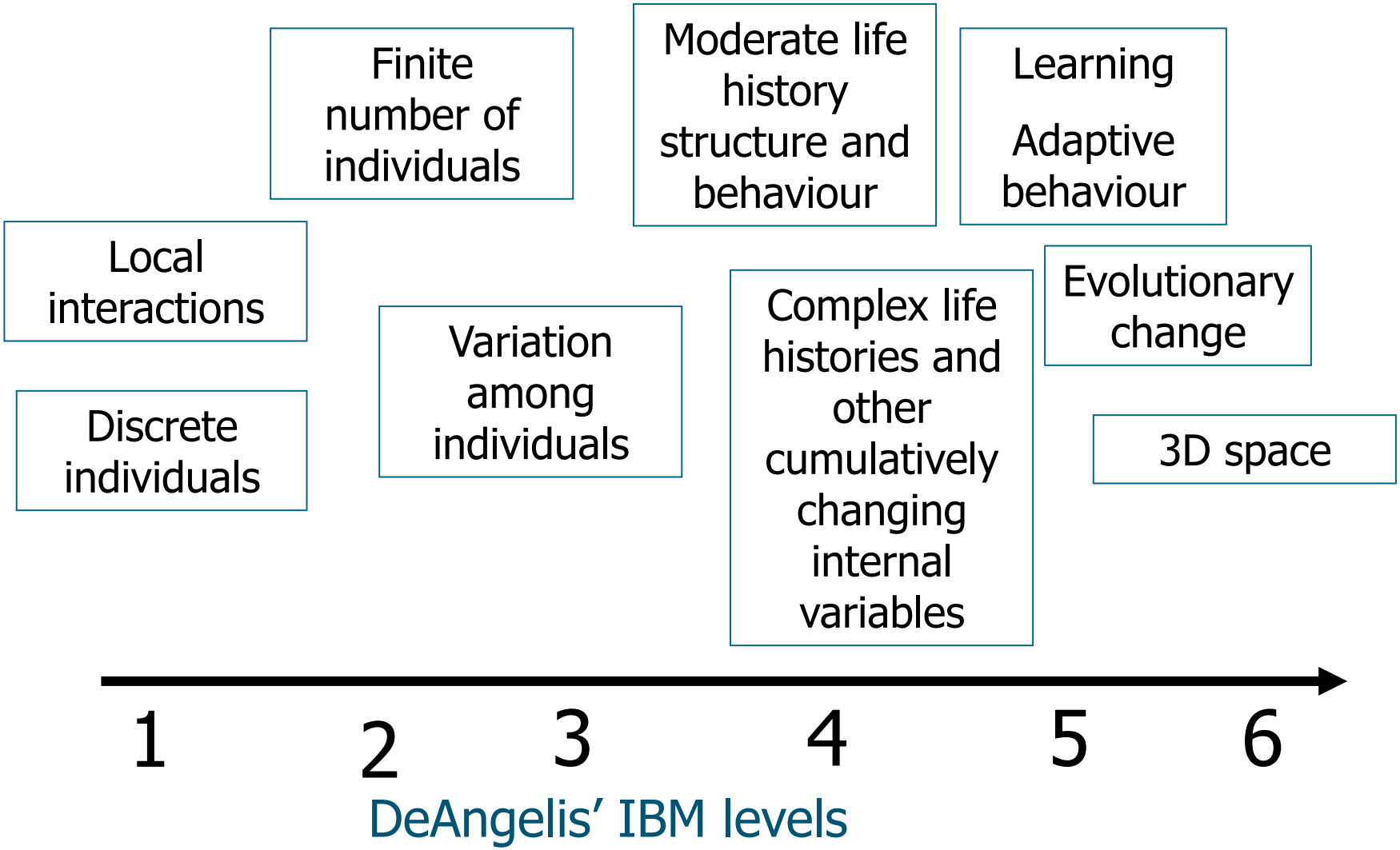
Trond
Kristiansen IMR

UNIVERSITY OF BERGEN

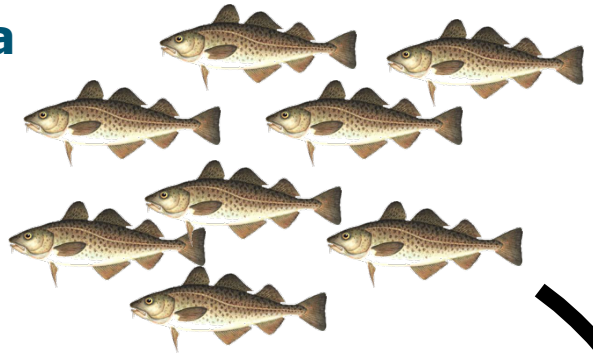
www.bio.uib.no/modelling



IBM – levels (DeAngelis, pers com)



A population is a collection of individuals and their actions



Evolution emerges

Predators,
prey,
competitors,
mates

Environment

Light,
temperature,
turbulence,
turbidity,
salinity,
pH…

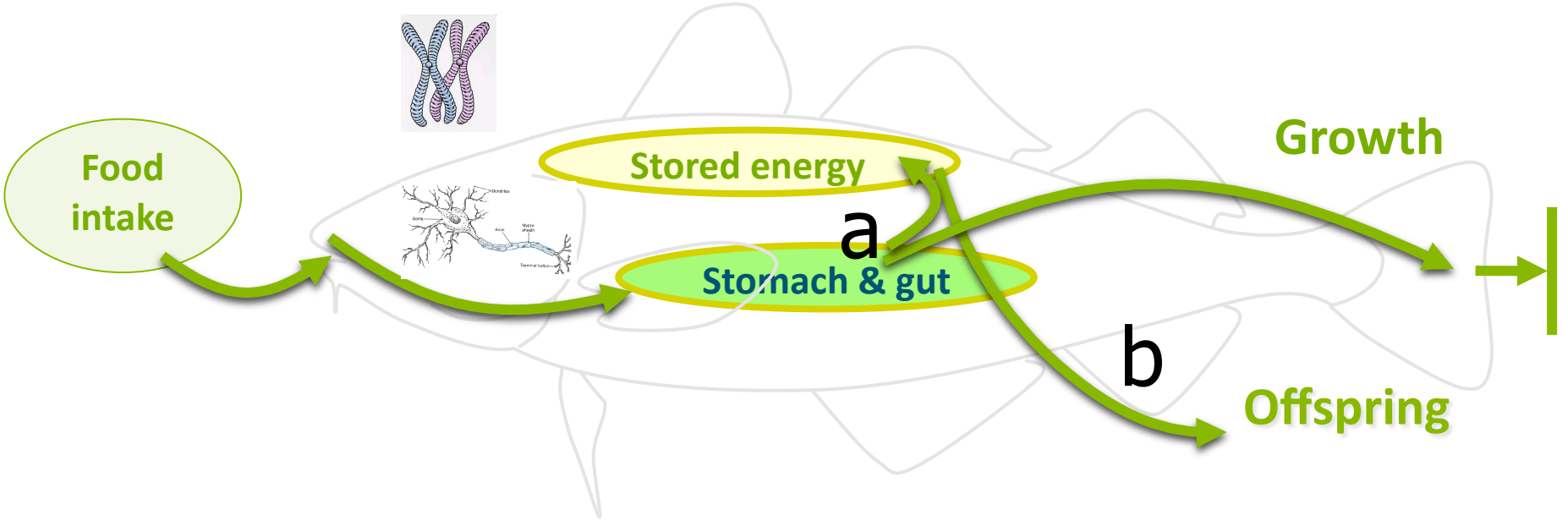
Trade-offs emerge

Individual state

Age,
sex,
size,
energy reserves,
position…

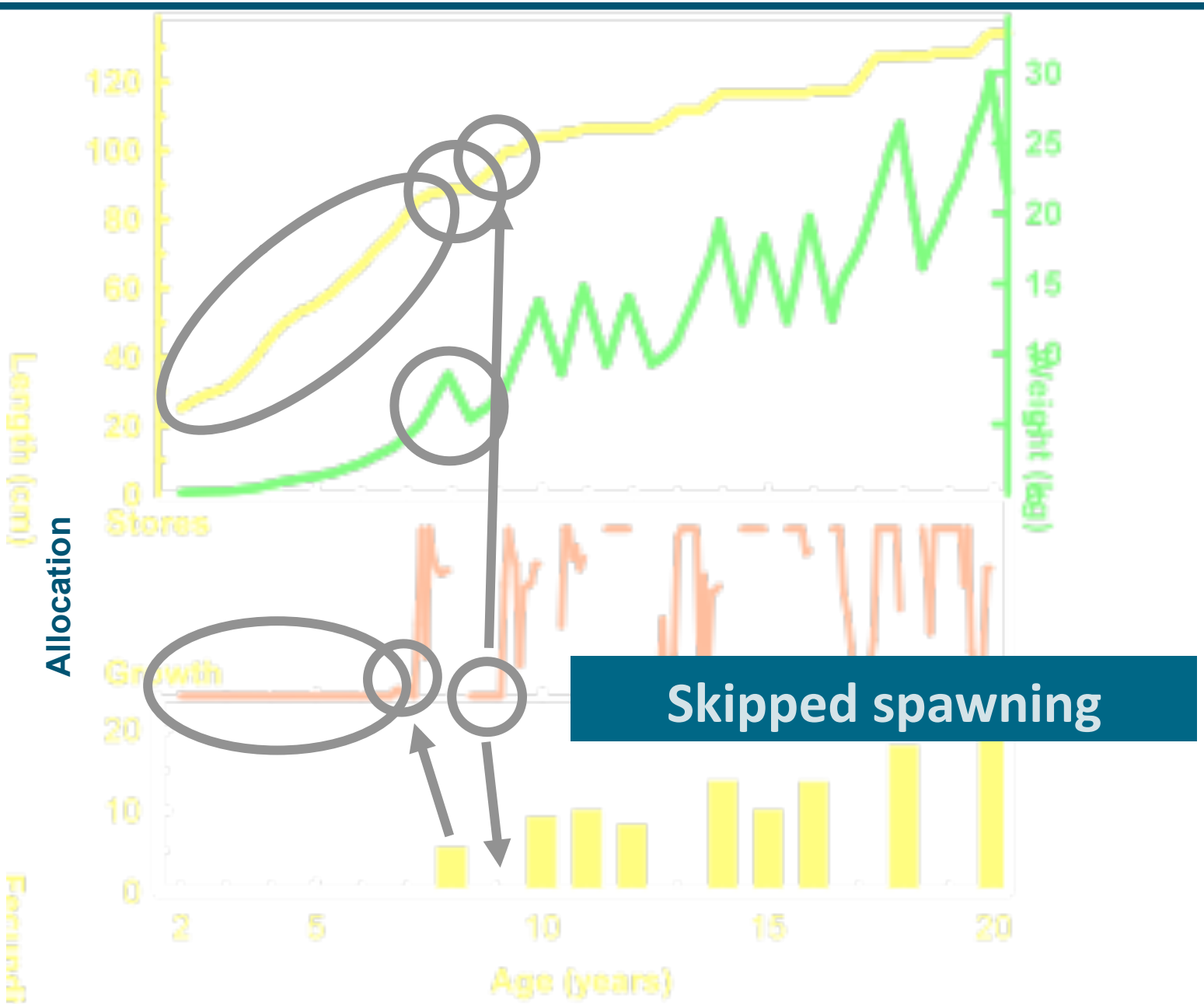
Patterns emerge

IBMs are intuitive (to biologists)



$Attributes_i(L, s, e, x, y, z, ..)$

$Strategies_i(a,b,c,d..)$

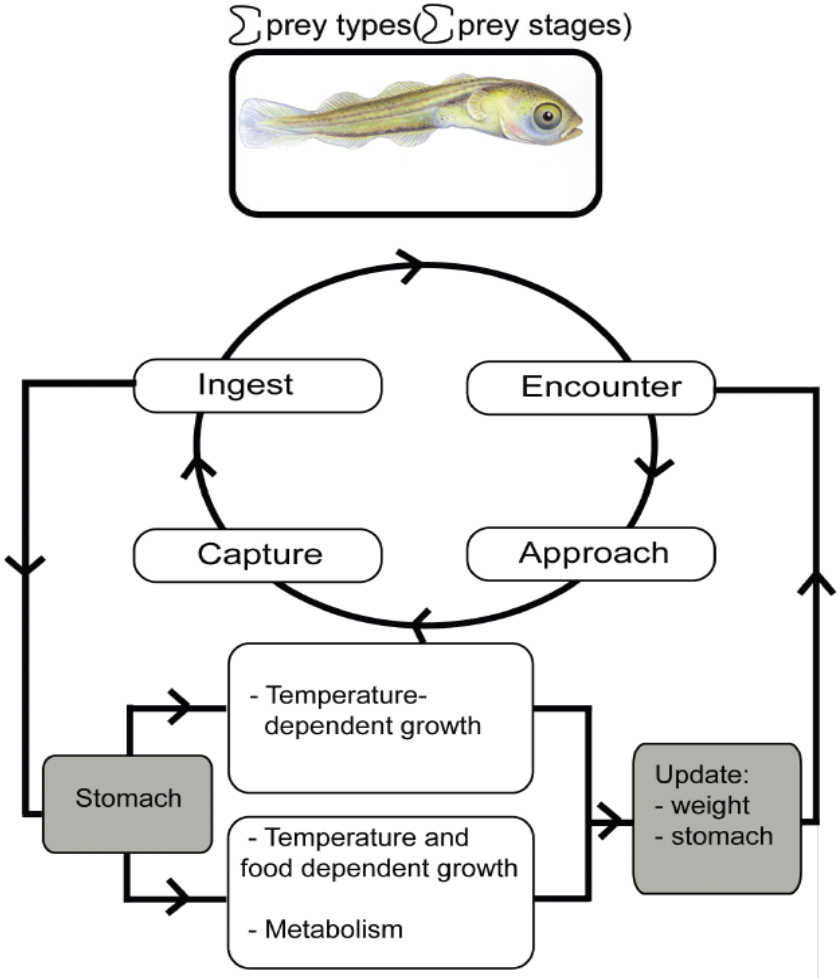


Jørgensen C and Fiksen Ø. 2006. *Can J Fish Aquat Sci.* **63**:186-199

Level 1 – build your animal

- Environment
- Physiology
- Foraging
- Predation
- Interactions
- Behaviour
- …

- Need data and experiments!

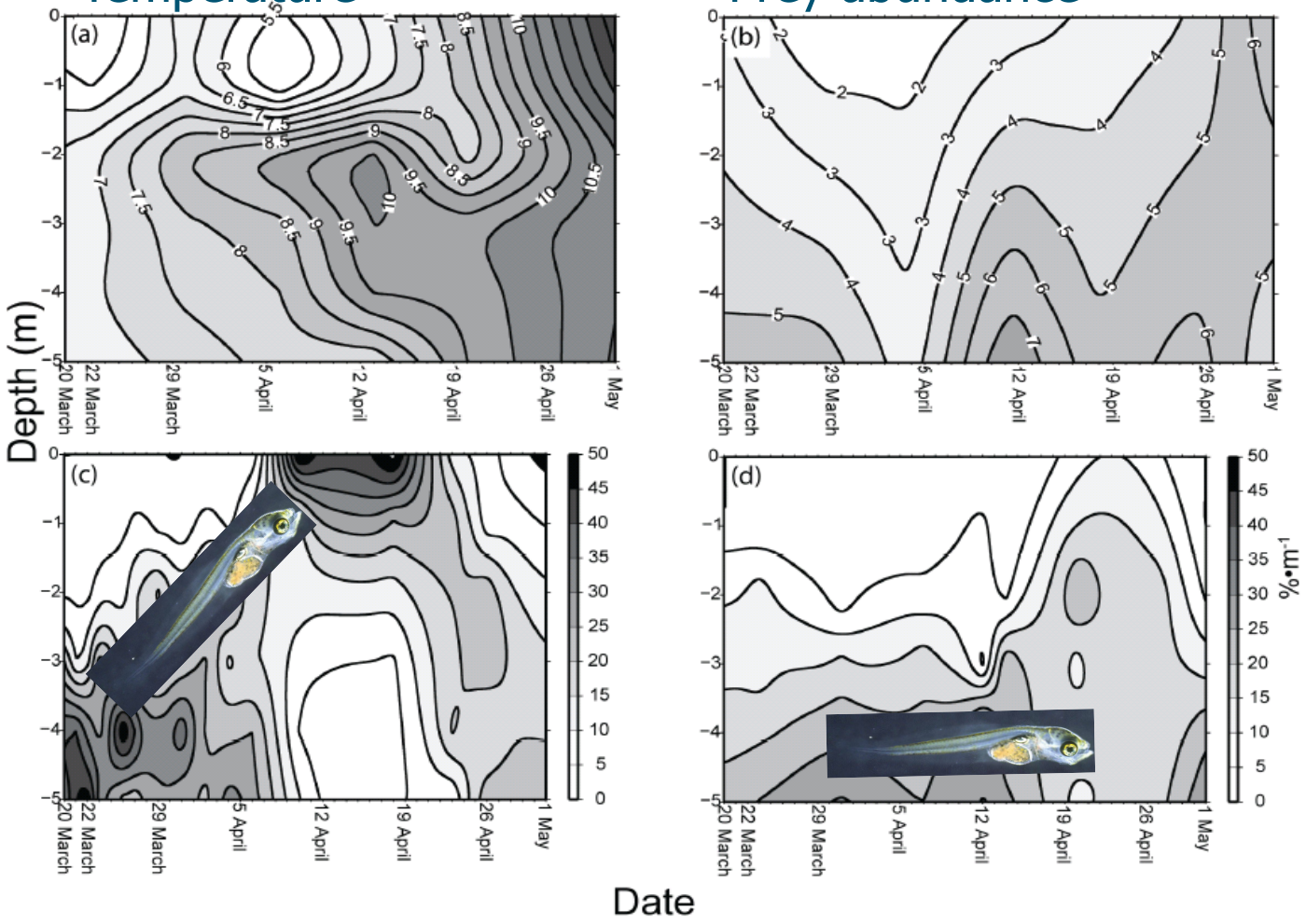


Kristiansen T, Fiksen Ø, and Folkvord A (2007). Modelling feeding, growth and habitat selection in larval cod: observations and model predictions in a macrocosm environment. *Canadian Journal of Fisheries and Aquatic Science.* 64:136-151

Playground environment – reality check

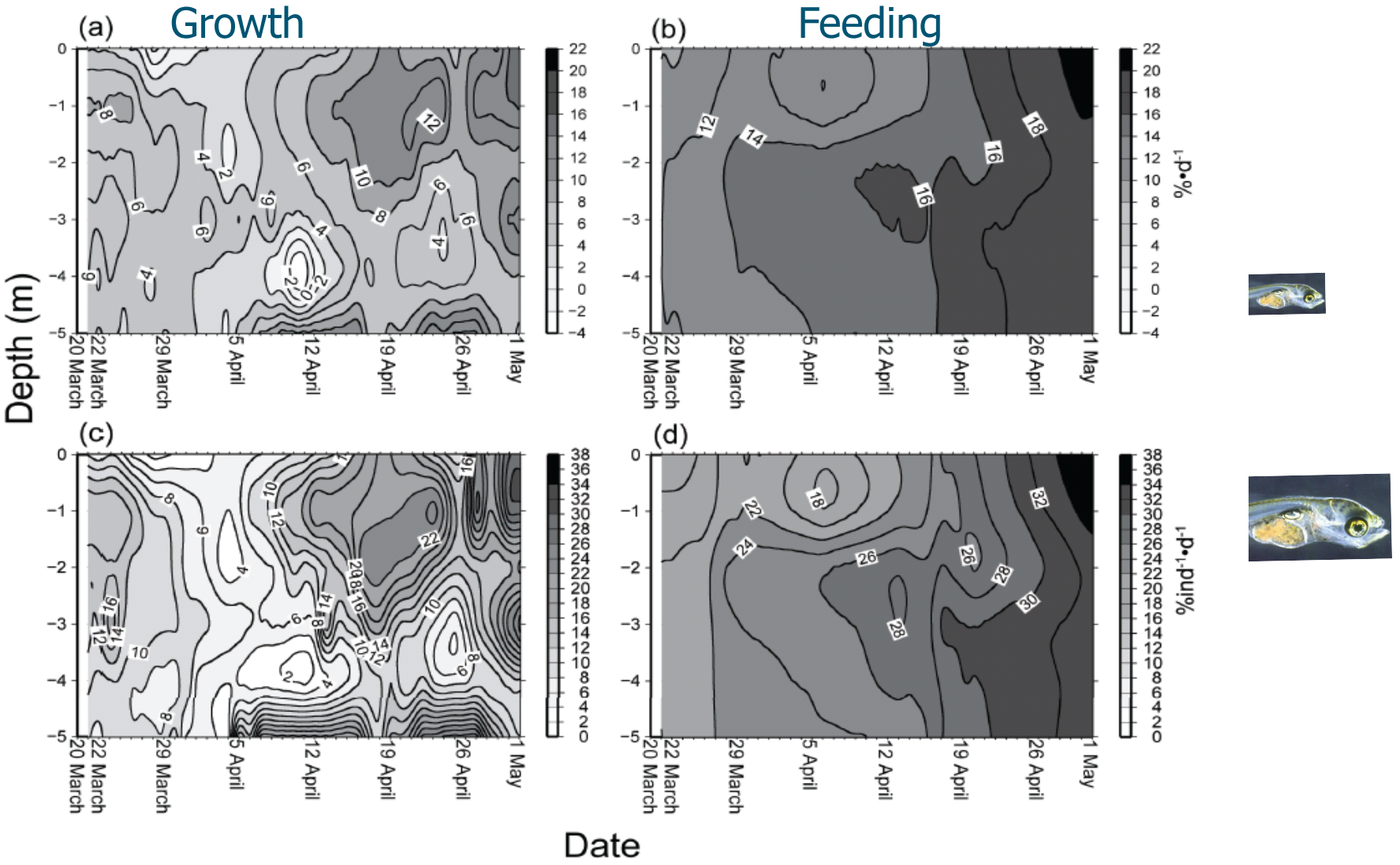
Temperature

Prey abundance



Kristiansen & al 2007

Model predictions in controlled environments



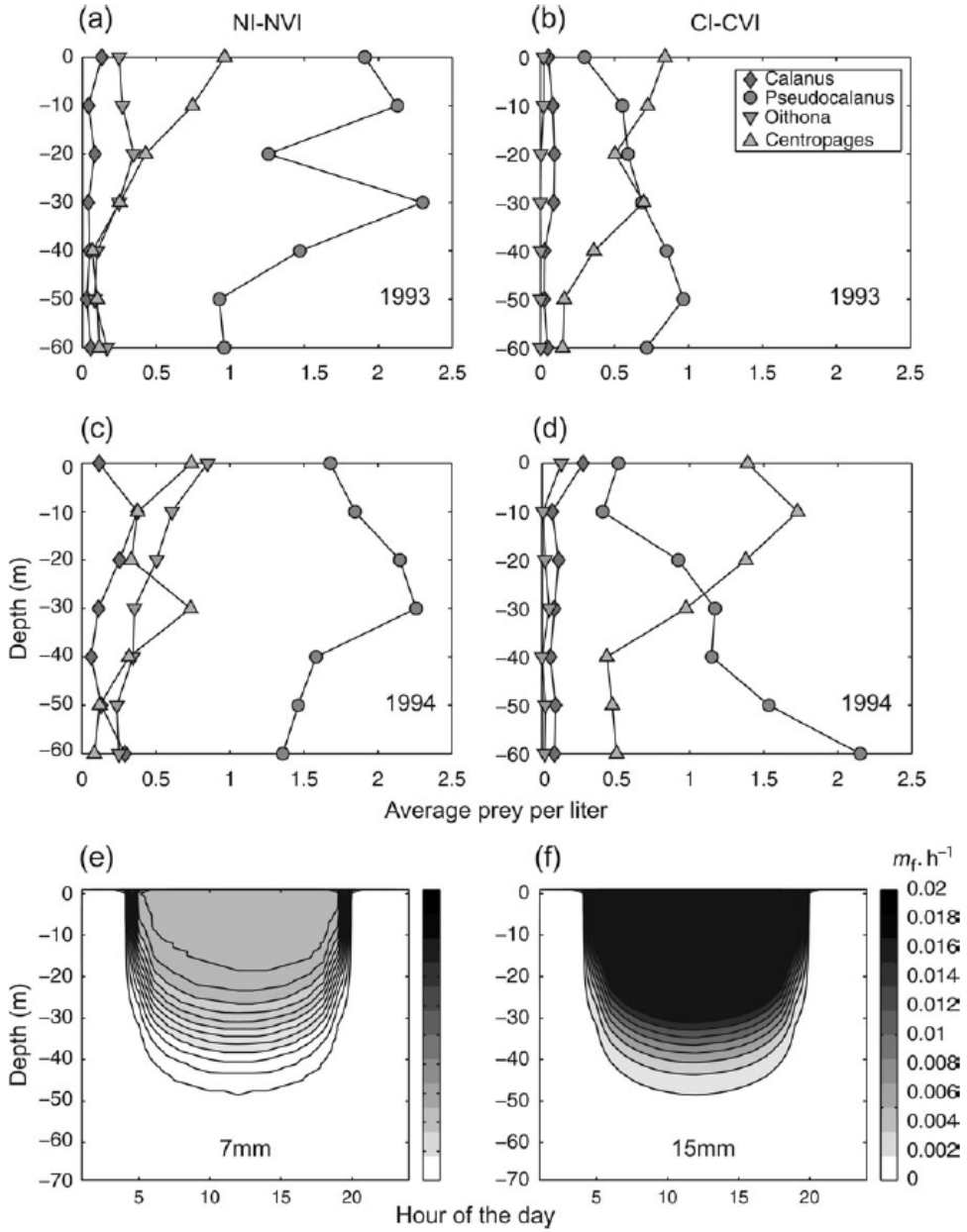
Kristiansen & al 2007

Real life for a cod larva…

Georges Bank

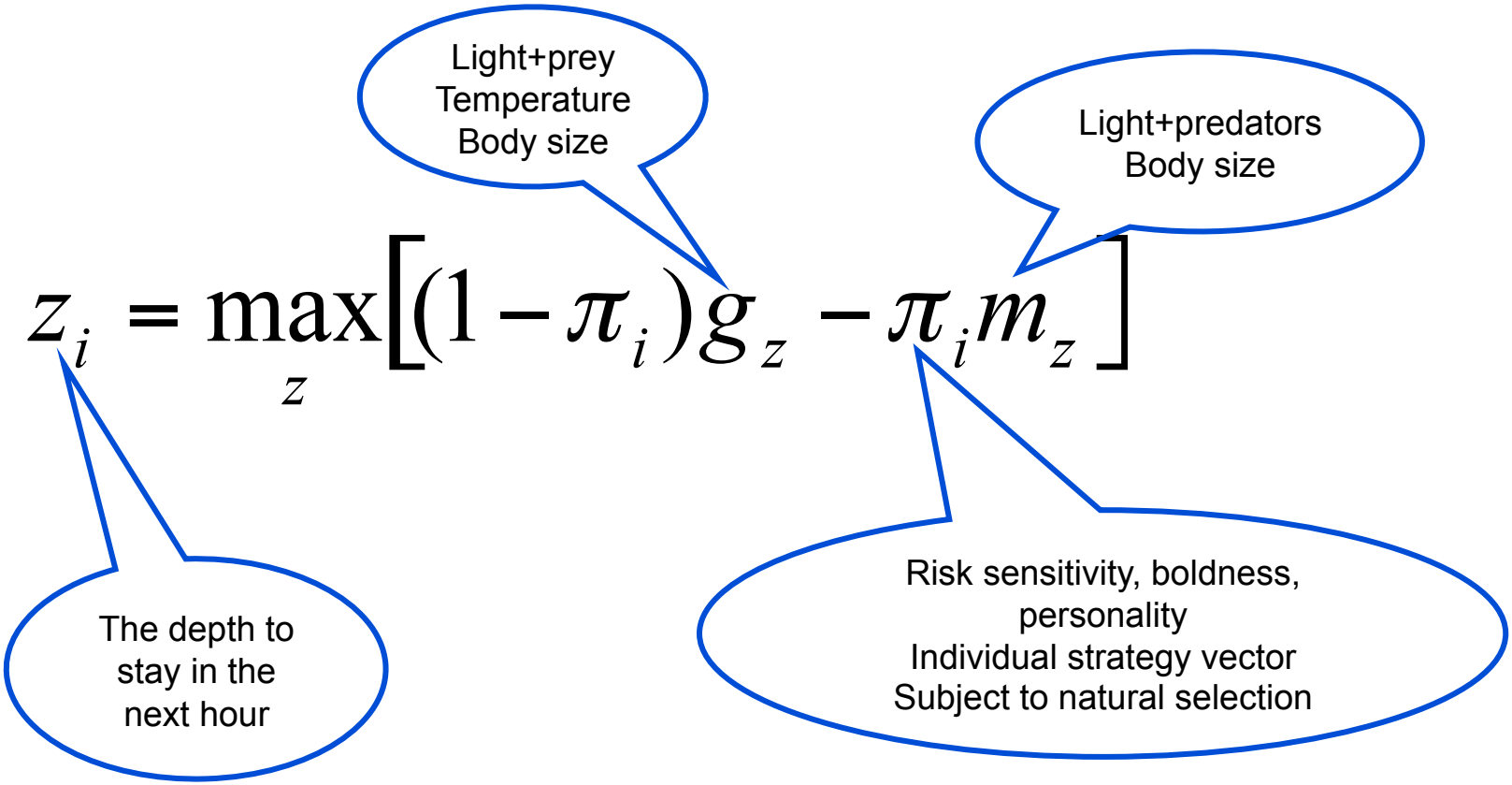
1993

1994



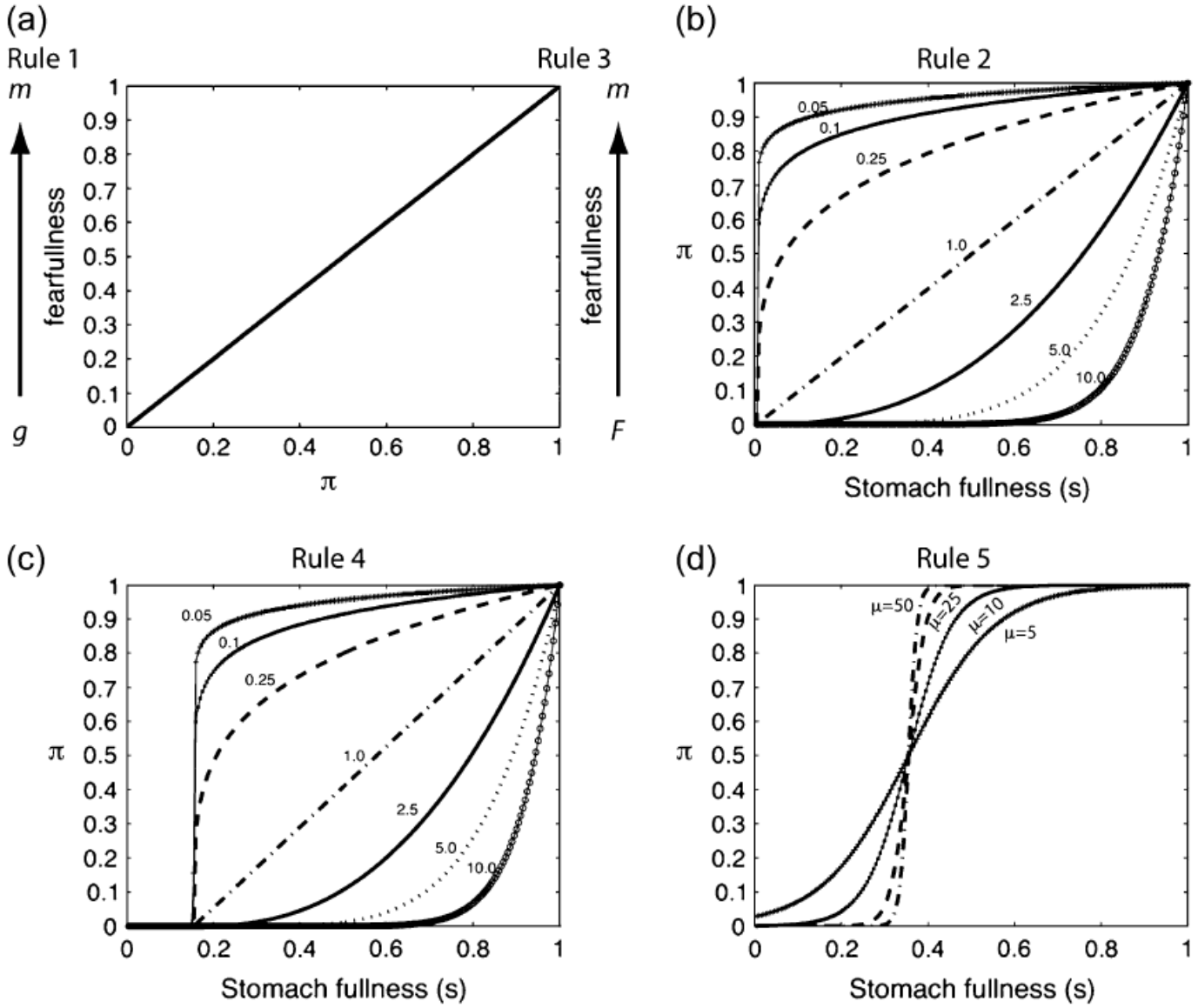
Kristiansen T, C. Jørgensen, R. G. Lough, F. Vikebø and Ø. Fiksen. 2009. Trading risk and growth: exploring behavioral rules of larval cod on Georges Bank. Behavioural Ecology 20:490-500.

Move? 'Rules of thumb' or 'myopic heuristics'



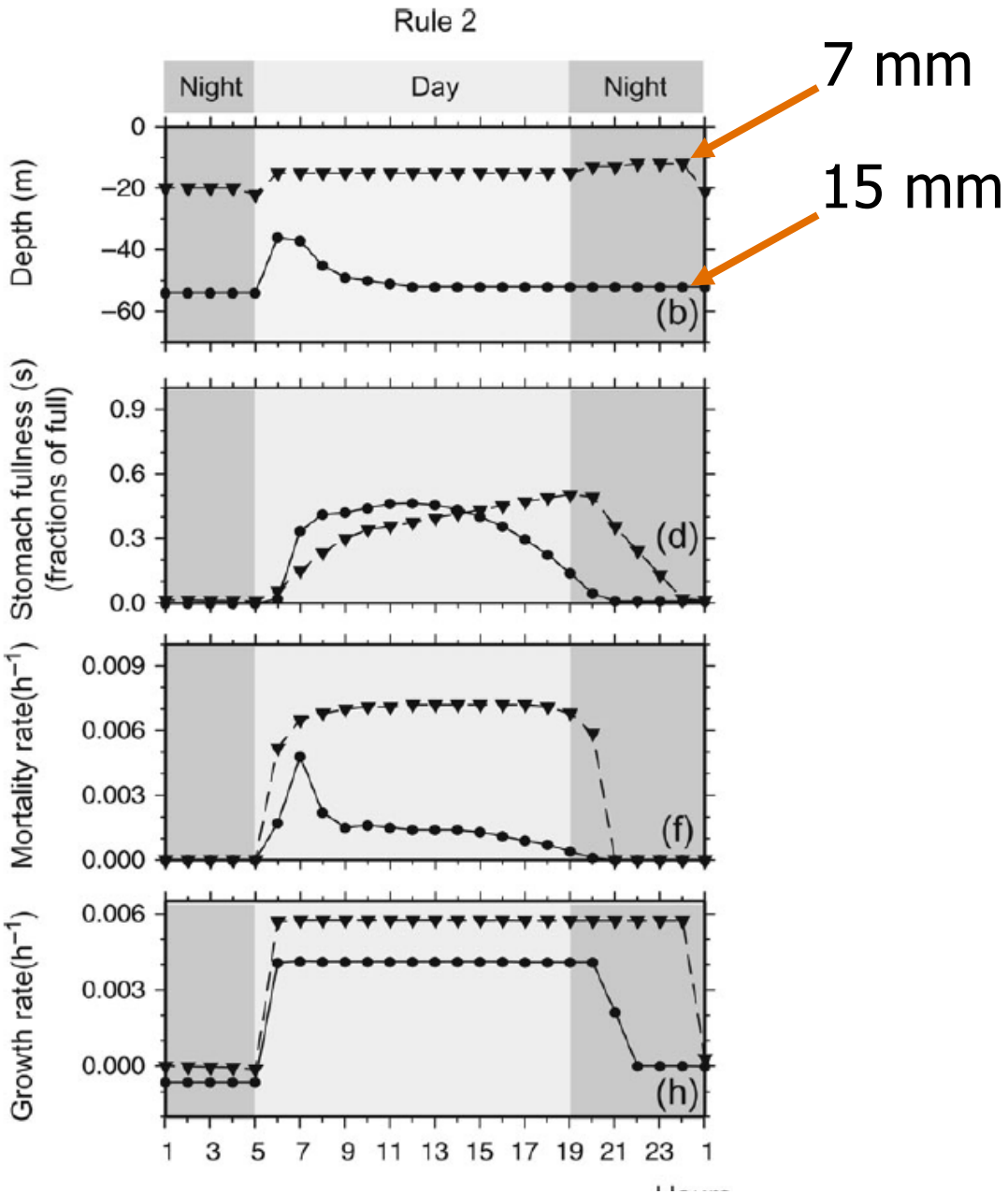
Kristiansen T, C. Jørgensen, R. G. Lough, F. Vikebø and Ø. Fiksen. 2009. Trading risk and growth: exploring behavioral rules of larval cod on Georges Bank. Behavioural Ecology 20:490-500.

State-dependent rules of behaviour



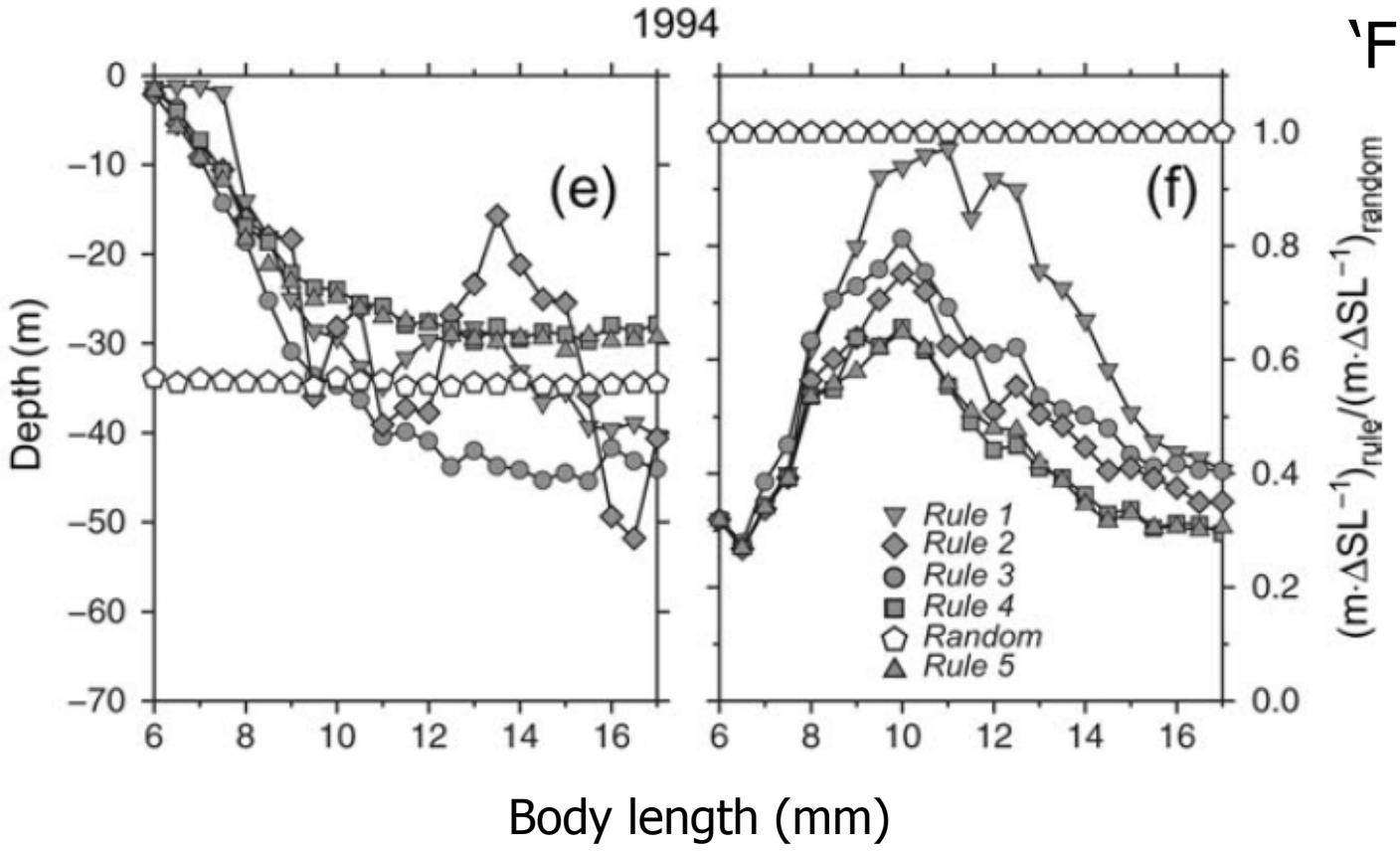
Kristiansen & al 2009

Following a single individual over one day



Kristiansen & al 2009

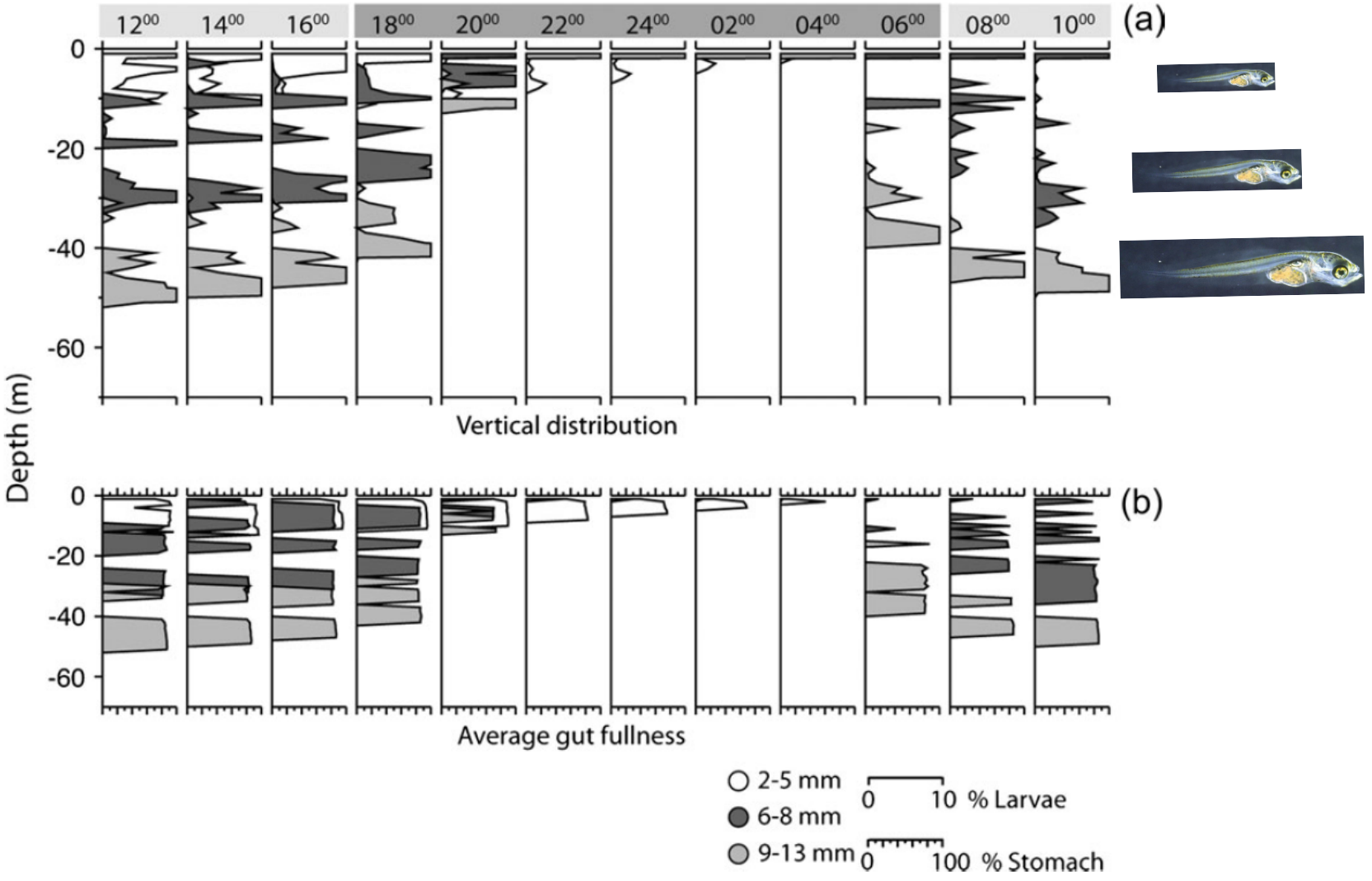
What is the best behavioural rule?



'Fitness'

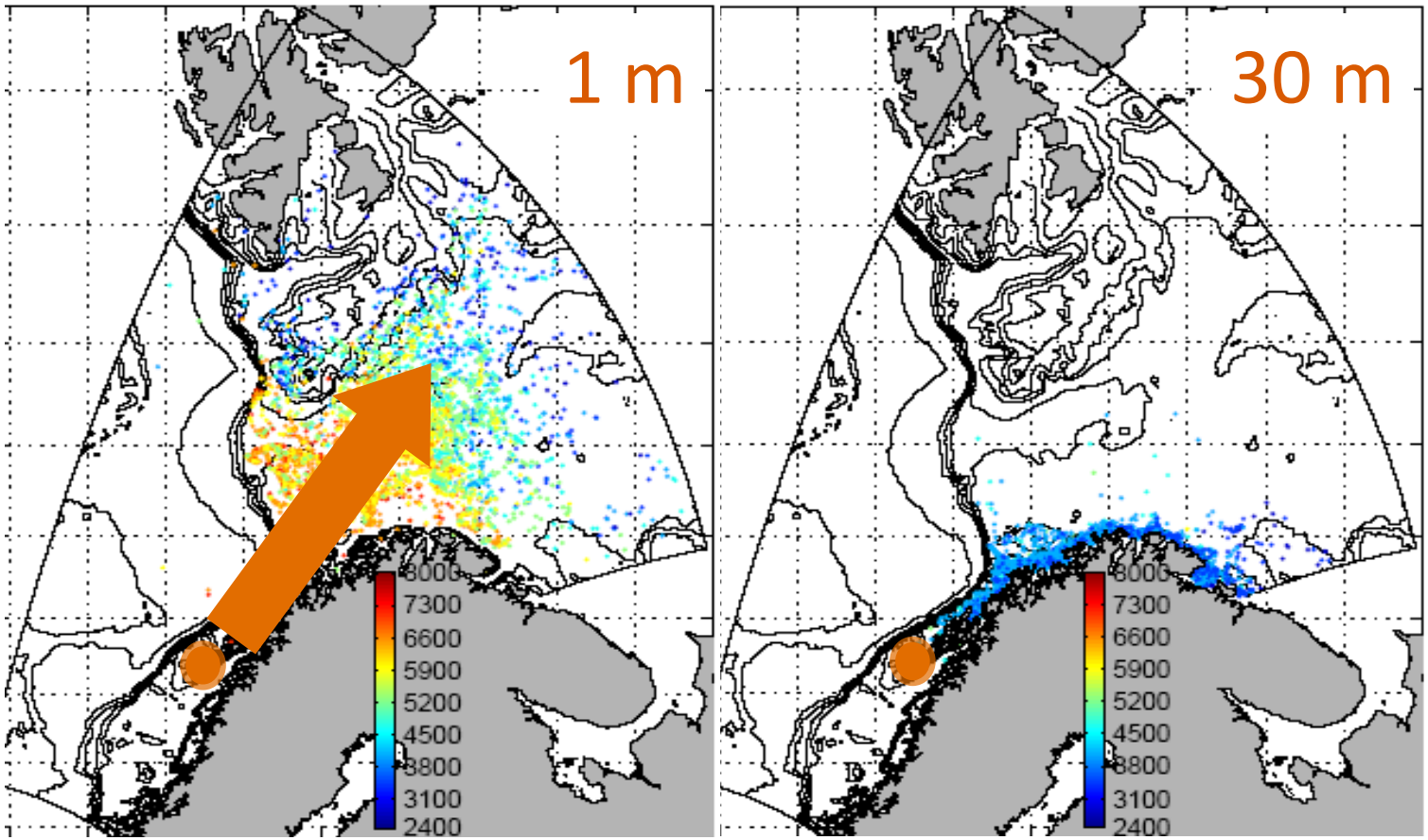
Kristiansen & al 2009

Population-level predictions



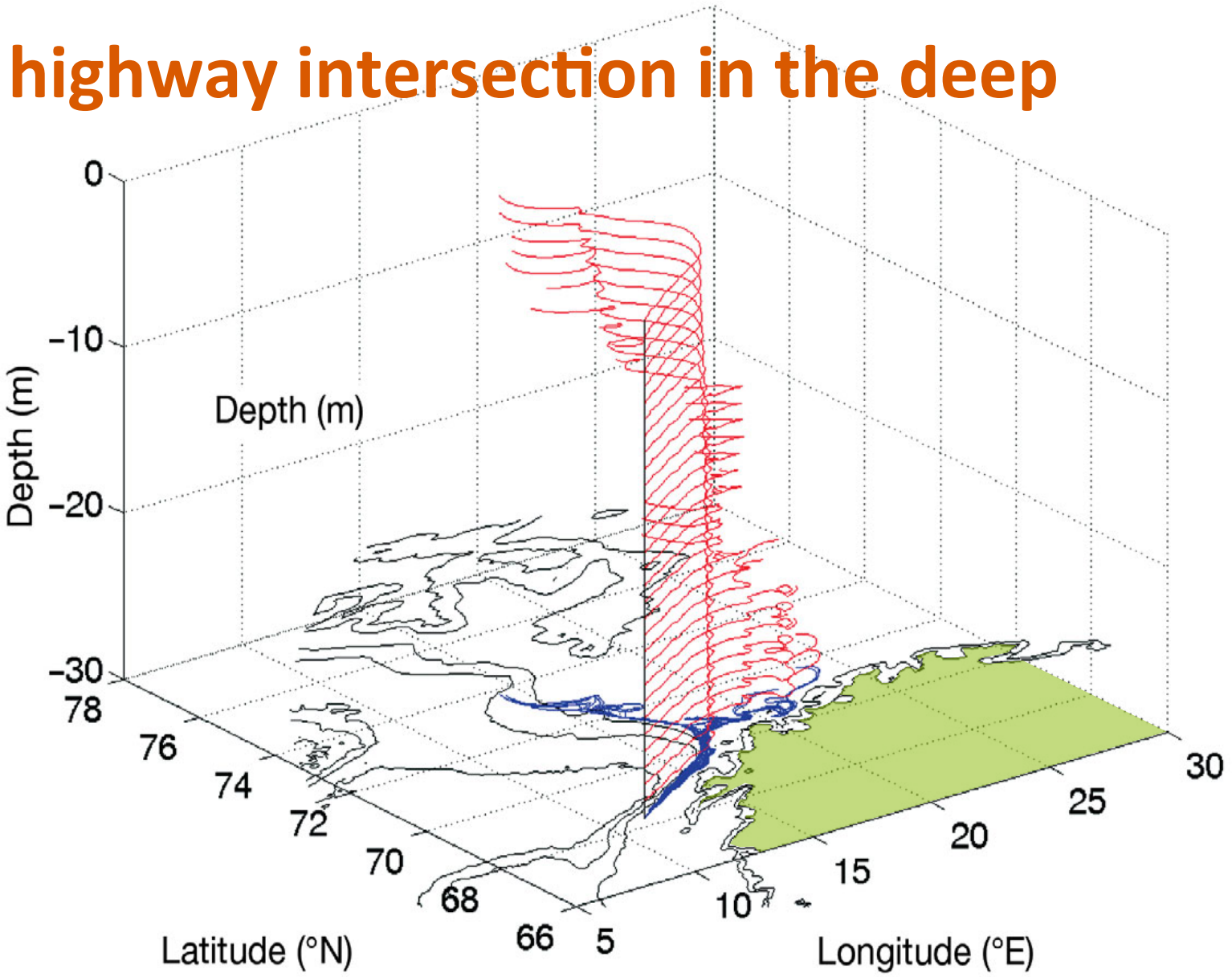
Kristiansen & al 2009

Drifting particles – IBMs in GCMs



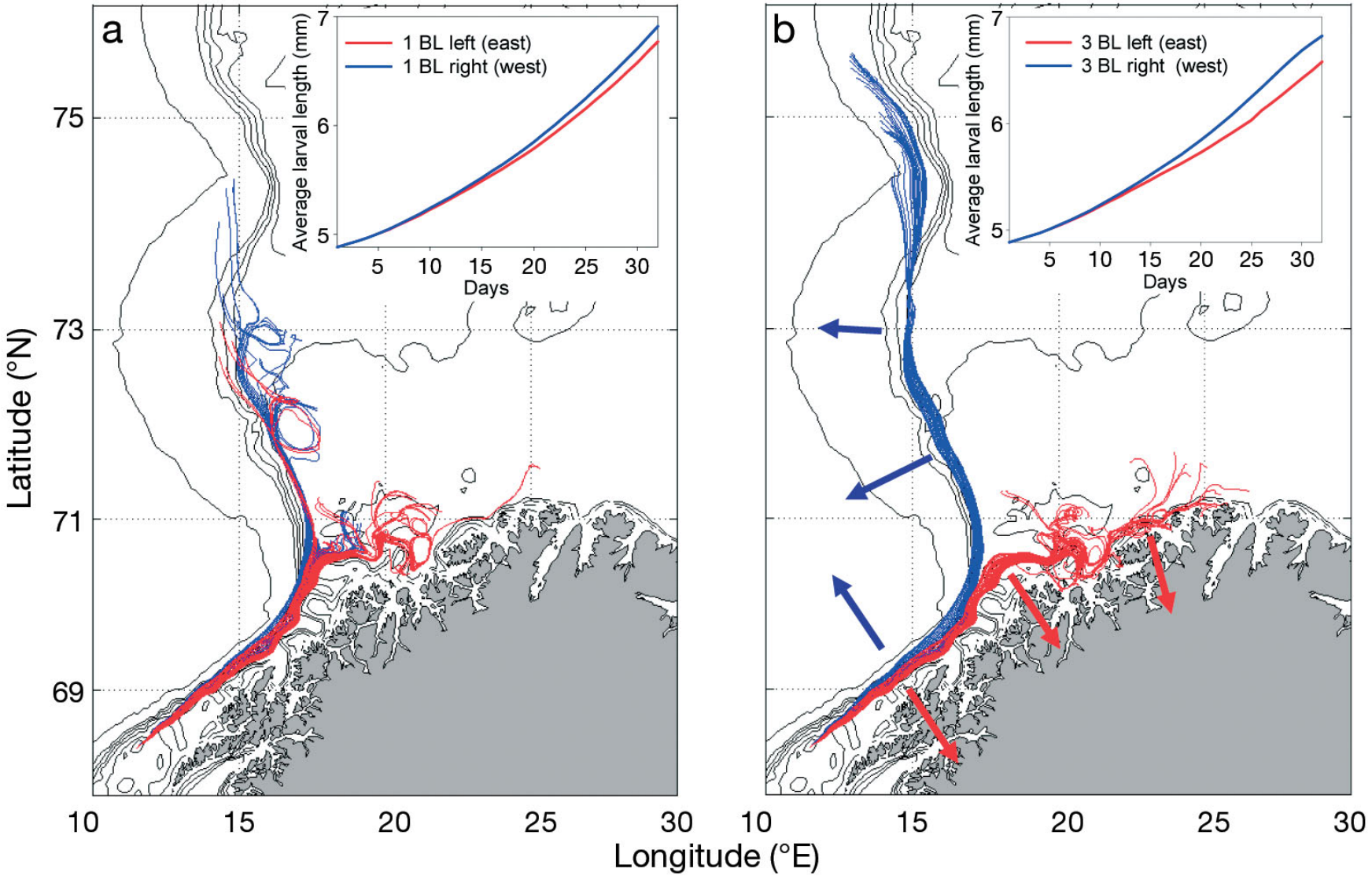
Vikebø F, Sundby S, Ådlandsvik B, and Fiksen Ø. 2005. *ICES J Mar Sci* **62**: 1375-1386.

A highway intersection in the deep



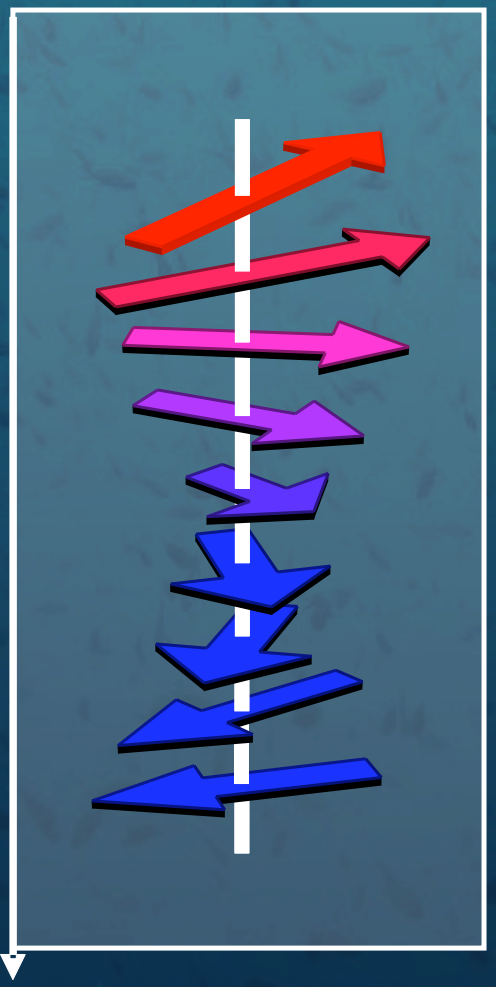
Fiksen Ø, Jørgensen C, Kristiansen T, Vikebø F, Huse G. 2007. *Mar. Ecol. Progr. Ser.*, **347**: 195-205.

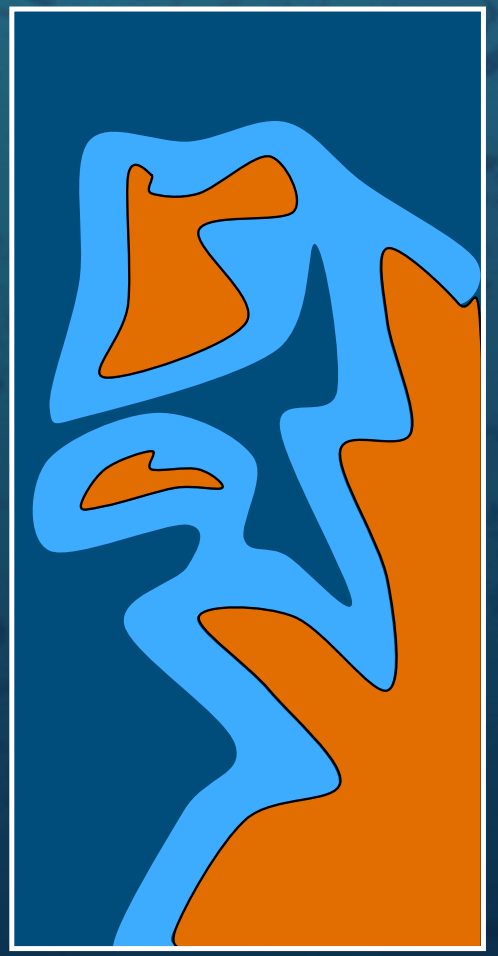
Changing lane even when swimming slowly



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

Life for a cod larva…





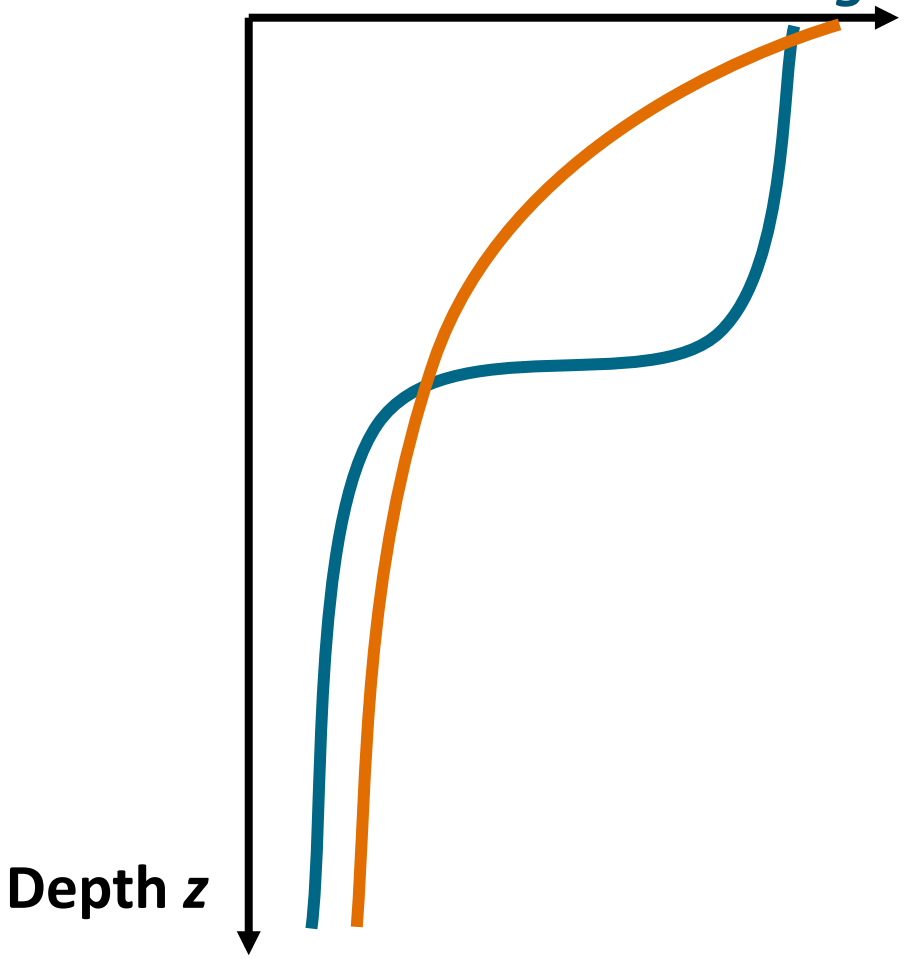
Fiksen Ø, Jørgensen C, Kristiansen T, Vikebø F, Huse G. 2007. *Mar. Ecol. Progr. Ser.*, **347**: 195-205.

Behaviour in ROMS

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

$$z_i^*(t) = \max_z[(1-\pi_i)g_z - \pi_i m_z]$$

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



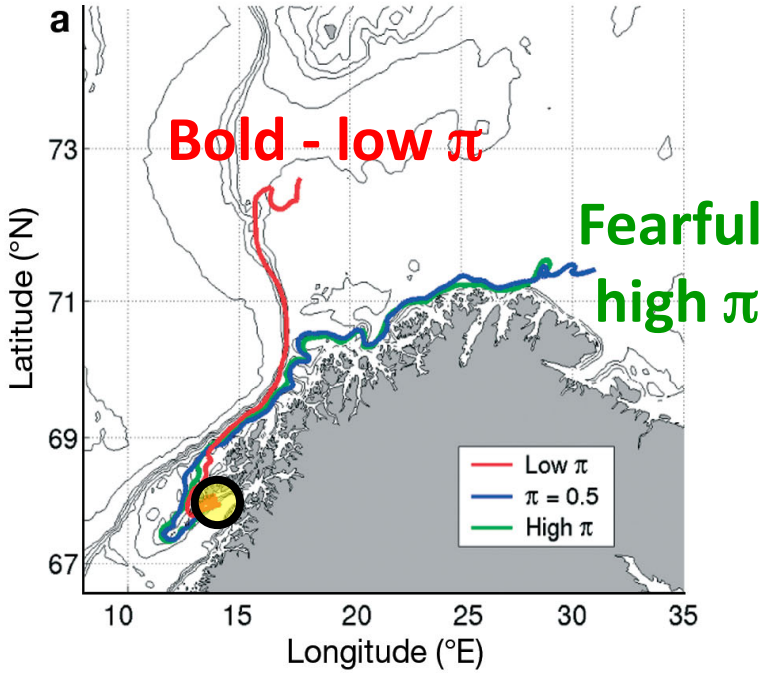
Vikebø F, Jørgensen C, Kristiansen T, Fiksen Ø. 2007. *Mar. Ecol. Progr. Ser.*, **347**: 207-219.

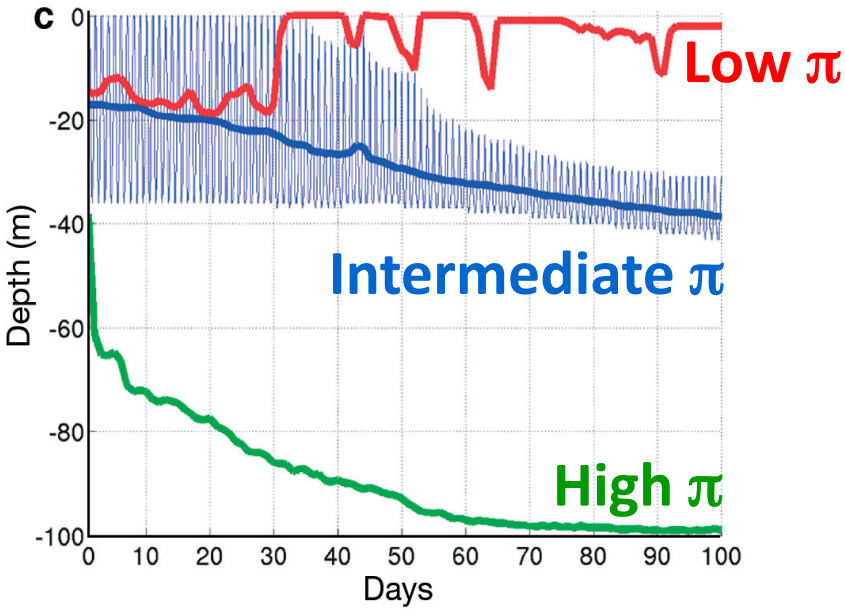
Behaviour in ROMS

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

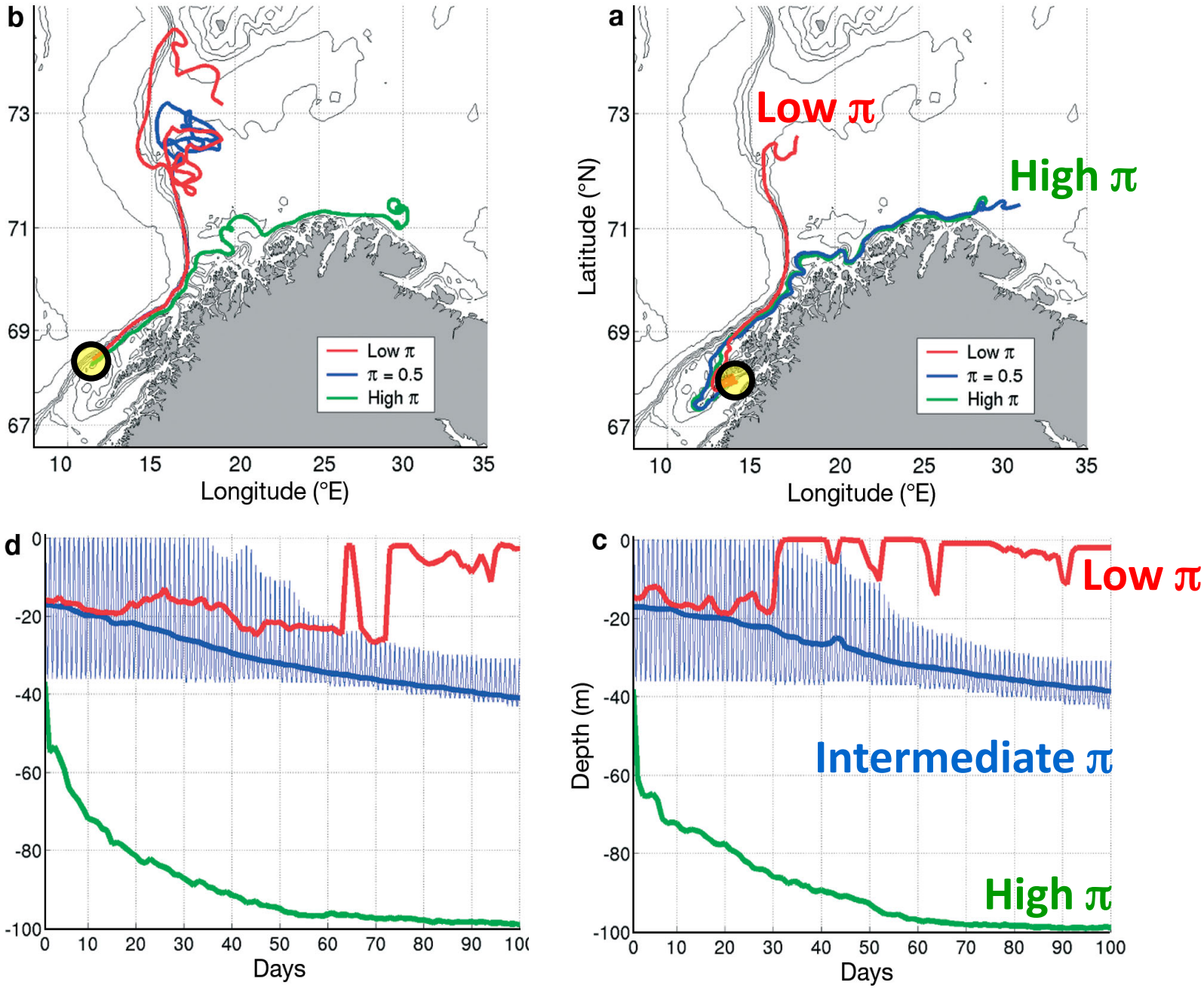
$$z_i^*(t) = \max_z[(1-\pi_i)g_z - \pi_i m_z]$$

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

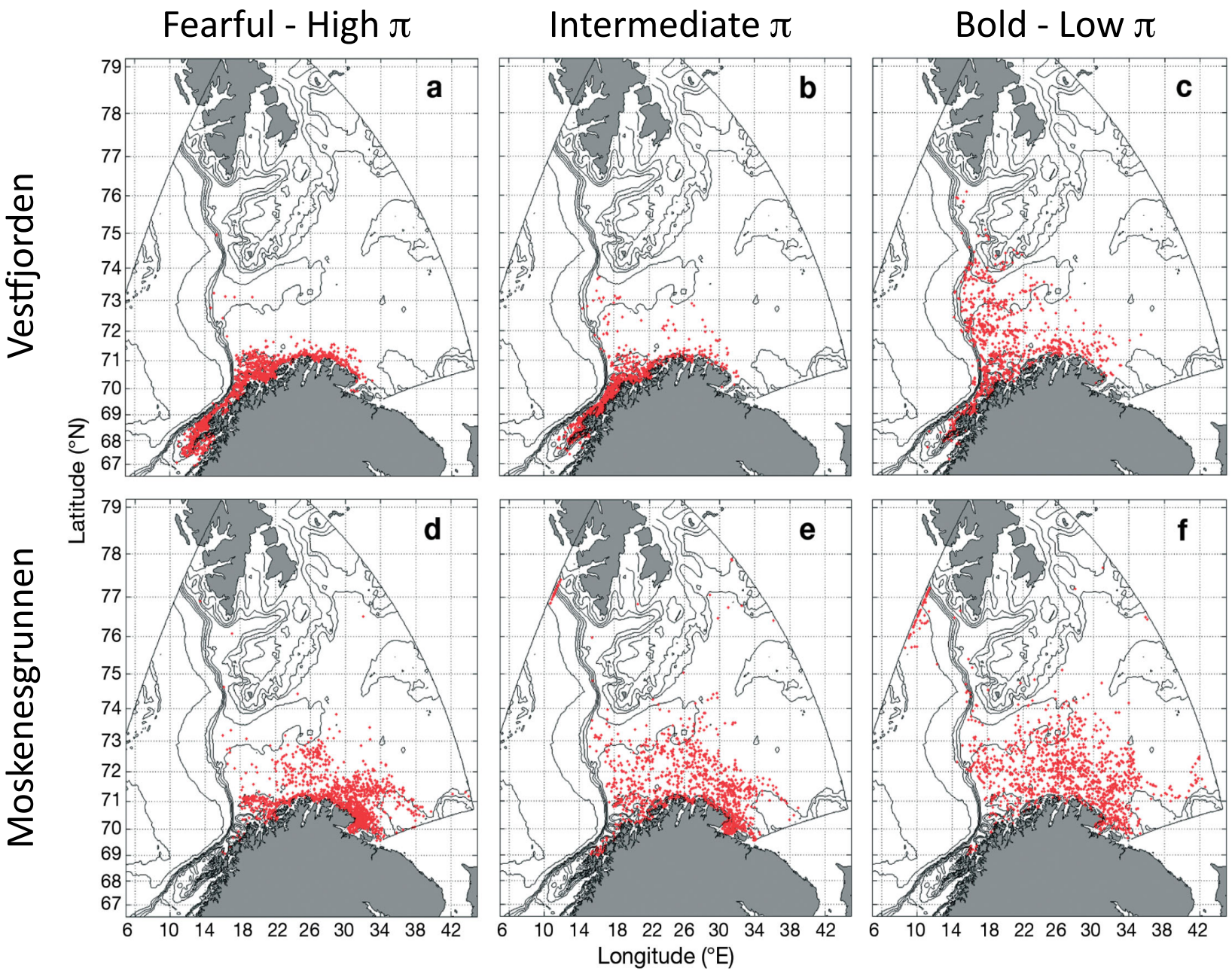




Vikebø F, Jørgensen C, Kristiansen T, Fiksen Ø. 2007. *Mar. Ecol. Progr. Ser.*, **347**: 207-219.



Vikebø F, Jørgensen C, Kristiansen T, Fiksen Ø. 2007. *Mar. Ecol. Progr. Ser.*, **347**: 207-219.



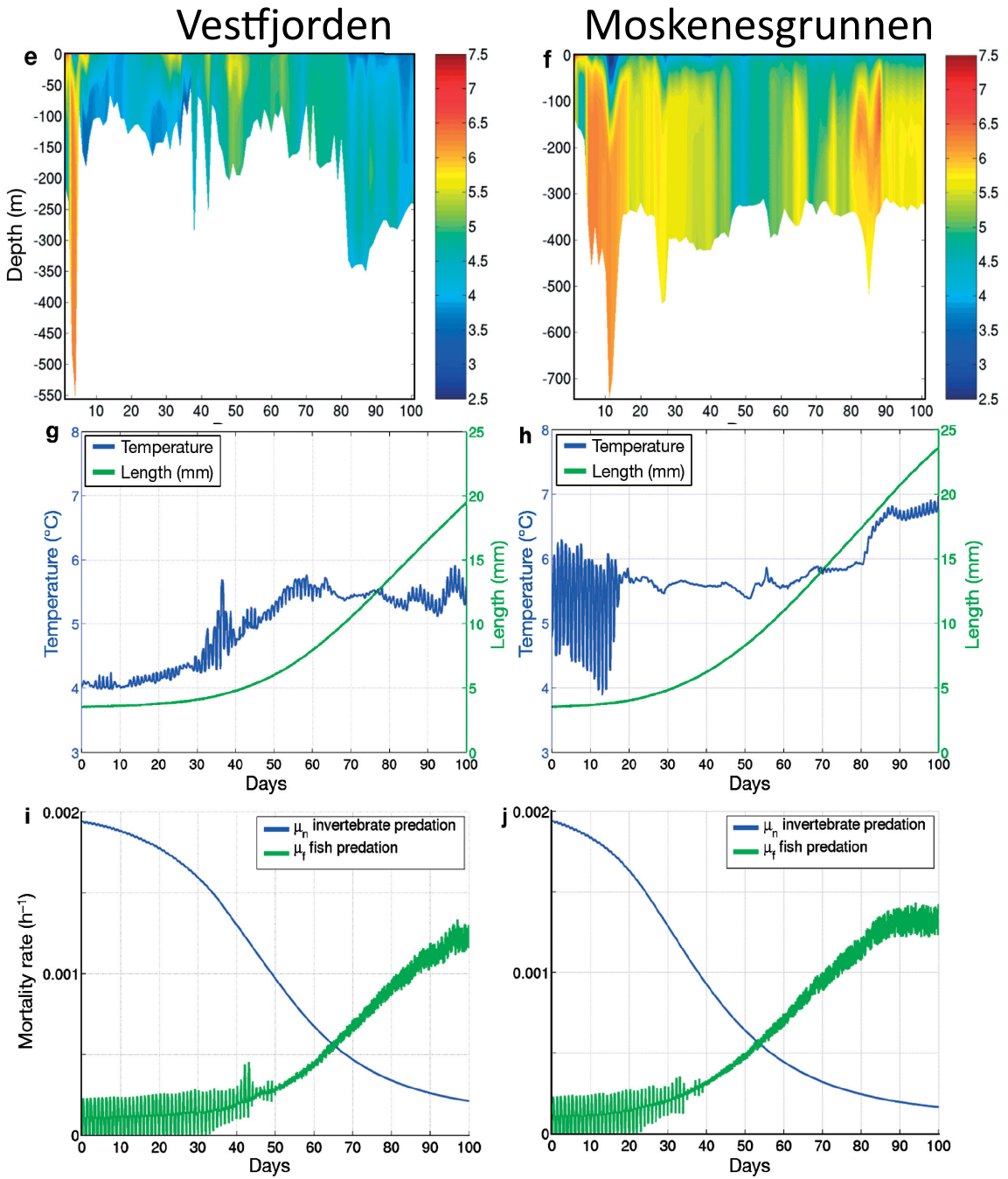
Vikebø F, Jørgensen C, Kristiansen T, Fiksen Ø. 2007. *Mar. Ecol. Progr. Ser.*, **347**: 207-219.

Information

Environment

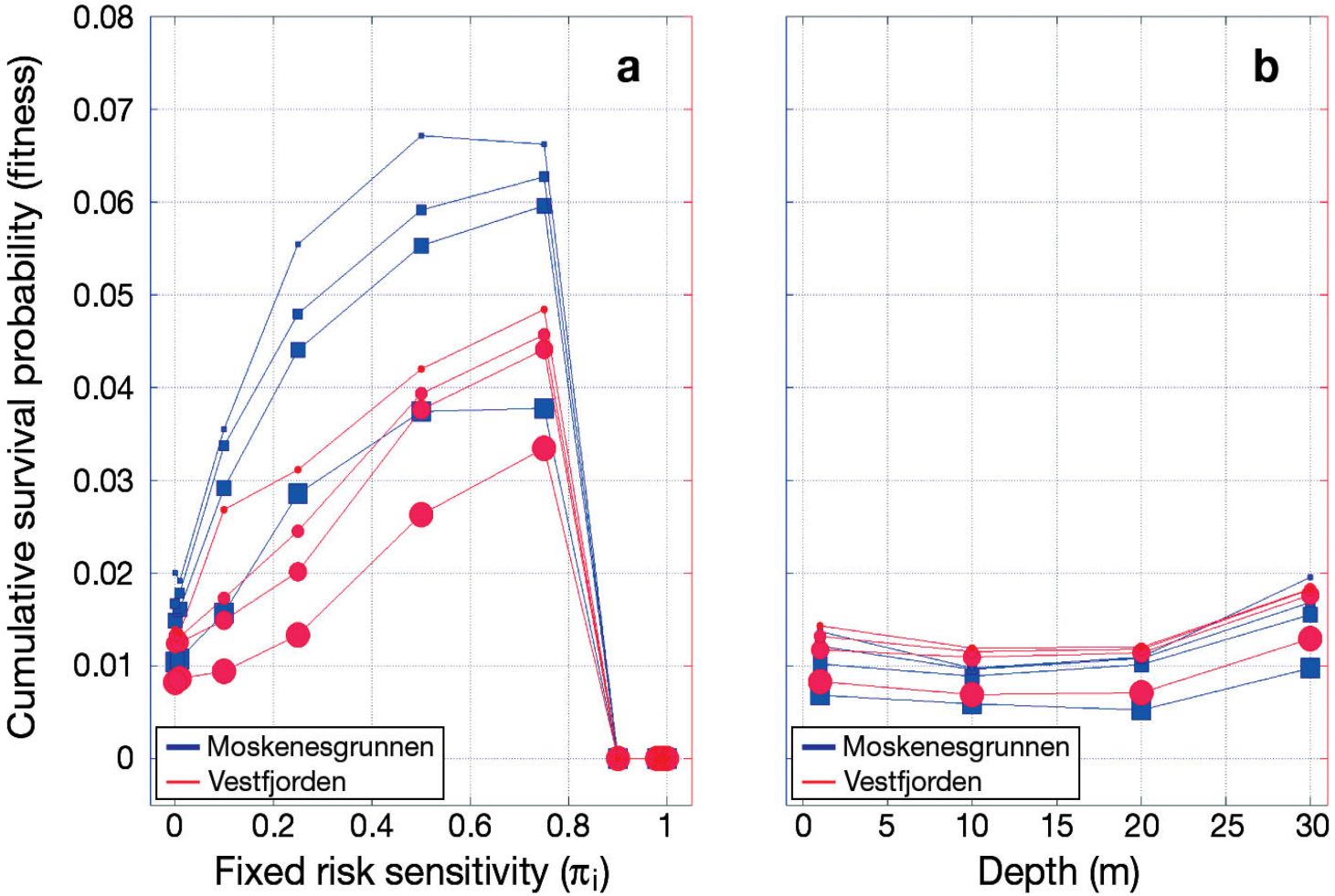
Growth

Survival



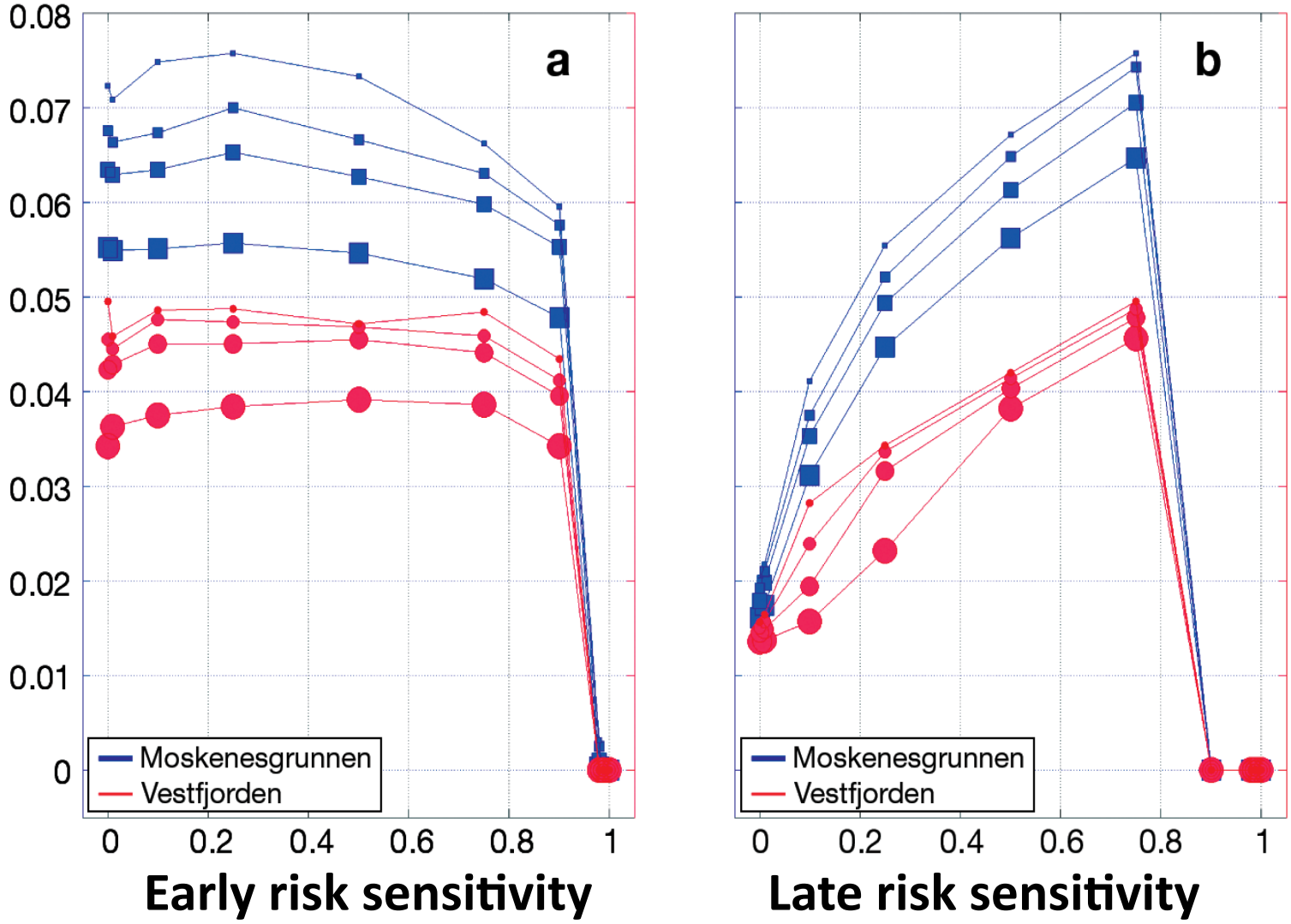
Vikebø F, Jørgensen C, Kristiansen T, Fiksen Ø. 2007. *Mar. Ecol. Progr. Ser.*, **347**: 207-219.

Behaviour significantly improves survival



Vikebø F, Jørgensen C, Kristiansen T, Fiksen Ø. 2007. *Mar. Ecol. Progr. Ser.*, **347**: 207-219.

Strategies should change with size



Vikebø F, Jørgensen C, Kristiansen T, Fiksen Ø. 2007. *Mar. Ecol. Progr. Ser.*, **347**: 207-219.

Study question level 2-6

- It is common to develop general circulation models predicting how flow fields will develop in future climate scenarios. How would you use such predictions to construct a model of possible adaptive responses in parents or their offspring?

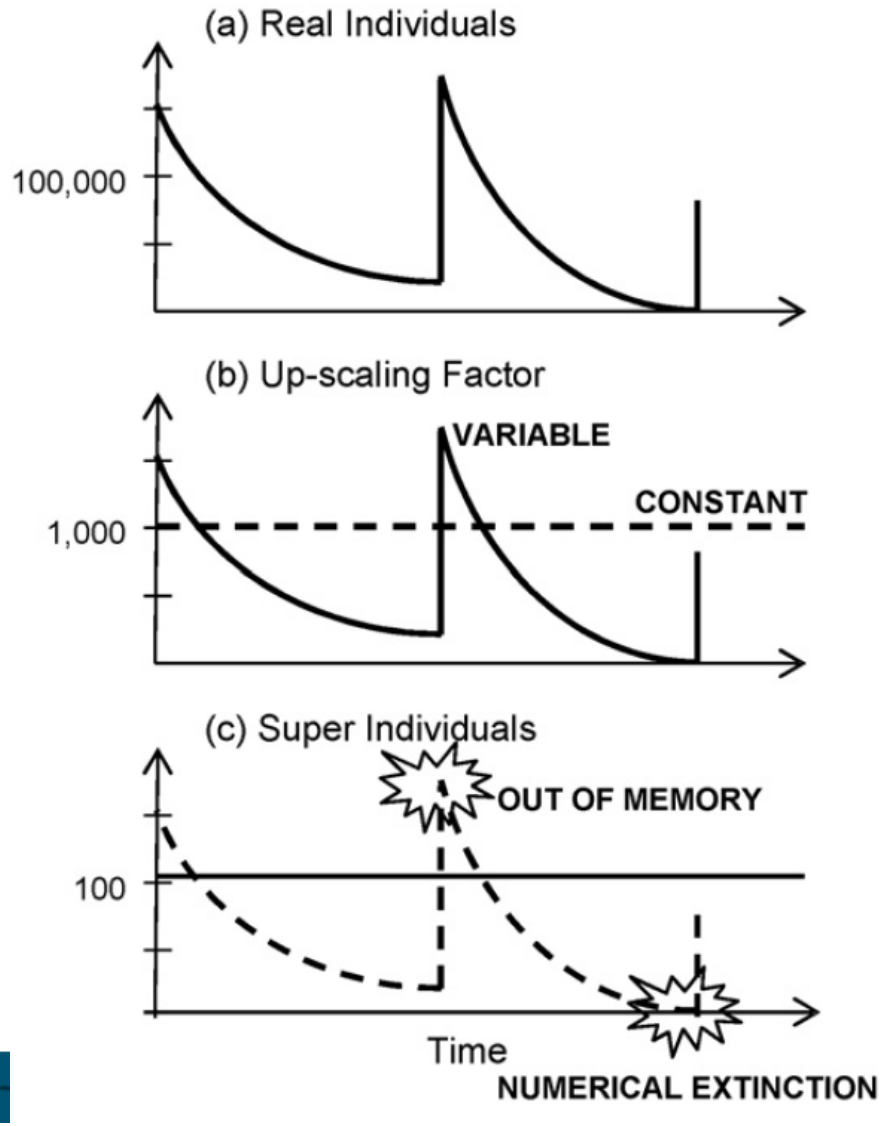
IBMs of microbes: Lagrangian Ensembles

Review

A bunch of tiny individuals—Individual-based modeling for microbes

Ferdi L. Hellweger, Vanni Bucci*

Civil and Environmental Engineering Department, 400 Snell Engineering Center, Northeastern University, Boston, MA 02115, USA



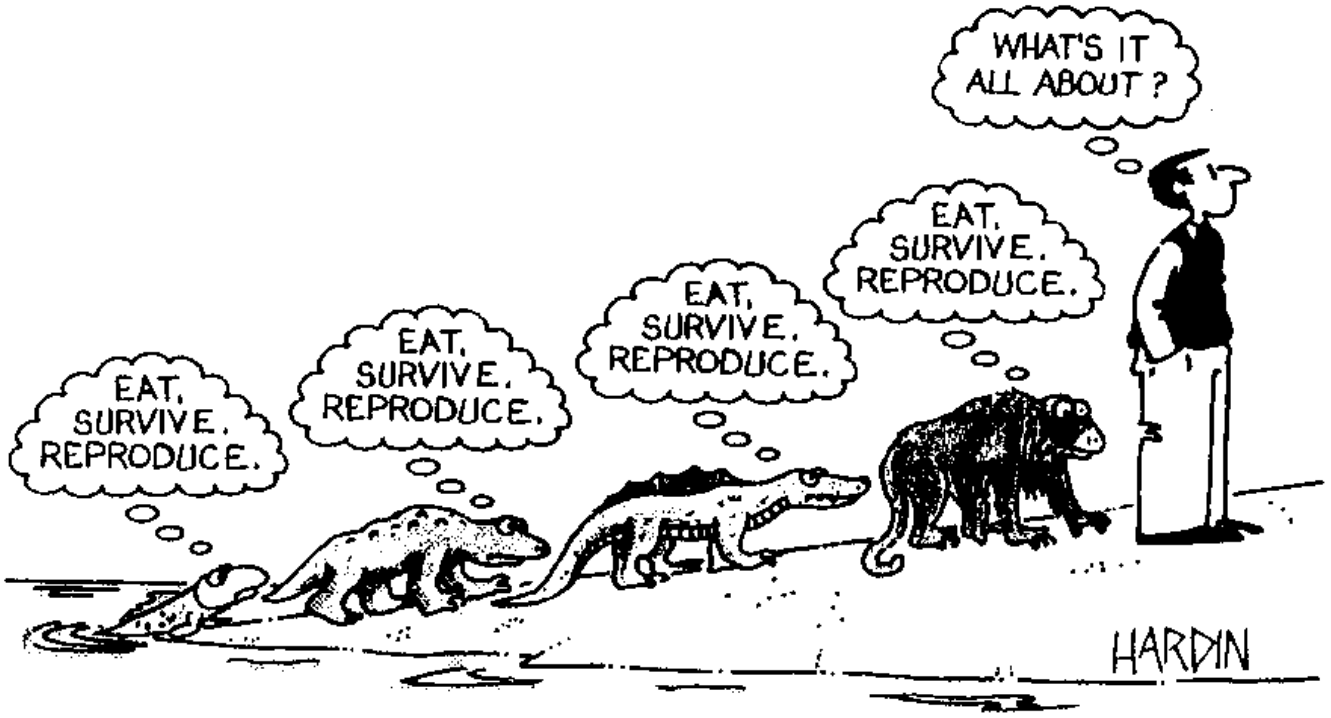
The presentation of IBMs - ODD

	Elements of the original ODD protocol (Grimm et al., 2006)	Elements of the updated ODD protocol
Overview	1. Purpose 2. State variables and scales 3. Process overview and scheduling	1. Purpose 2. Entities, state variables, and scales 3. Process overview and scheduling
Design concepts	4. Design concepts • Emergence • Adaptation • Fitness • Prediction • Sensing • Interaction • Stochasticity • Collectives • Observation	4. Design concepts • Basic principles • Emergence • Adaptation • Objectives • Learning • Prediction • Sensing • Interaction • Stochasticity • Collectives • Observation
Details	5. Initilization 6. Input 7. Submodels	5. Initialization 6. Input data 7. Submodels

Grimm & al 2006, 2010 (Ecological Modelling)

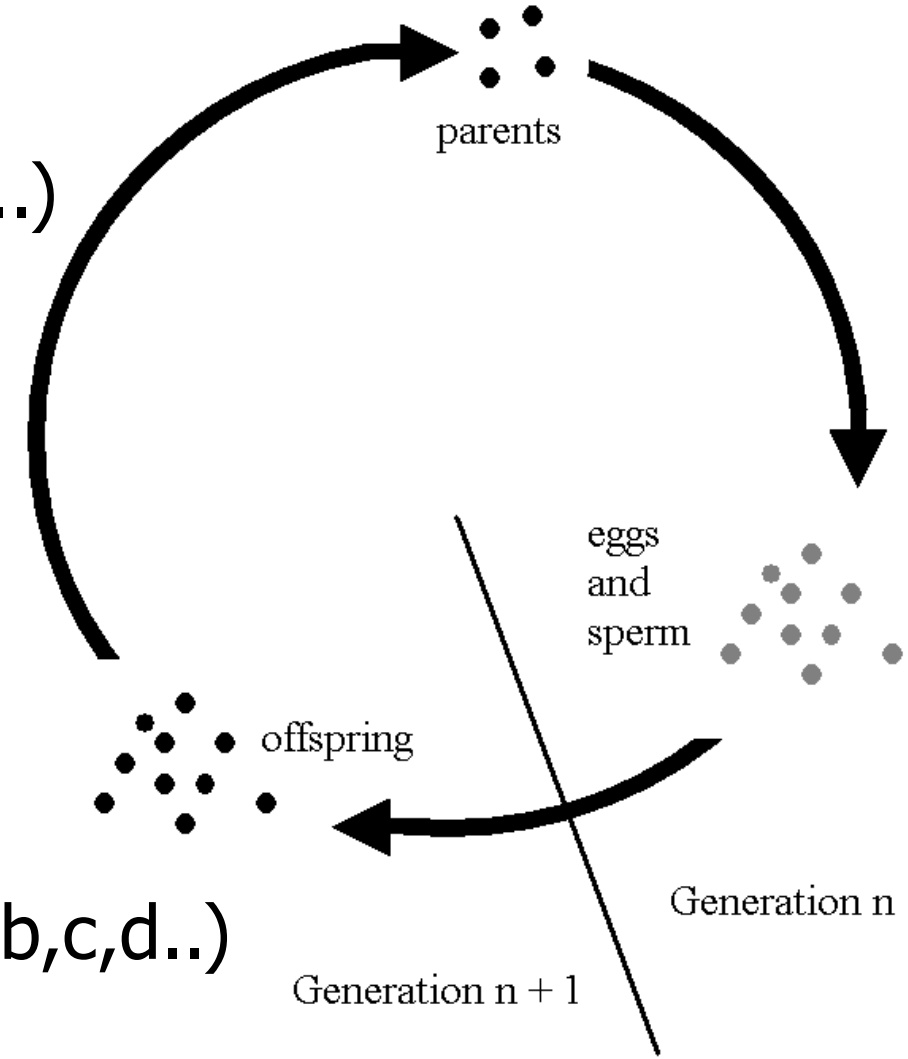
And next…

Evolutionary individual-based models


EAT, SURVIVE. REPRODUCE.
EAT, SURVIVE. REPRODUCE.
EAT, SURVIVE. REPRODUCE.
EAT, SURVIVE. REPRODUCE.
WHAT'S IT ALL ABOUT ?
HARDIN

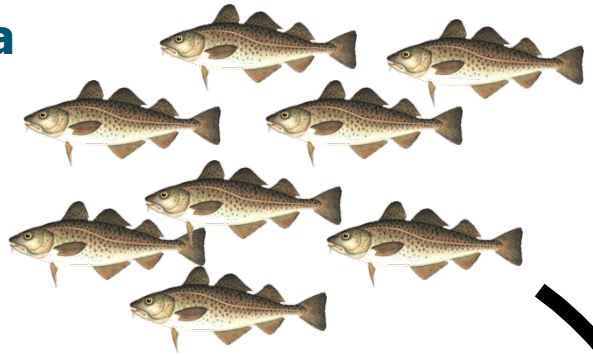
Modelling the full life cycle – with inheritance between generations (DeAngelis level 5)

$Attributes_i(L, s, e, x, y, z, ..)$



$Strategies_i(a,b,c,d..)$

A population is a collection of individuals and their actions



Evolution emerges

Predators,
prey,
competitors,
mates

Environment

Light,
temperature,
turbulence,
turbidity,
salinity,
pH…

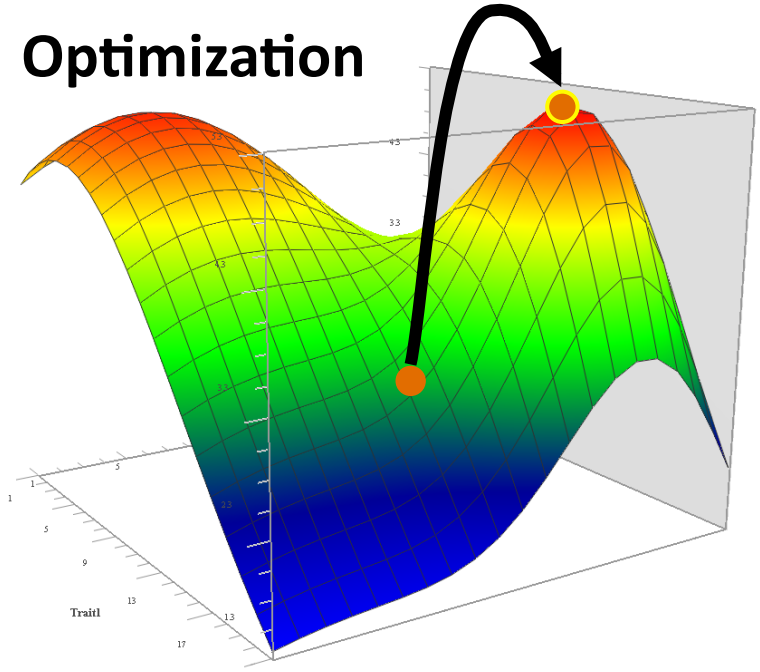
Trade-offs emerge

Individual state

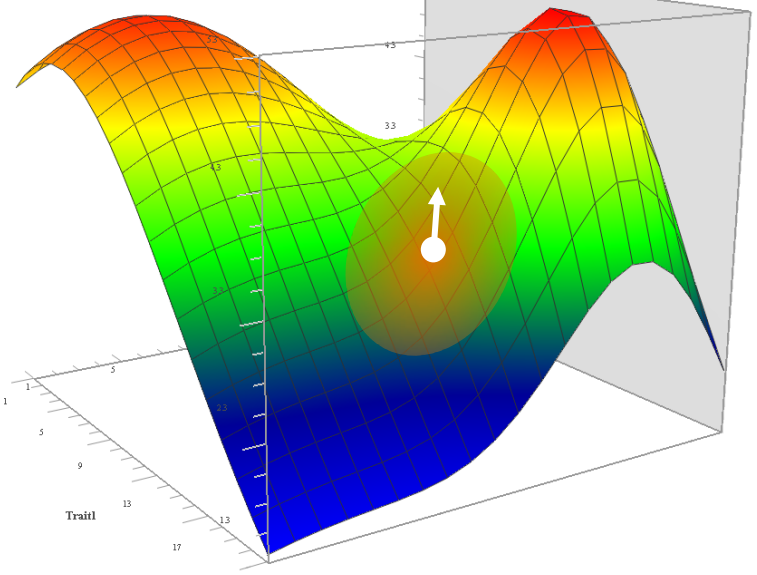
Age,
sex,
size,
energy reserves,
position…

Patterns emerge

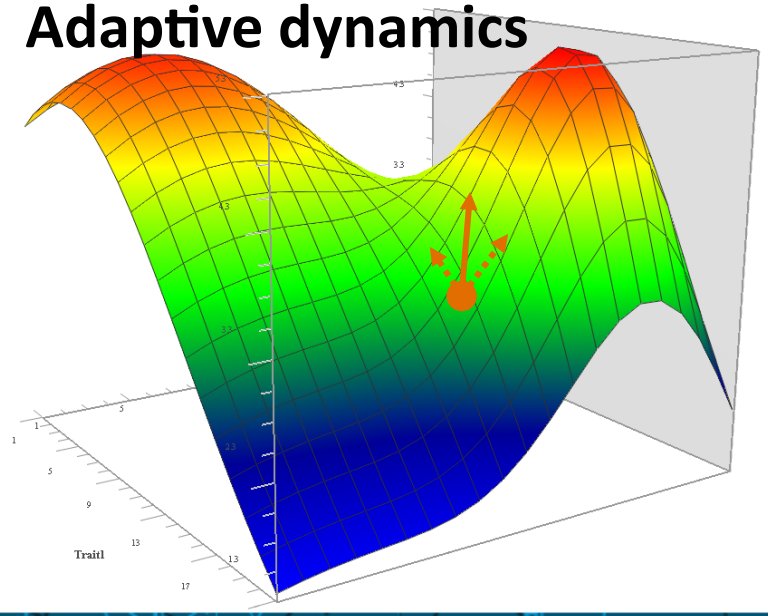
Optimization



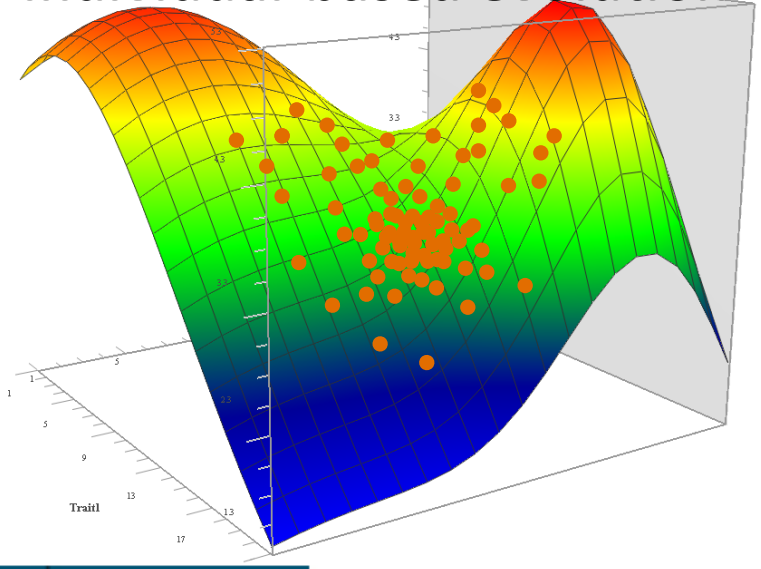
Quantative traits



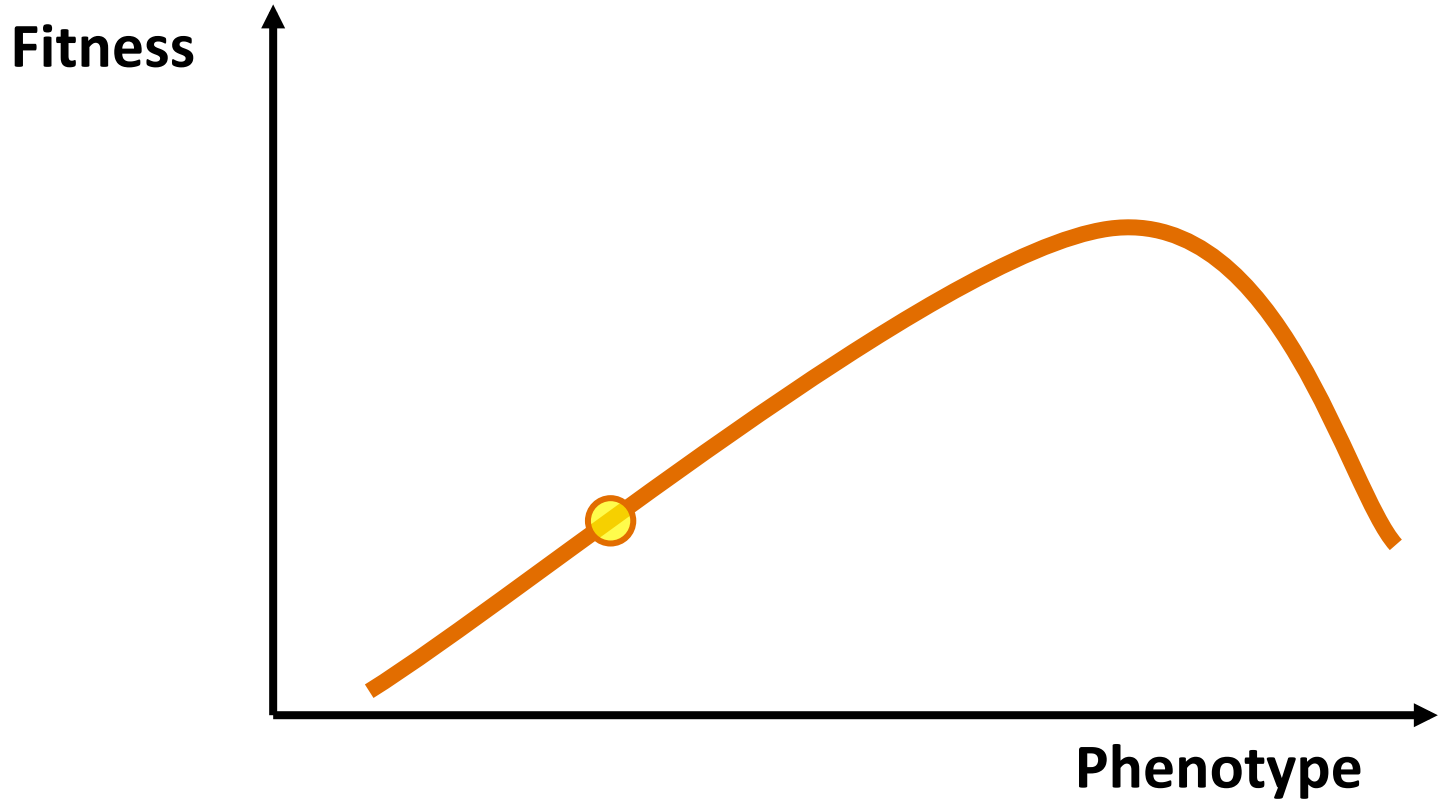
Adaptive dynamics



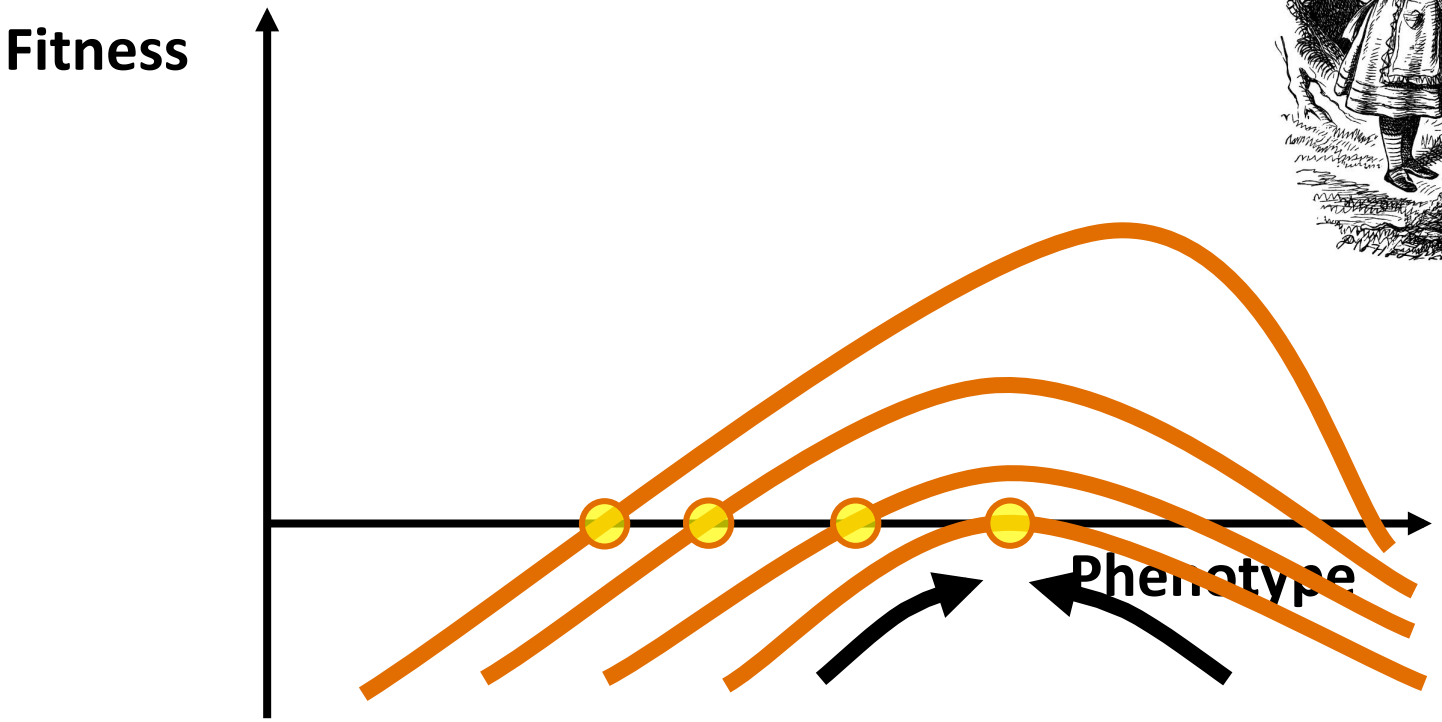
Individual-based evolution



Fitness in a population

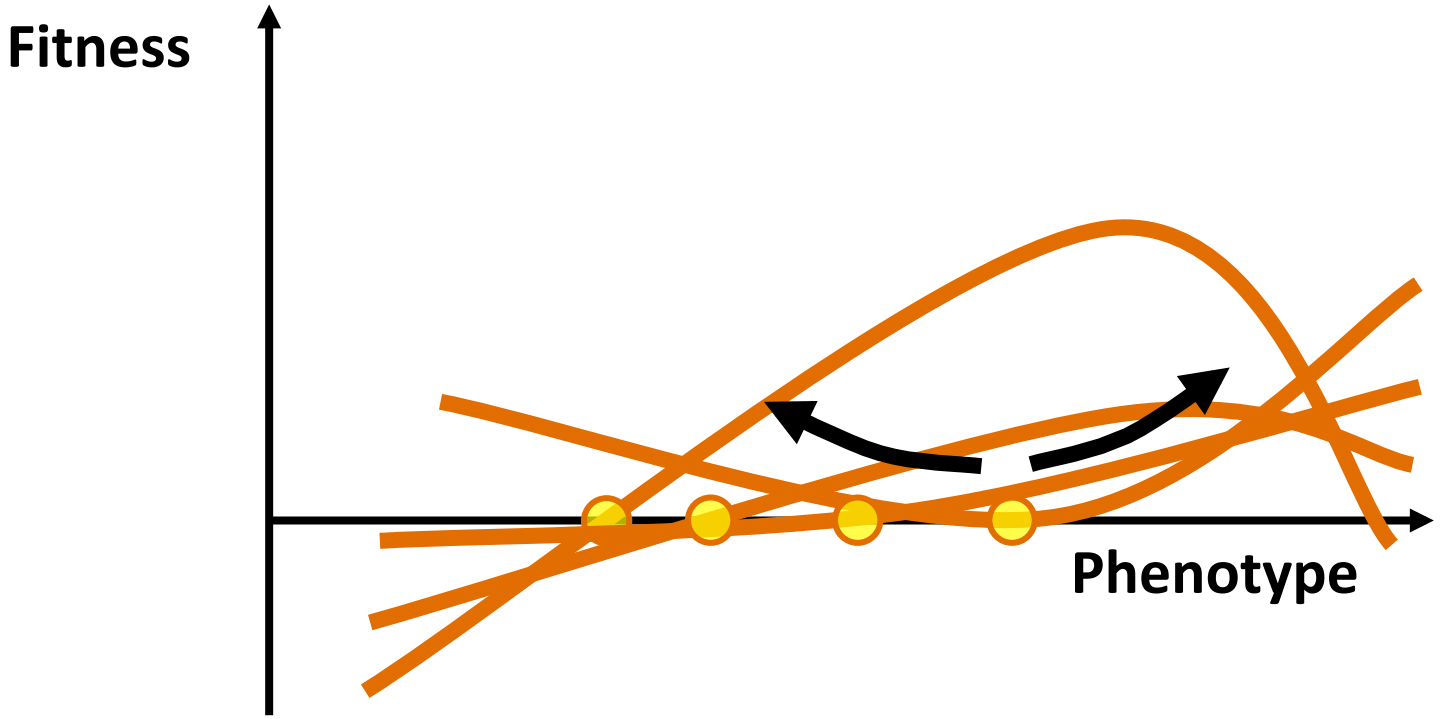


Fitness in a population



"It takes all the running you can do, to keep in the same place"
The Red Queen – Alice in Wonderland

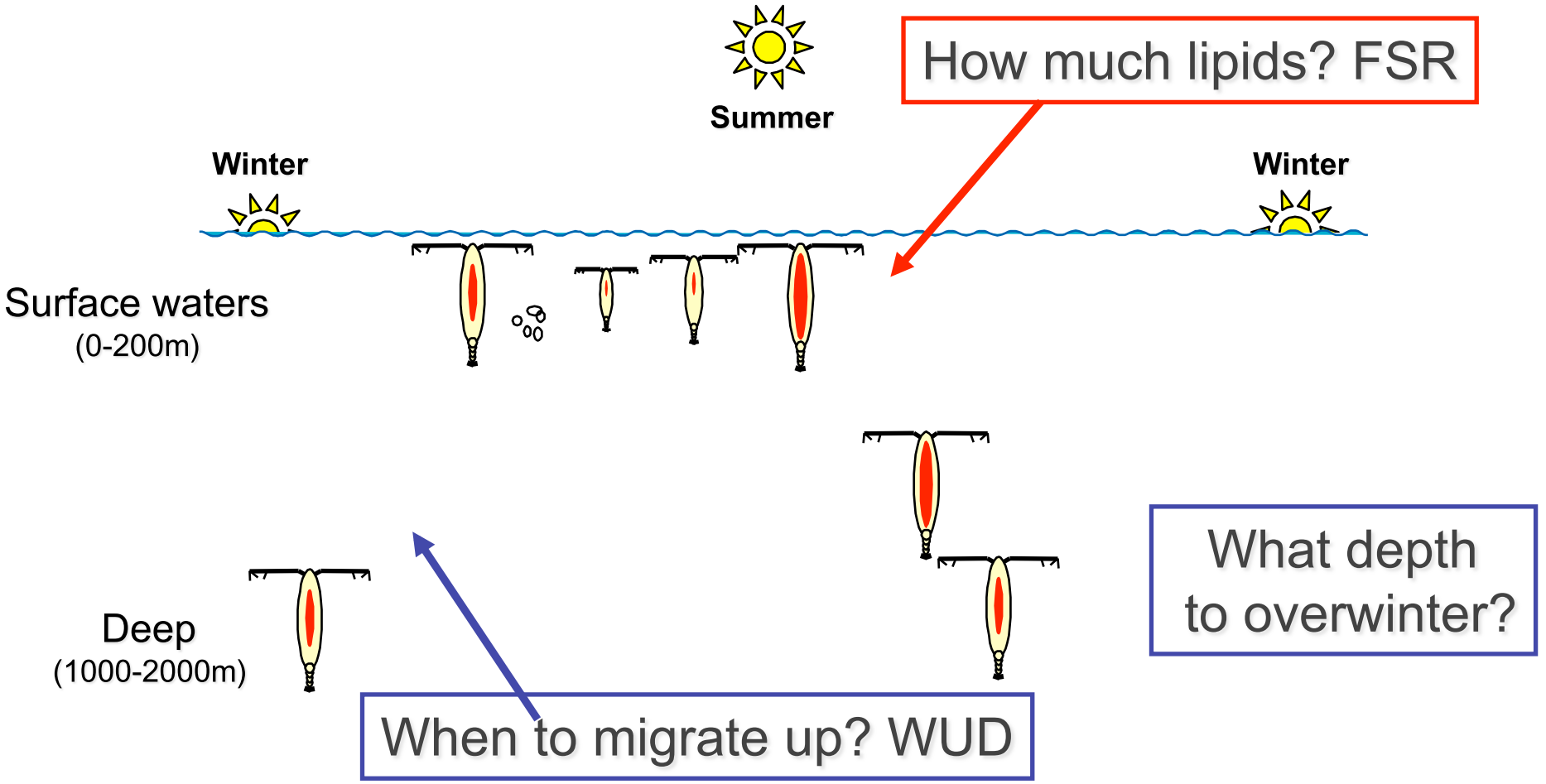
Evolutionary branching



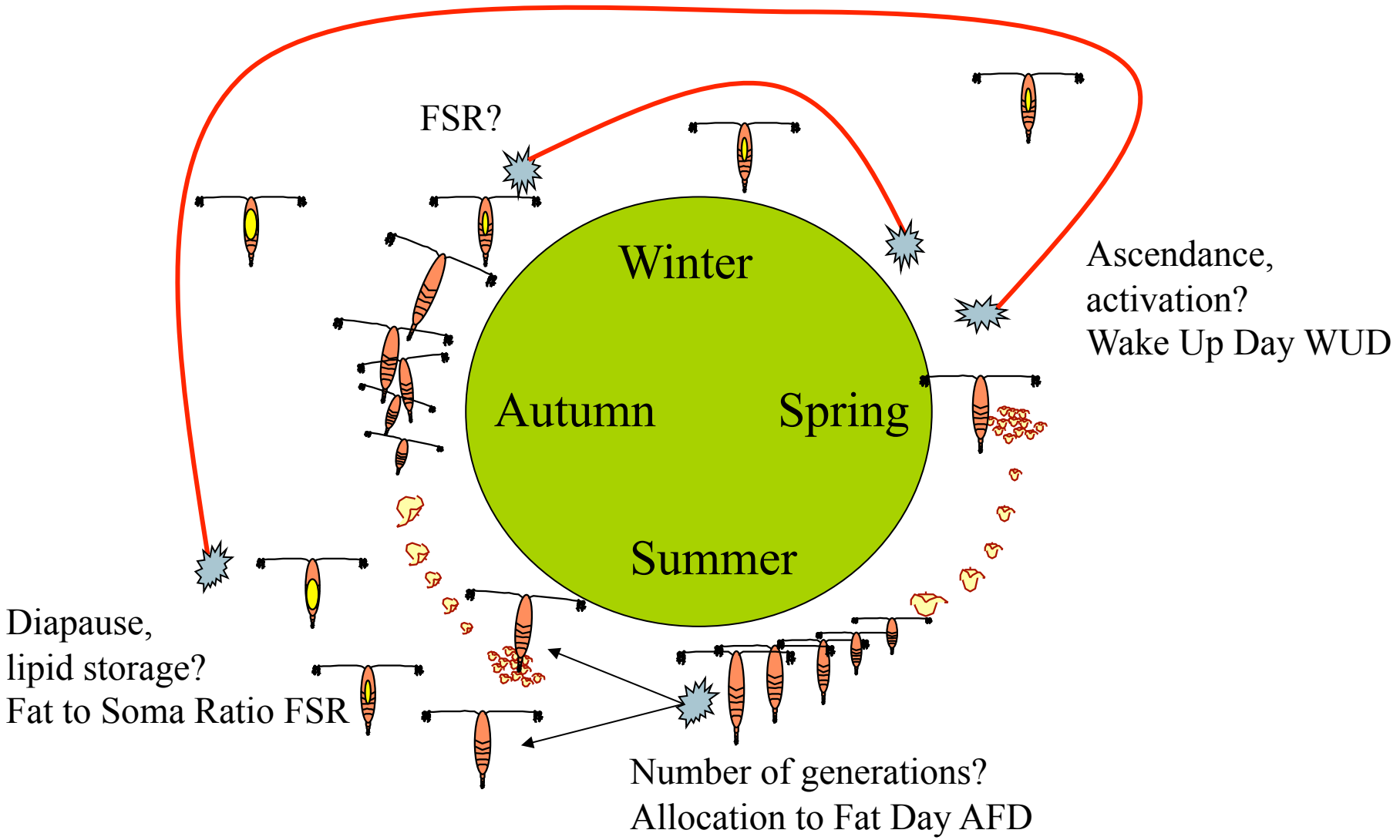
Design questions for evolutionary IBMs

- Individual **interactions**
  - Individual-to-individual or mediated via e.g. mean density or mean environment?
- Complexity of the **environment**
- Complete **life-cycle** or only part
  - Fitness emerging from reproducing individuals or replaced by proxy?
- Choose **trade-offs** with care
- 'Evolutionary' **aim**
  - Frequency-dependent ESS or trajectories and rates?
- Evolving **traits**
  - Neural networks or quantitative traits?

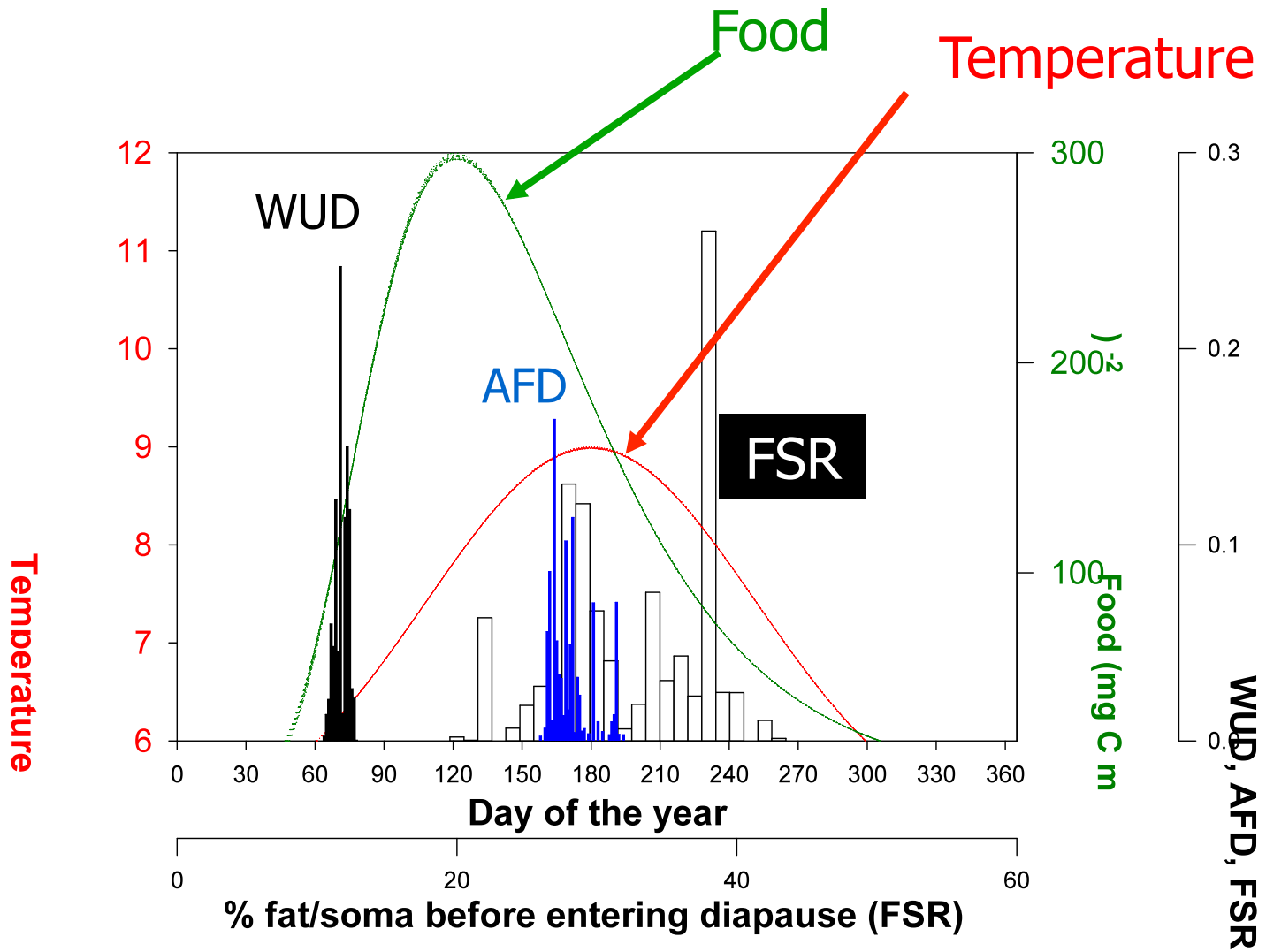
Annual routines of seasonally migrating zooplankton



Non-spatial IBM with simple inheritance

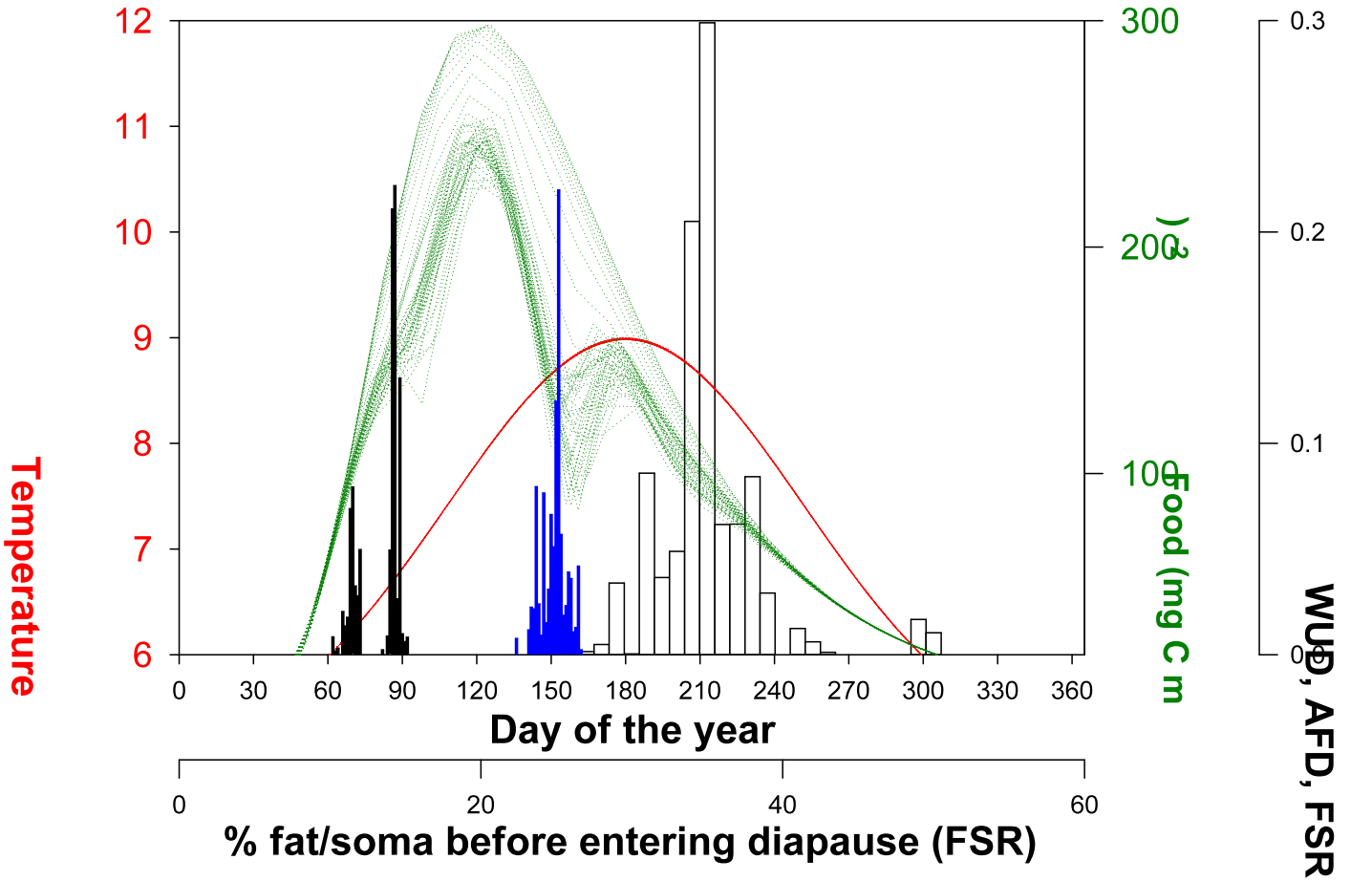


No density dependence



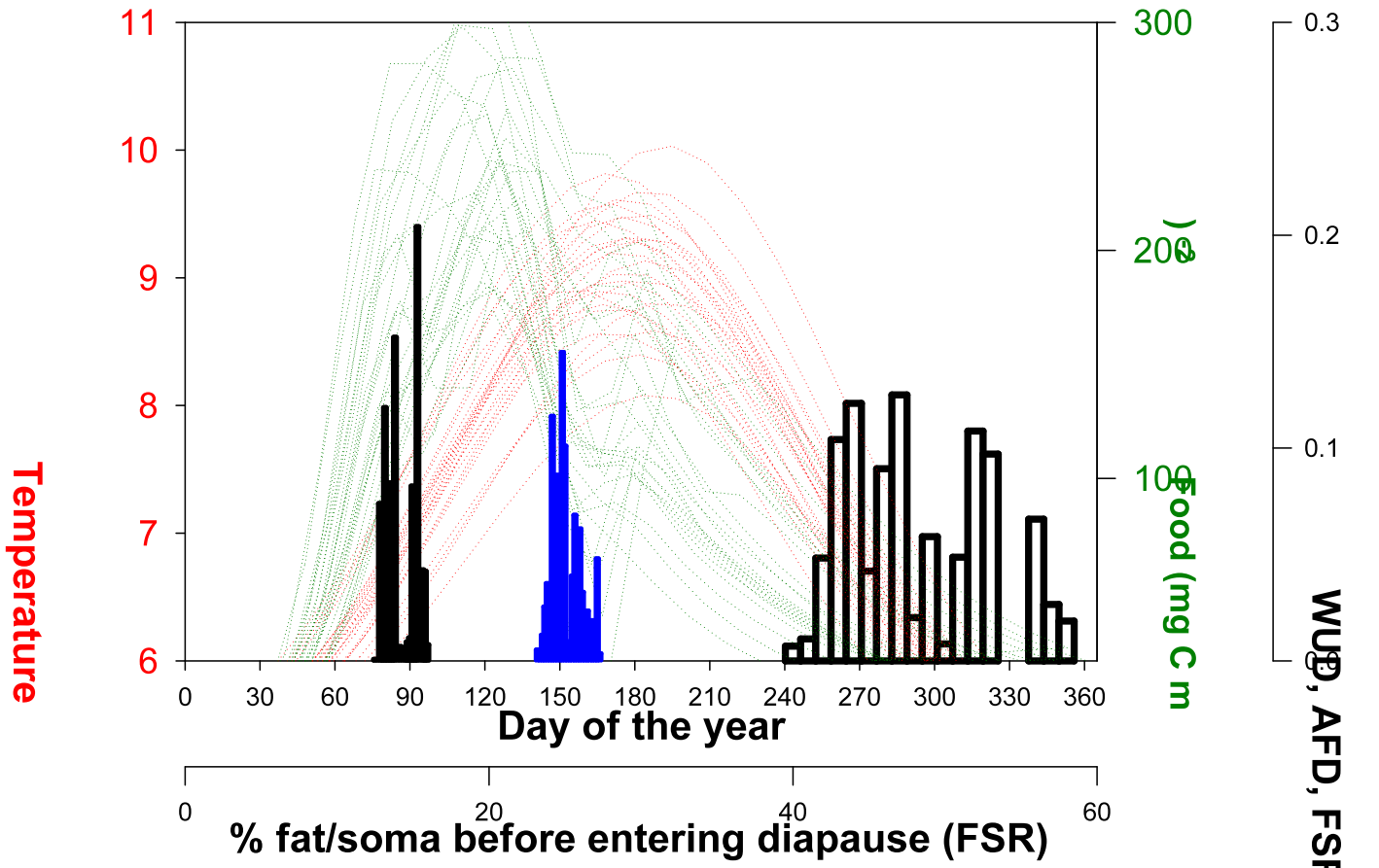
Fiksen Ø 2000. The adaptive timing of diapause – a search for evolutionarily robust strategies in C. finmarchicus. ICES Journal of Marine Science 57:1825-1833.

Stable environment with density dependence



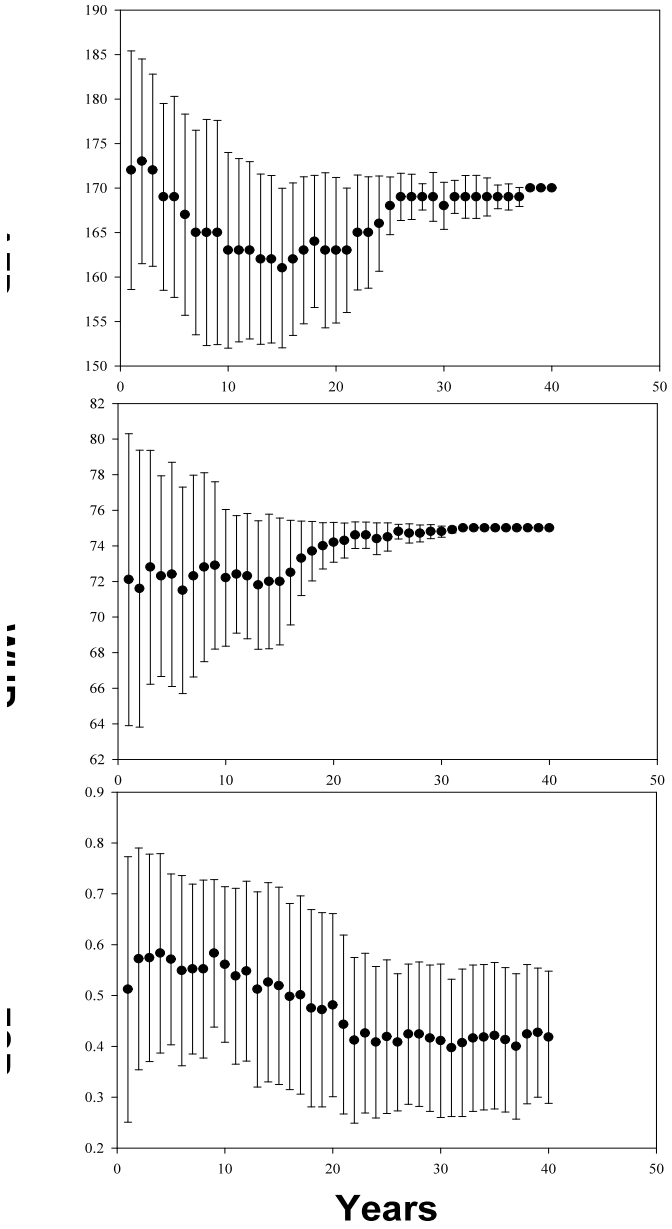
Fiksen 2000

Variable environment + density dependence



Fiksen 2000

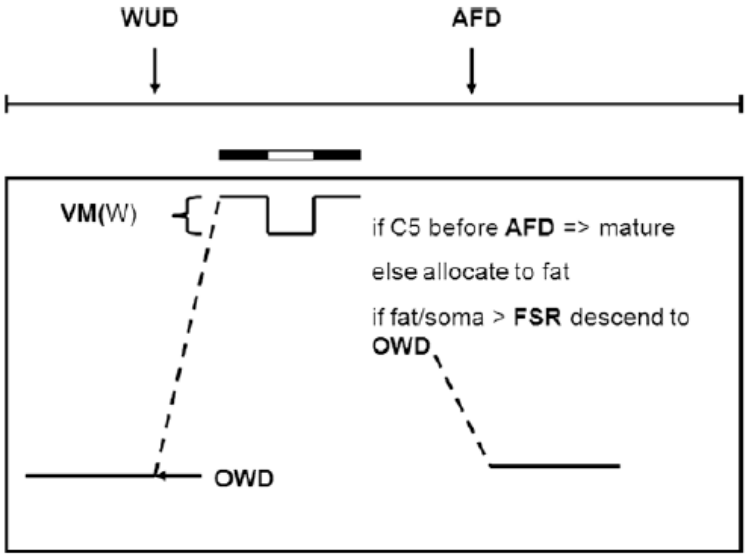
Evolution



Fiksen 2000

‘Gene’ combinations in adaptive population

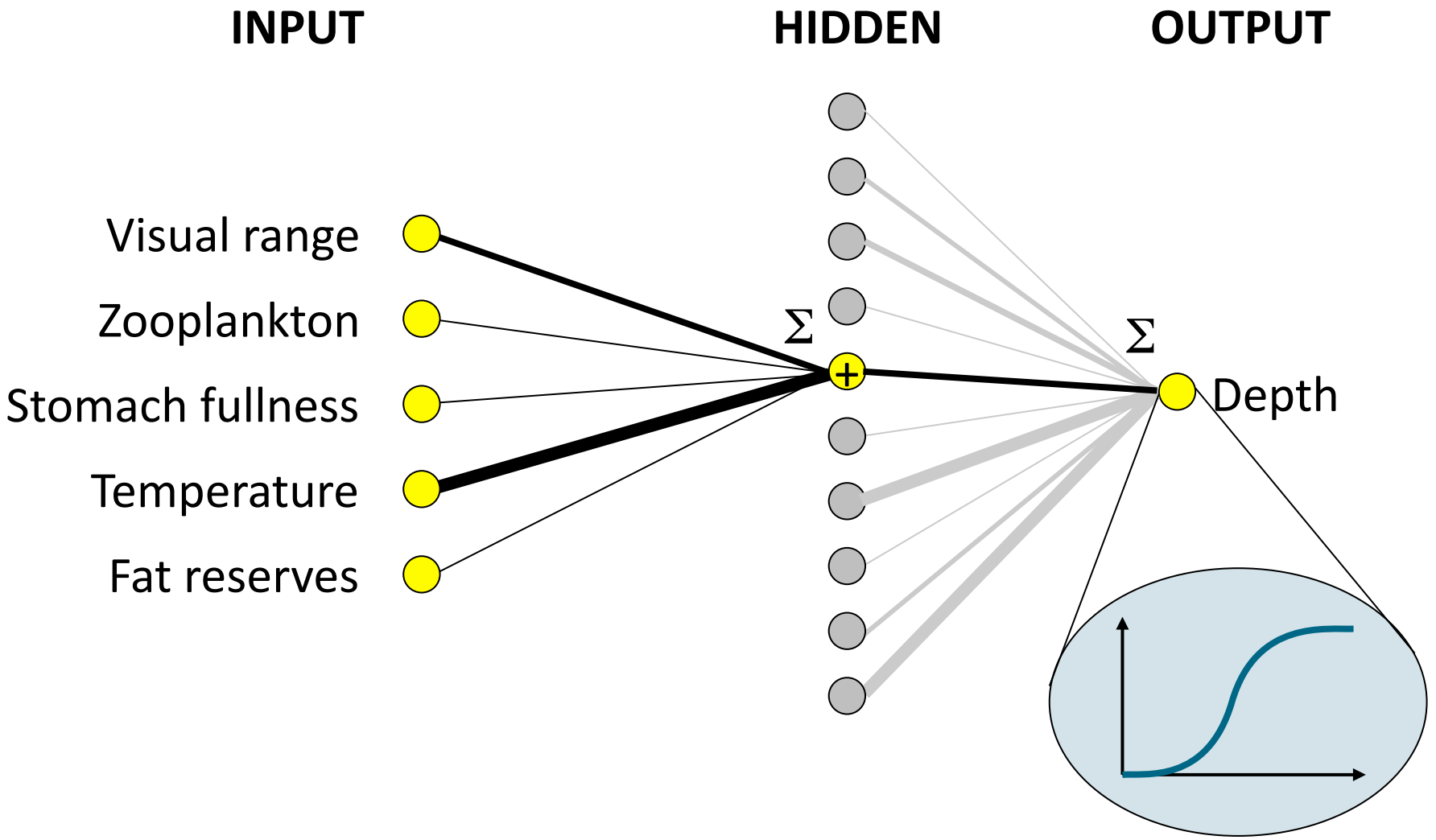
IBM with copepod life history in 3D



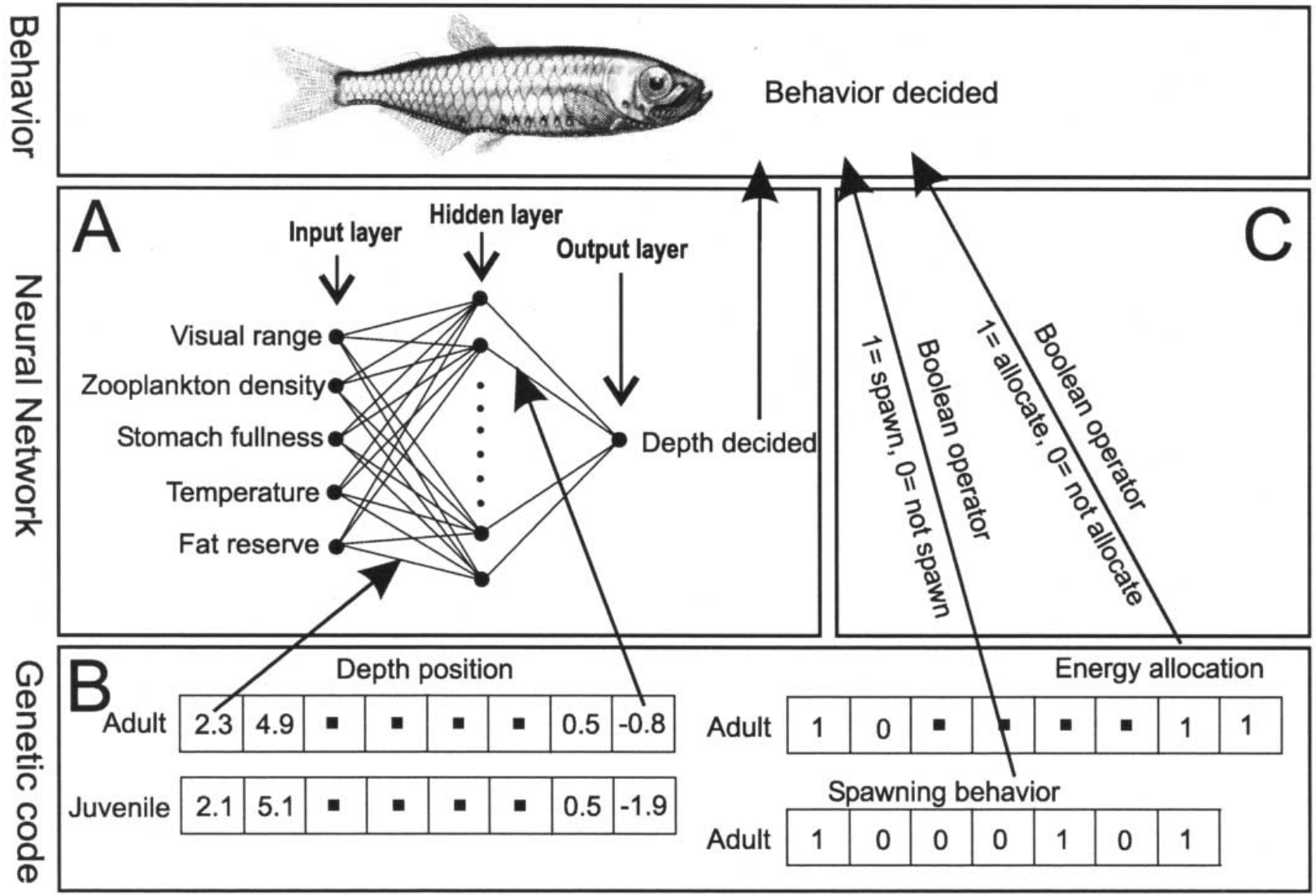
Samuelsen, A., Huse, G. & Hansen, C. 2009 Shelf recruitment of Calanus finmarchicus off the west coast of Norway: role of physical processes and timing of diapause termination. Mar Ecol Prog Ser 386, 163-180.

Huse G and Ø. Fiksen. 2010. Modelling encounter rates and distribution of mobile predators and prey. Progress in Oceanography. 84: 93-104.

Neural network governing behaviour



The Individual-based Neural network Genetic algorithm (ING)



Strand E, Huse G, Giske J. 2002. *American Naturalist* **159**:624-644.

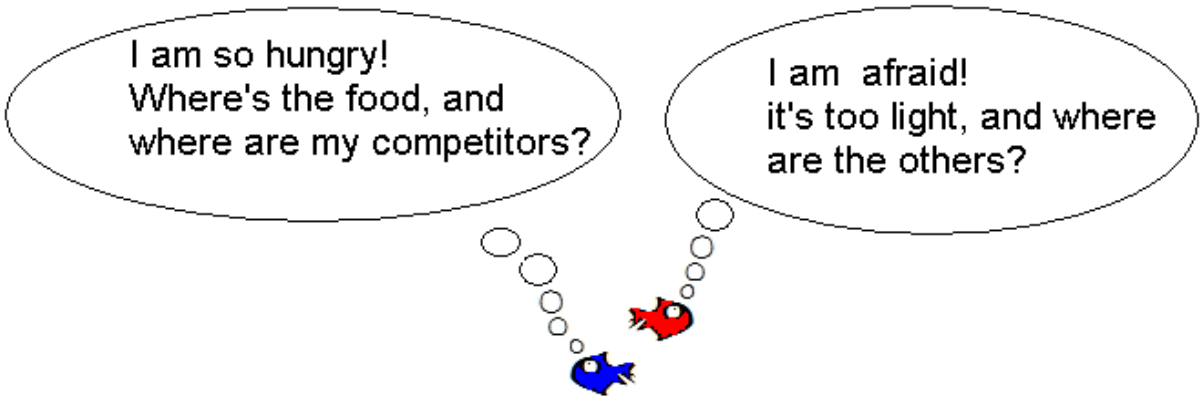
Hedonic models – individuals driven by feelings and affects (adaptive proximate responses)

Evolutionary Ecology Research, 2003, 5: 835–865

Explicit trade-off rules in proximate adaptive agents

Jarl Giske,[1]* Marc Mangel,[3] Per Jakobsen,[2] Geir Huse,[1]‡
Chris Wilcox[4]§ and Espen Strand[1]

Aristippus

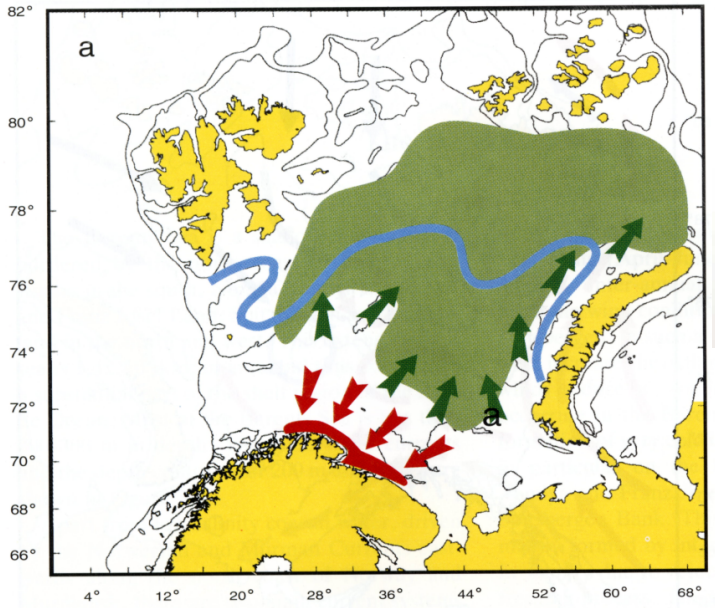


Climatic Change (2008) 87:177–197
DOI 10.1007/s10584-007-9347-z

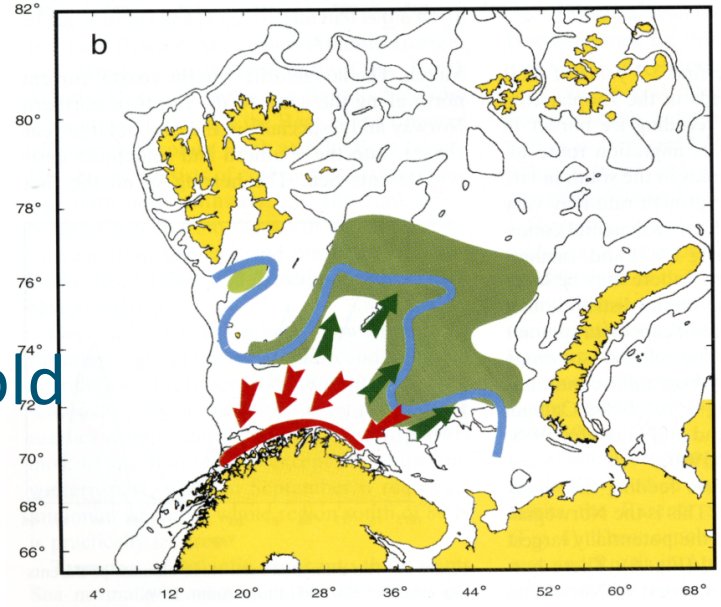
Capelin migrations and climate change – a modelling analysis

Geir Huse · Ingrid Ellingsen

Northeast distribution in warm years

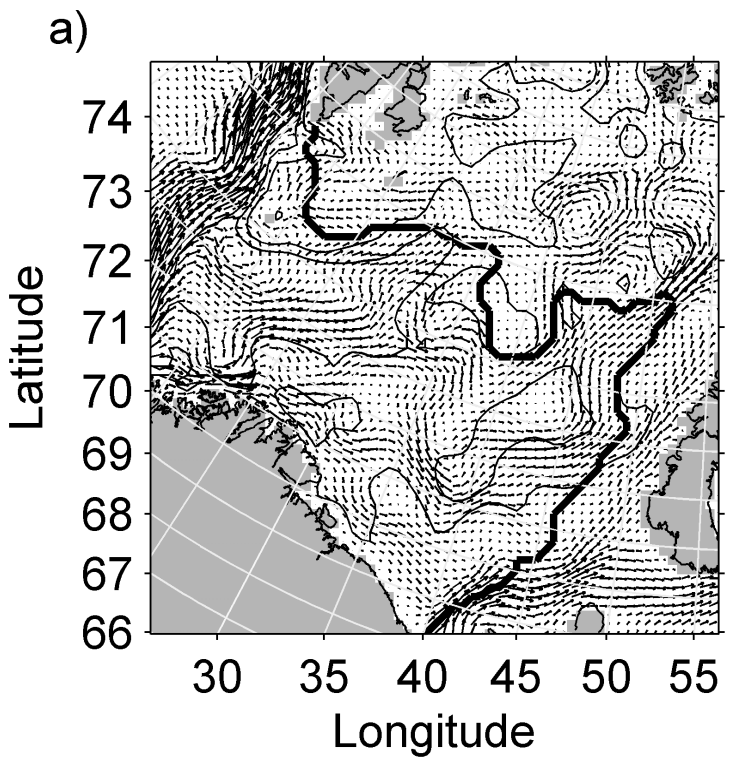


Southwest distribution in cold years

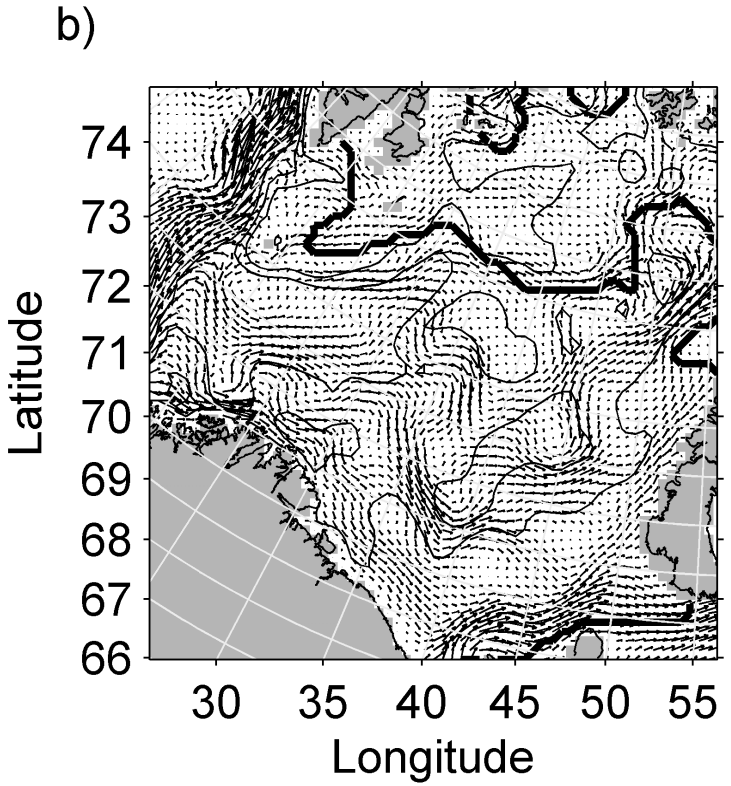


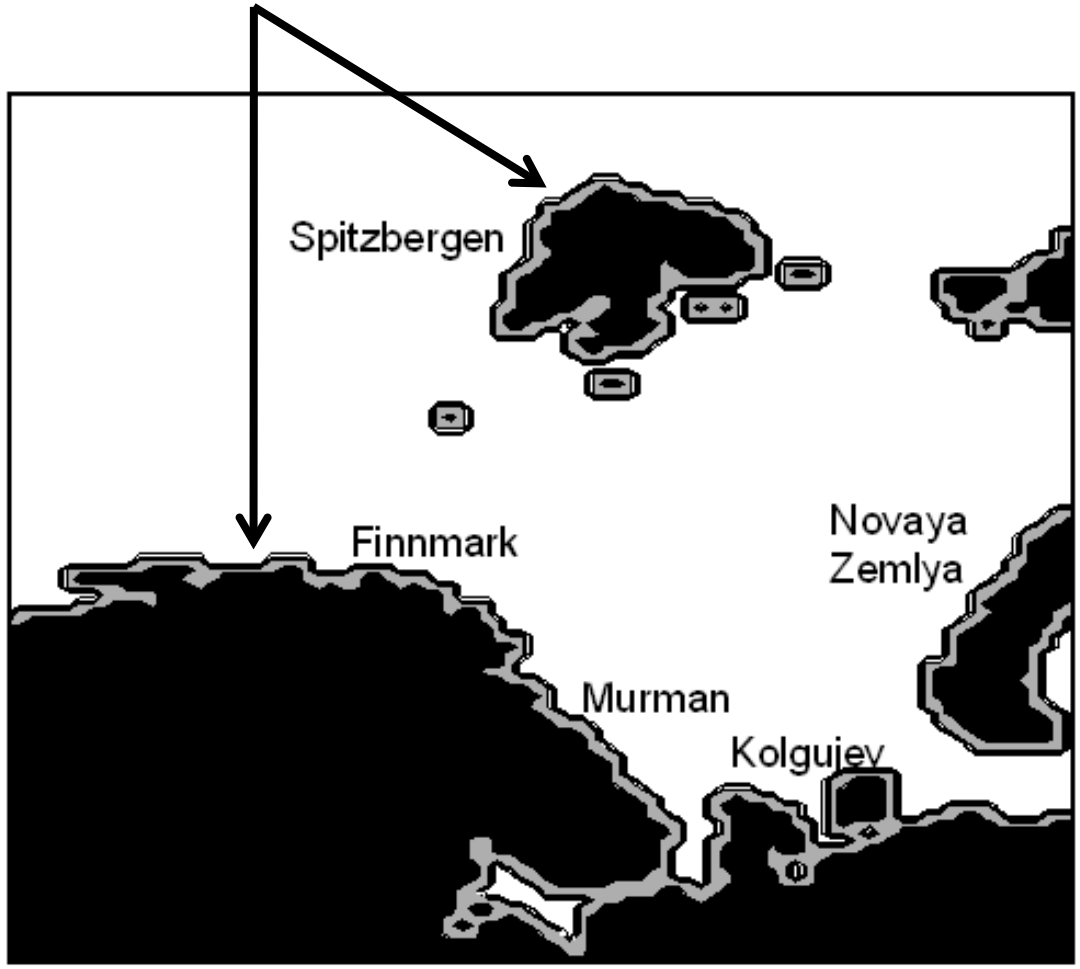
Mean current fields at 50m and polar front

Year 2000



Year 2047



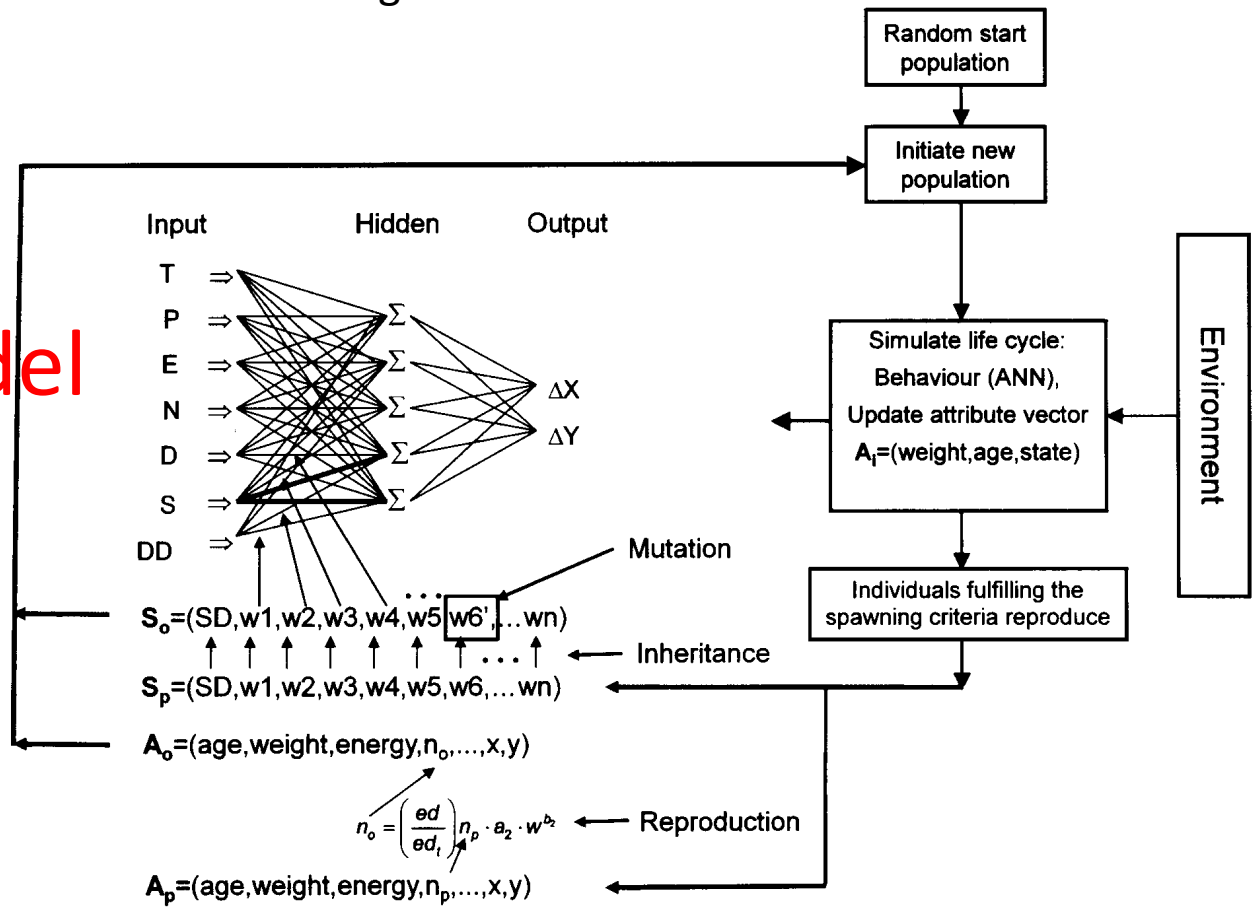


Huse & Ellingsen 2008

Movement and reproduction

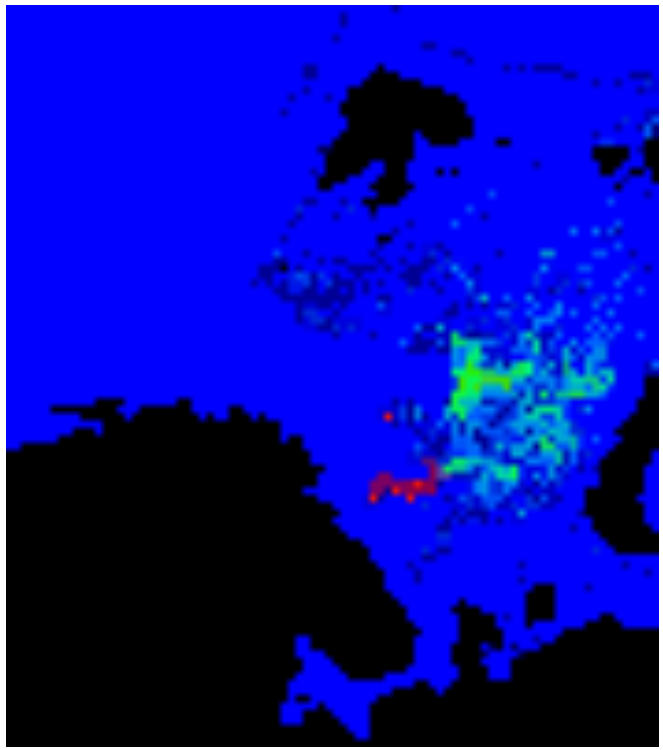
- **Eggs:** Benthic
- **Larvae:** Drift
- **Adults:** Active movement using the ANN and drift

ING model

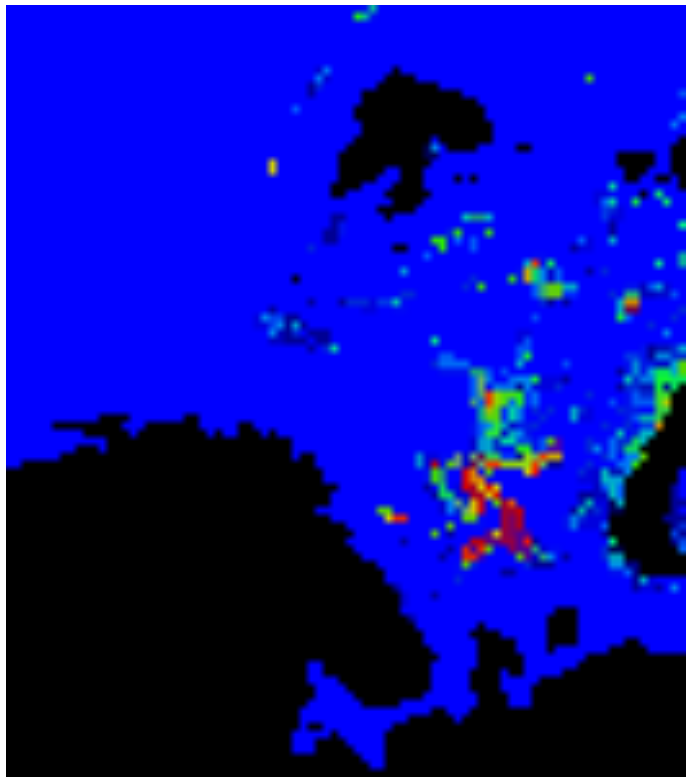


Huse & Ellingsen 2008

Present climate

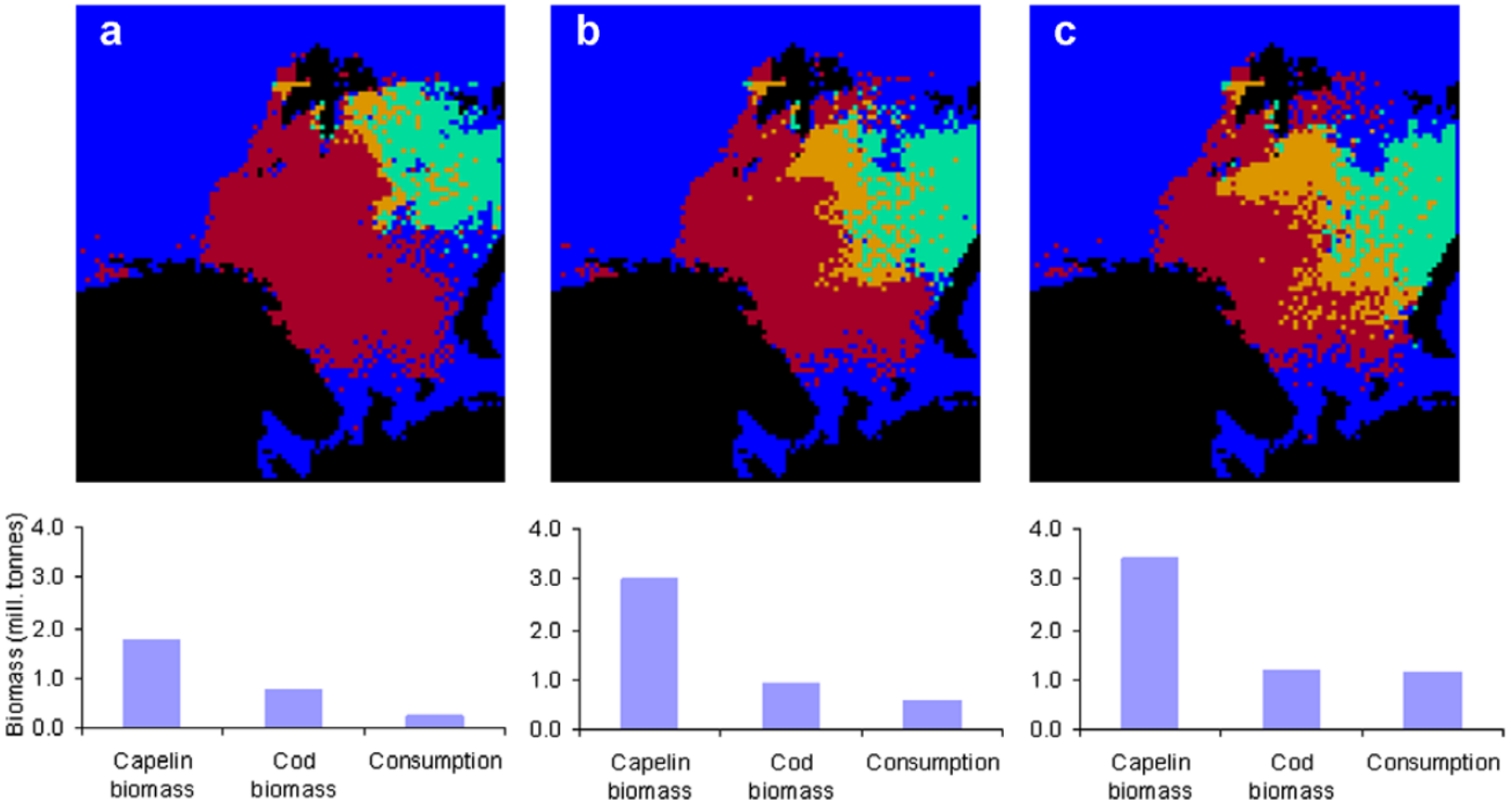


Future warming



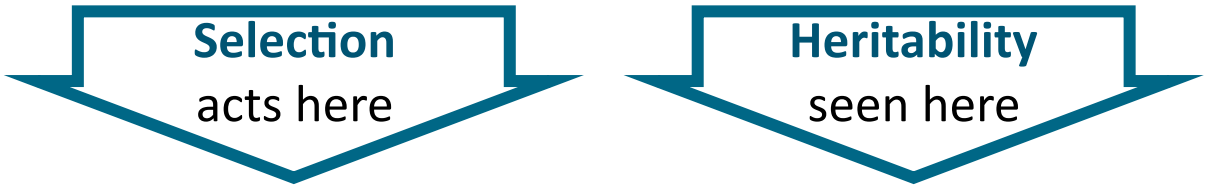
Huse & Ellingsen 2008

Cod and capelin in the Barents Sea



Huse, G., Johansen, G.O., Gjøsæter, H., Bogstad, B., 2004. Studying spatial and trophic interactions between capelin and cod using individual-based modelling. ICES Journal of Marine Science 61, 1201–1213
Huse G & Ø Fiksen 2010. Modelling encounter rates and distribution of mobile predators and prey. Progress in Oceanography. 84: 93-104

Eco-genetic models



Phenotype

Environmental variance

Non-additive genetic effects

Offspring phenotype

Environmental variance

Non-additive genetic effects

Genotype **Mid-parental value** **Other parent**

+Mutation, segregation, recombination

Enberg & al 2009, 2010.
Dunlop & al 2009

Quantitave genetics and noise processes

- The **phenotype** results from genes and environment

$$P = G_A + E + G_A \times E + \varepsilon$$

- **Heritability** depends on additive genetic variance

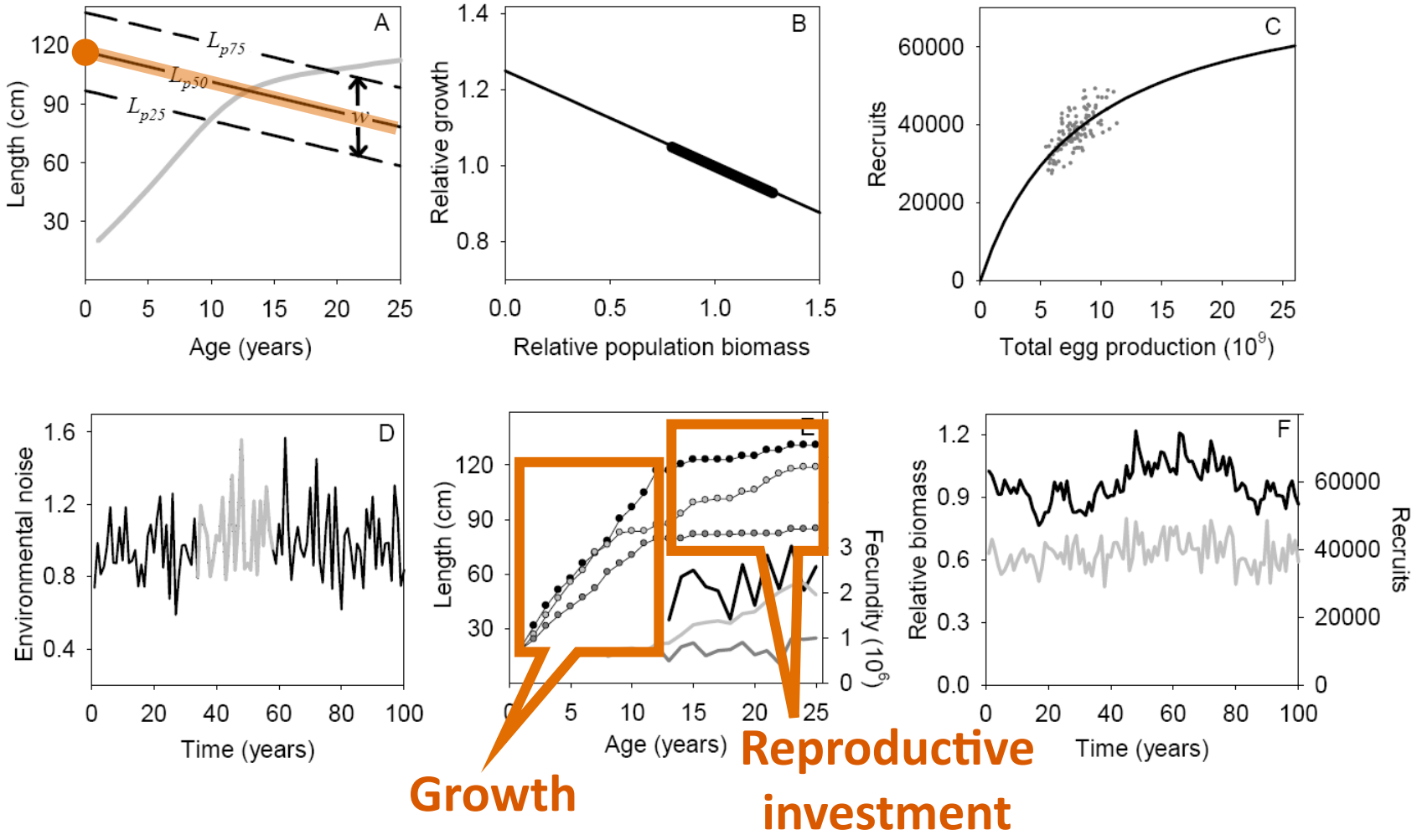
$$h^2 = \frac{var(G_A)}{var(P)}$$

- **Evolution** depends on h^2 and selection differential

$$R = h^2 S$$

Enberg & al 2009, 2010.

A model with quantitative genetic traits

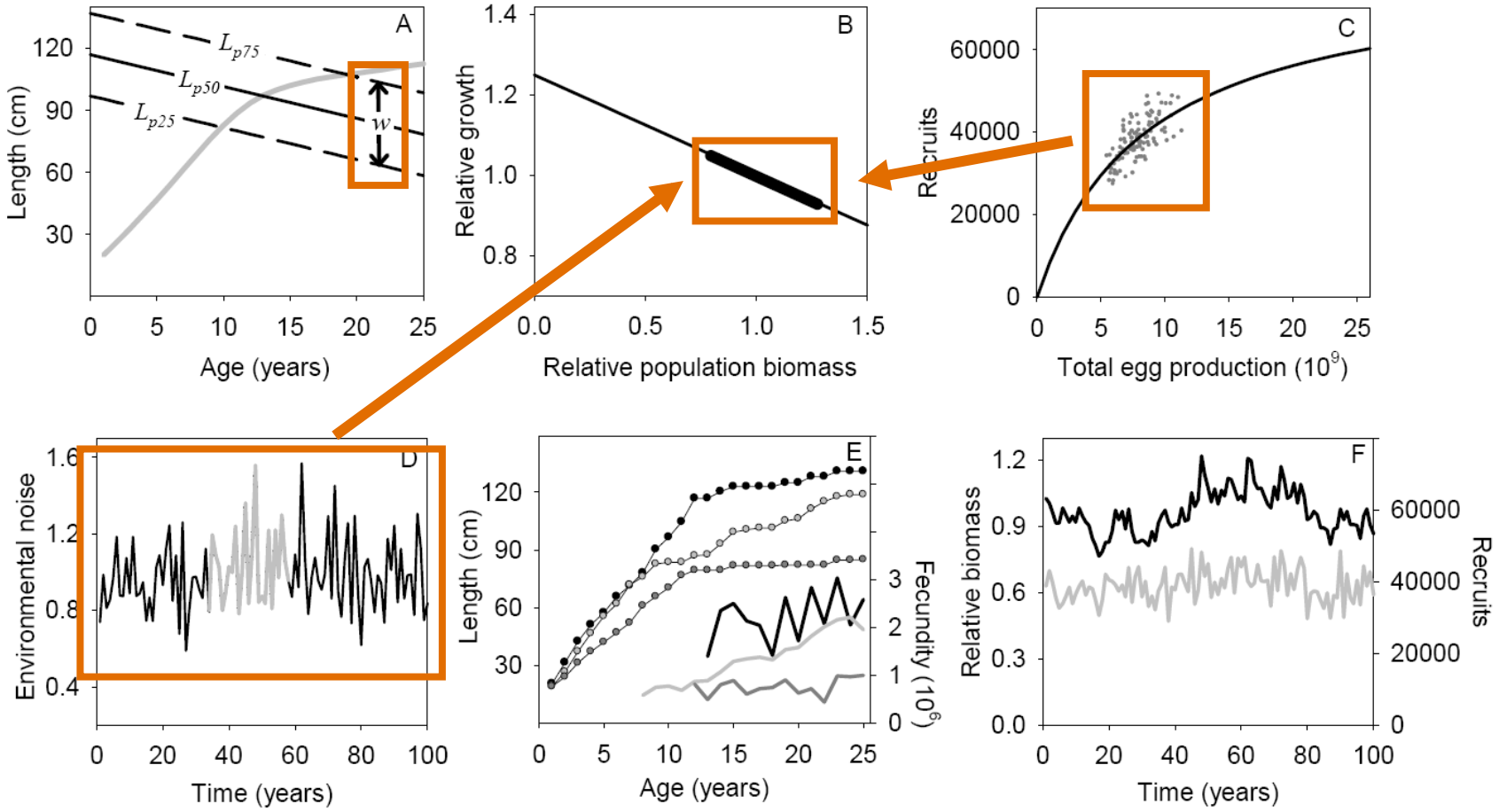


Enberg, K., Jørgensen, C., Dunlop, E.S., Heino, M., and Dieckmann,U. 2009. Implications of fisheries-induced evolution for stock rebuilding and recovery. Evol. Appl. 2(3): 394–414

Enberg K, Jørgensen C, Mangel M. 2010. Fishing-induced evolution and changing reproductive ecology of fish: the evolution of steepness. CJFAS 67: 1708–1719

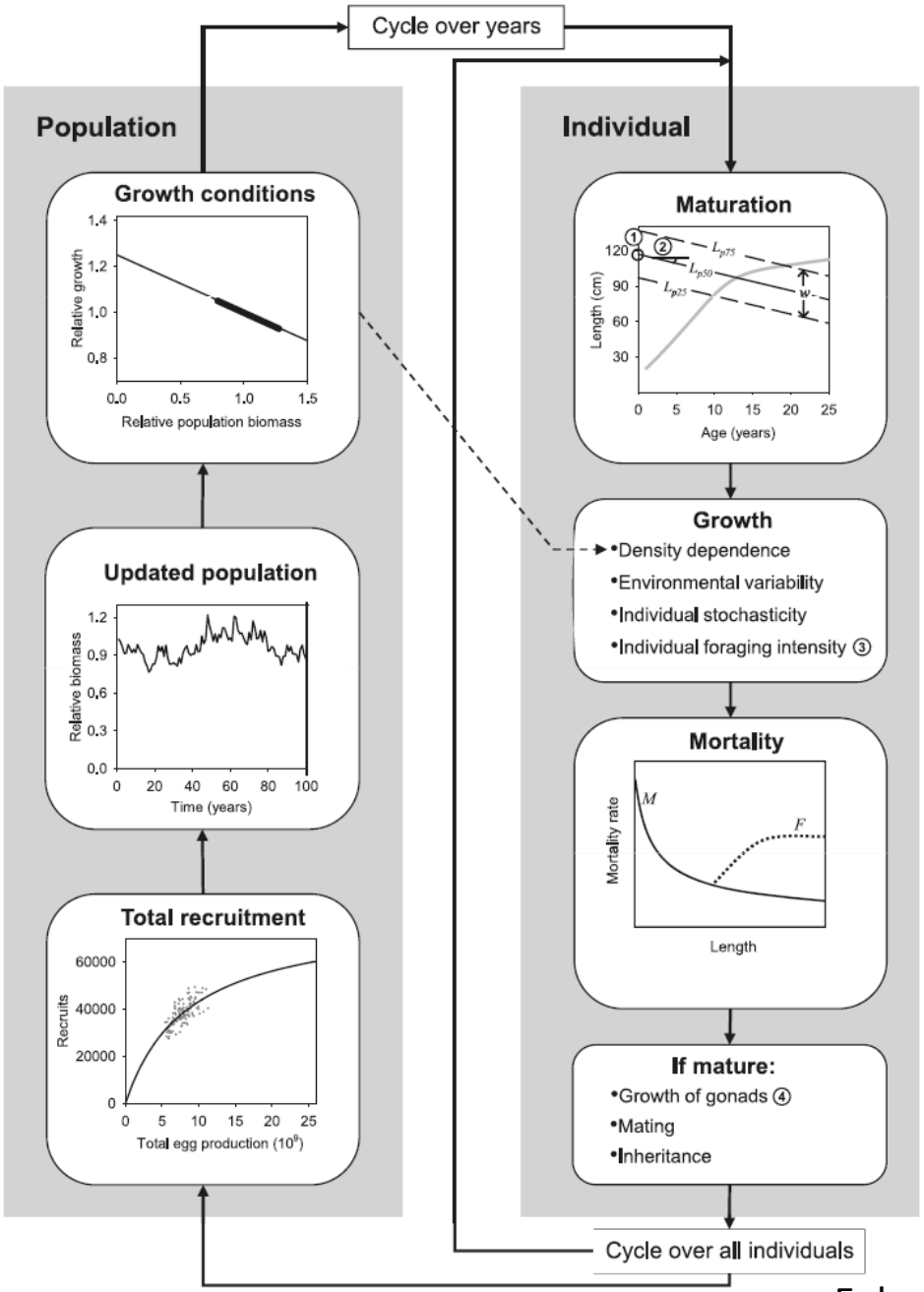
Enberg & al 2009, 2010.

A model with quantitative genetic traits



+ Inter-individual noise in growth

Enberg & al 2009, 2010.



Enberg & al 2009, 2010.

Summary

- Evolutionary individual-based models have wonderful **potential** but take **years to develop**.
- **Feedbacks** are both ecological and evolutionary.
- Good understanding of **trade-offs** essential.
- **Tractability** can be awkward - use simpler models also.

- **Lack of general theory for EvoIBMs (level 5).**