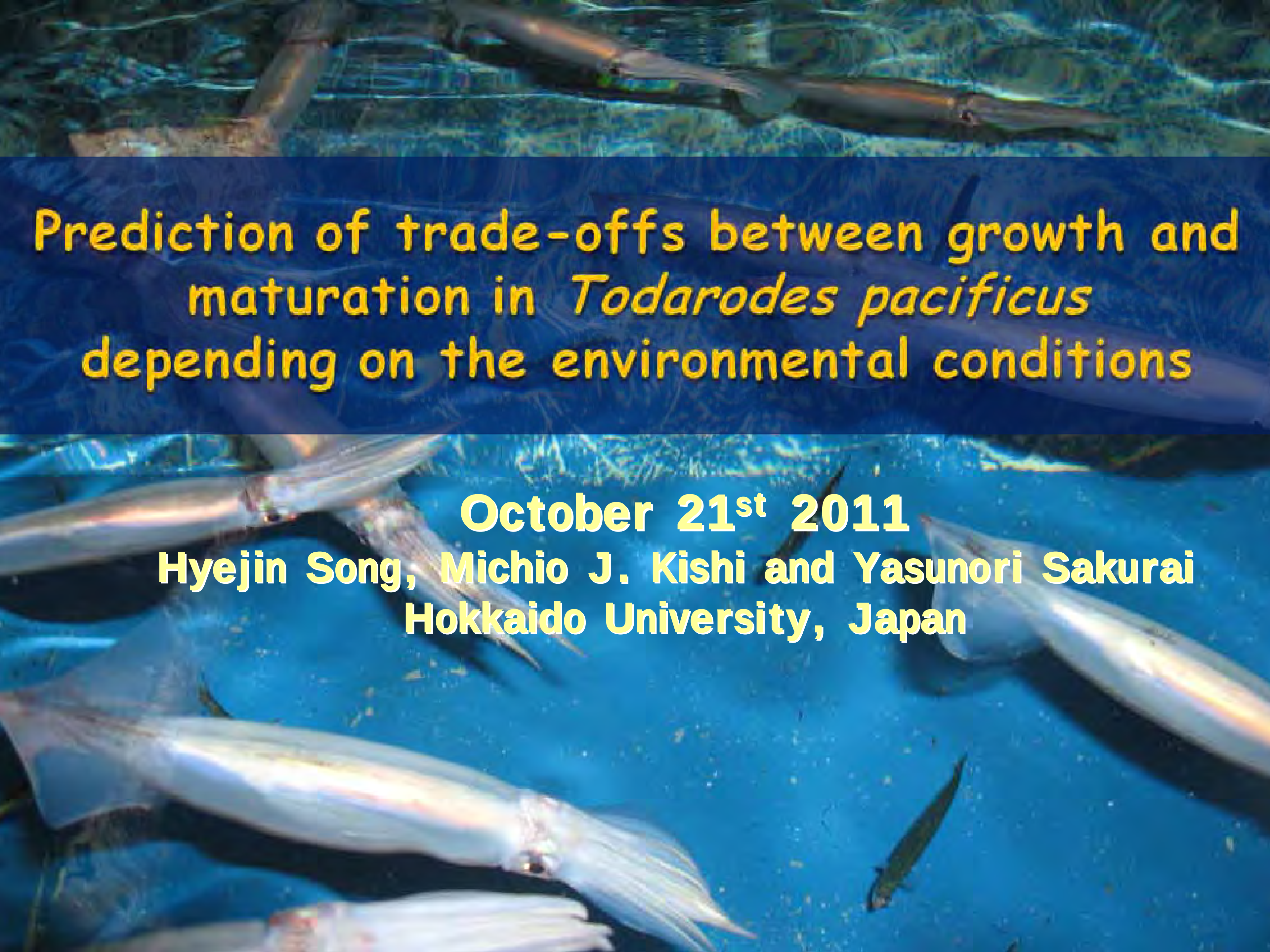

Prediction of trade-offs between growth and maturation in *Todarodes pacificus* depending on the environmental conditions

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IMPETUS FOR THIS STUDY

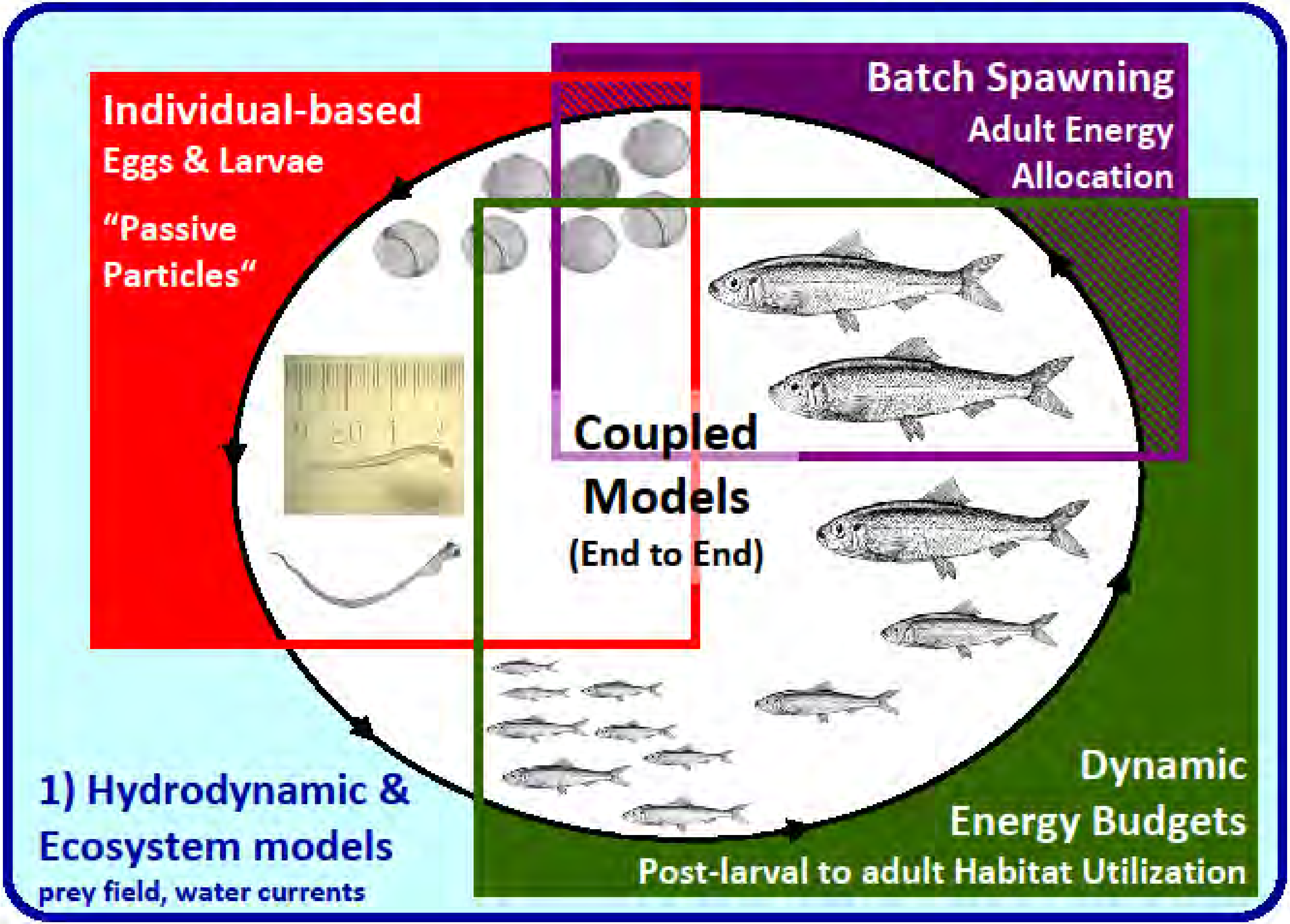
- Episodic “regime shifts” involving entire biological communities occur worldwide (Liuch-Belda *et al*., 1992), and are a key area of research.

- Temperature is thought to be an important causative factor in regime shifts, and many scientists have suggested that species‐specific “*optimal growth temperature*” are important (Climate Effects on Fish and Fishery, Sendai, 2010).

- However, there are multiple, synergistic / interacting factors having indirect effects based on trophodynamics.

- Future climate situations may produce novel combinations of factors – thus ecosystem‐ and full life cycle modeling will be required to make the best possible projections.

Projecting Climate Impacts using Coupled Models



Individual-based
Eggs & Larvae
“Passive Particles“

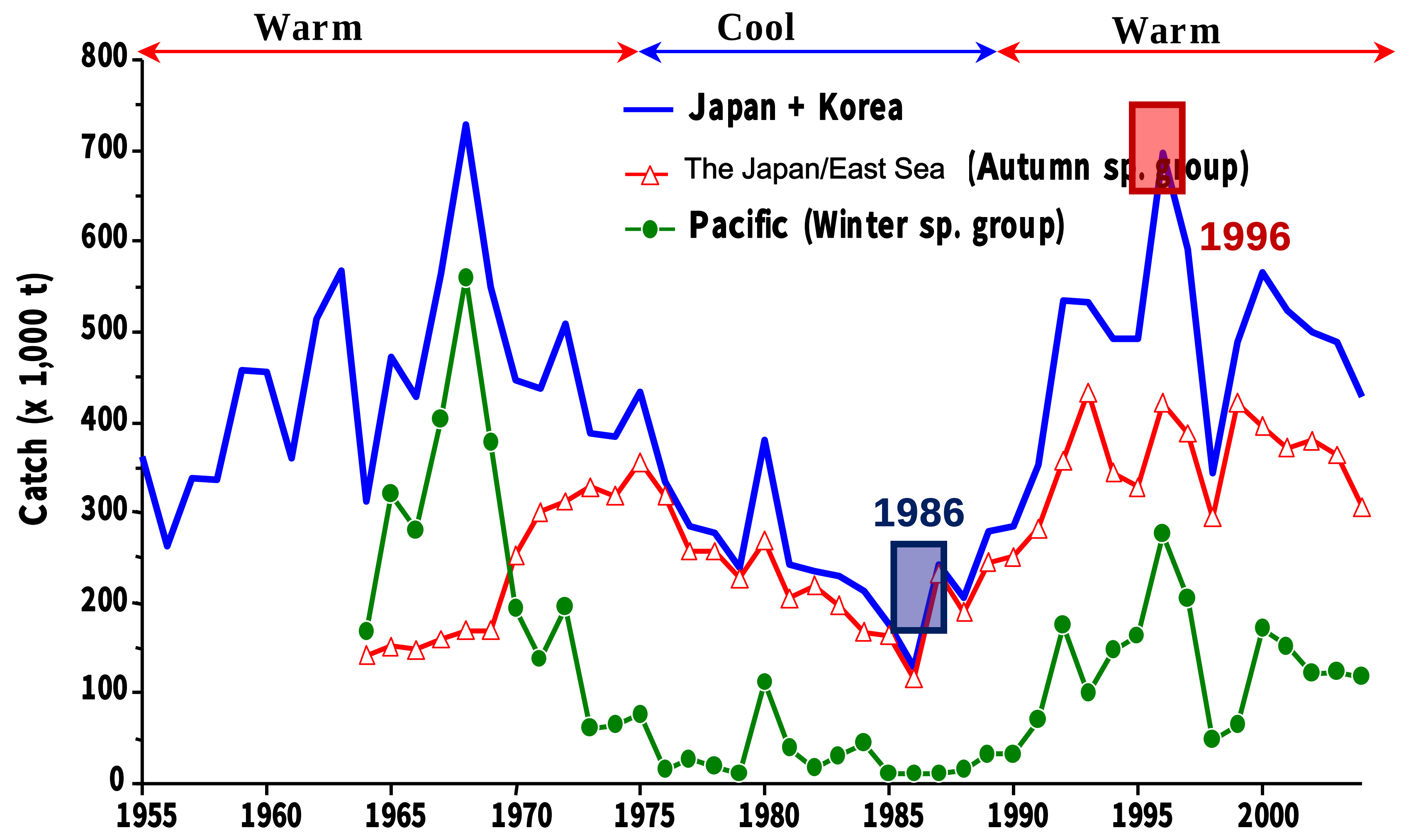
Batch Spawning
Adult Energy Allocation

Coupled Models
(End to End)

Dynamic Energy Budgets
Post-larval to adult Habitat Utilization

1) Hydrodynamic & Ecosystem models
prey field, water currents

By Peck *et al.*, 2010

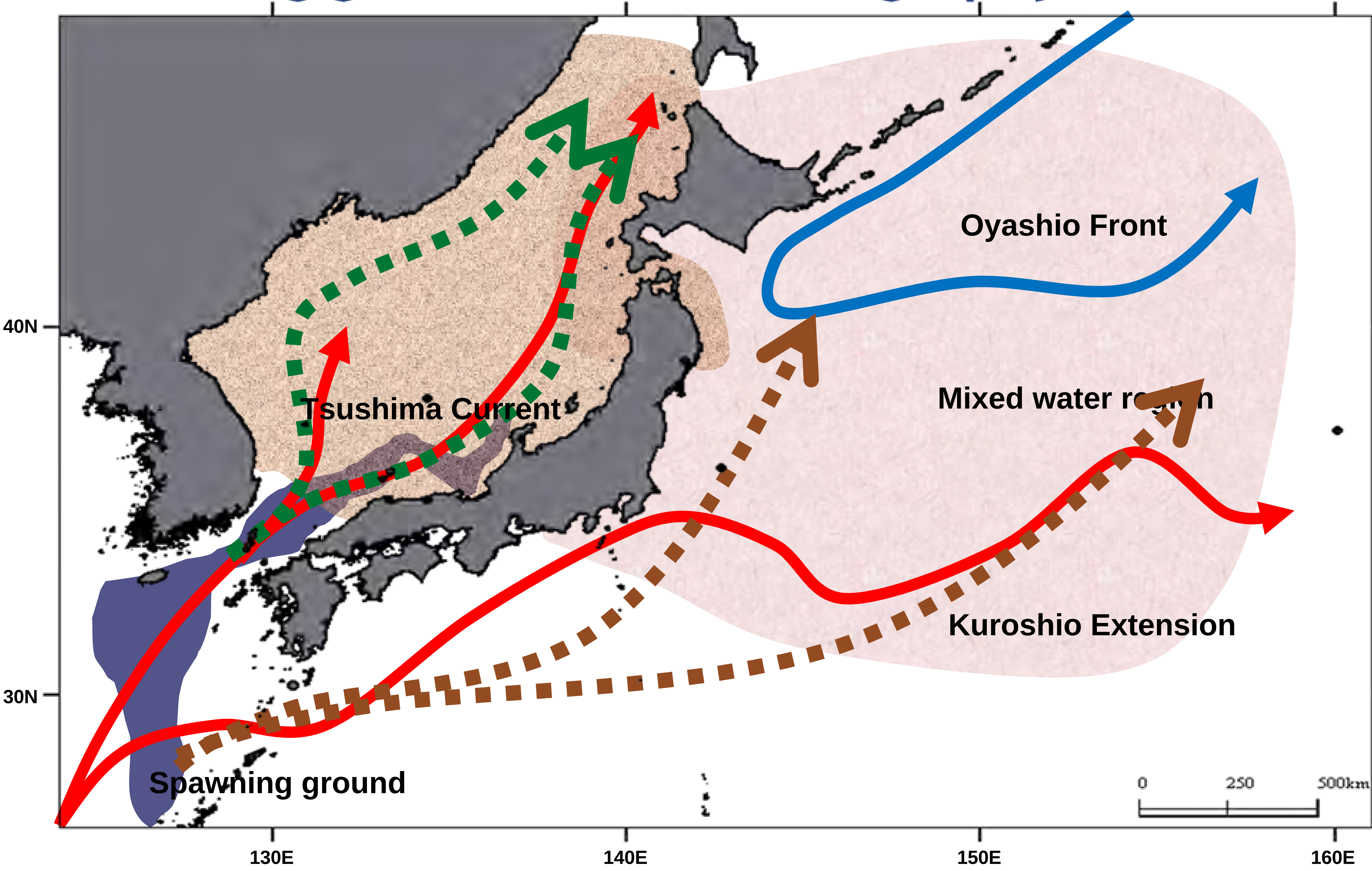


Annual fluctuation in common squid, *T. pacificus* catches of Korea and Japan during 1955 - 2004.

(Data derived from the Japan Sea Research Institute, Japan and the National Fisheries Research and Development Institute, Korea).

Sakurai, 2000

Feeding ground with oceanography features



PURPOSE

Can we predict trade-offs between growth and maturation corresponding to environmental condition/climate change in *Todarodes pacificus* using a coupled model?

->Yes, we can! (Obama & Kishi)...

- **Simulate success or fail of growth and reproduction by the optimum temperature along different migration routes.**
- **Predict how migration route and spawning area will change due to global warming.**

MODEL DESCRIPTION

- **Bioenergetics model** (Rustam, 1988 ; Kishi *et al*., 2009)
  - **Captive experimental data during 2006-2010**

- **NEMURO** (North Pacific Ecosystem Model for Understanding and Regional Oceanography; Kishi *et al*., 2007)
    - **Temperature (average 0-50m depth)**
    - **Prey density (large and predatory zooplankton biomass)**

Bioenergetics Model

$$\frac{dW}{W \cdot dt} = [C - (R + SDA + F + E + P)] \cdot \frac{CAL_Z}{CAL_F}$$

W: wet weight (g),   **t**: time (day)

C: consumption (gprey/gfish/day),

R: respiration or losses through metabolism (gprey/gfish/day)

SDA: specific dynamic action or losses due to energy costs of digesting food (gprey/gfish/day)

F: egestion or losses due to feces (gprey/gfish/day)

E: excretion or losses of nitrogenous excretory wastes (gprey/gfish/day)

P: egg production or losses due to reproduction (gprey/gfish/day)

CAL_Z : caloric equivalent of zooplankton (cal /gzooplnkton)

CAL_F : caloric equivalent of squid (cal /gsquid)

consumption

NEMURO

$$C = C_r \cdot f_c(T)$$

$$C_r = \sum_{j=1}^{n} C_j$$

$$C_j = \frac{C_{MAX} \cdot \dfrac{PD_{ij} \cdot v_{ij}}{K_{ij}}}{1 + \sum_{k=1}^{n} \dfrac{PD_{ik} \cdot v_{ik}}{K_{ik}}}$$

$$C_{MAX} = a_c \cdot W^{b_c}$$

$$f_c(T) = gcta \cdot gctb$$

PD_{ij}	:density of prey type j (g wet weight/m^3),
v_{ij}	:vulnerability of prey type *j* to predator *i*
K_{ij}	:half saturation constant (g wet weight/m^3),
C	consumption rate (g/g/d),
C_{MAX}	:maximum consumption rate (g/g/d),
$f_c(T)$	:temperature dependence function for consum
i	predator type

where

$$tt5 = \frac{1}{(te2 - te1)}$$

$$t5 = tt5 \cdot a\log\left[0.98 \cdot \frac{(1.0 - xk1)}{(0.02 \cdot xk1)}\right]$$

$$t4 = e^{[t5 \cdot (T - te1)]}$$

$$tt7 = \frac{1}{(te4 - te3)}$$

$$t7 = tt7 \cdot a\log\left[0.98 \cdot \frac{(1.0 - xk4)}{(0.02 \cdot xk4)}\right]$$

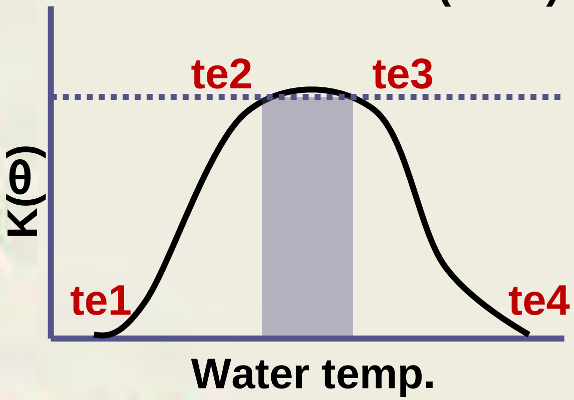
$$t6 = e^{[t7 \cdot (te4 - T)]}$$

$$gcta = \frac{(xk1 \cdot t4)}{(1.0 + xk1 \cdot (t4 - 1.0))}$$

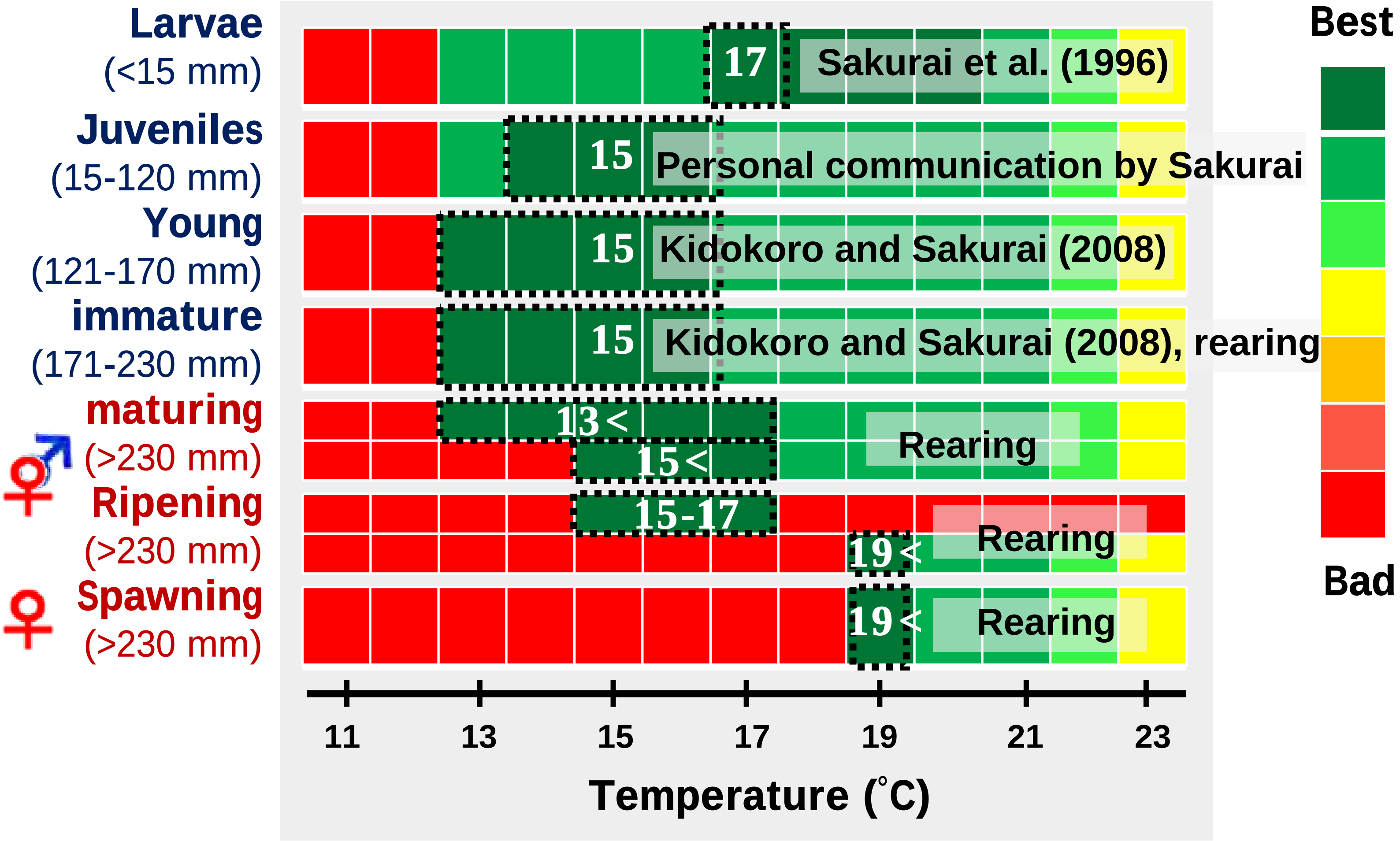
$$gctb = \frac{(xk4 \cdot t6)}{(1.0 + xk4 \cdot (t6 - 1.0))}$$

Physical model

Thornton & Lessem (1978)



Growth & Reproduction potential vs Temperature



Optimum Temp. for function

MALE	TEMP (°C)				TIME	TEMP (°C)				FEMALE
	te1	te2	te3	te4	DAY	te1	te2	te3	te4	
Larvae					1-30					Larvae
Juveniles	6	17	21	23	31-61	6	17	21	23	Juveniles
					62-92					
					93-120					
					121-151					
Young	6	15	21	23	152-181	6	15	21	23	Young
					182-212					
Immature	6	15	21	23	213-242	6	15	21	23	Immature
					243-273					
Maturing	13	15	19	23	274-304					
Ripening	13	15	17	23	305-334	13	15	19	23	Maturing
					335-365	17	19	21	23	Ripening & spawning

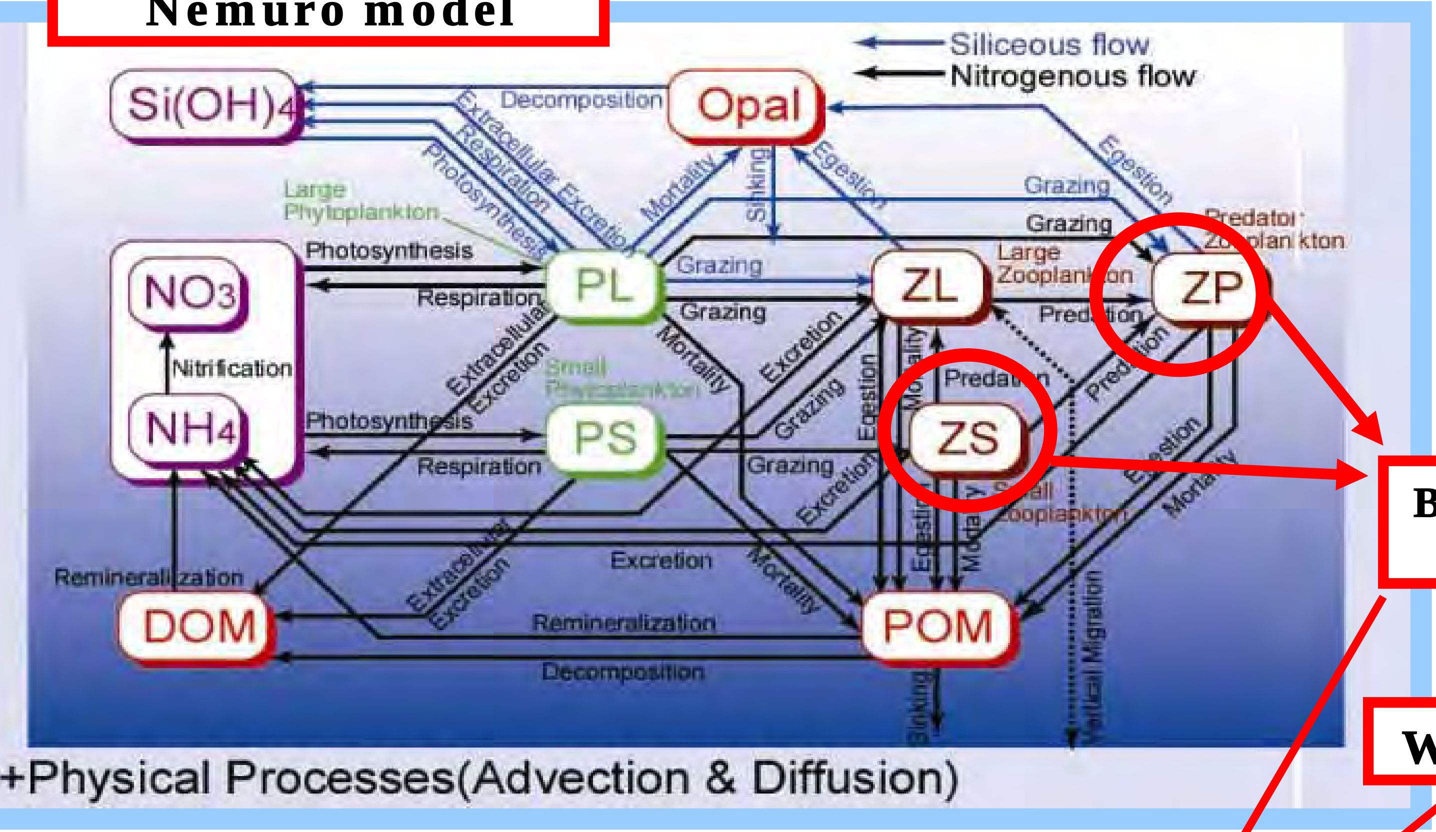
⬚ Suitable temperature

🟧 For growth

🟩 For maturation

Trade-offs between growth and maturation; Temperature dependence

Nemuro model



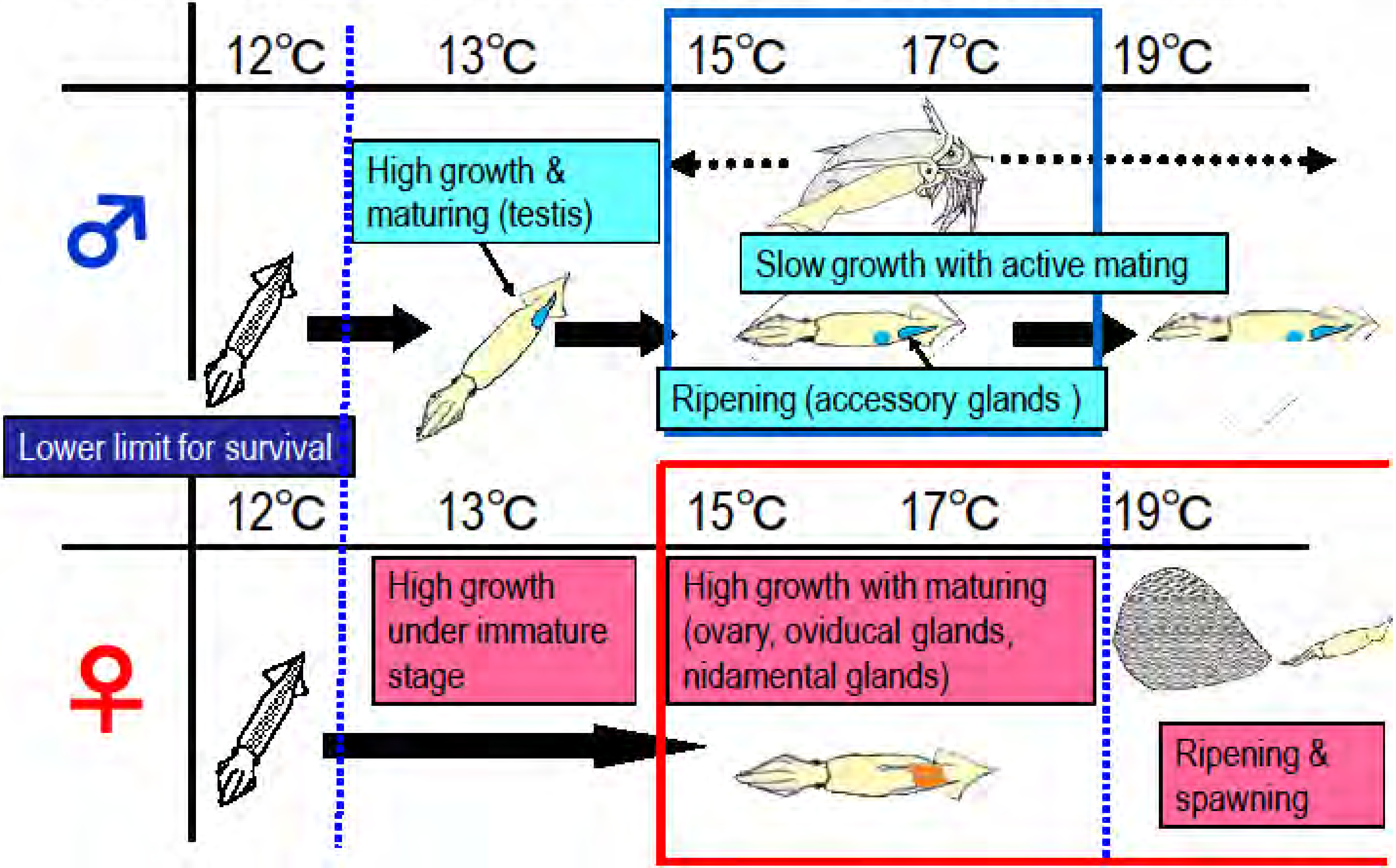
+Physical Processes(Advection & Diffusion)

Bio-energetic model of

Water Temperature

Maturation

Summary of effects of different temperature to growth and maturation of *T. pacificus* by captive experiments during 2006–2009 (p.c. Sakurai)



♂

12°C | 13°C | 15°C | 17°C | 19°C

High growth & maturing (testis)

Slow growth with active mating

Ripening (accessory glands)

Lower limit for survival

♀

12°C | 13°C | 15°C | 17°C | 19°C

High growth under immature stage

High growth with maturing (ovary, oviducal glands, nidamental glands)

Ripening & spawning

- # Equations of maturation

1) Gonad W: gonad + nidamental gland + ovary + oviduct

2) Testis W: testis + accessory gland

$$G = G_r \cdot f_G(T)$$

te1
te2
te3
te4

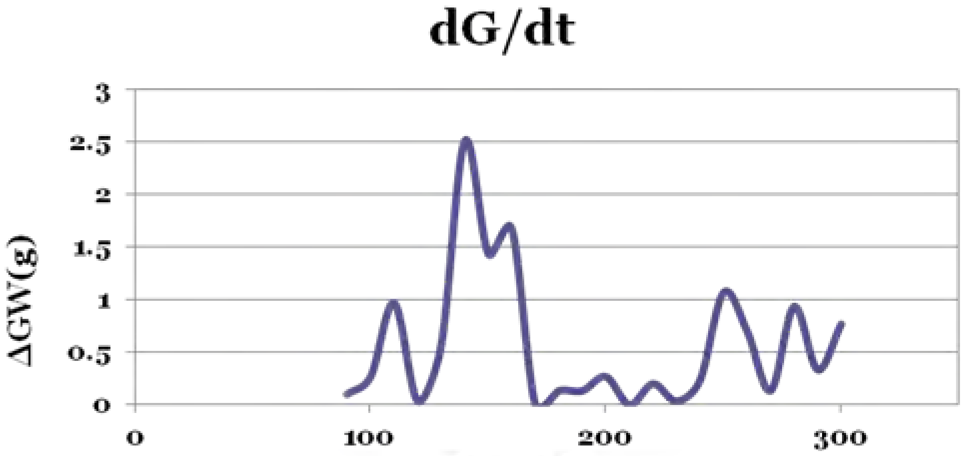
$$G_r = \sum G_j$$

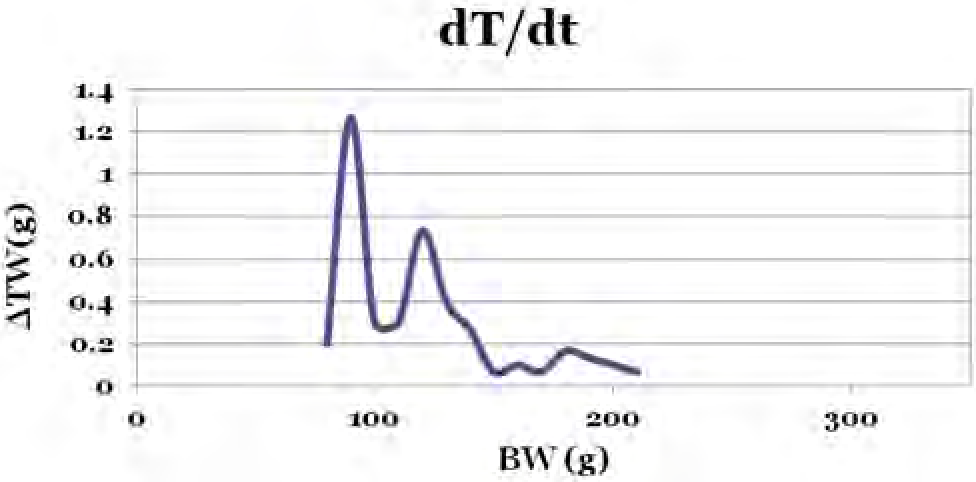
$$G_j = \frac{G_{MAX} \cdot \dfrac{PD_{ij} \cdot v_{ij}}{K_{ij}}}{1 + \sum\limits_{K=1}^{n} \dfrac{PD_{ij} \cdot v_{ij}}{K_{ij}}}$$

$$G_{MAX} = a_G W + b_G$$

$$\mathbf{G_{MAX} = -0.0011W + 0.7795}$$

$$\mathbf{T_{MAX} = -0.0047W + 0.9807}$$

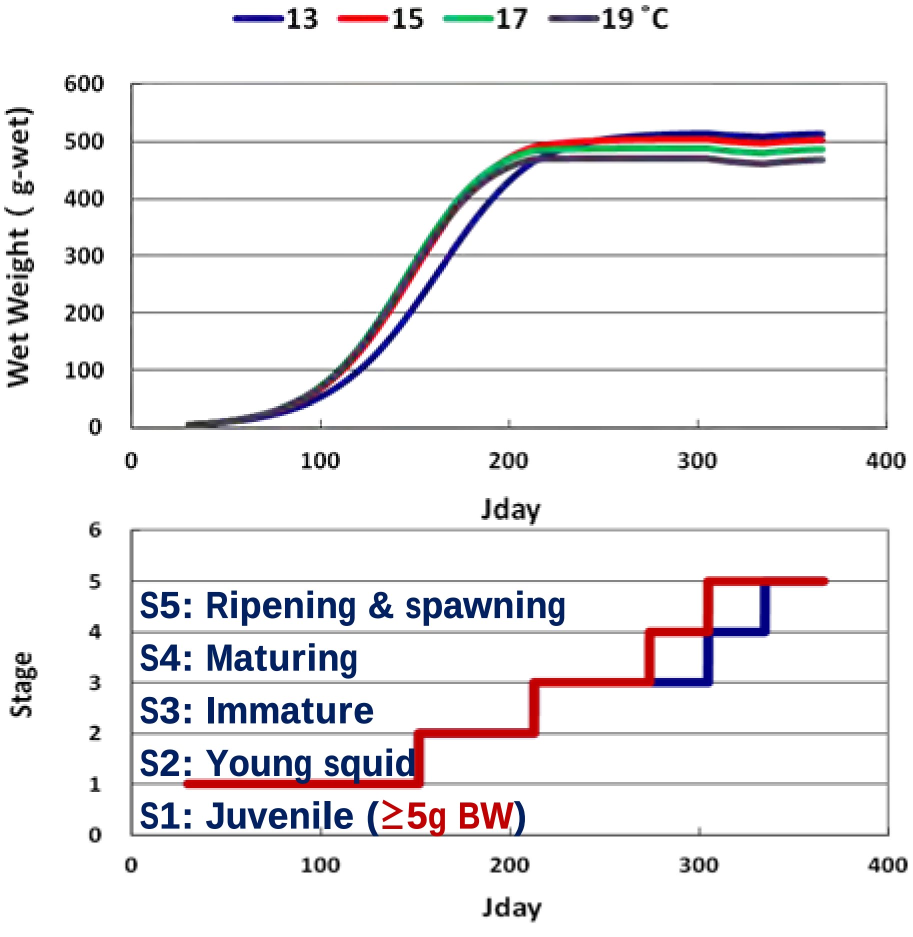




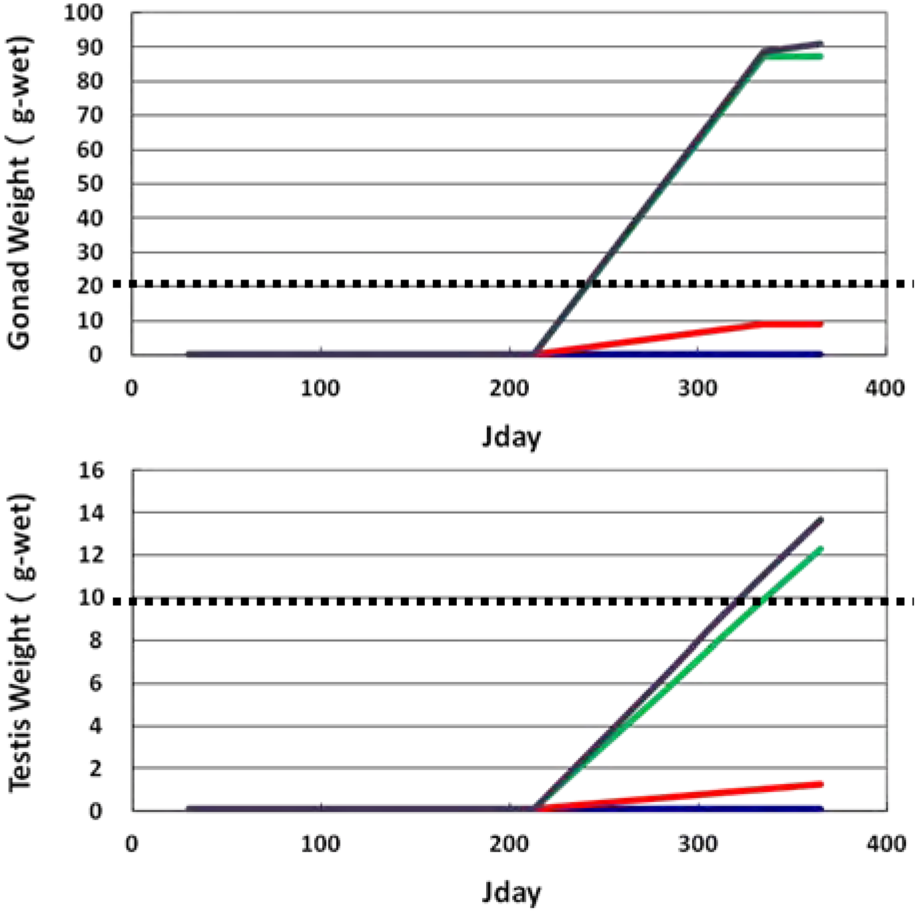
TEST RUN

CASE: AN CAPTIVE INDIVIDUAL UNDER 13/ 15/ 17/ 19°C (No food limitation)

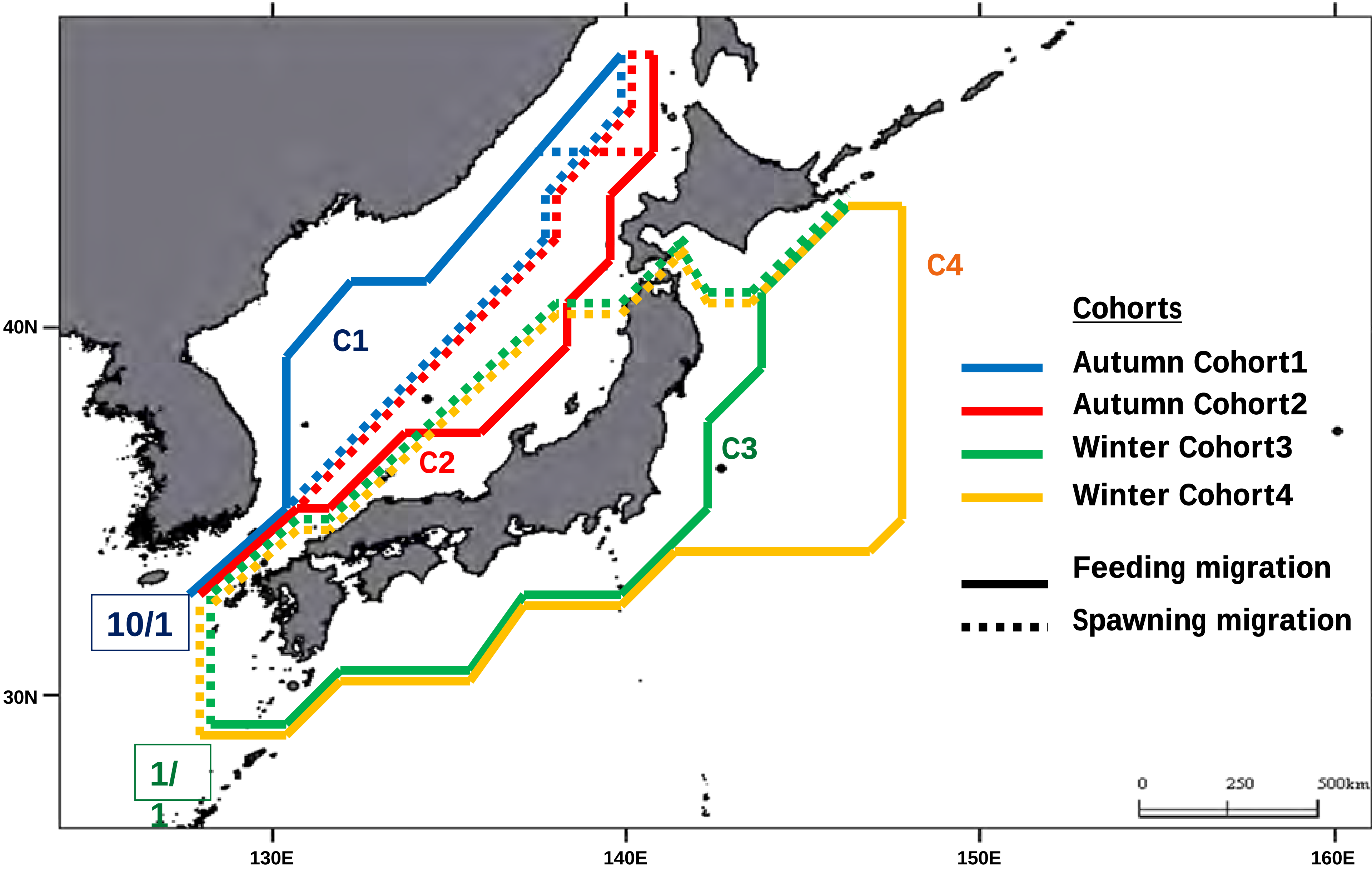
✓ **Growth**



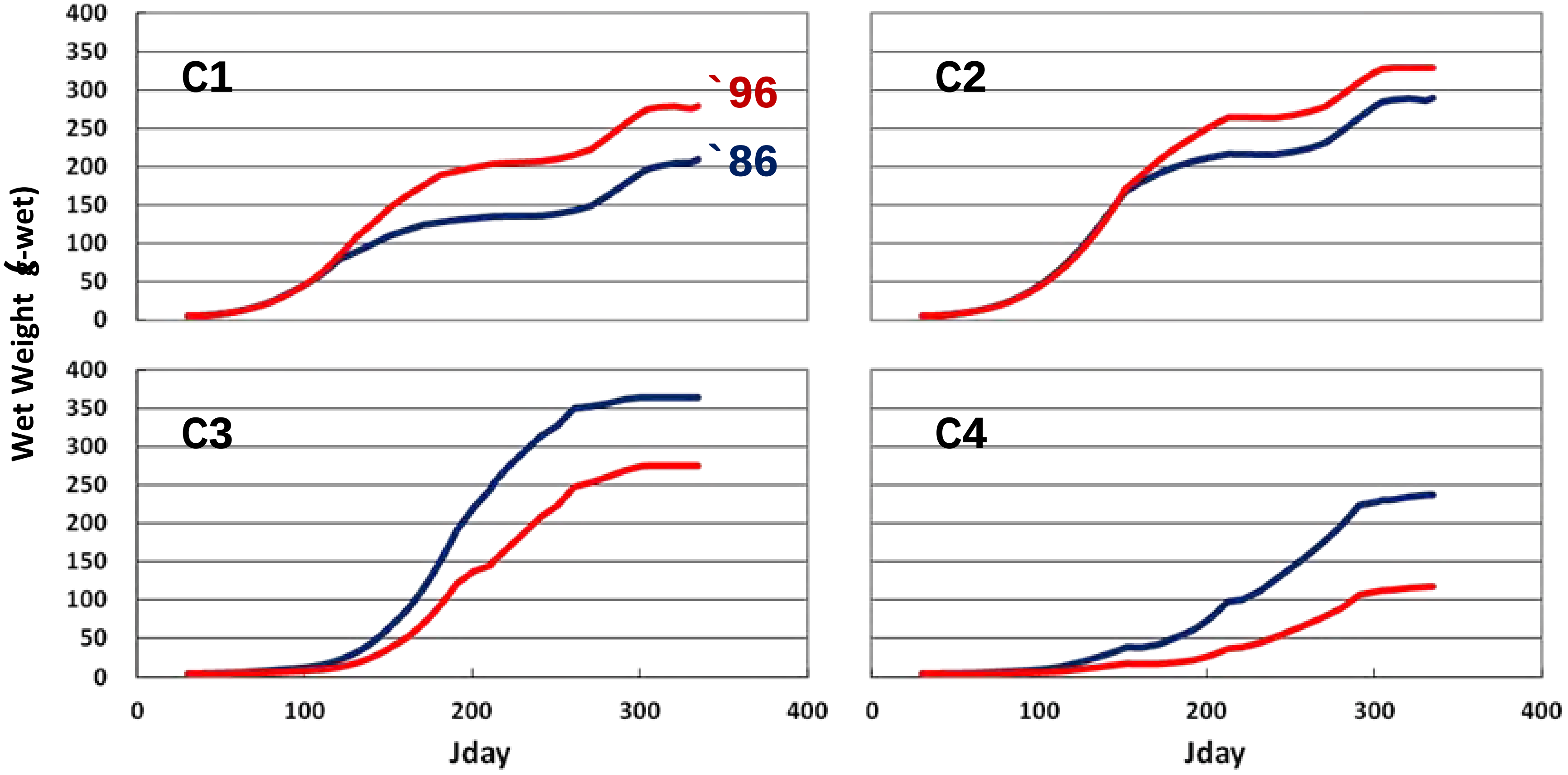
✓ **Maturation**



Migration routes for the modeling



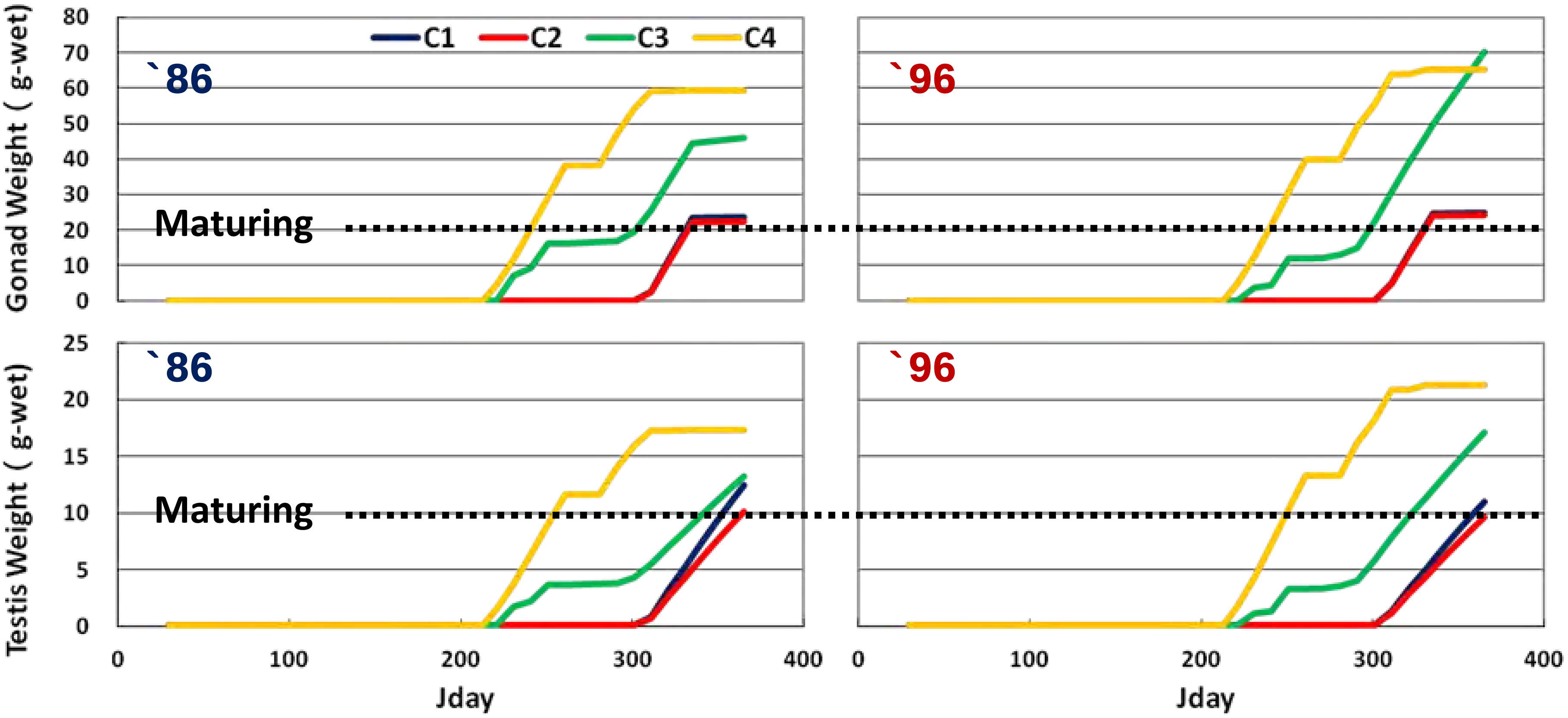
Body weight along migration route and 1989RS



- ✓ **86yr: C3 - C2 - C4 - C1**
- ✓ **96yr: C2 - C1 : C3 - C4**

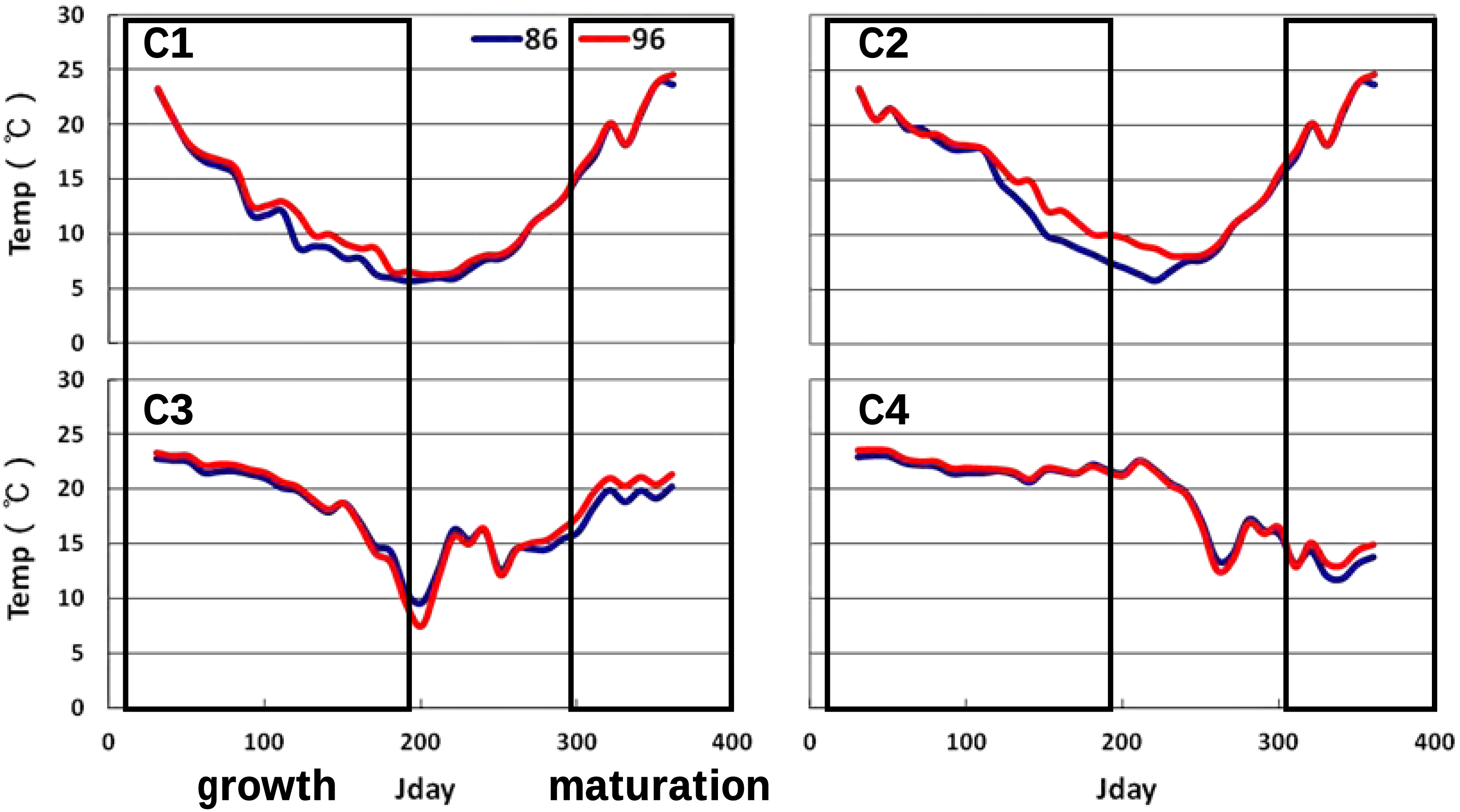
- ✓ **C1, C2: 86yr < 96yr**
- ✓ **C3, C4: 86yr > 96yr**

Maturation along migration route and 1989RS

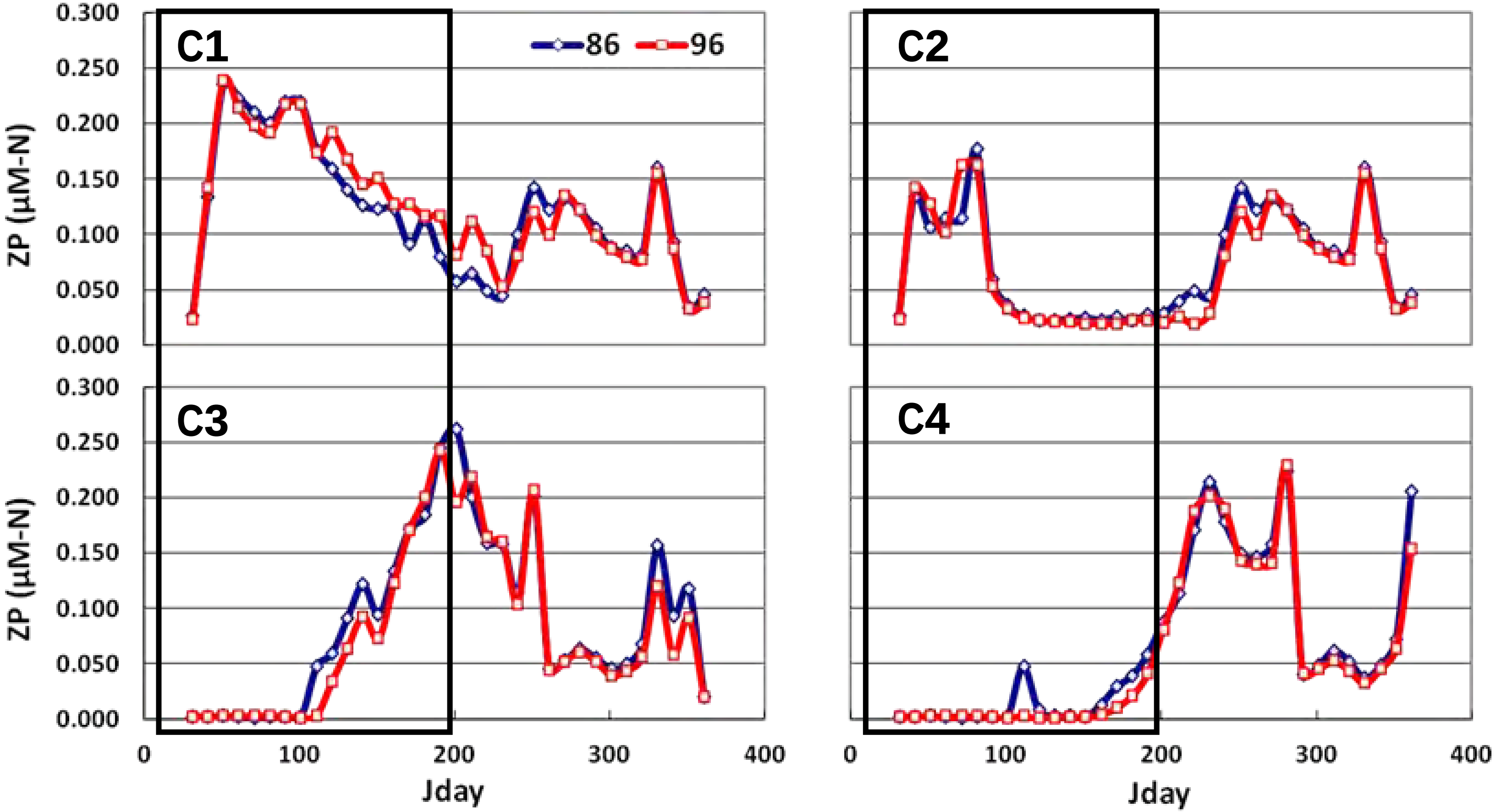


- ✓ **86yr < 96yr: C4 – C3 – C1 – C2**
- ✓ **C3, C4 had the earlier and better maturation than C1, C2**

Temperature along migration route and 1989RS



Prey density along migration route and 1989RS



DISCUSSION & CONCLUSION

- **Autumn cohorts-C1, 2 and winter cohort-C3 showed normal growth due to proper prey density and temperature, but C4 had poor growth; 86yr-winter cohorts / 96yr-autumn cohorts**

- **All cohorts showed successful maturation in both years.**

  Although the winter cohort occurred the earlier trade-off, *it might not successfully reproduce if it didn't reach the spawning ground*.

- **Water temperature of migration routes showed the same trend with cool- and warm RS only in autumn cohorts.**

This coupled model can be used to changes in growth and maturation depending on environmental conditions that occur in climate regime shifts.