A population dynamics model for Japanese sardine, *Sardinops melanostictus*, off the Pacific coast of Japan, consisting of spatial early-life stage and age-structured adult sub-models

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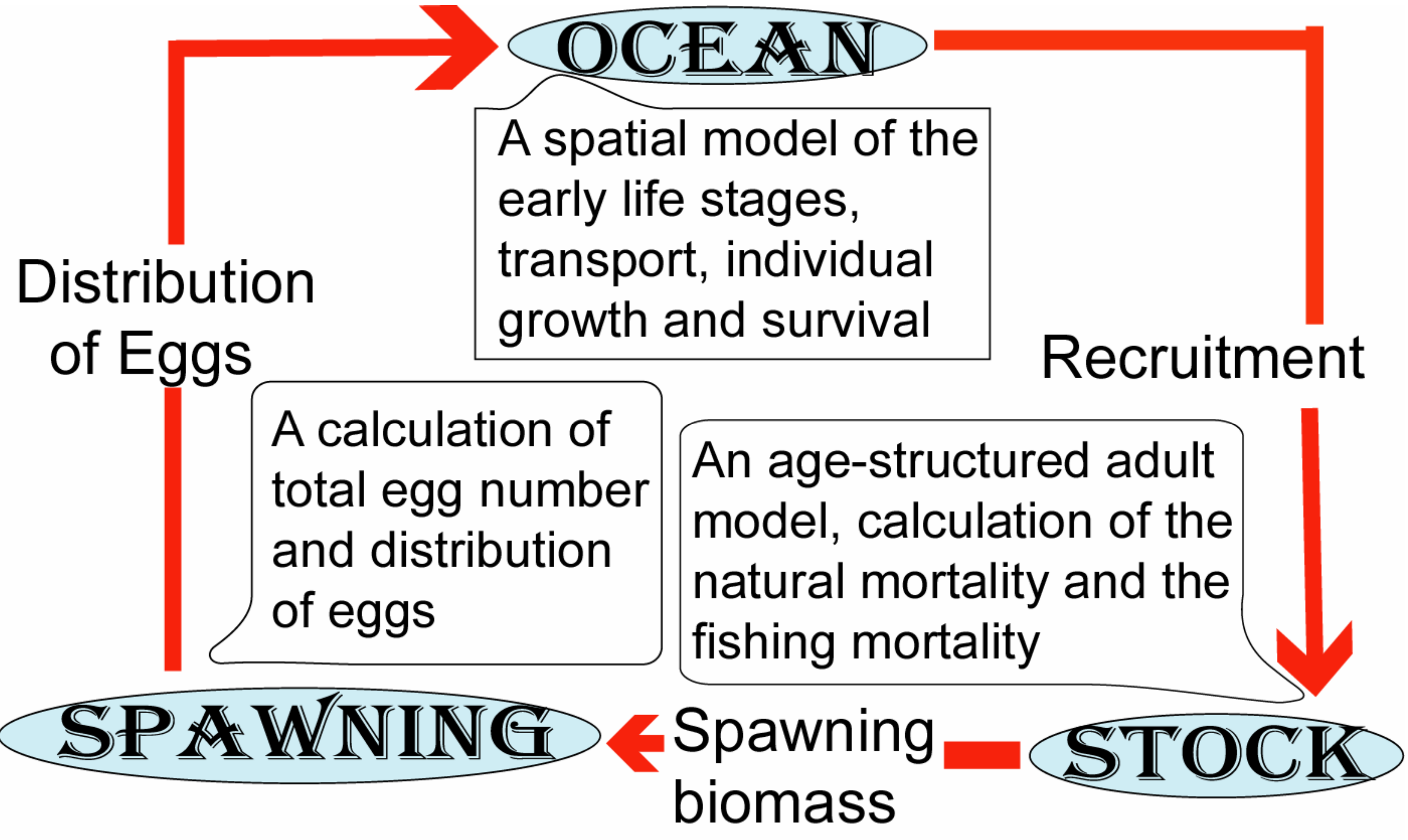
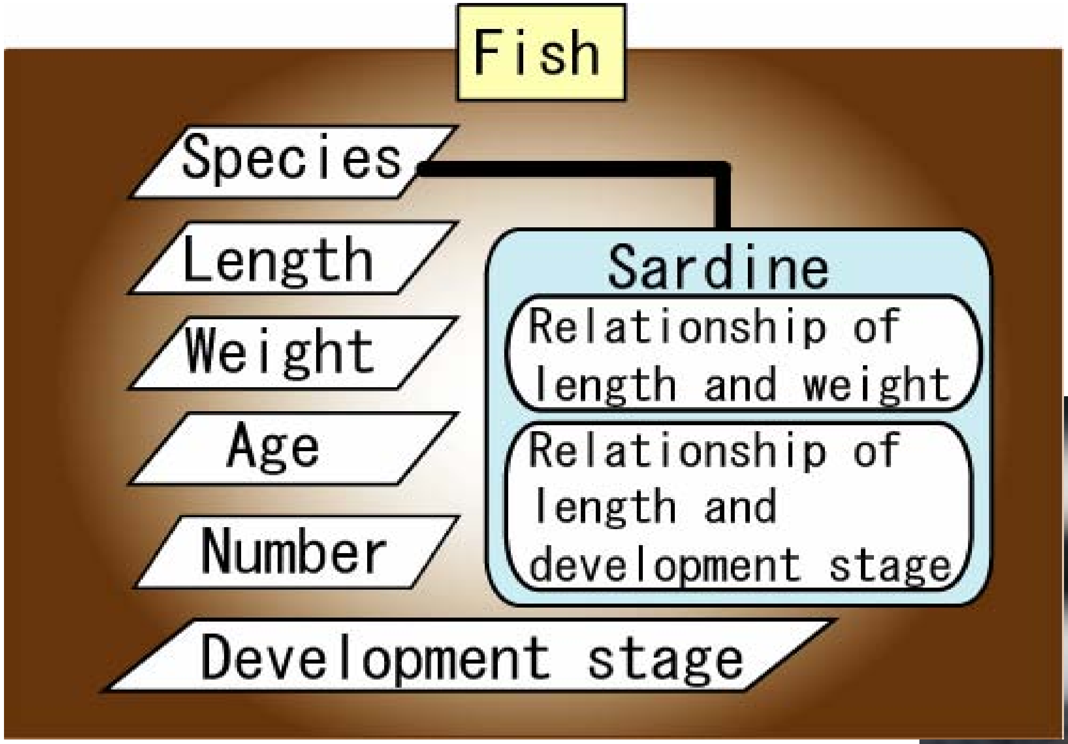
Concepts of model



FISH object



A group of fish

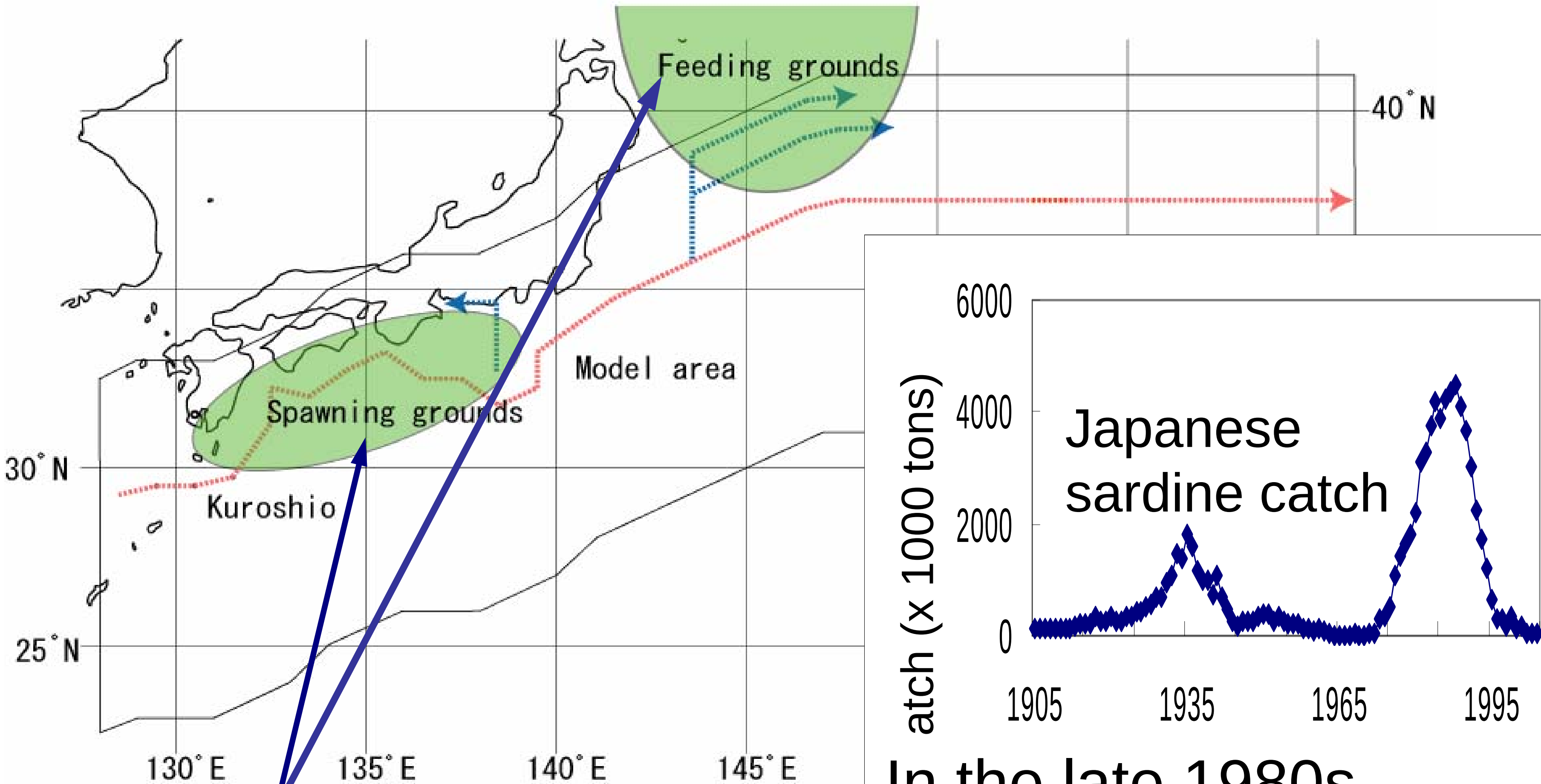
Contents

1 Stock fluctuation of Japanese sardine

2 Life cycle model for Japanese sardine

3 Example of the simulation

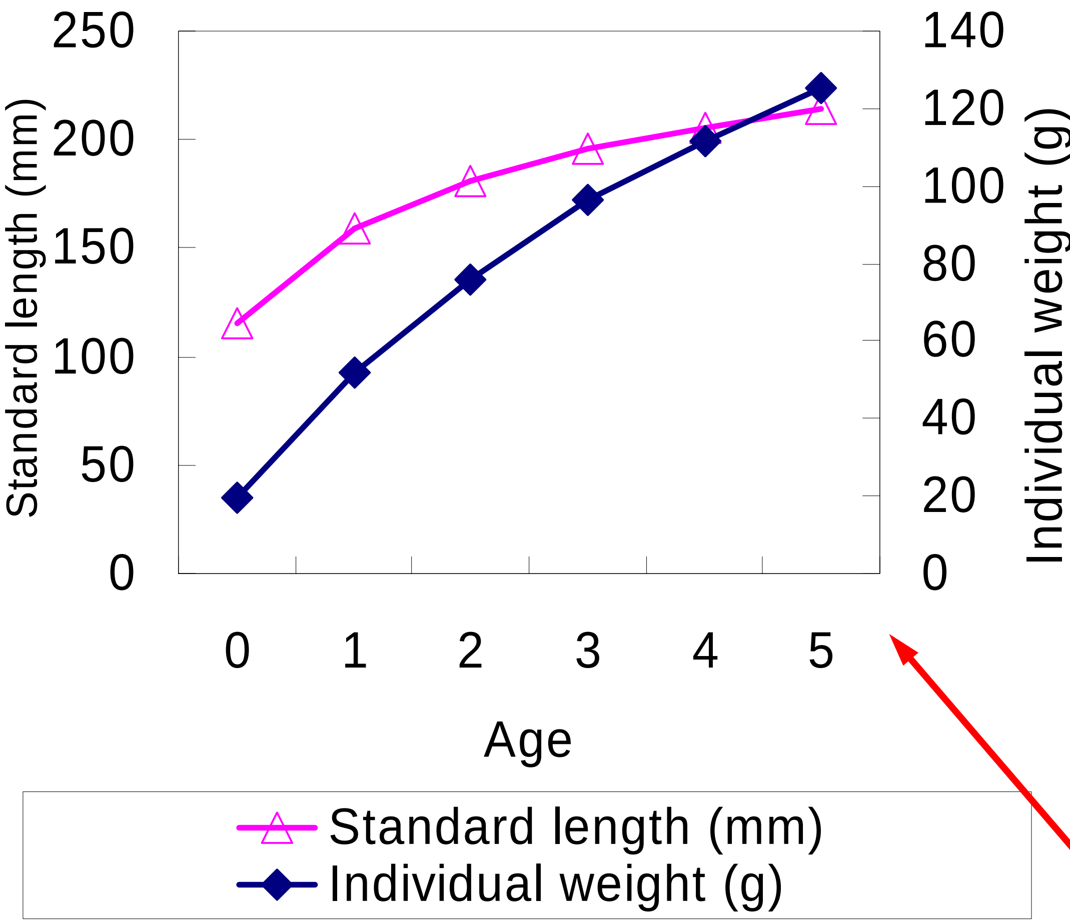
Japanese sardine

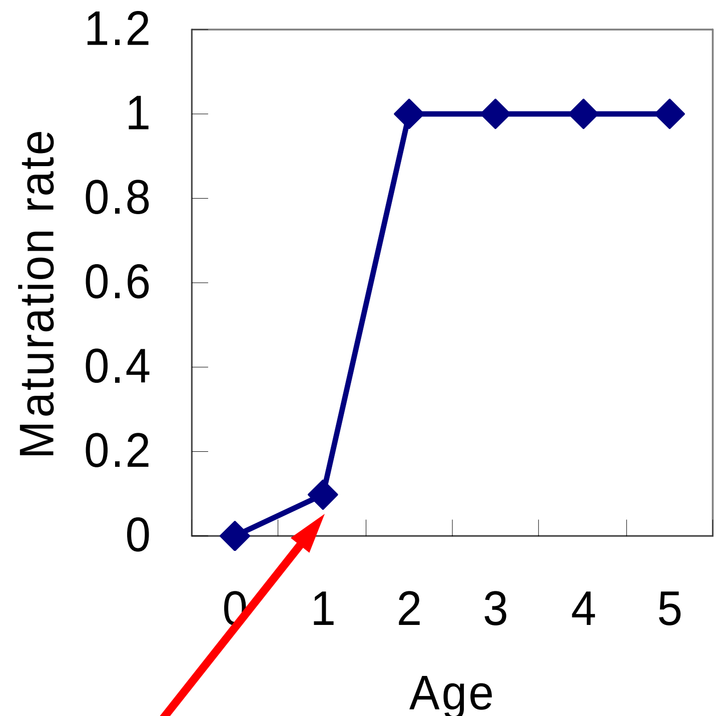


vary according to the level of stock abundance (high and low)

In the late 1980s, successive recruitment failures occurred.

Japanese sardine





Maturation rate

Individual growth
(by the catch data)

vary according to the level of stock abundance (high and low)

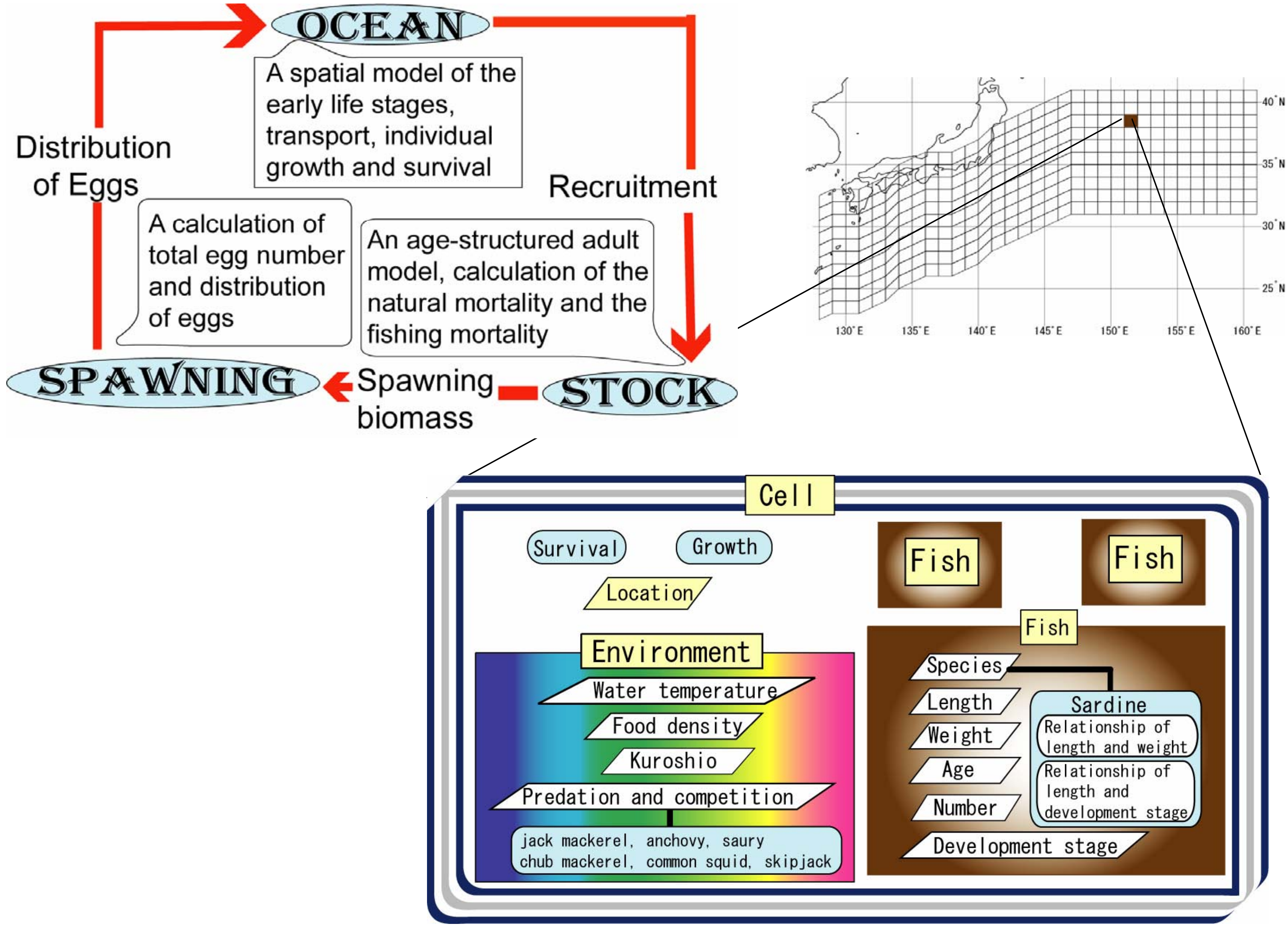
What are the causes of sardine stock fluctuation?

- Environmental factors (Water temperature, Food density, Ocean Current)
- Interspecific-relationship
- Fishing mortality

Model planning

- Life cycle model
- Spatial early-life-stage model
  - Transportation
  - Growth
  - Survival
- Age-structured adult model
- Object-oriented modeling

Contents


OCEAN
A spatial model of the early life stages, transport, individual growth and survival
Distribution of Eggs
Recruitment
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An age-structured adult model, calculation of the natural mortality and the fishing mortality
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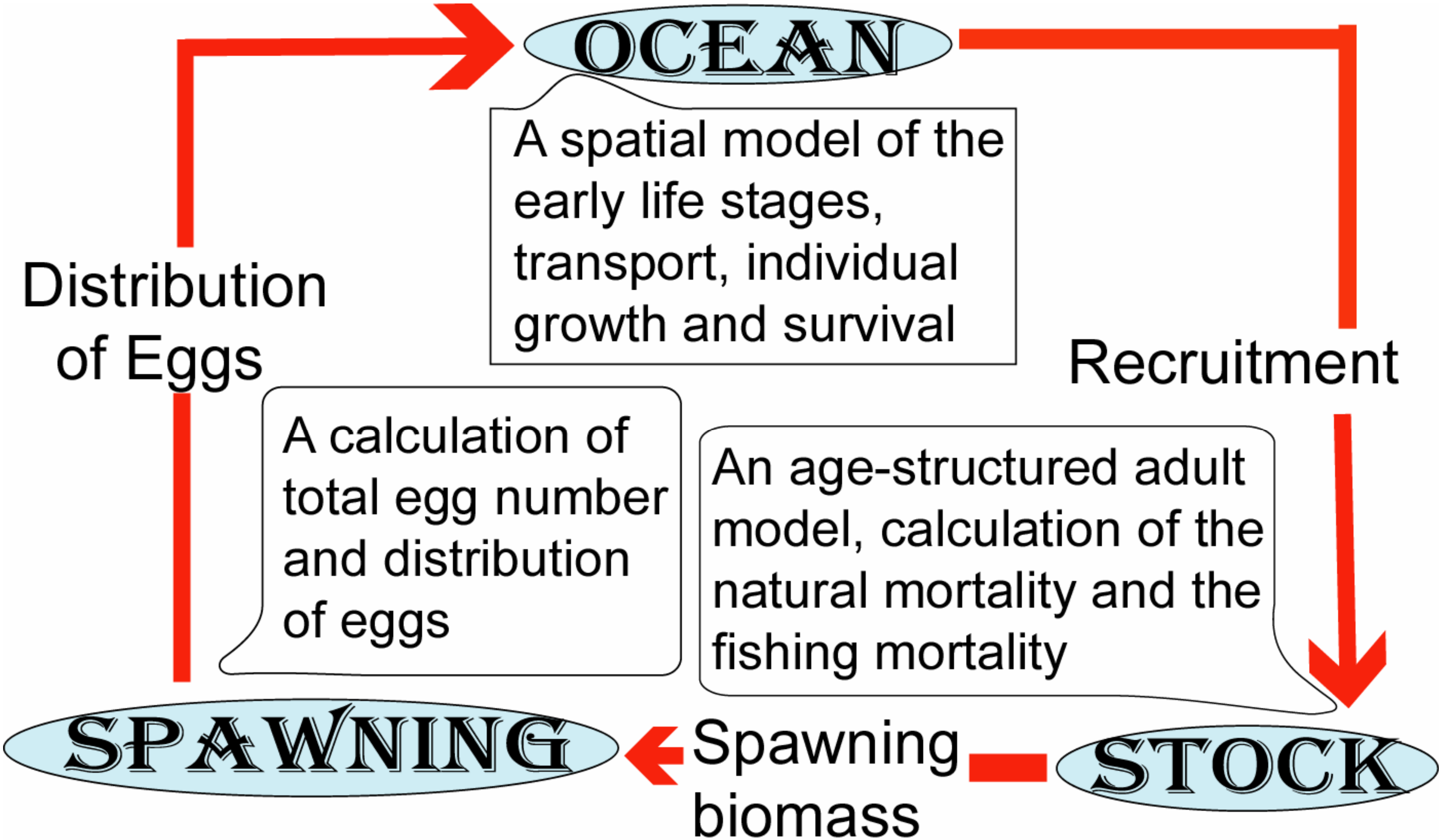
145°E
150°E
155°E
160°E
Cell
Survival
Growth
Location
Fish
Fish
Fish
Environment
Water temperature
Food density
Kuroshio
Predation and competition
jack mackerel, anchovy, saury
chub mackerel, common squid, skipjack
Species
Length
Weight
Age
Number
Development stage
Sardine
Relationship of length and weight
Relationship of length and development stage

Concepts of model



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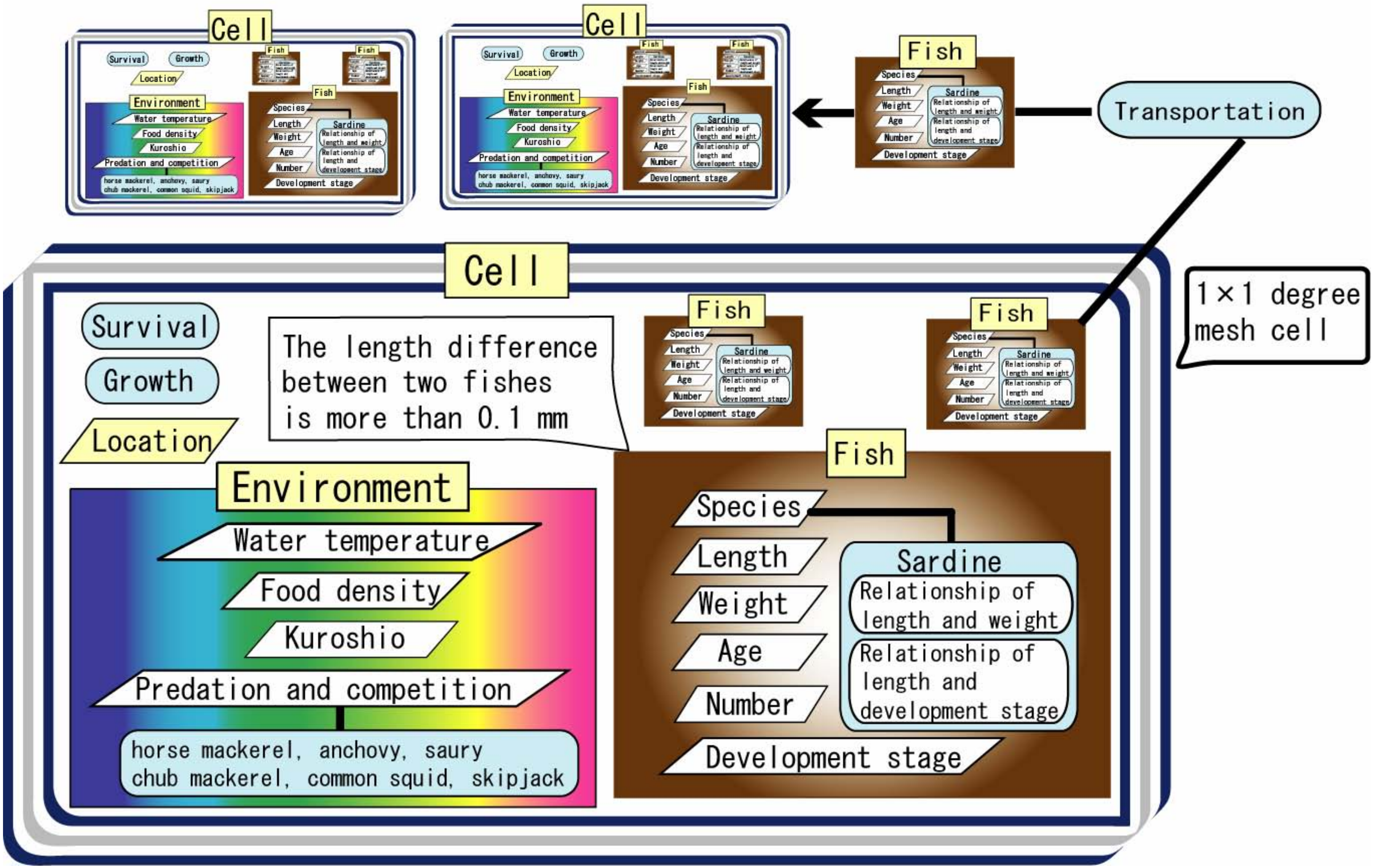
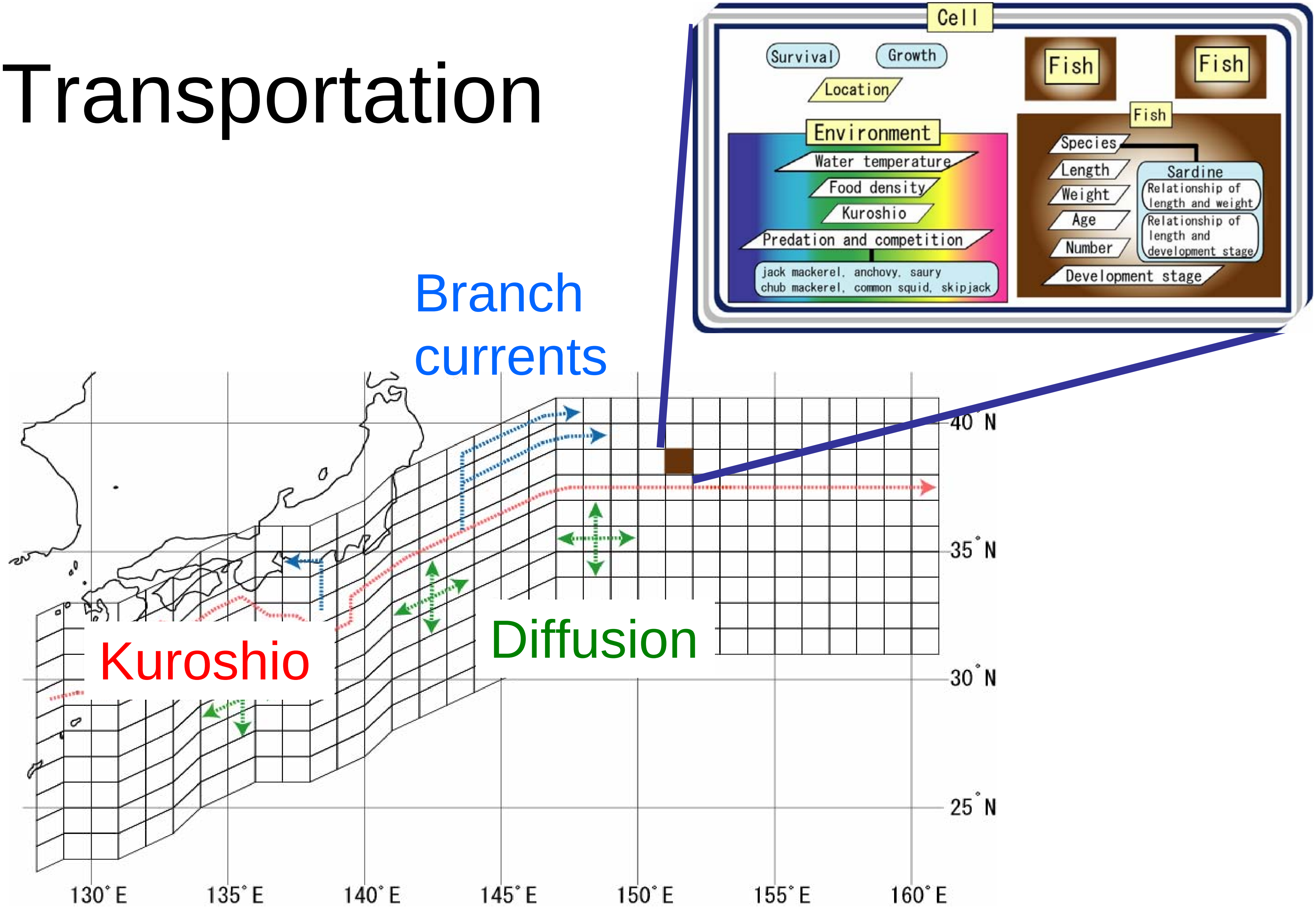
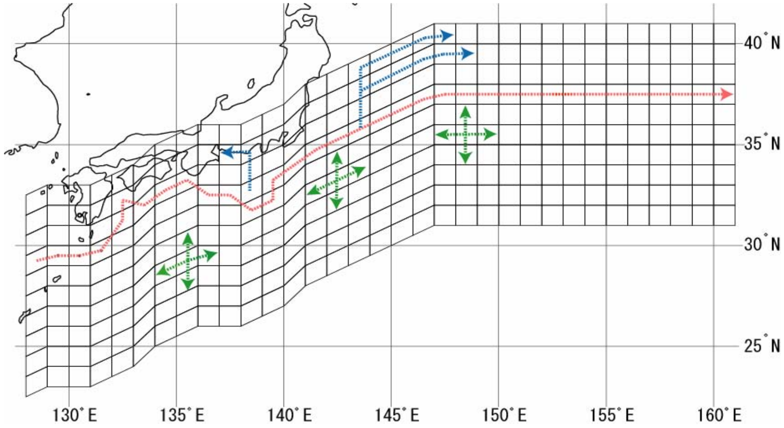
From egg to 60-day sardine



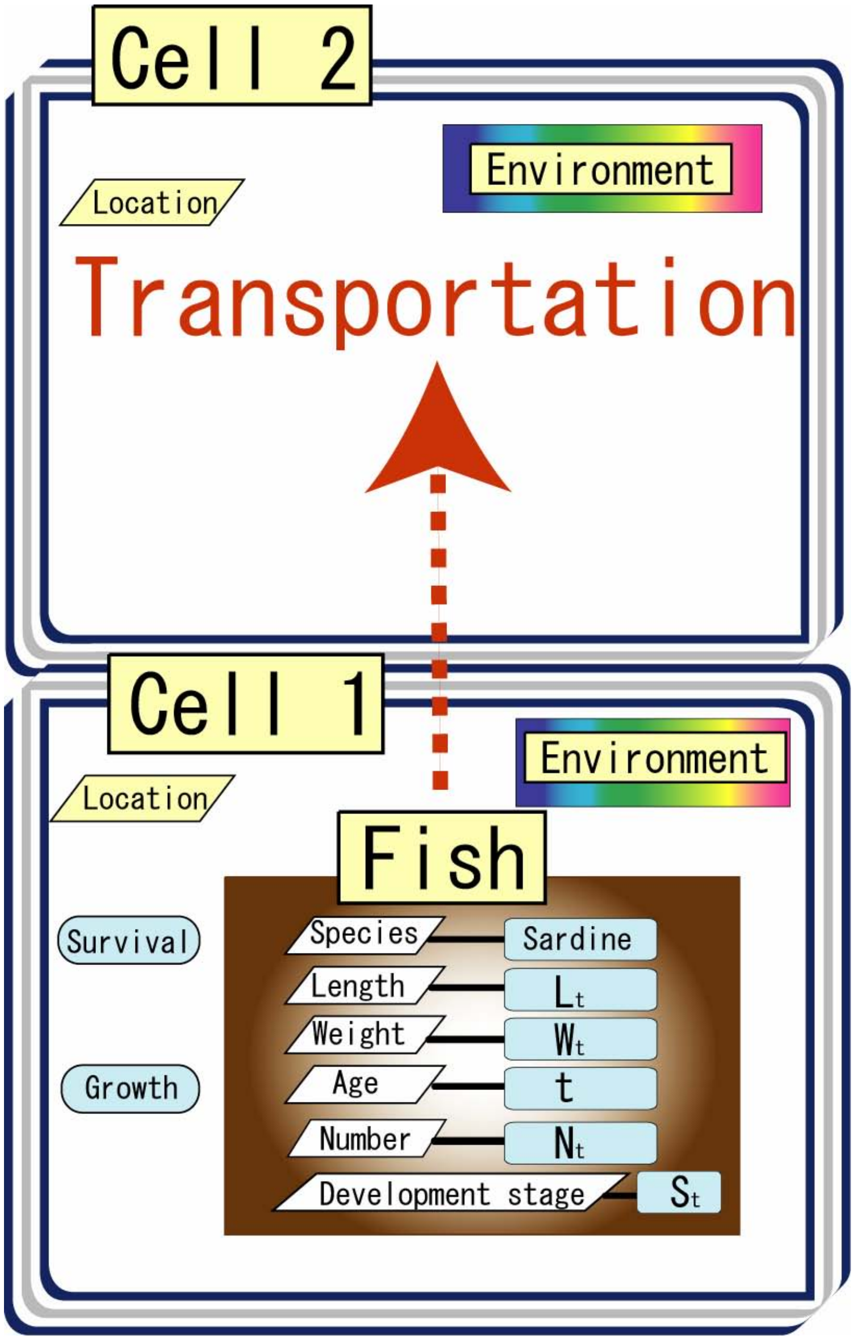
Transportation



Transportation



N_t: the survival number of a *FISH* object at *t* days after spawning

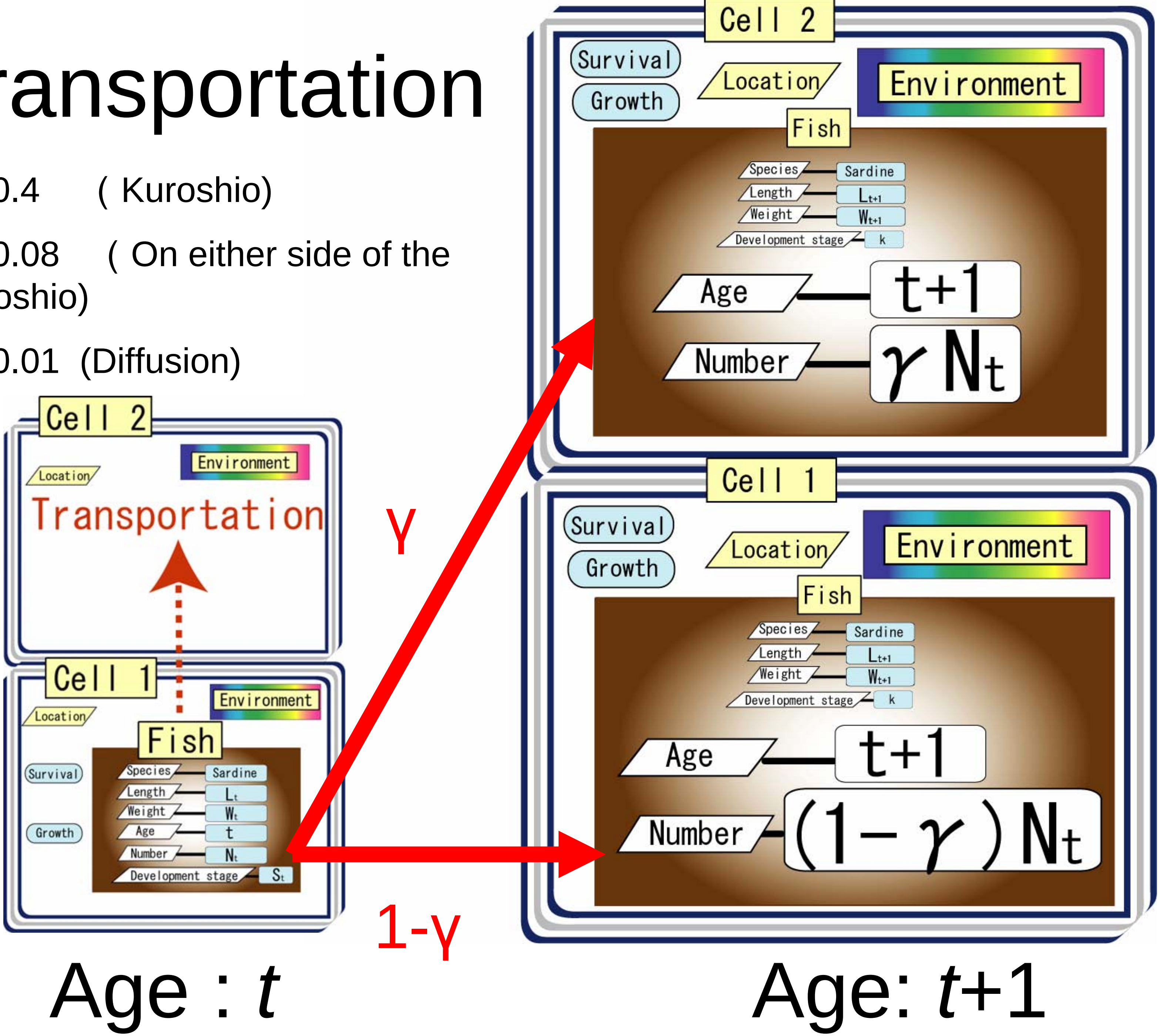


Transportation

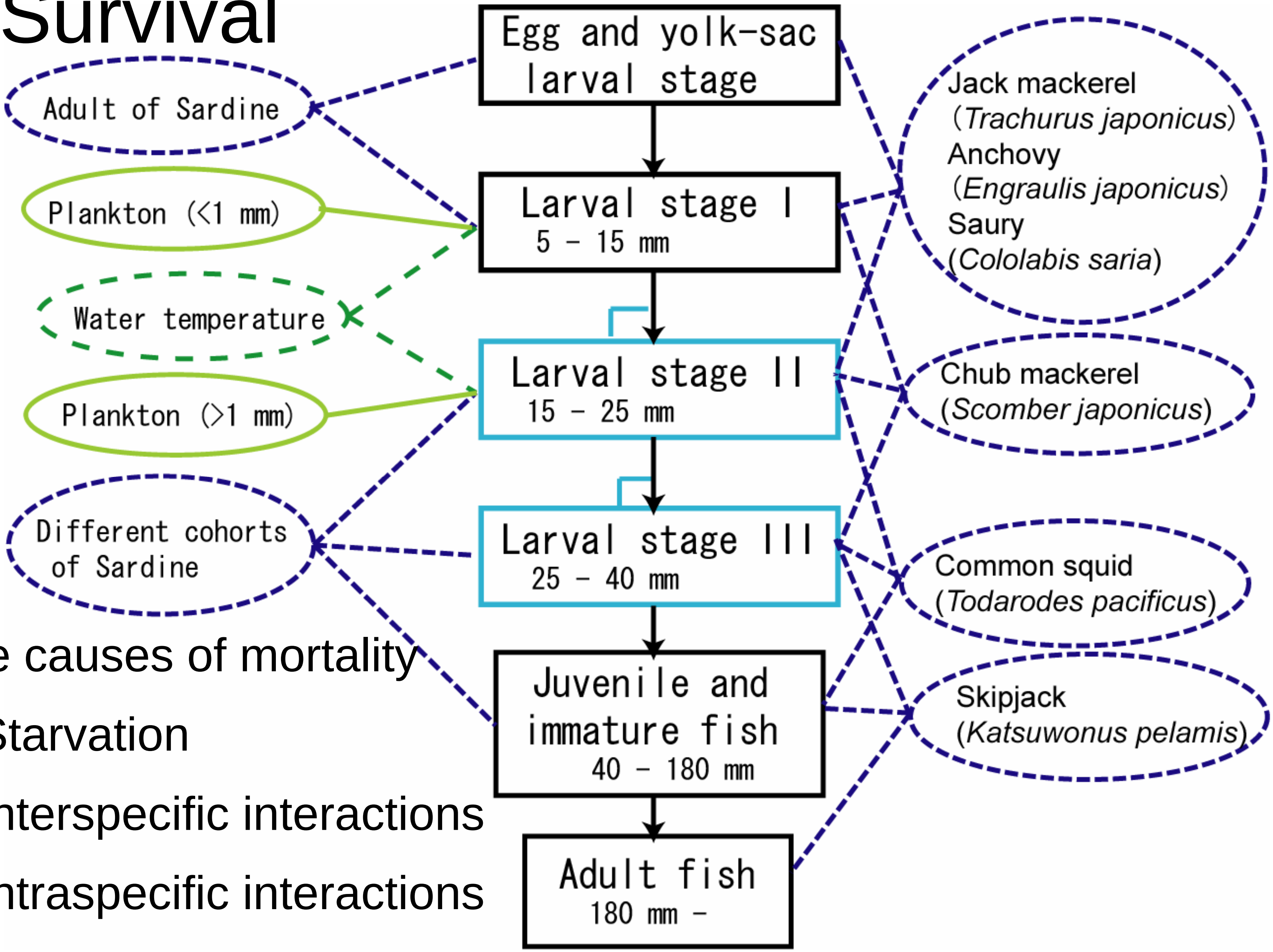
γ = 0.4 (Kuroshio)

γ = 0.08 (On either side of the Kuroshio)

γ = 0.01 (Diffusion)



Survival



The causes of mortality

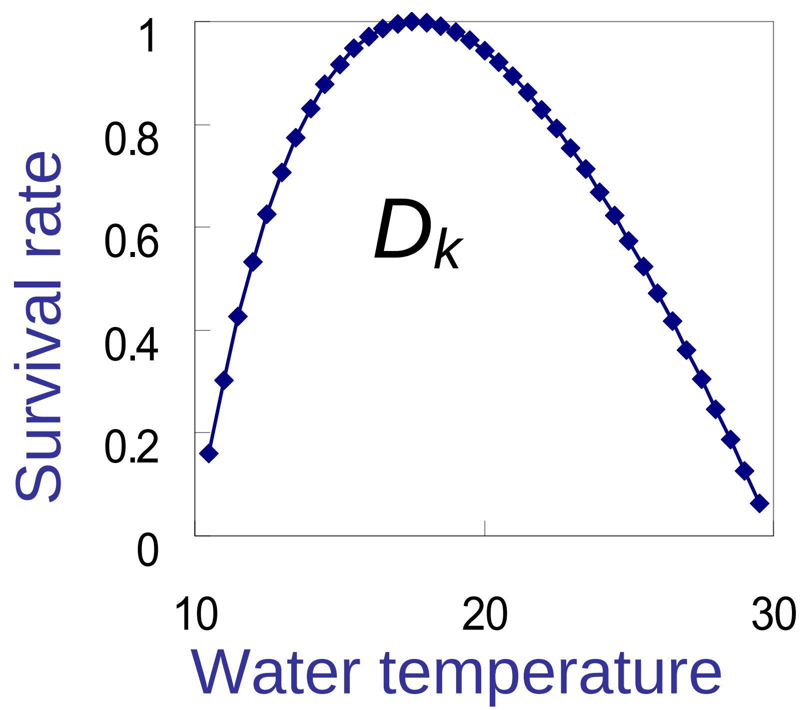
- Starvation
- Interspecific interactions
- Intraspecific interactions
- Water temperature effects

Survival

$$N_{t+1}=N_t D_k \exp(-Z_k)$$

N_t : Survival number of a *FISH* object at t days after spawning

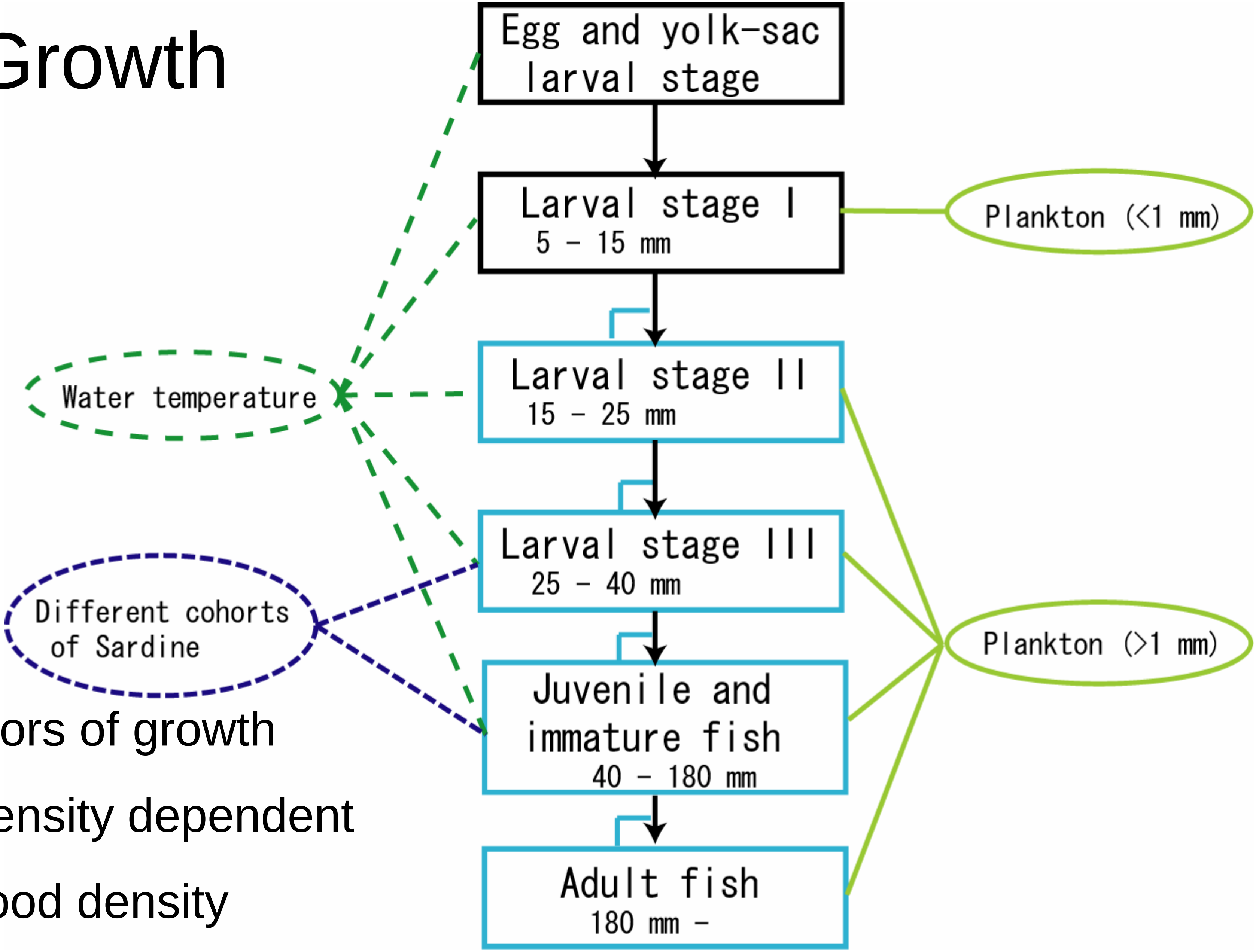
D_k : Survival rate associated with the water temperature



Z_k : Sum of the food density effect, interspecific interactions and intraspecific interactions

k : Development stage

Growth



Factors of growth

- Density dependent
- Food density
- Water temperature

Growth

$$W_t = \delta_t \, C_k \, F_k \, V \, G_t + W_{t\text{-}1}$$

W_t: the weight of a Fish object at t days after spawning

δ_t : Parameter

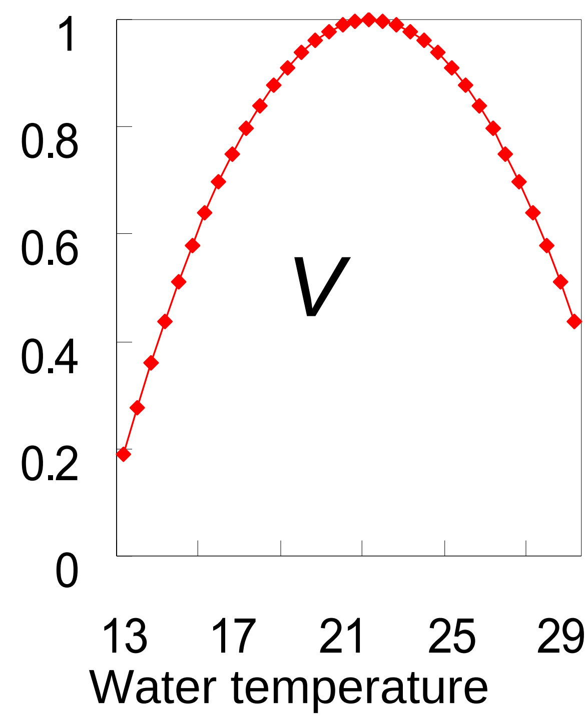
C_k : Density-dependent effect

F_k : Food density effect

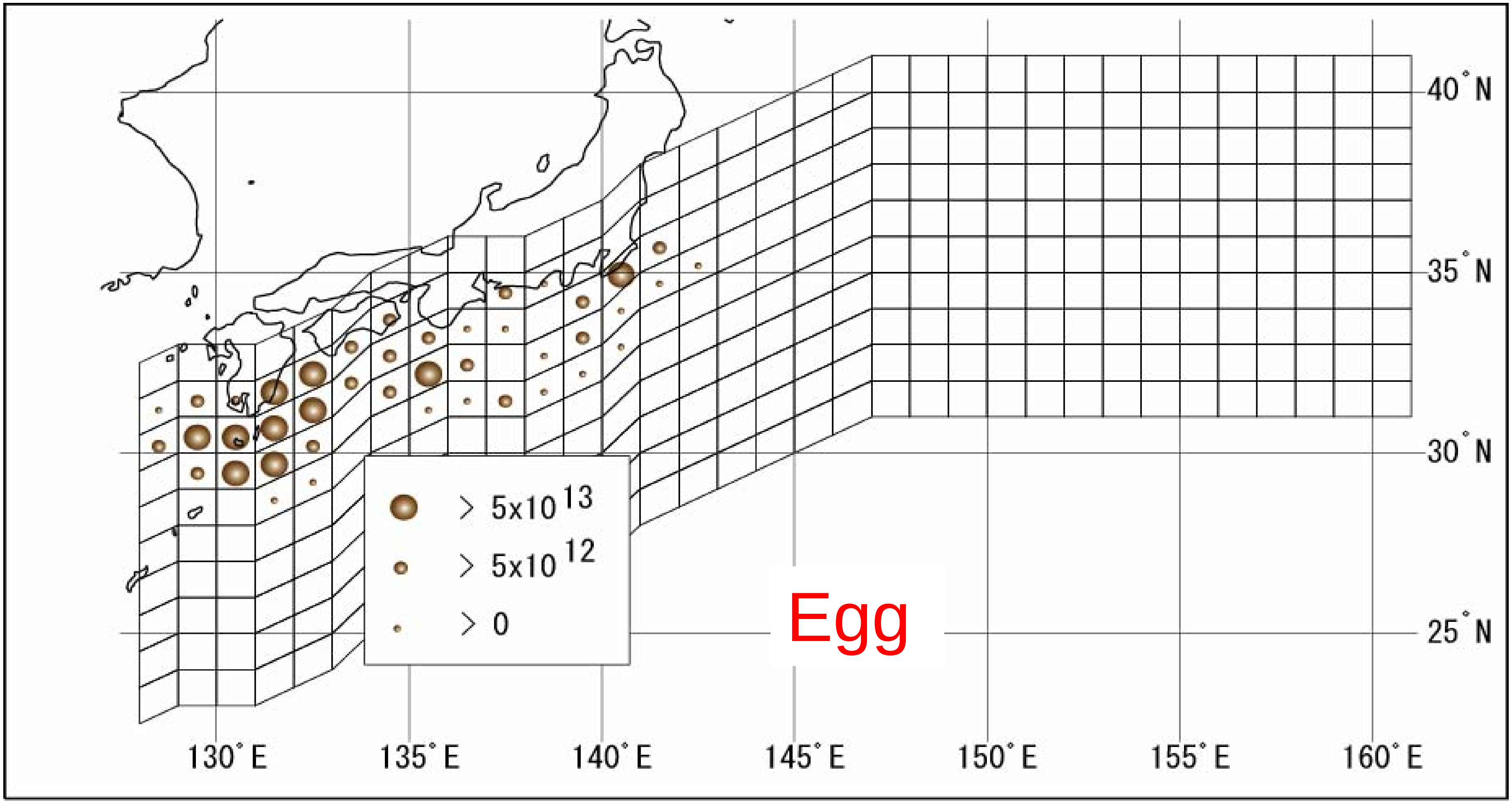
V : Water temperature effect

G_t : Daily increment function

k : Development stage



Distribution of simulated egg and larvae by sub-model OCEAN in 1983



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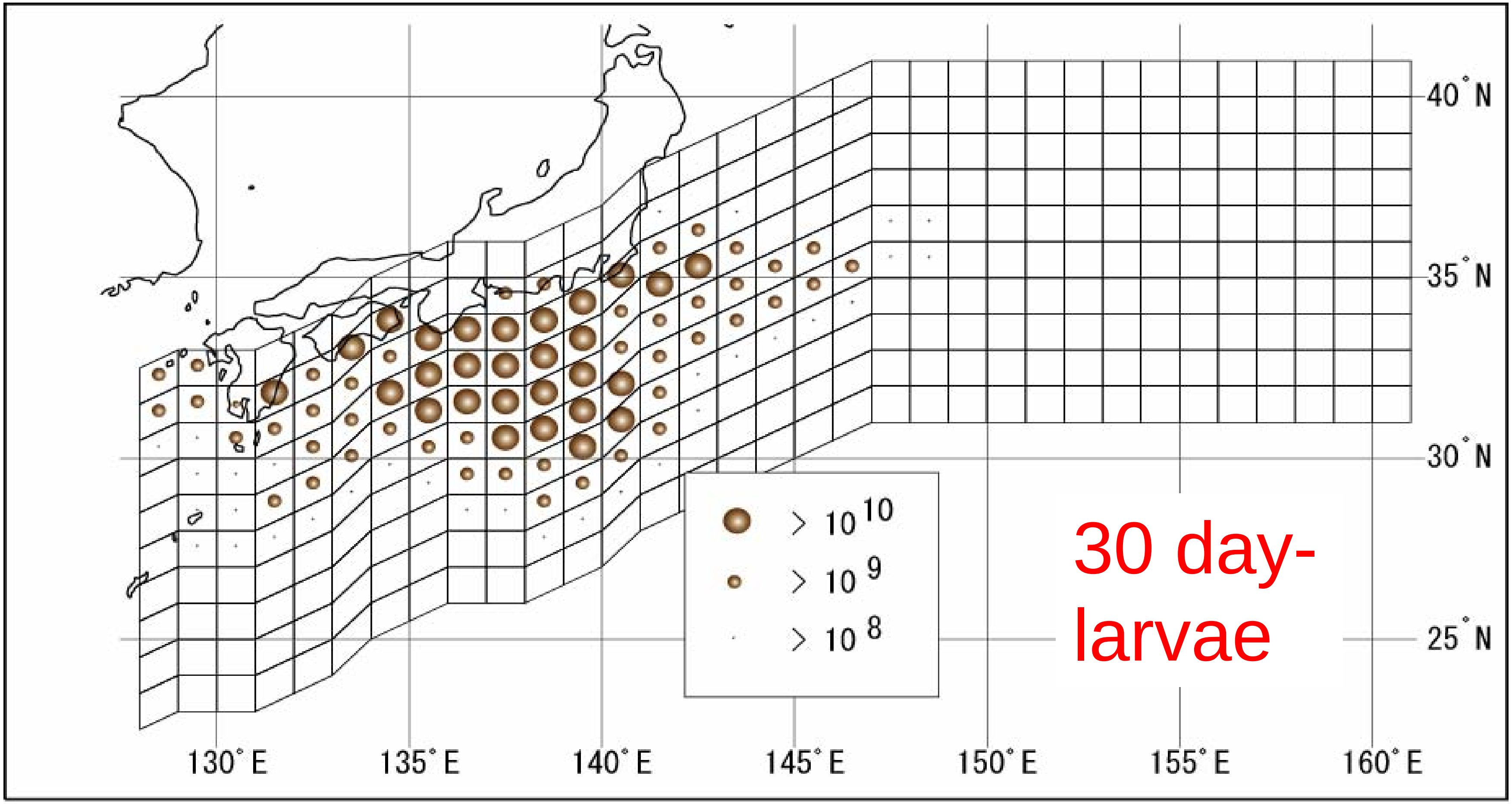

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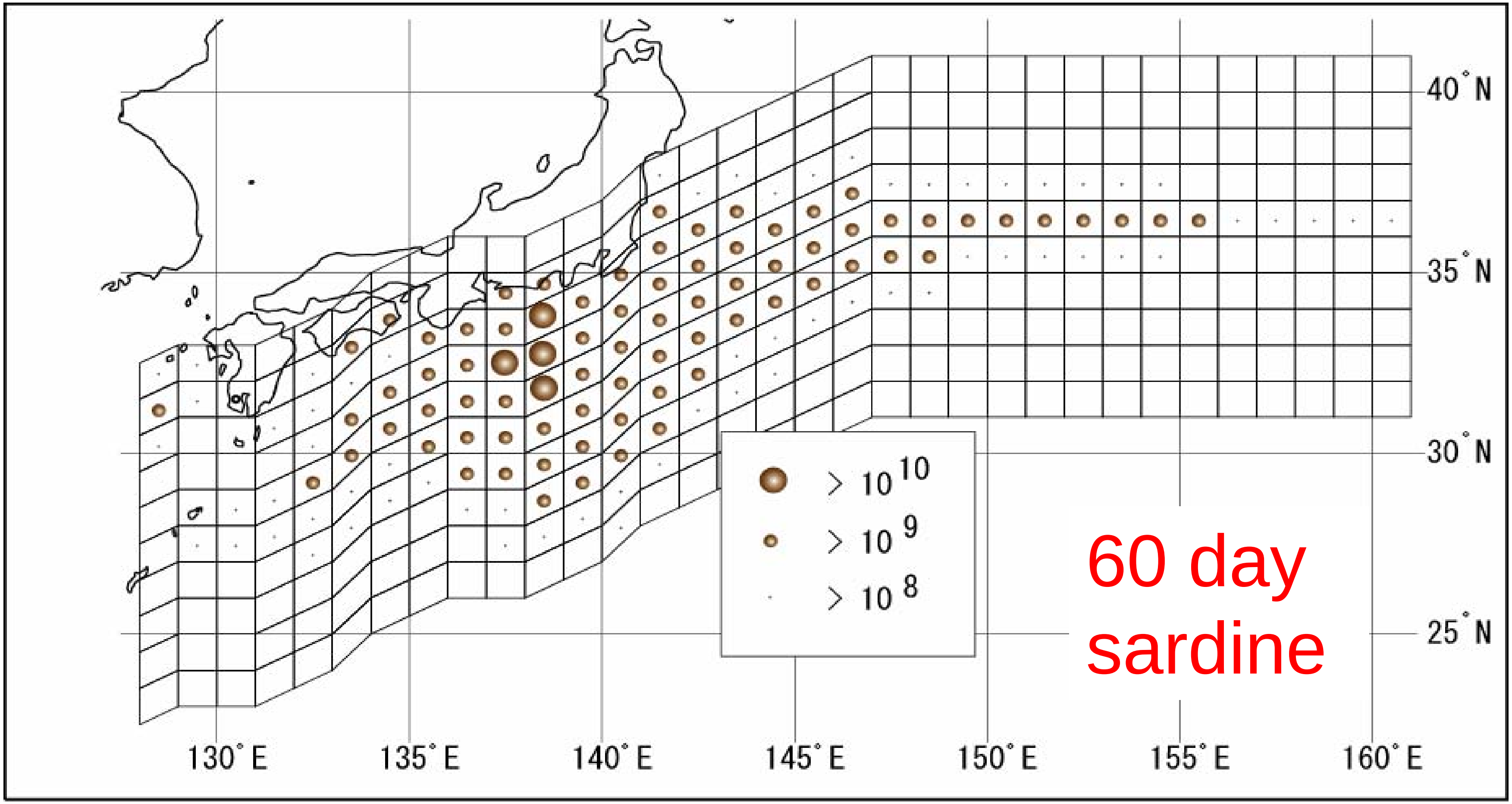
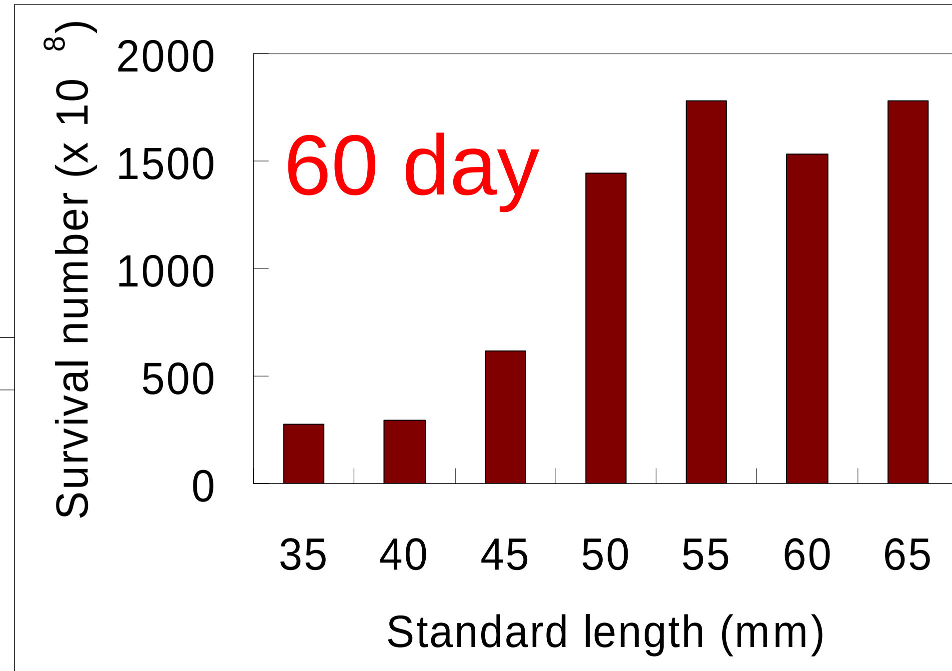
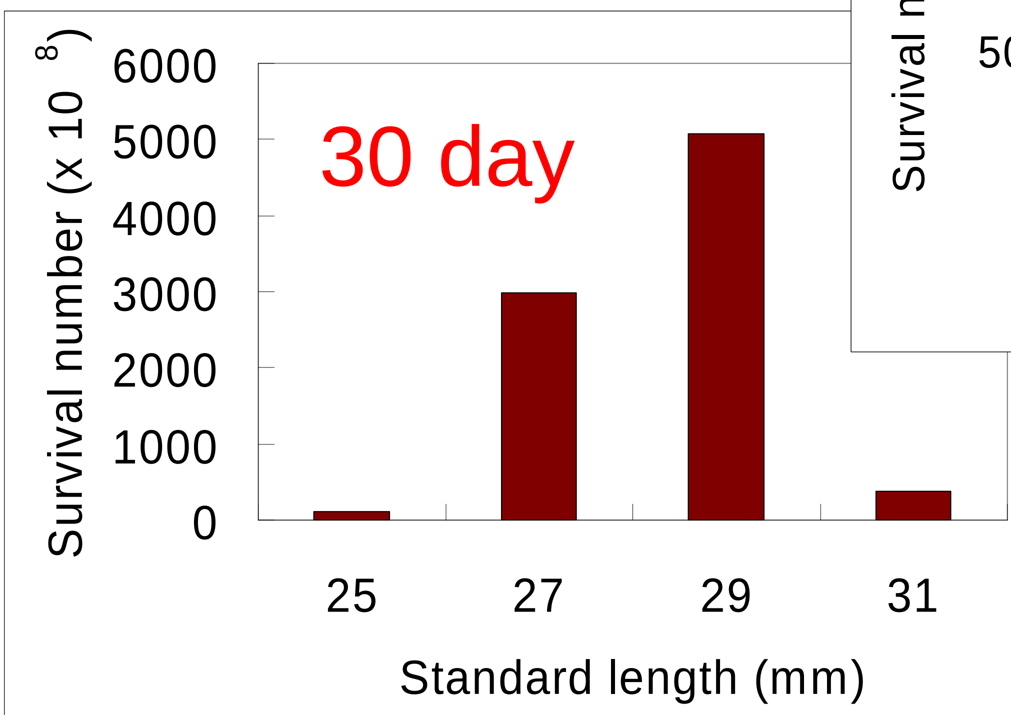


Standard length frequency distribution (Simulated 30 day , 60 day sardine) by sub-model

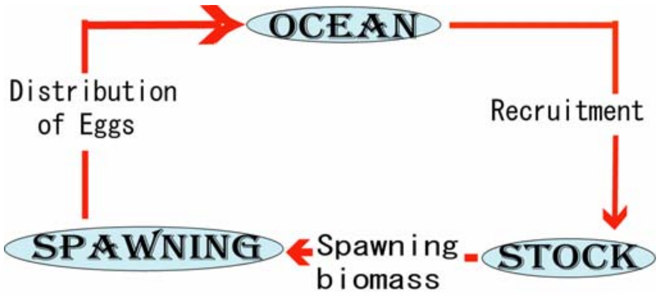
OCEAN

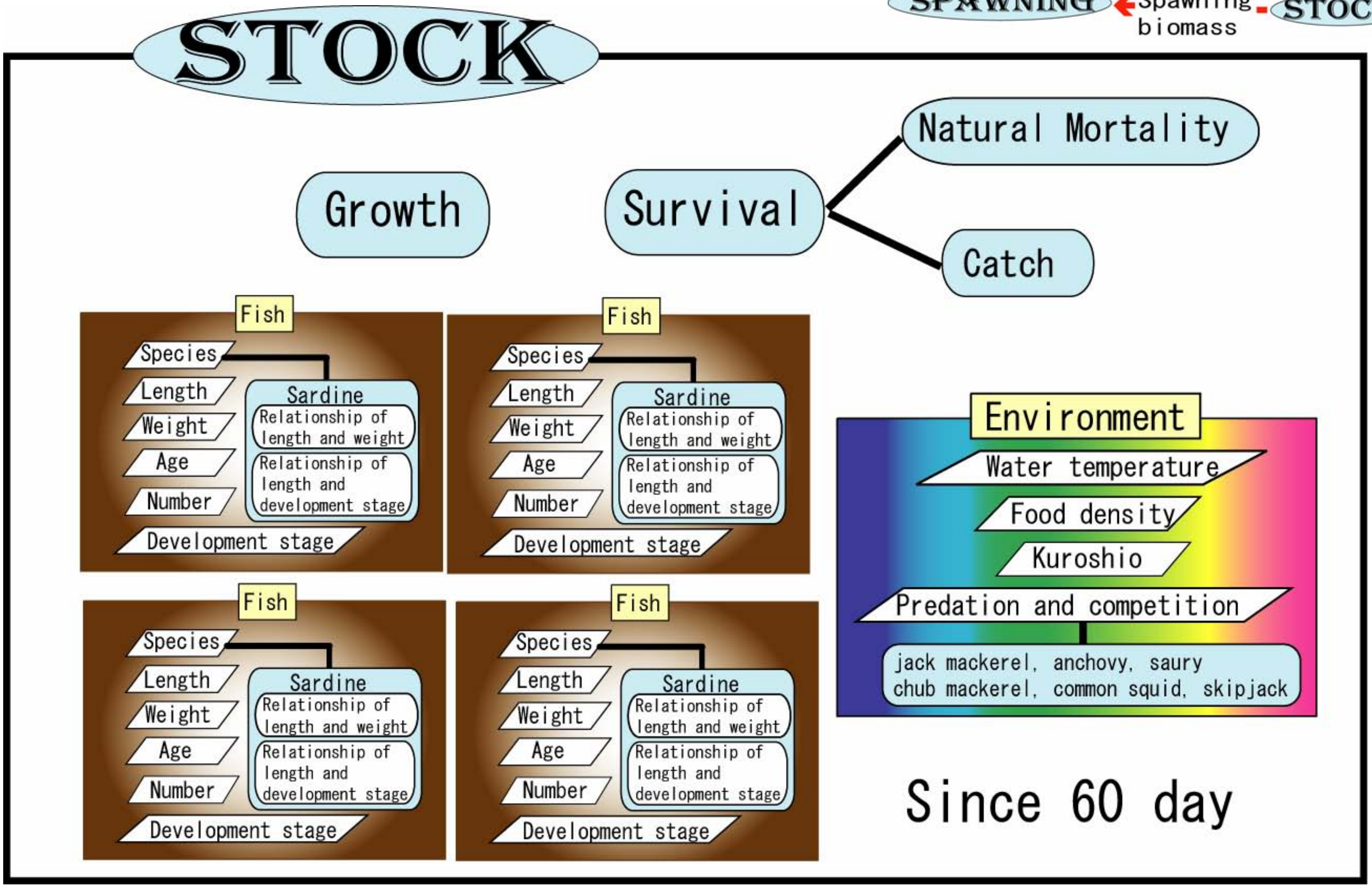
in 1 9 8 3



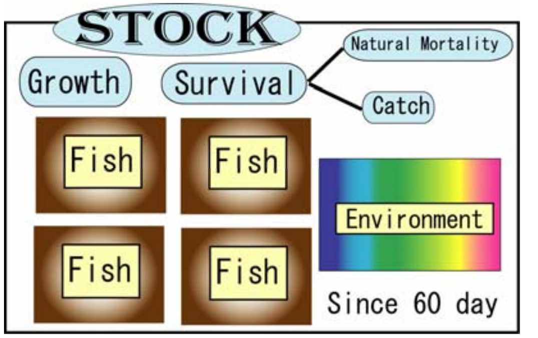


Age-structured model





Age structured model



- N_t : the number of a *Fish* object at t days after spawning

$$N_{t+1}=N_t\, D_k \exp(-Z_k)$$

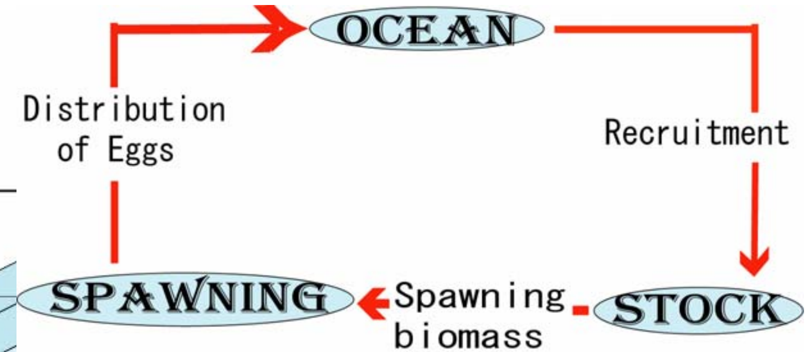
- Assuming the catch at once t_0 for each year

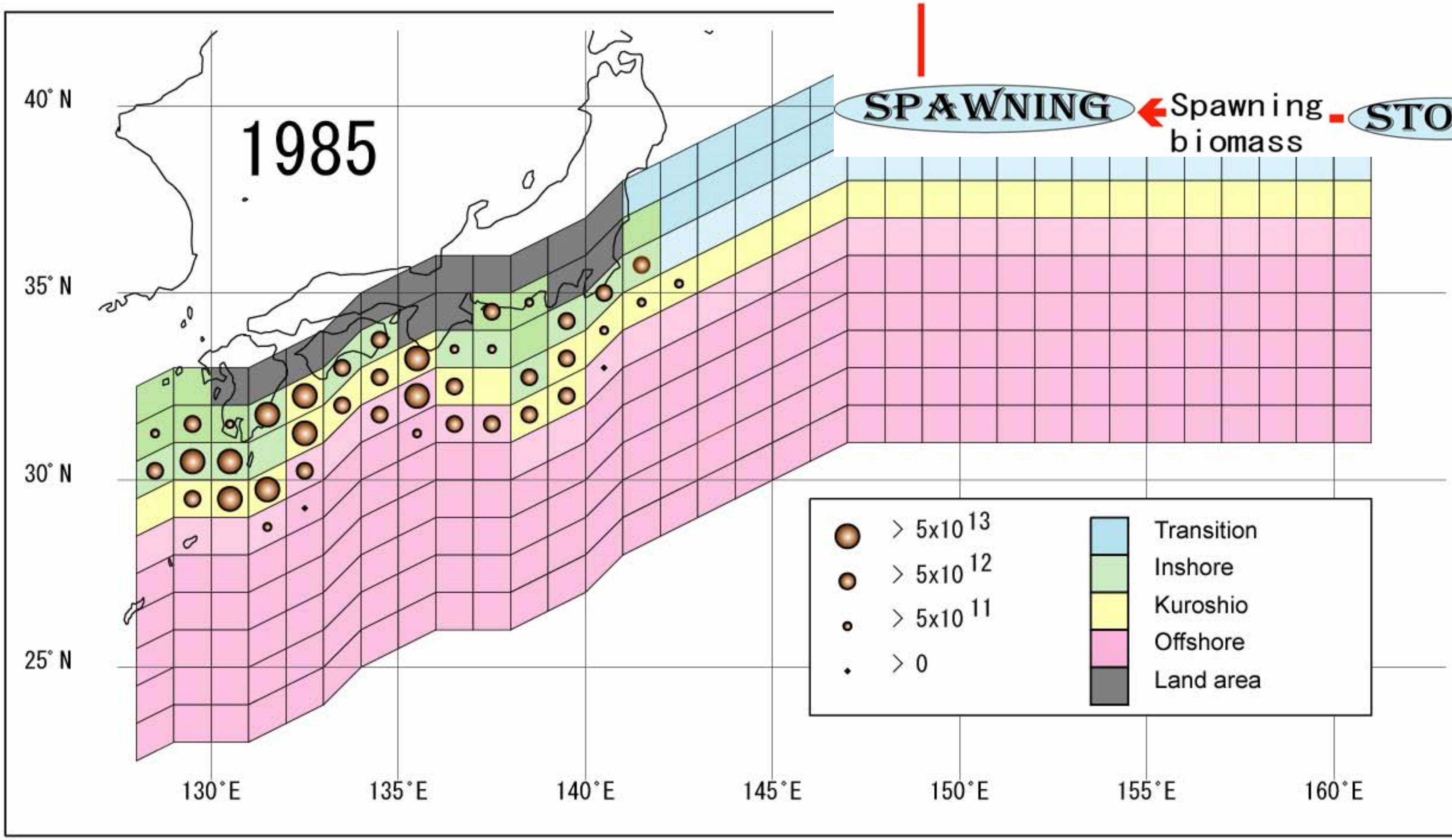
$$Catch=N_{t_0}(1-\exp(-F))$$

$$N_{t_0+1}=(N_{t_0}-Catch)D_k \exp(-Z_k)$$

- k: Development stage

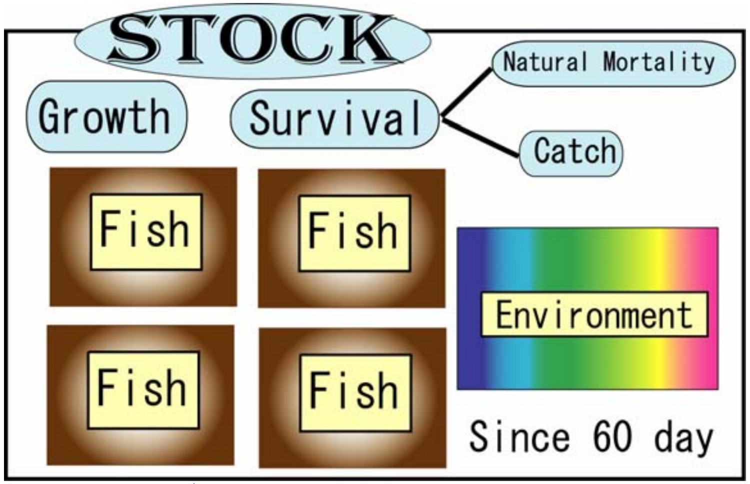
SPAWNING





Distribution of simulated egg

Spawning



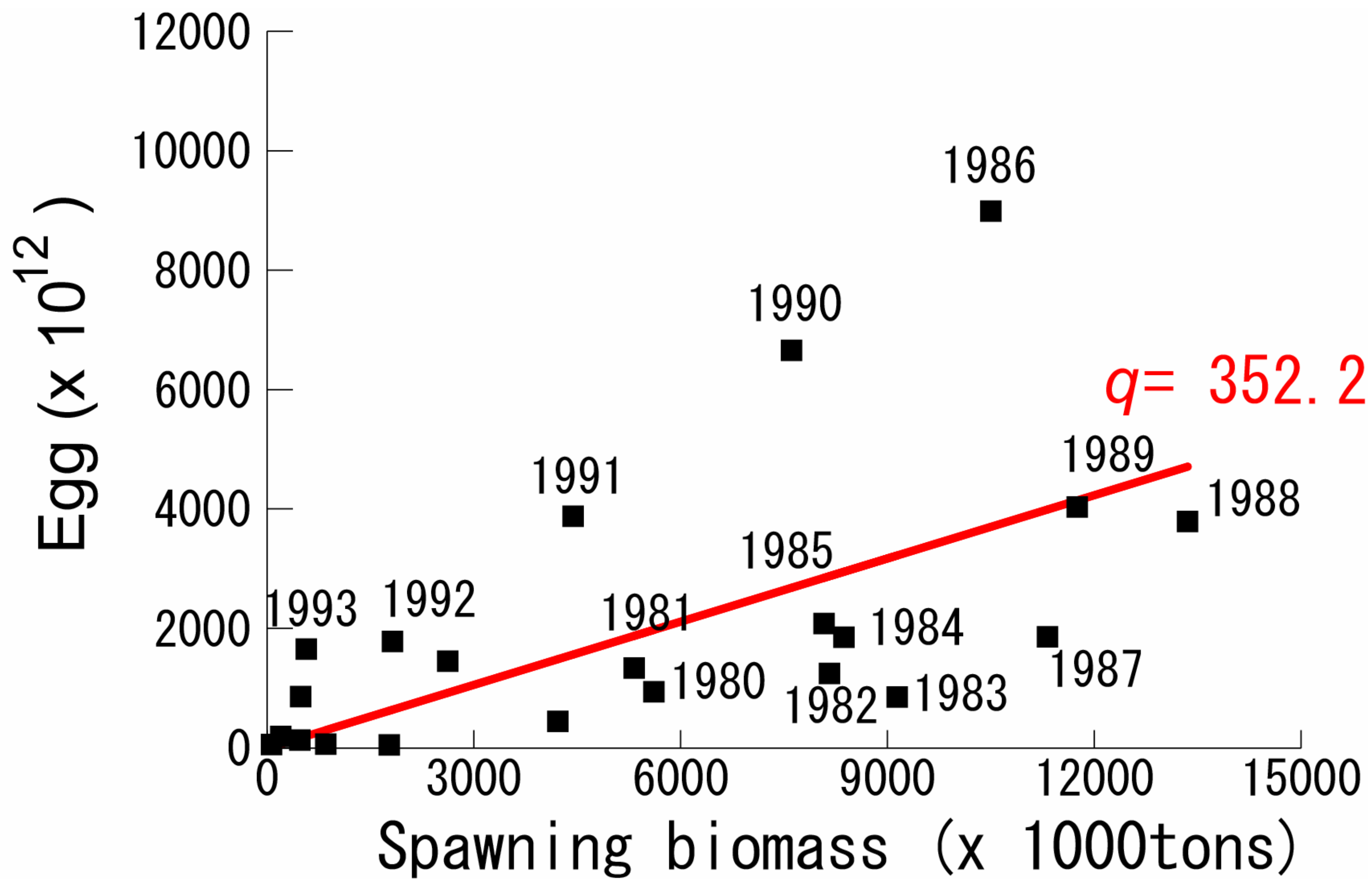
- *Egg* = *q* *Weight*

the total weight (g) of the sardine exceeding 180 mm SL

the total number of eggs of a year

q: Parameter

Actual Spawning Biomass and Total Egg (*Egg* = *q Weight*)



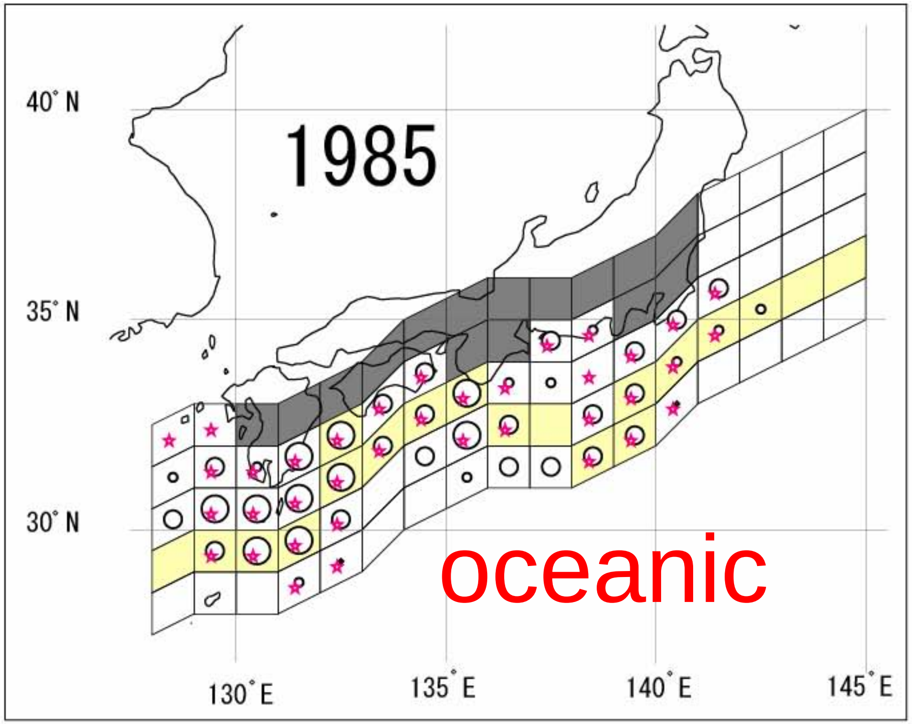
Distribution of eggs

- Assuming that the spawning grounds expanded, if eggs was more than 10^{15}

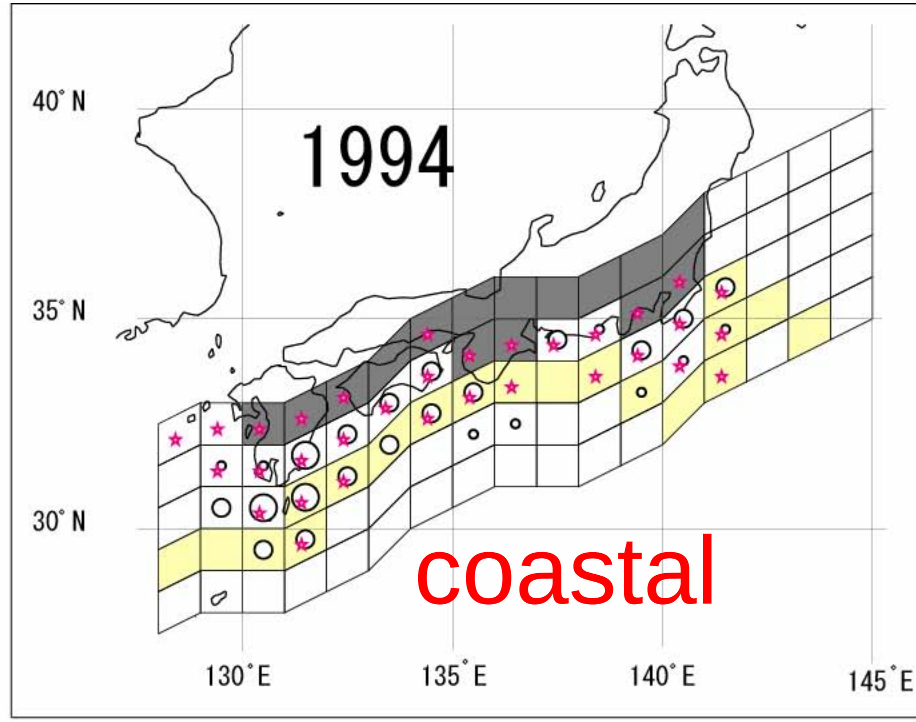
$$N(0) = \begin{cases} Egg\ r1_i\, p1_{ij} & \text{if } Egg < 10^{15} \\ 10^{15} r1_i\, p1_{ij} + (Egg - 10^{15})\, r2_i\, p2_{ij} & \text{otherwise} \end{cases}$$

Distribution of eggs

Egg > 10^{15}



Egg < 10^{15}

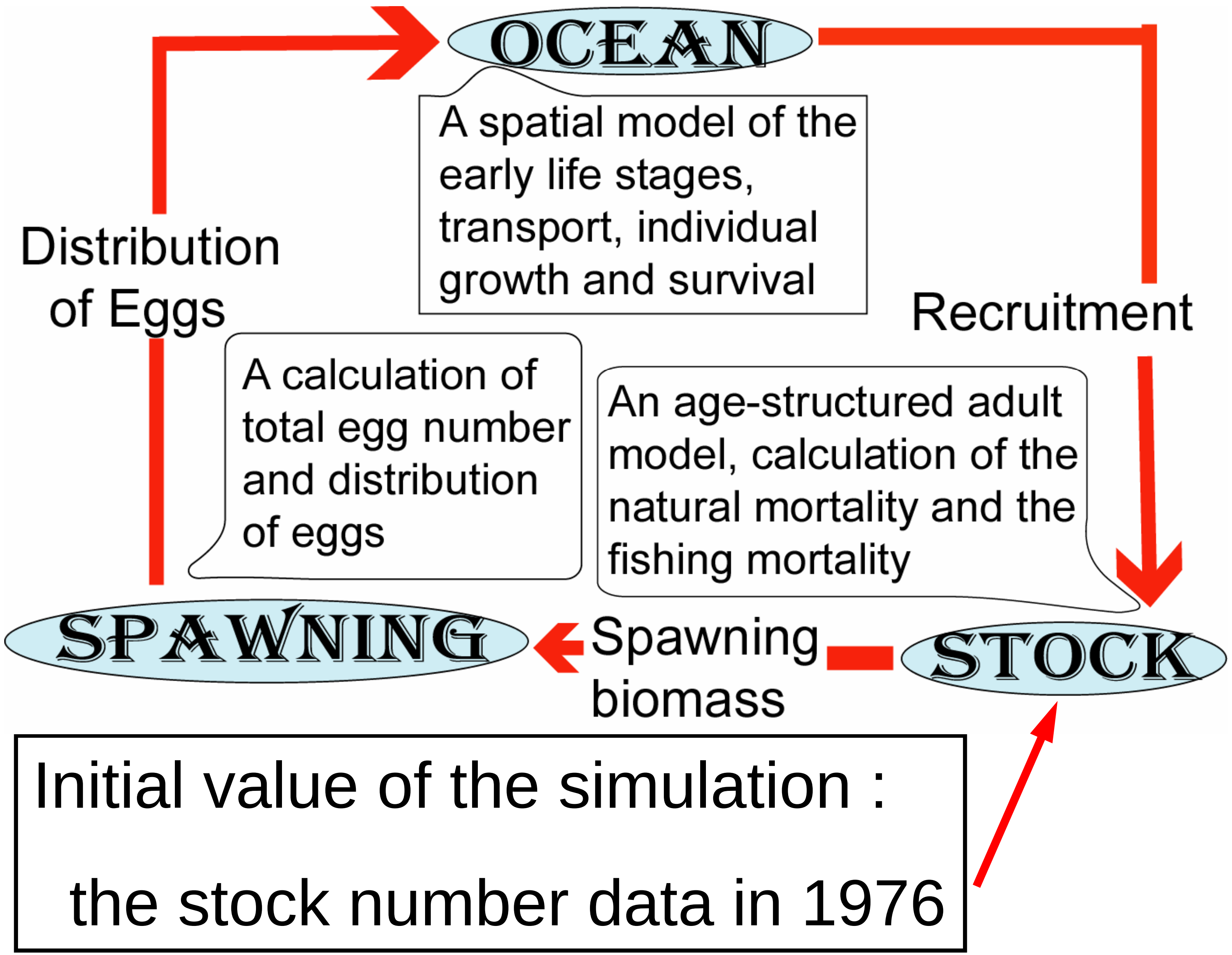


Simulated (○) and actual (★) distribution of eggs

○ > 5×10^{13}
○ > 5×10^{12}
∘ > 5×10^{11}
• > 0
★ Actual egg data (>0)

Land area
Kuroshio

Concepts of Model



Input Data

- Sea surface temperature

  Oceanographic normals and analyses for the period 1971-2000 published by the Meteorological Agency

- Location of Kuroshio axis, Ocean current statistics

  Prompt Report of Oceanographic Conditions, published by the Japan Coast Guard

- Stock abundance index of jack mackerel, anchovy, saury, common squid and skipjack

  Catch data compiled by the Ministry of Agriculture, Forestry and Fisheries

- Stock abundance index of chub mackerel

  Stock assessment Report

- Zooplankton biomass

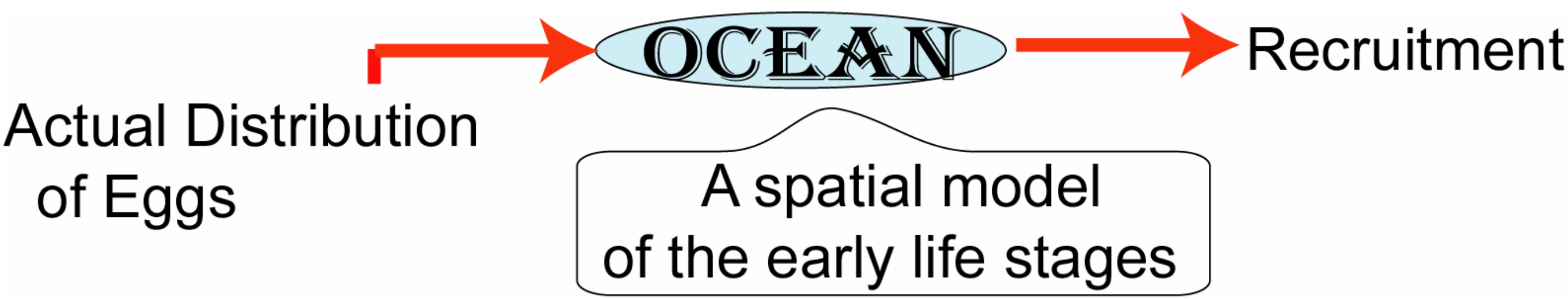
  Nakata et al. (2001), Nakata and Koyama (2003), Odate (1994)

Parameter

The correlation

of the simulated survival number and the actual abundance of year-class of sardine in 1978-1990

> 0.7



Contents

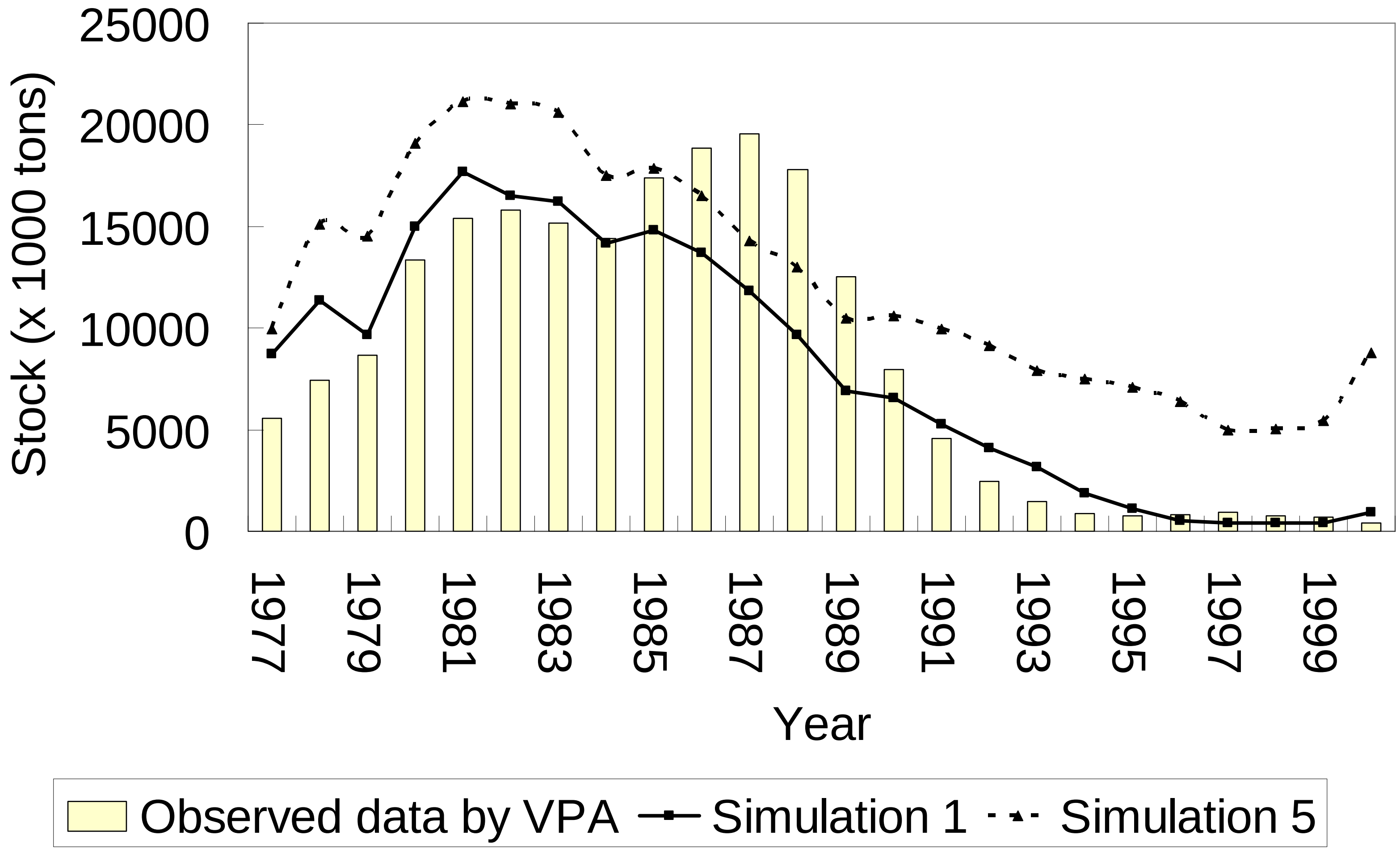
Simulation Planning

OD: observed data, CD : constant data

Simulation	1	2	3	4	5
Fishing mortality	OD	OD	CD	CD	0.0
Environmental data	OD	CD	OD	CD	OD
Interspecific relationship	OD	CD	CD	OD	OD

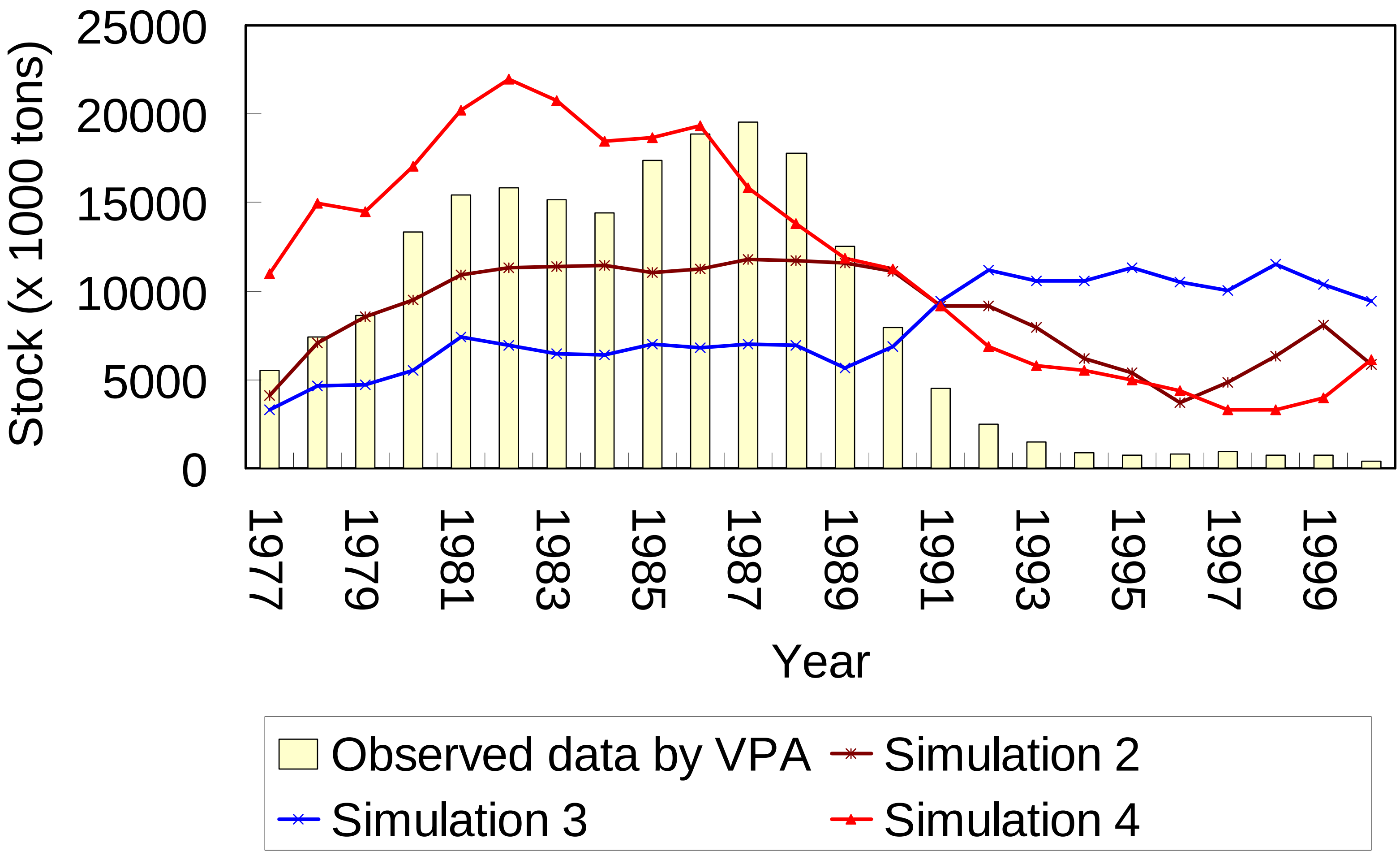
Result (Stock)

Simulation	1	2	3	4	5
Fishing mortality	O	O	C	C	0.0
Environmental data	O	C	O	C	O
Interspecific relationship	O	C	C	O	O

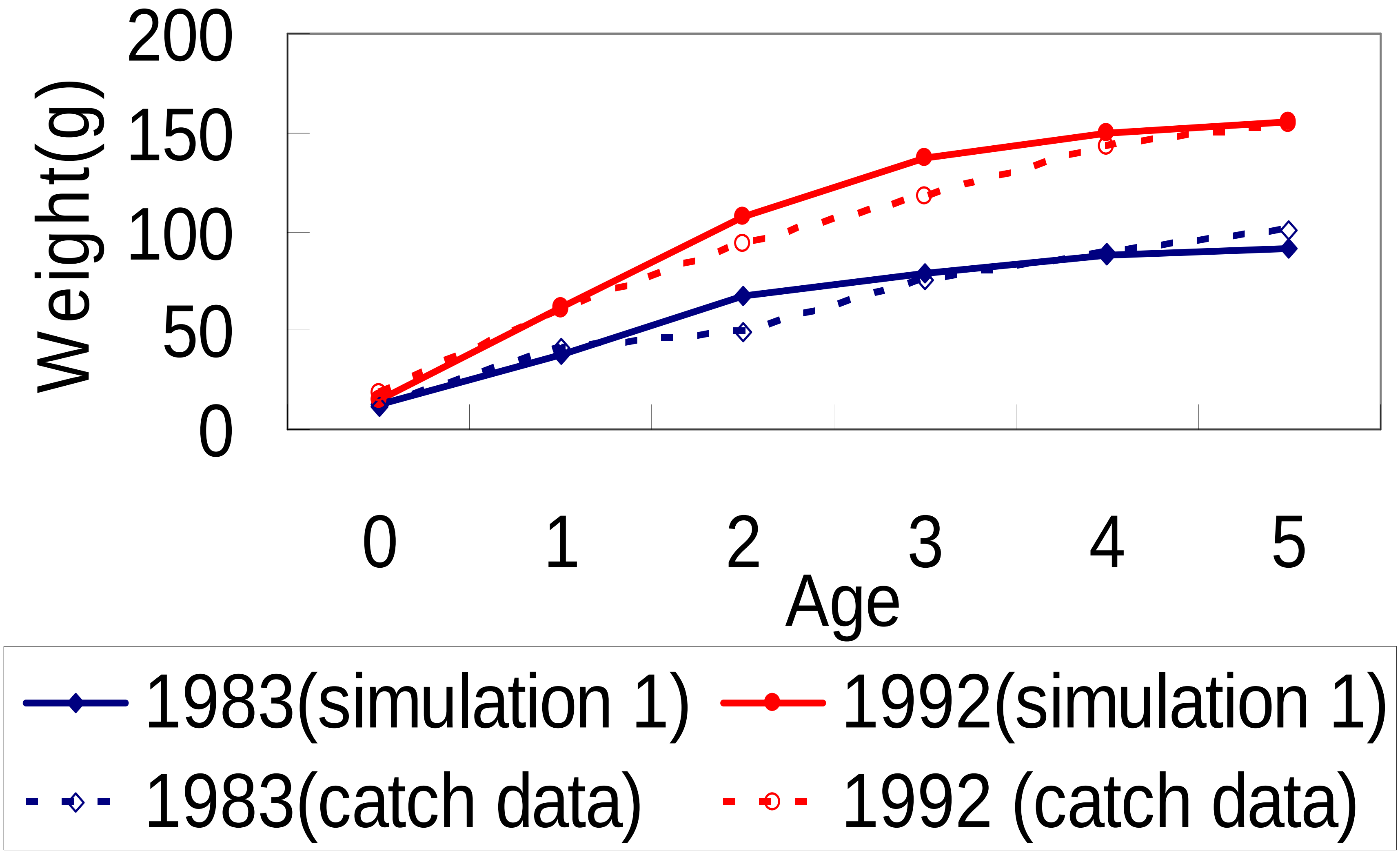


Result (Stock)

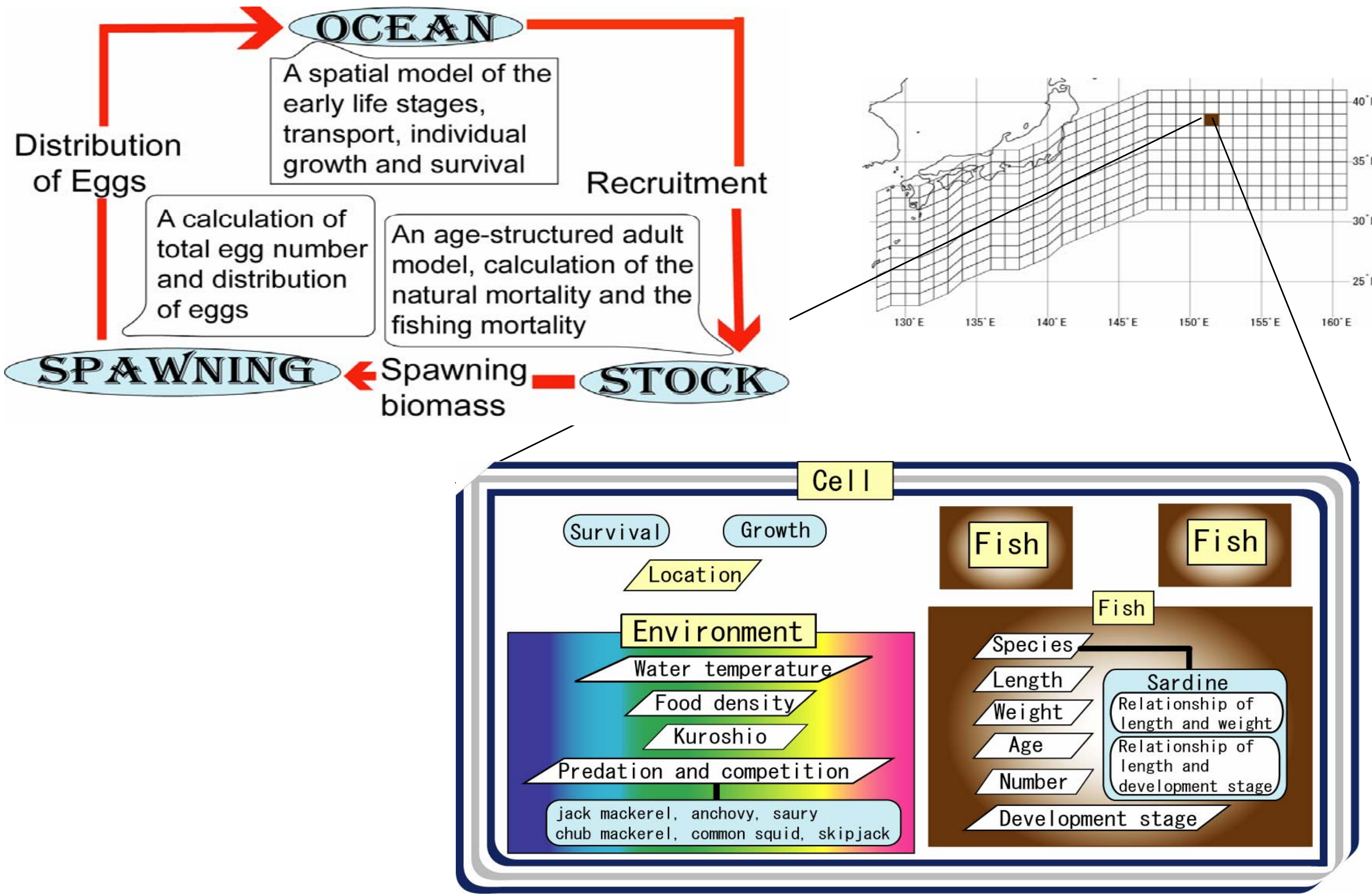
Simulation	1	2	3	4	5
Fishing mortality	O	O	C	C	0.0
Environmental data	O	C	O	C	O
Interspecific relationship	O	C	C	O	O



Result (Individual weight)



Summary



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Length
Weight
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Number
Development stage
Sardine
Relationship of length and weight
Relationship of length and development stage

Summary

- Development of the individual–based life cycle model, consisting of spatial early-life stage and age-structured adult sub-models

- Population dynamics under heterogeneous environmental conditions, in the early life-stage sub-model

- Object oriented modeling to link the spatial stage-based model with the population-based model

- Flexibility and extensibility in the model