Review of Population Dynamics of Japanese Sardine in the Northwestern Pacific

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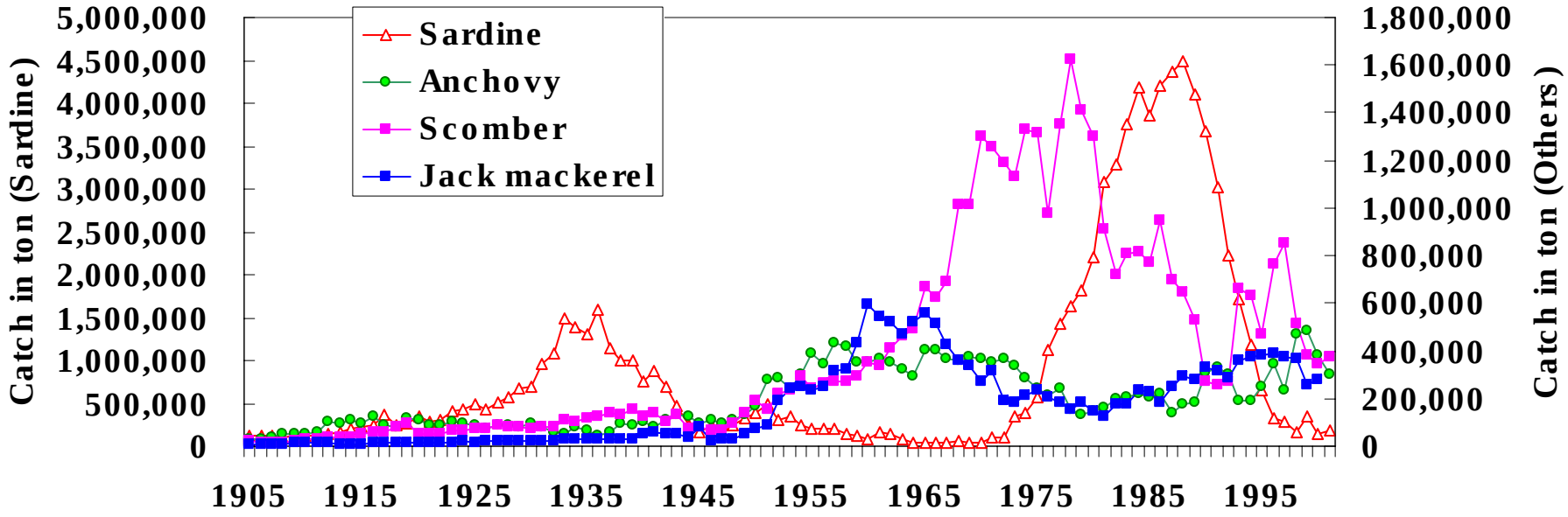
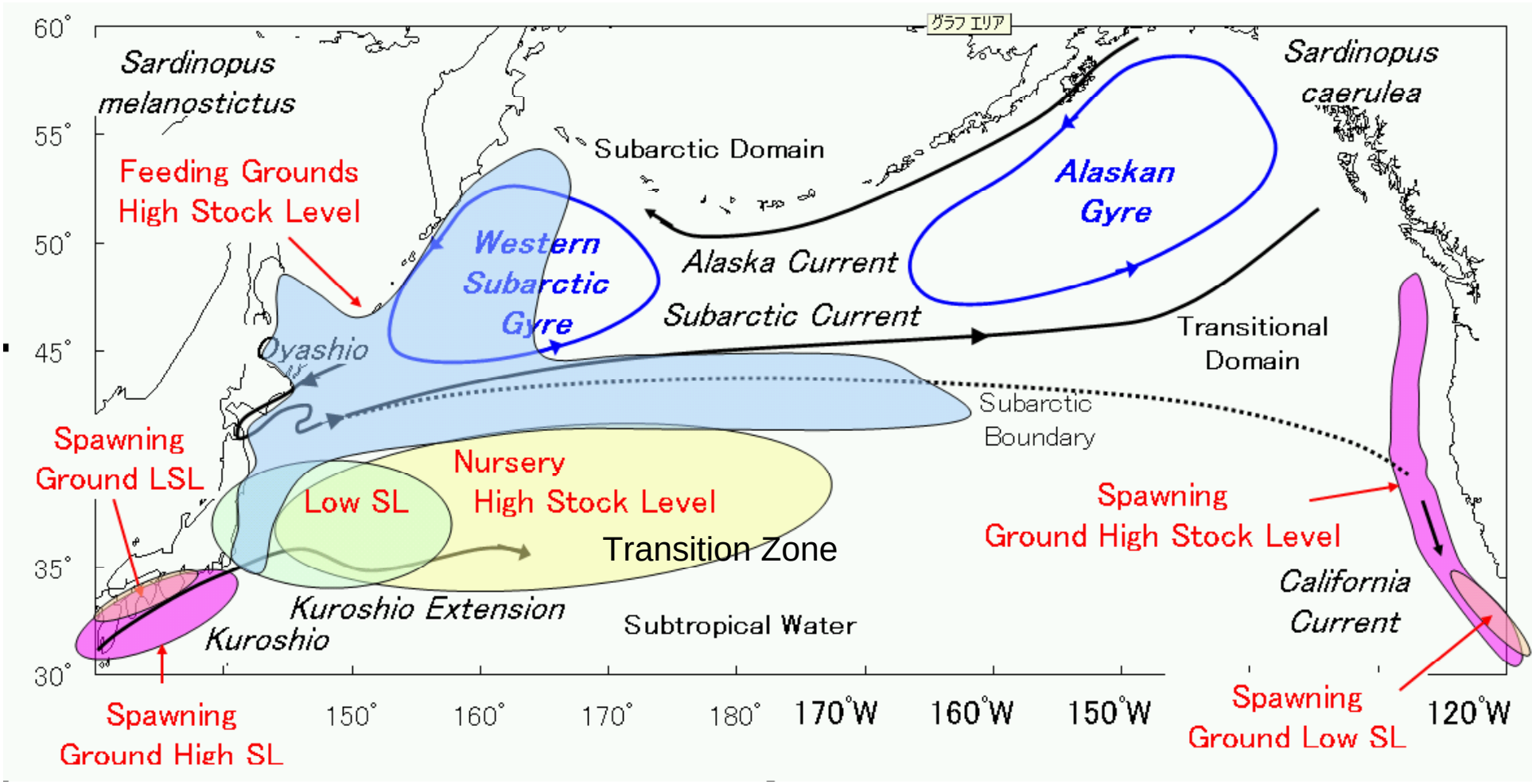
- Distribution, migration and population dynamics
- Inter-annual and inter-decadal variations
- Possible factors causing these variations
- Existing models for Japanese sardine dynamics

Japanese Catch of Japanese Sardine, Anchovy, Mackerels and Jack during 1905-2001



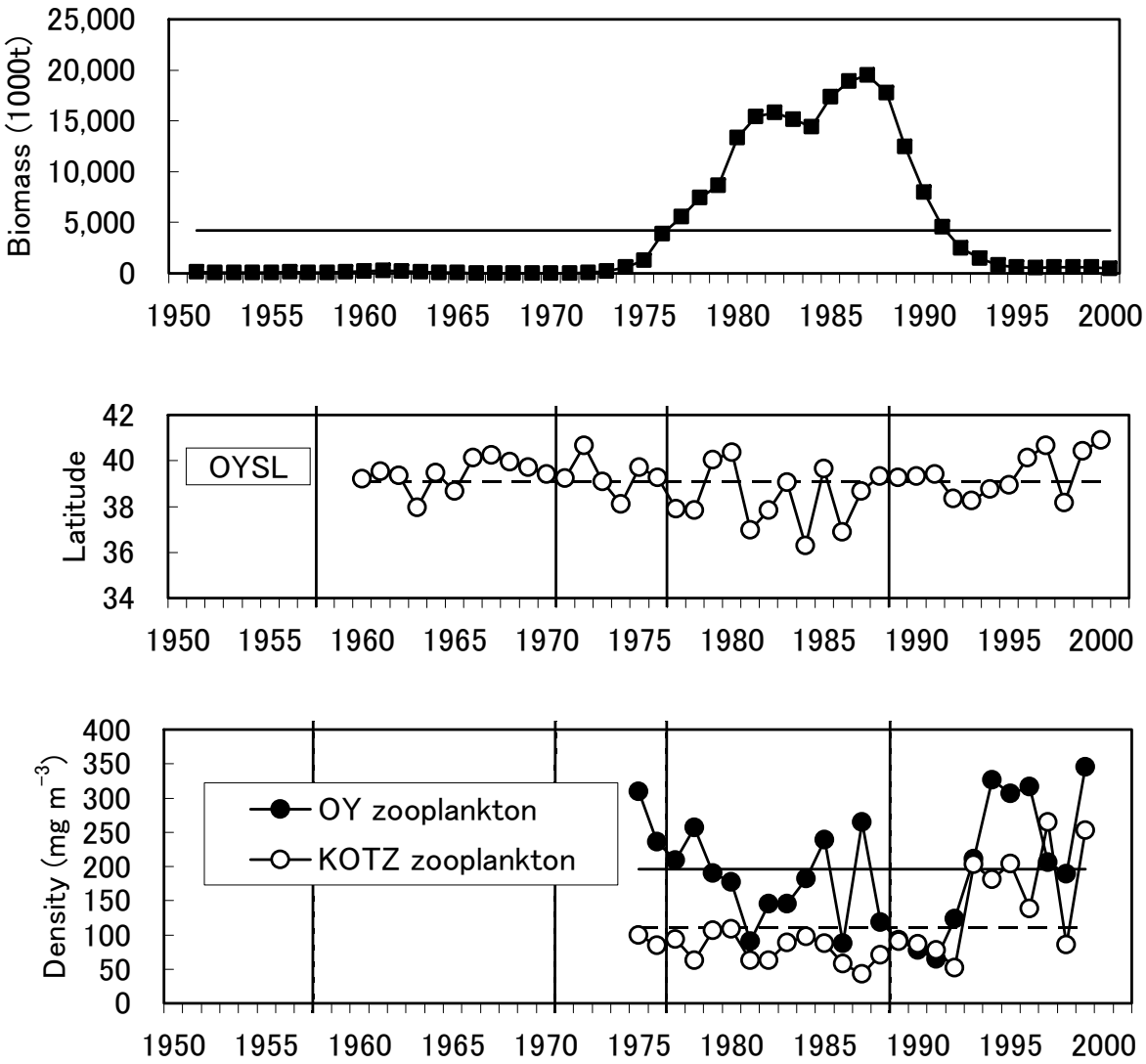
Scomber: chub mackerel + spotted mackerel

Distribution and migration of Japanese sardine and California sardine



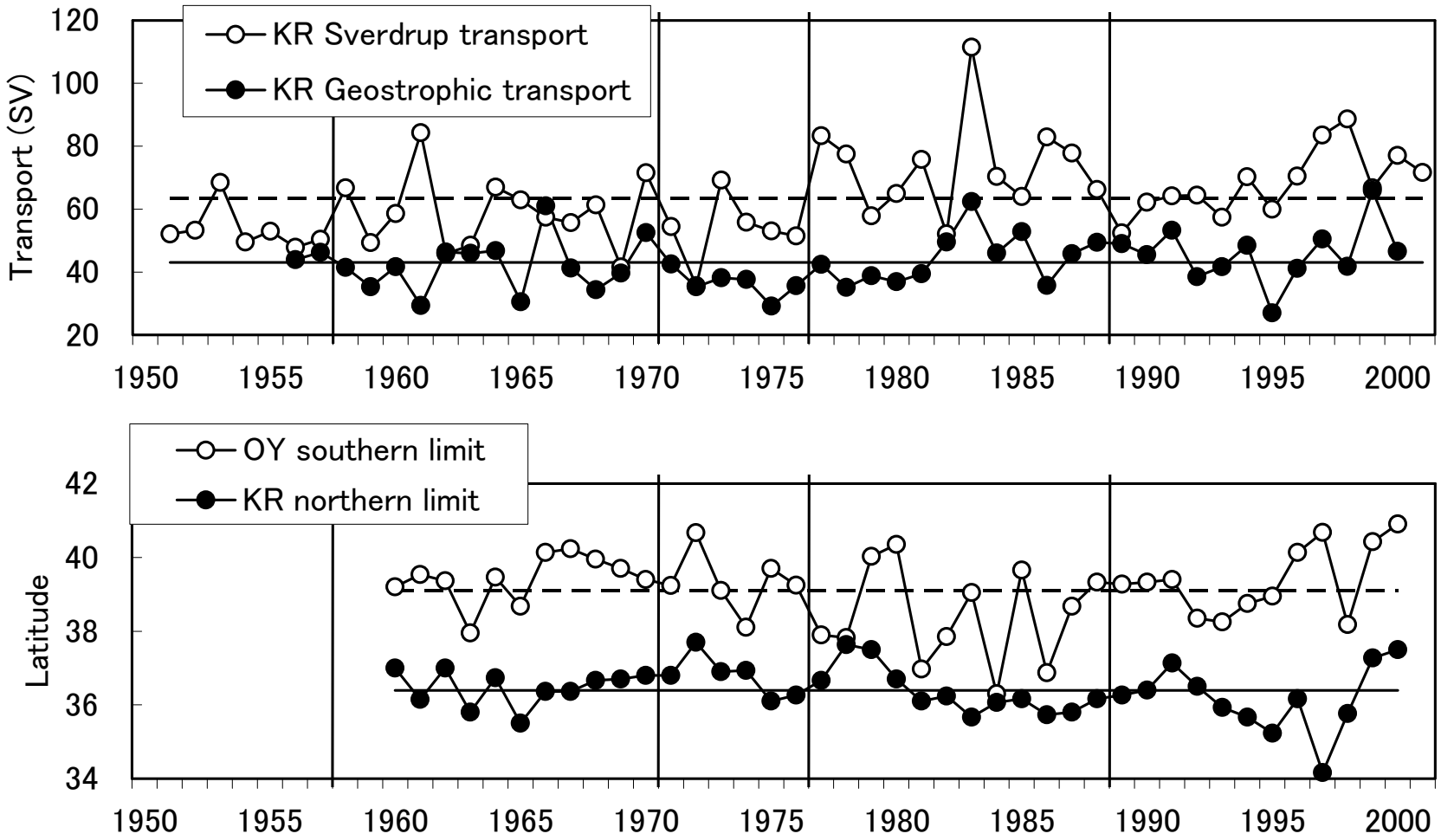
Sardine Biomass, Oyashio Southern Limit (OYSL) and Zooplankton Density in Oyashio and KOTZ

(Yatsu et al., in press Fish Oceanogr)



- *Sardine biomass increased with intensified Oyashio*
- *Intrusion of Oyashio would enhance productivity*
- *But, ZP density was inversely related to Oyashio*
- *Predation by sardine (Tadokoro et al., in press Fish. Oceanogr.) : Sardine fed 32-138% of daily Neocalanus production in 1984*

Kuroshio Transport, Kuroshio Northern Limit and Oyashio Southern Limit



Winter SST of Kuroshio Extension South Area (KESA) and Early Mortality Noto and Yasuda (1999, CJFAS)

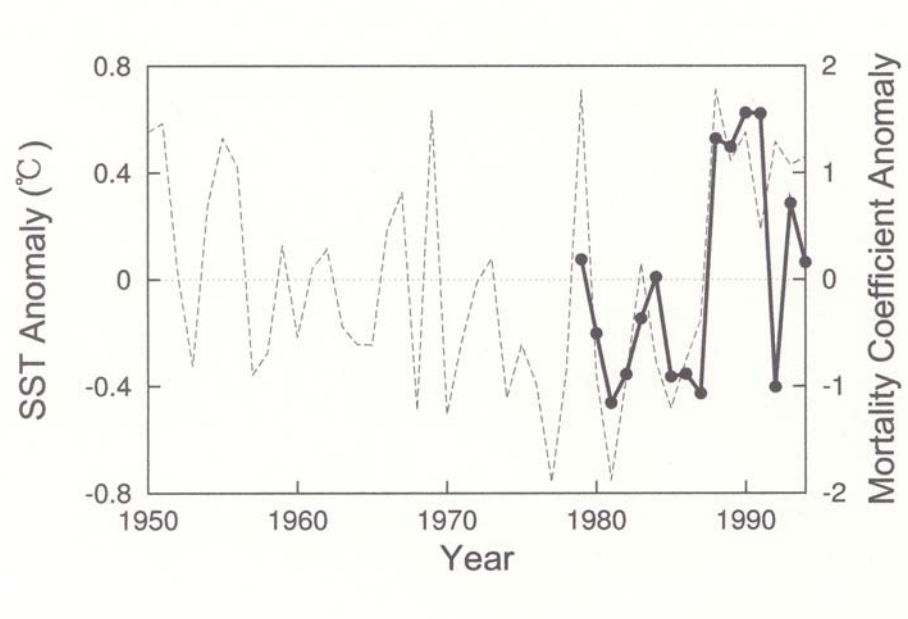
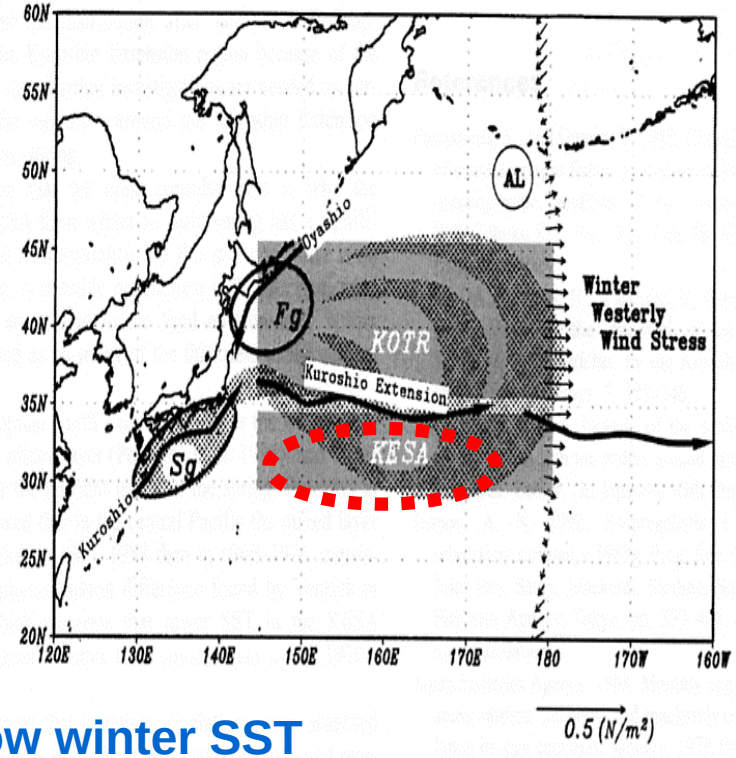


Fig. 10. Schematic illustration of the possible migration route of the Japanese sardine (broken curves) and winter atmosphere–ocean conditions. Sg, spawning grounds; Fg; feeding grounds; AL, Aleutian Low. $N = kg \cdot m \cdot s^{-2}$.

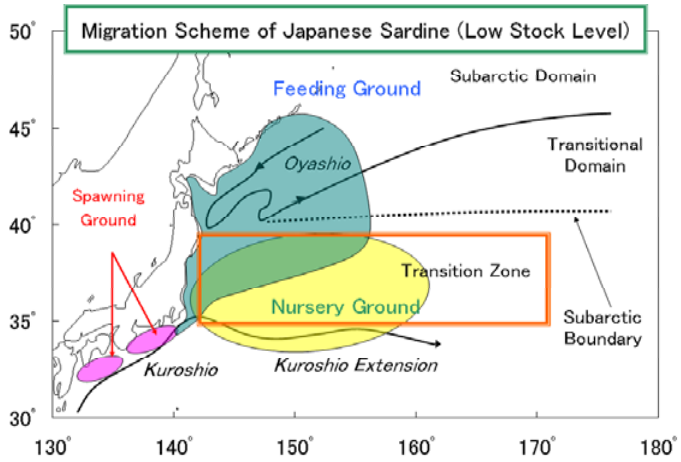


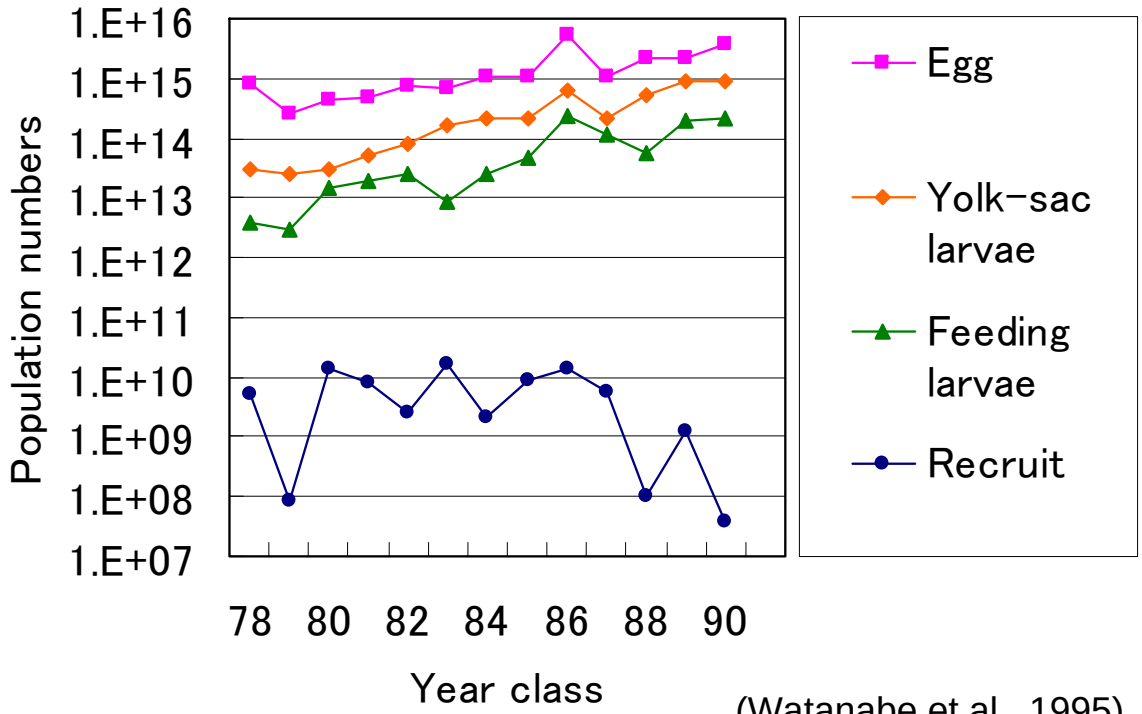
Possible mechanistic link

Intensified vertical mixing in winter ⇒ Low winter SST

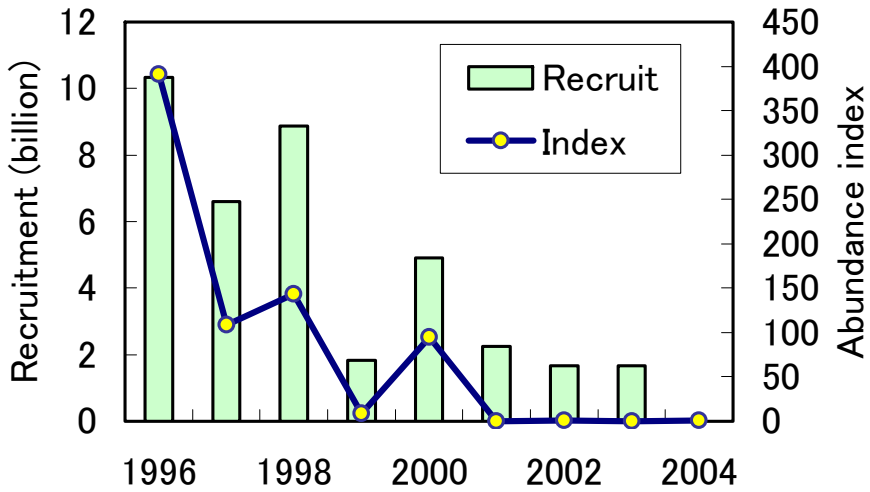
Intensified westerly wind ⇒ More transport of Oyashio waters ⇒ Low SST

Survival of Feeding Larvae is the Key



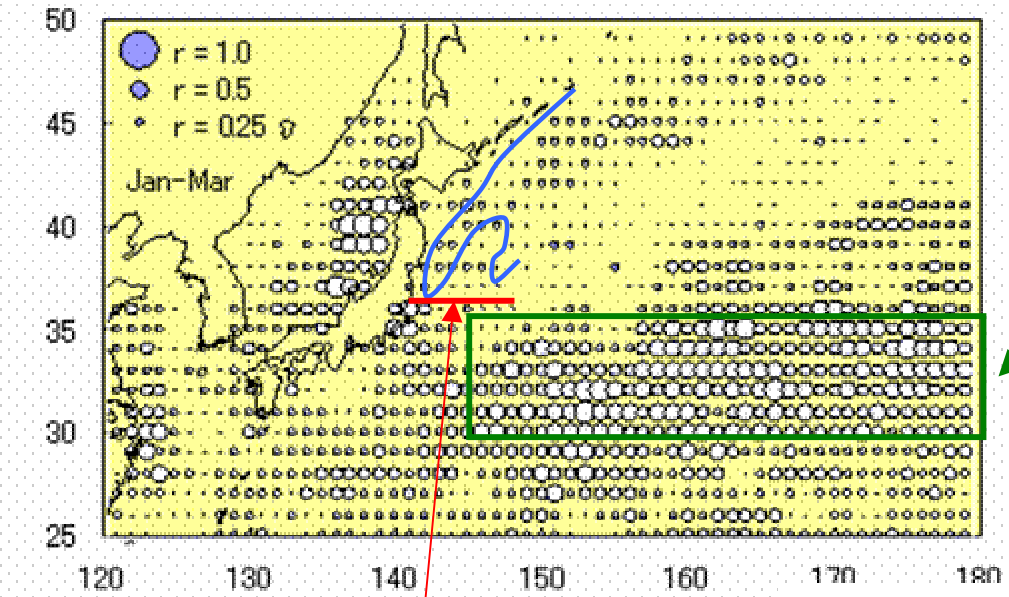


(Watanabe et al., 1995)



Fairly good relation indicate early survival is mainly determined after the feeding larvae distributing in Kuroshio and KOTZ

Correlation Coefficient (*r*) Map between Winter SST and LNRR of Japanese Sardine (Yatsu et al., in press)



●: positive *r*

○: negative *r*

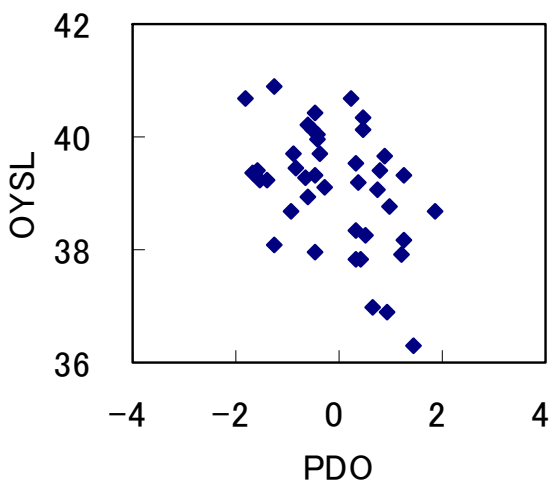
KESA

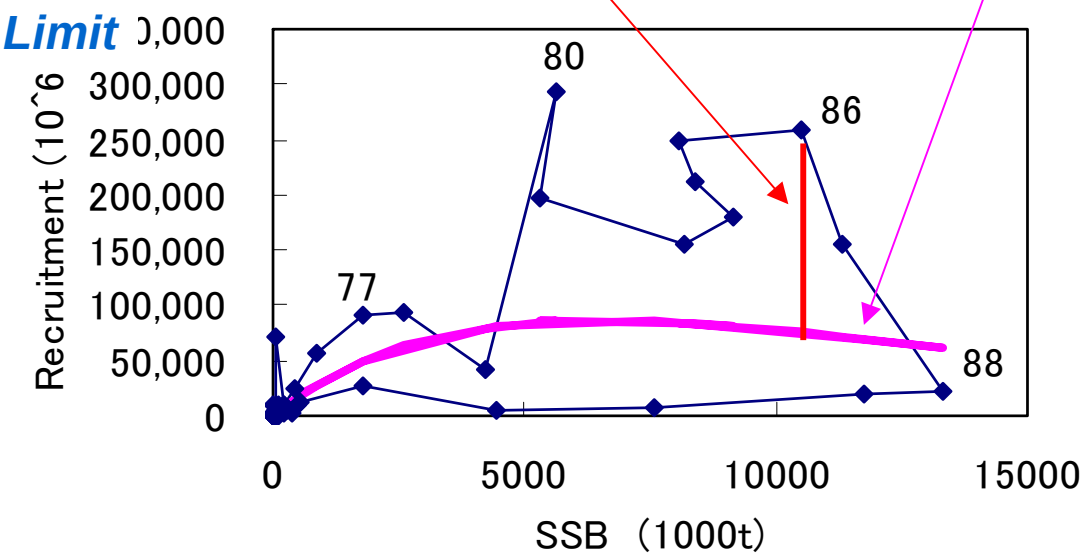
LNRR=

ln (Recruitment Residuals)

Ricker curve

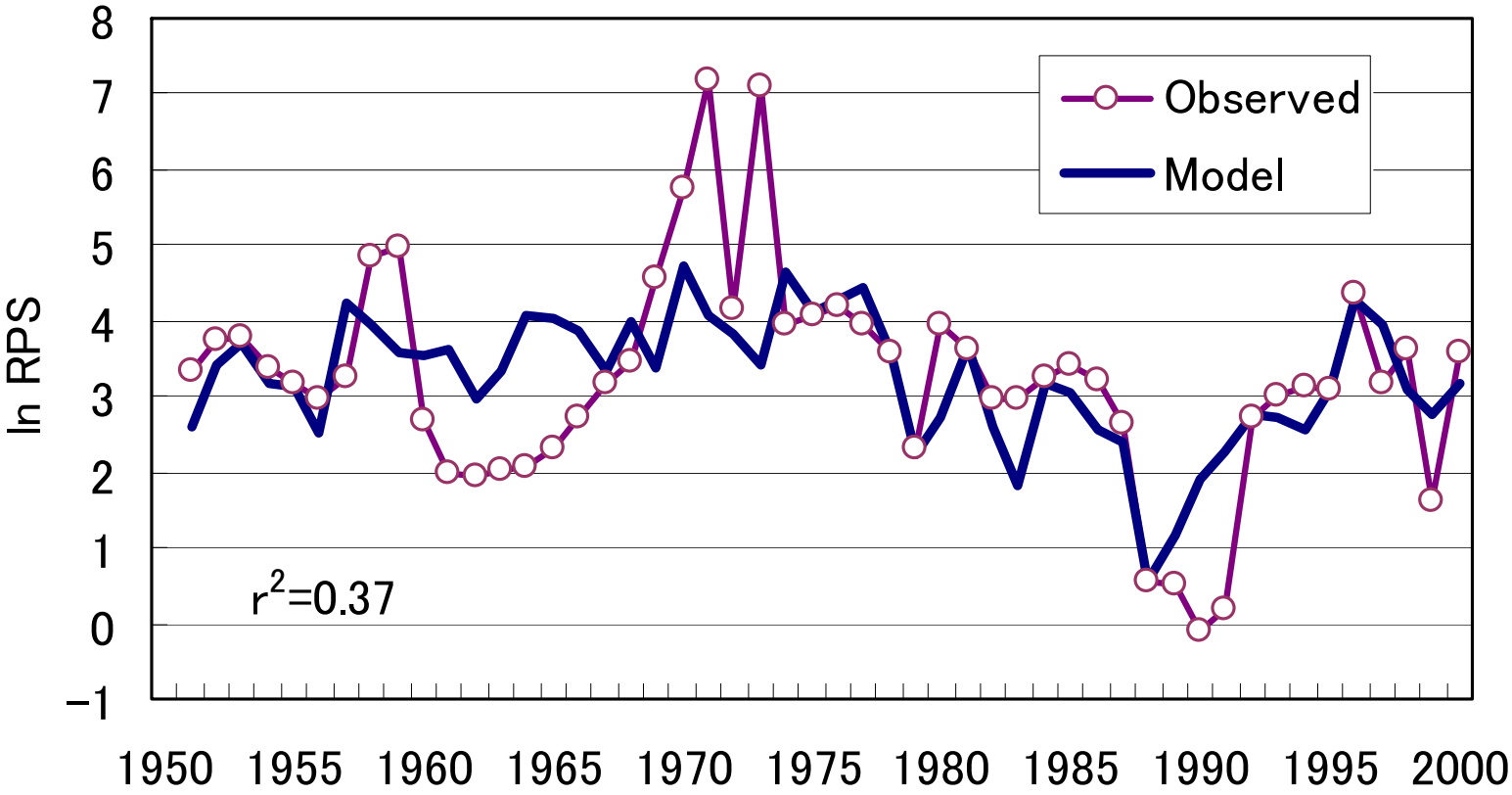
OYSL: Oyashio (1st br.) Southern Limit





Extended Ricker Model

ln RPS= -0.00017 SSB -1.59 KESASST + 30.68



RPS=Recruitment No. per Spawning Stock Biomass (SSB)

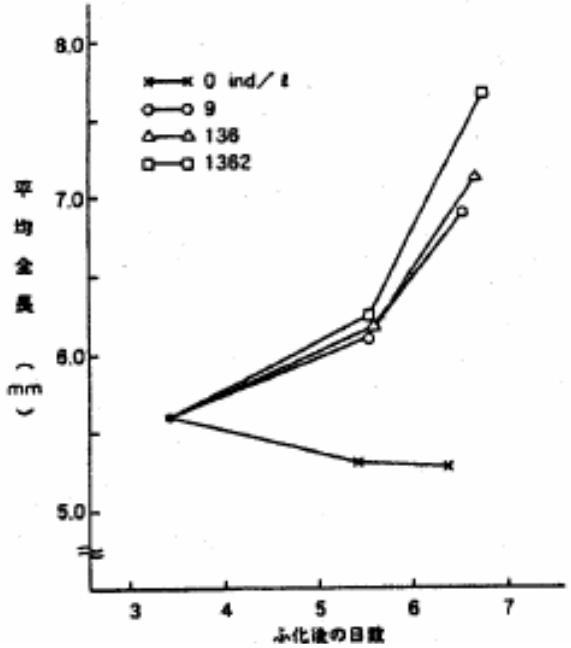
Correlation Map between OCTS/SeaWiFS Spring Chl-a and Japanese Sardine LNRR during 1996-2000

Saito (unpublished)

Tank Exp

Mean total length (mm)

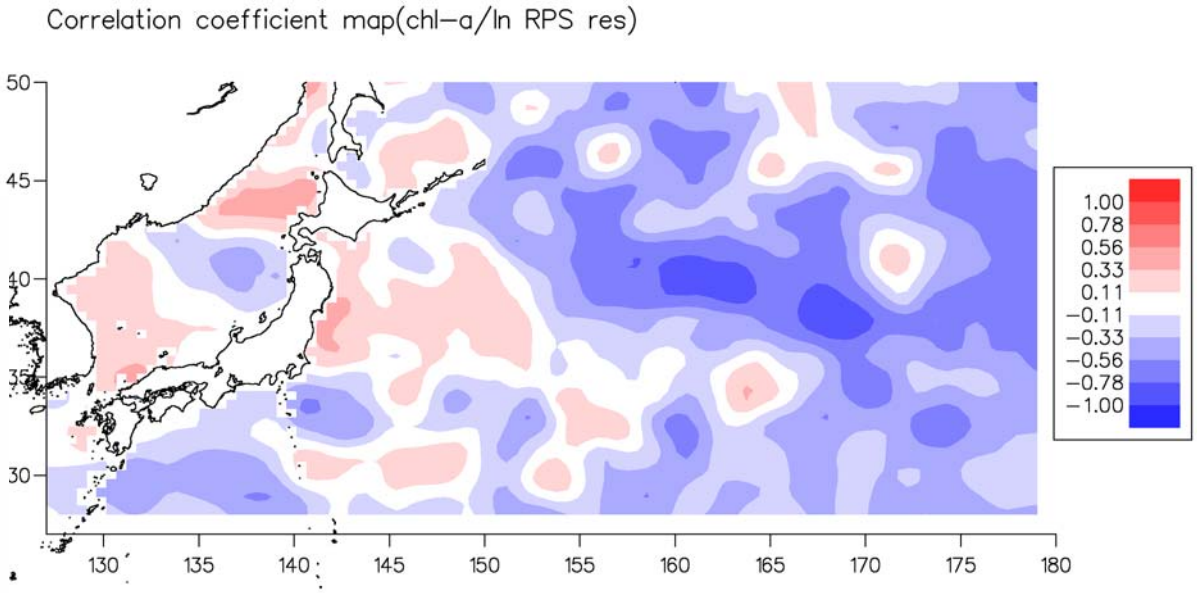
by prey density



Days after hatching

(after Umeda 1996)

Kuroshio Spec. Vol., 19

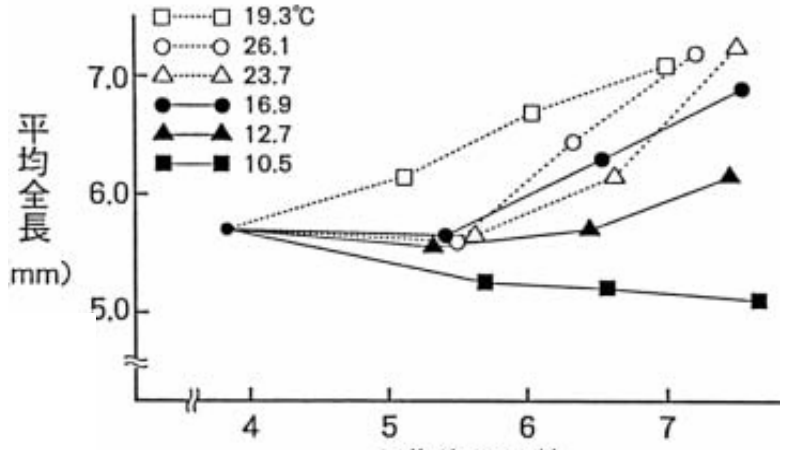


Kuroshio Extension and KOTZ as Key Areas of Sardine Recruitment: Implications of SST

- Vertical mixing and Intensified Oyashio - bottom up
- Stratification - timing of spring bloom
- ZP species/size compositions
- Growth of sardine larvae
- More arrival of tropical tunas and squids

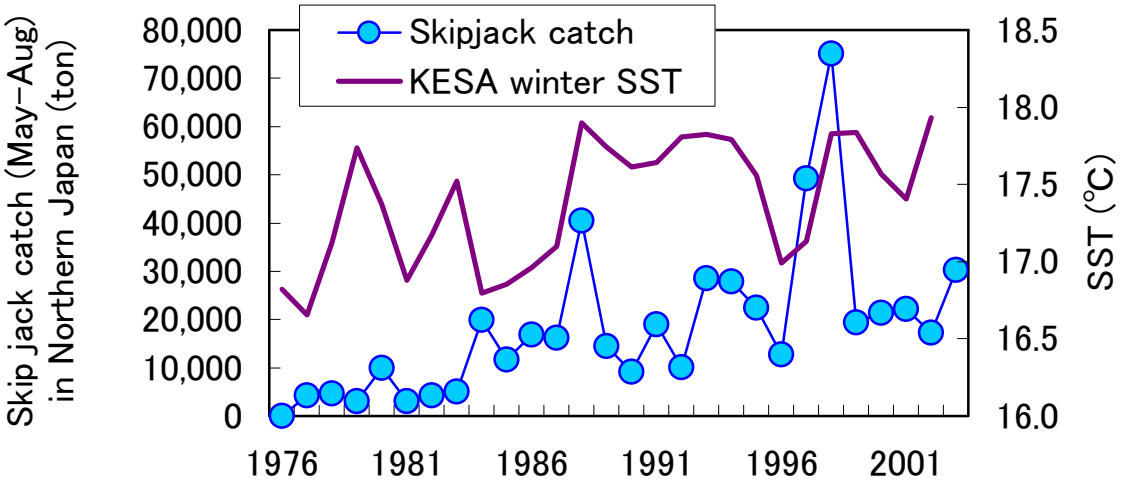
Tank Exp

Mean total length (mm) by temp.

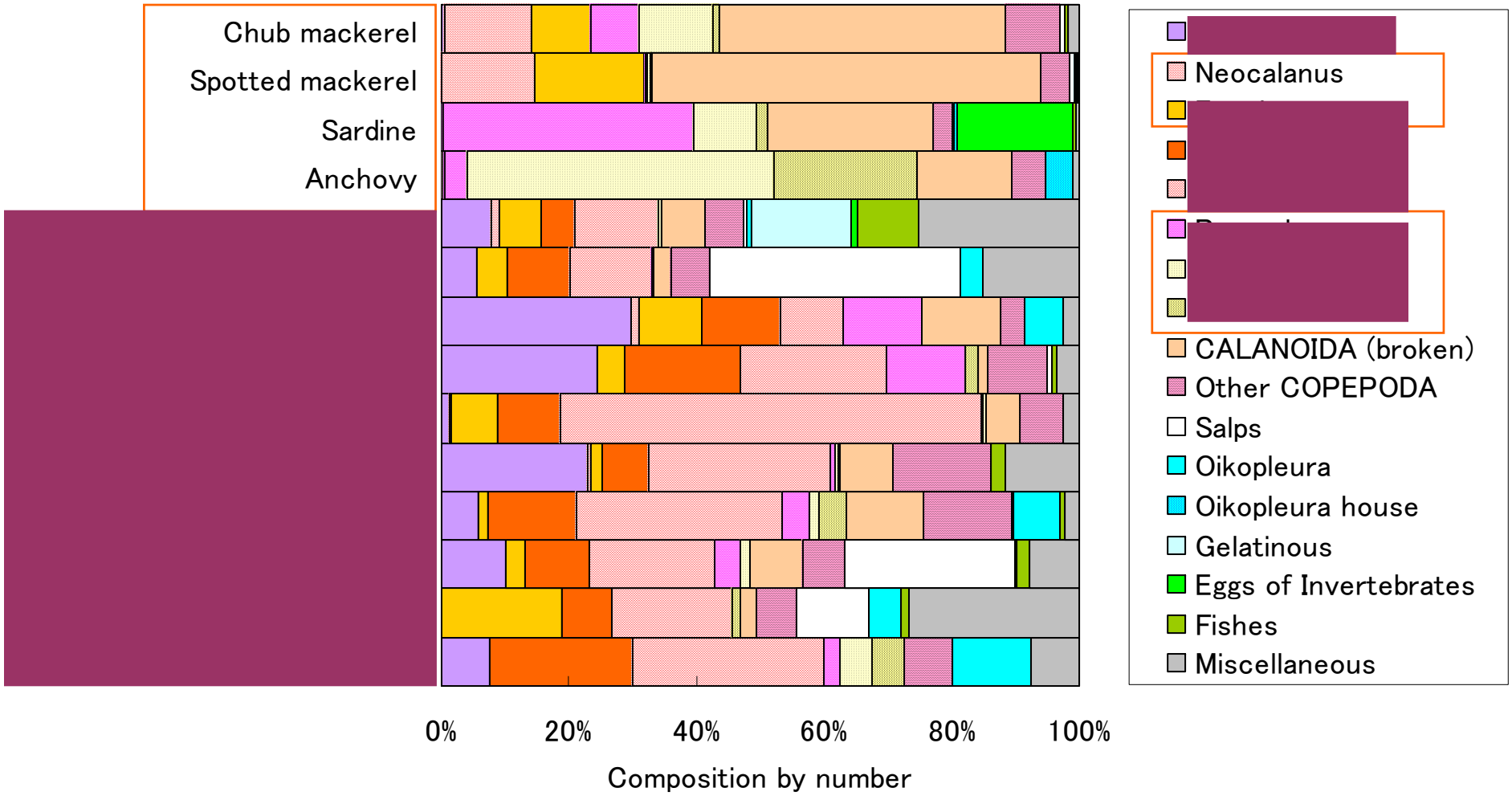


Days after hatching

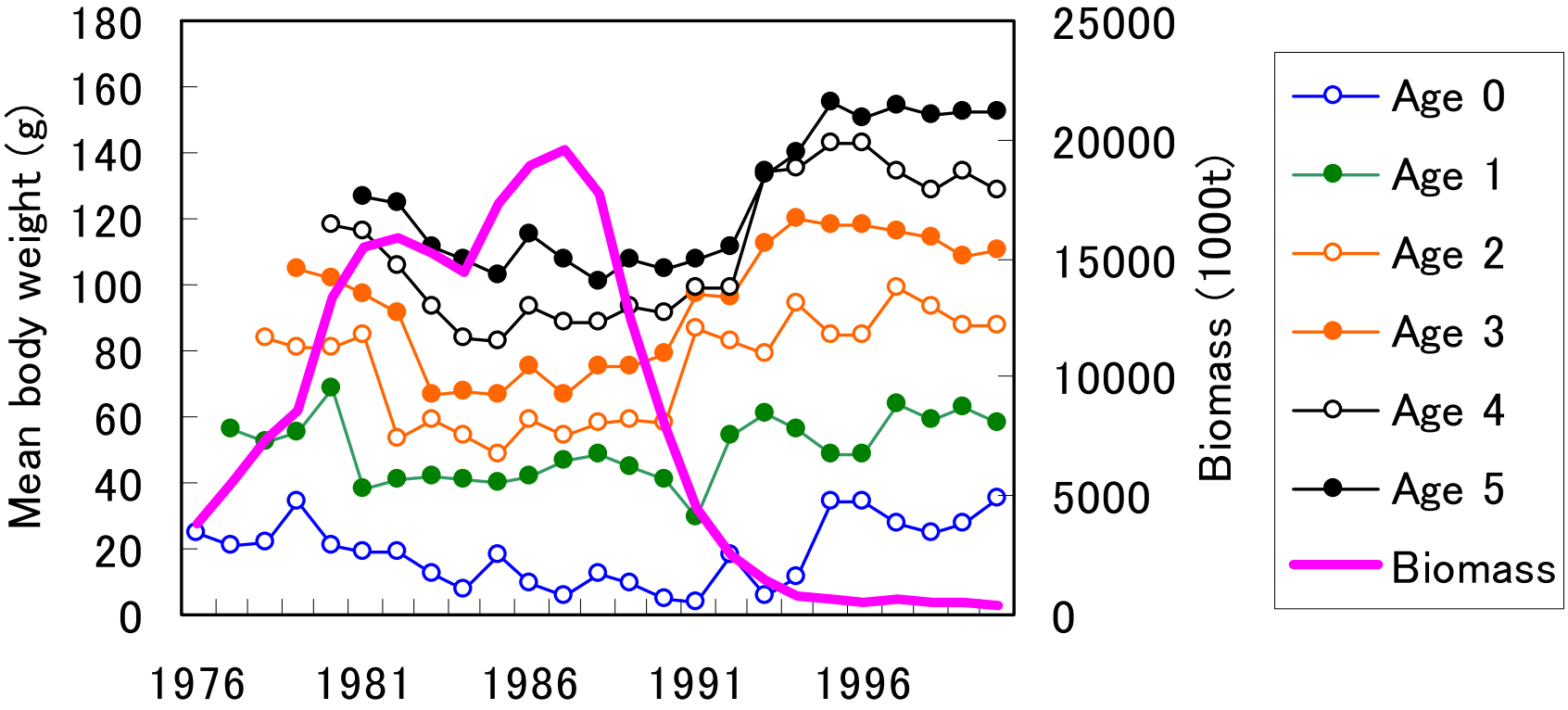
(after Umeda and Iwasaki, 2001; Biocosmos Report)



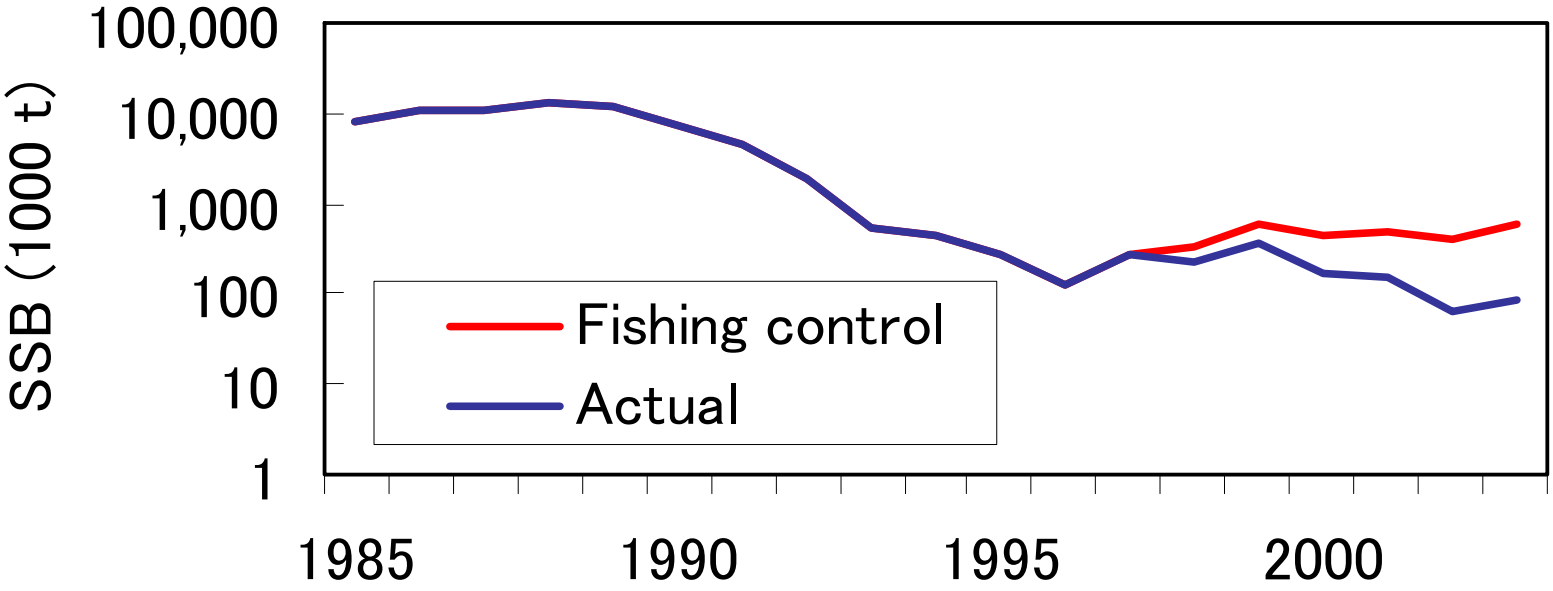
Prey Composition of Juvenile Small Pelagic Fishes and Myctophids (Adults & Juveniles) in May 2002



Density-dependent Growth



If Fishing Mortality Coefficient *F* were Reduced



Simulation by reduction of actual *F* by half after 1997, using observed RPS values

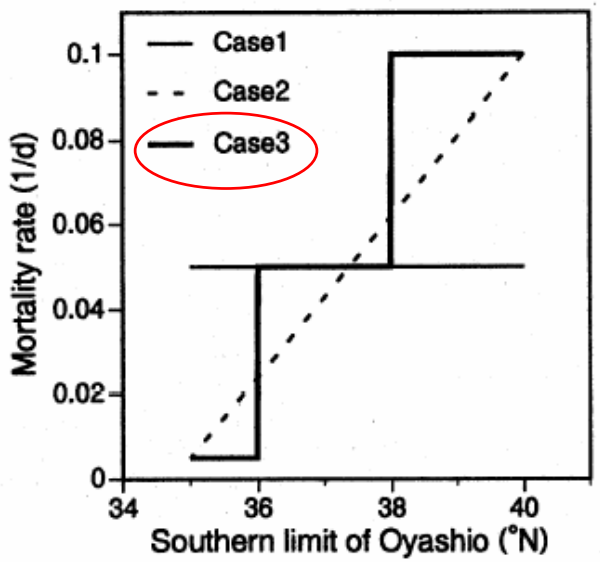
Transport and Survival Model from Spawning Ground to KE and KOTZ

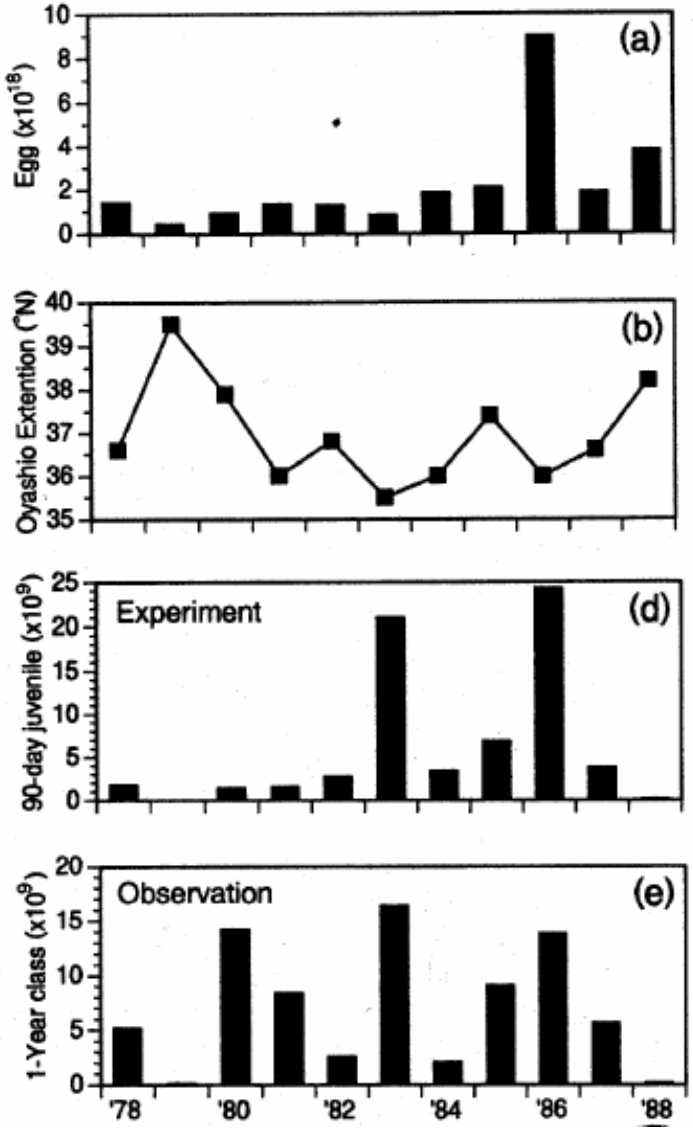
(Kasai et al., 1997 Fish. Sci.)

- Input 1: Egg distribution and abundance
- Input 2: Wind stress and Kuroshio transp.
- Input 3: Mortality rates day^{-1}

  0.5: offshore, 0.15: Kuroshio & coastal

  step function in KOTZ





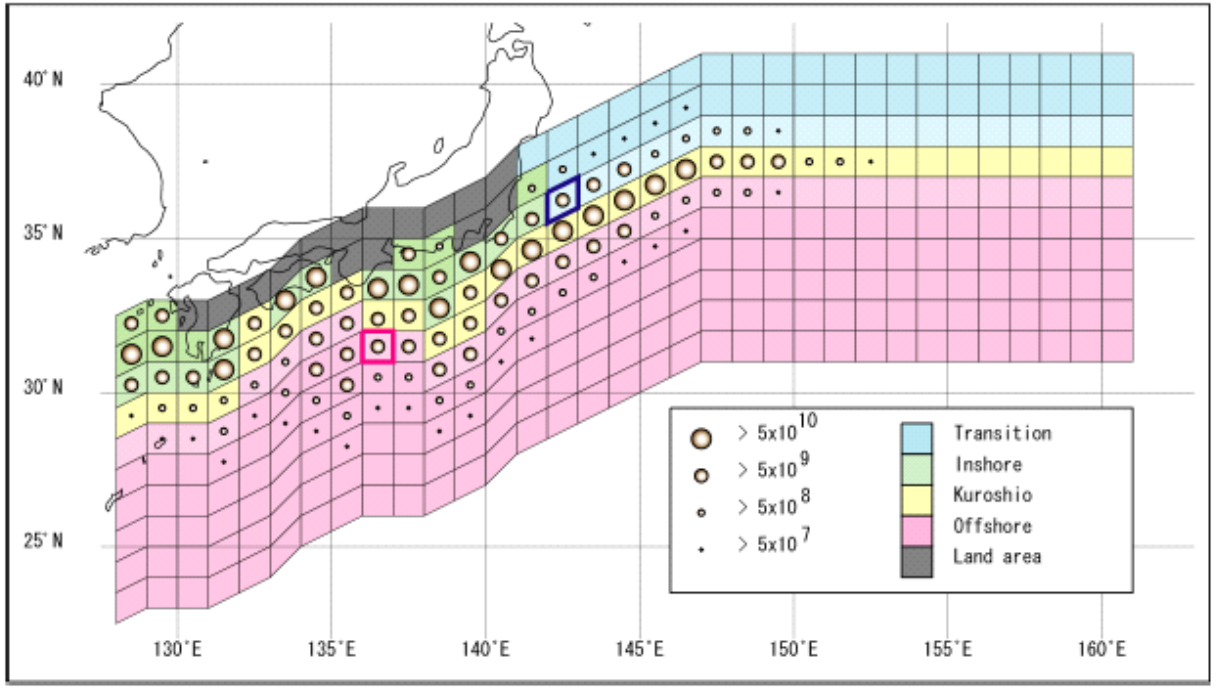
A Spatial "Individual" Based Model of Early Life

(Suda and Kishida, 2003 Fish. Oceanogr.)

•*Super-individual or Fish School = 1x1degree cell*

Distribution of sardine larvae

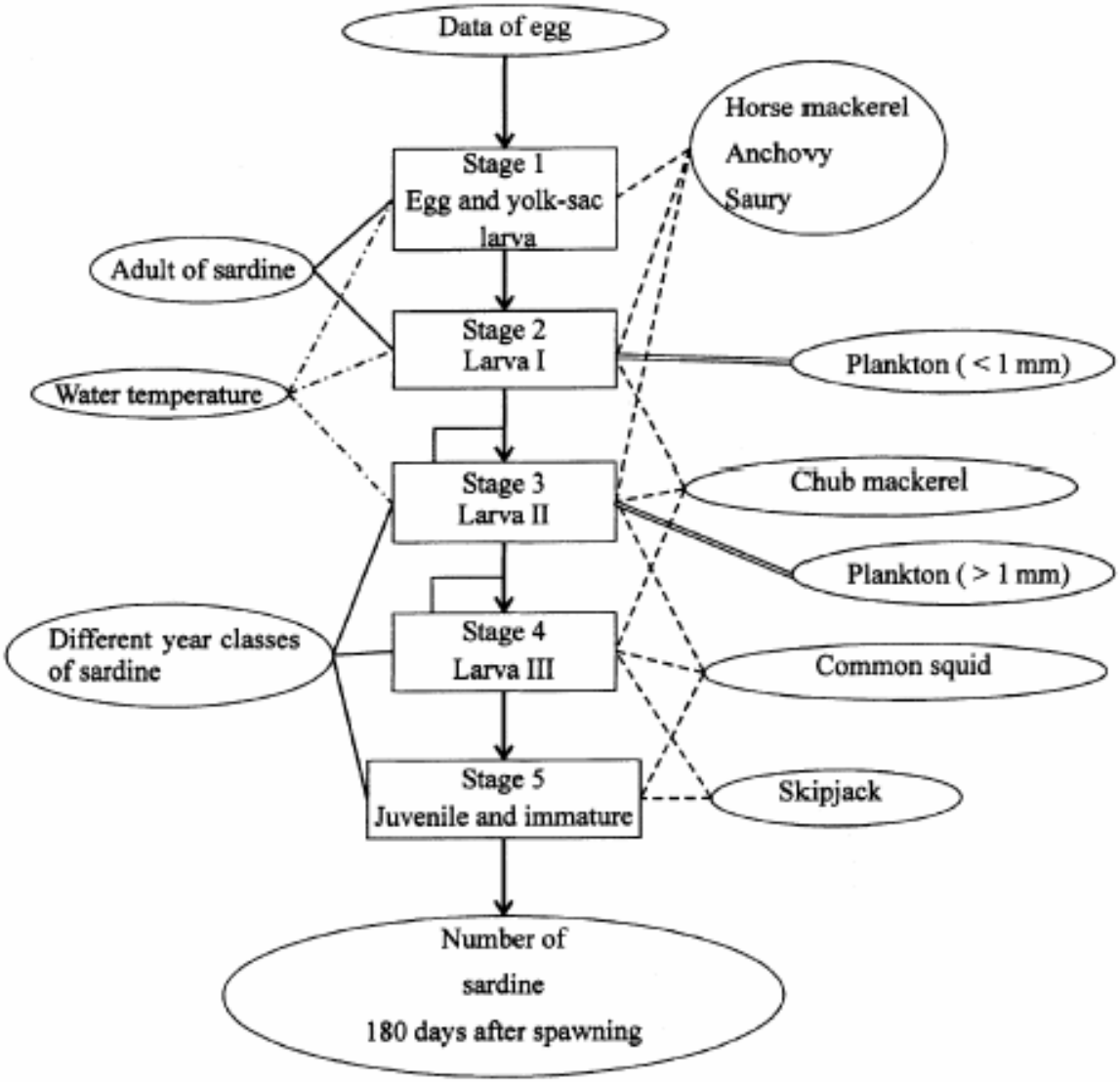
after 40 days from spawning



A Spatial "Individual" Based Model of Early Life

(Suda and Kishida, 2003 Fish. Oceanogr.)

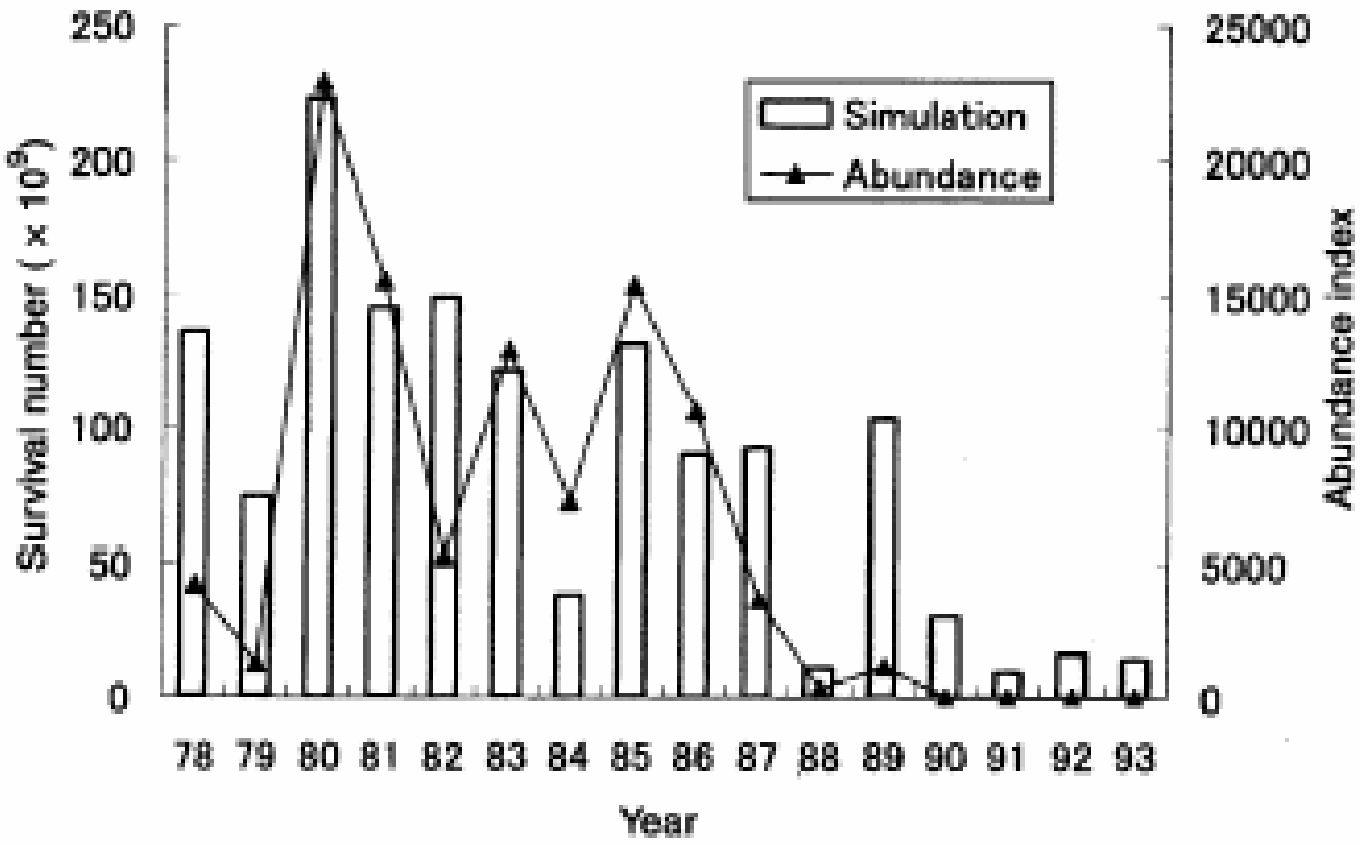
- For each CELL
- *Input 1: Egg census data*
- *Input 2: actual temperature, prey density and predator biomass for each area*
- *Survival and growth are both density-dependent and independent*



A Spatial "Individual" Based Model of Early Life

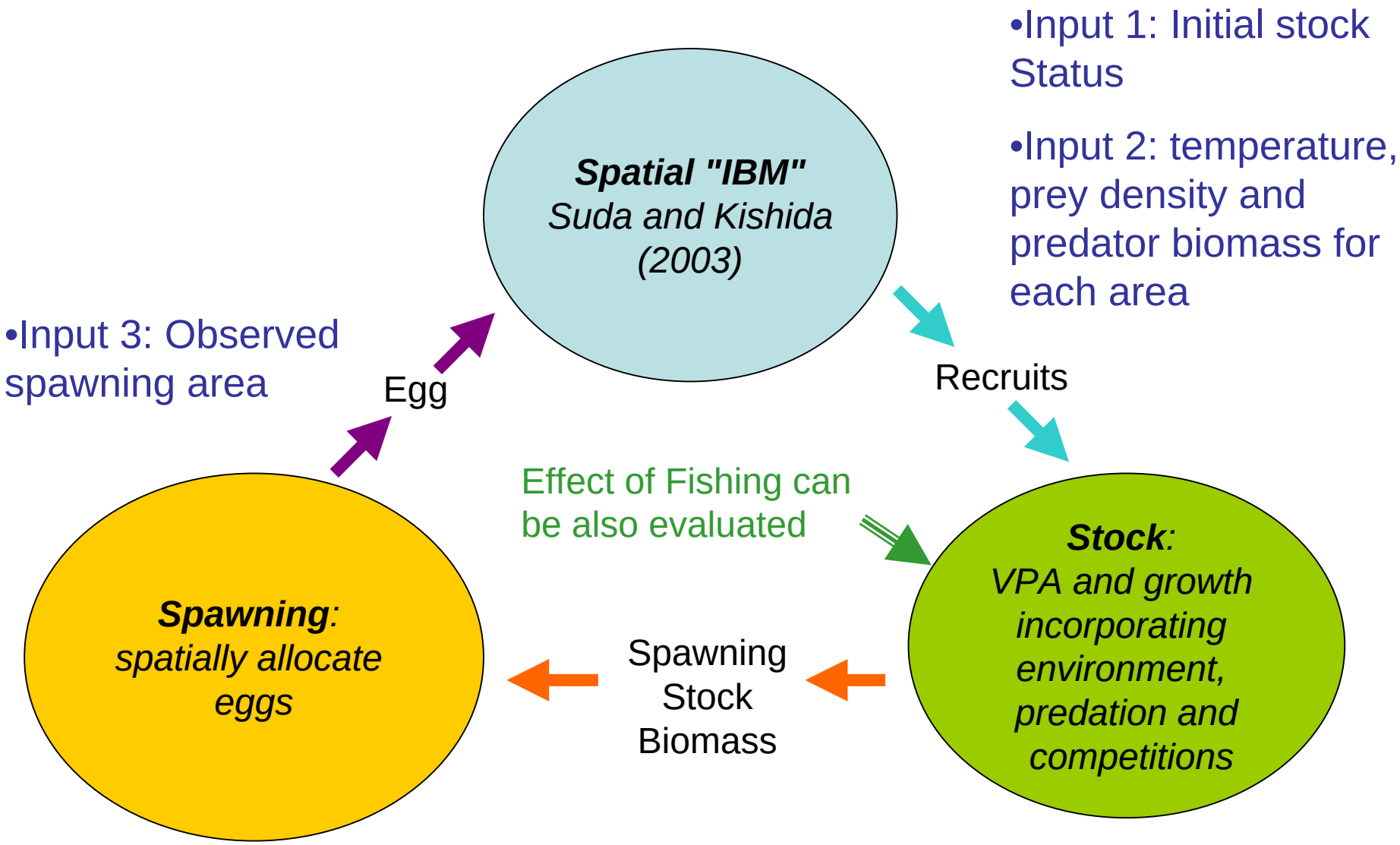
(Suda and Kishida, 2003 Fish. Oceanogr.)

Results: actual and simulated recruits



A Life history "Individual" Based Model

(Suda et al., in preparation)



Summary

- Reproductive success (RPS)= *f* {SSB (density effects), SST of Kuroshio Extension, unparameterized factors (e.g., Oyashio, predators, competition with anchovy, nutrient condition of spawners)}
- Growth = *f* {density, water temperature, prey}
- Biomass accumulation = *f* {

  SSB, RPS, Growth, Survival (after recruit) }

  NB: intensive fishing may prevent stock recovery
- WSA Gyre and central NP are feeding grounds, only during high stock periods

- Possible combinations of NEMURO (PICES), Circulation Models (Kasai et al., 1997; Komatsu's OGCM) and Spatial "IBM" (Suda et al., in prep.)

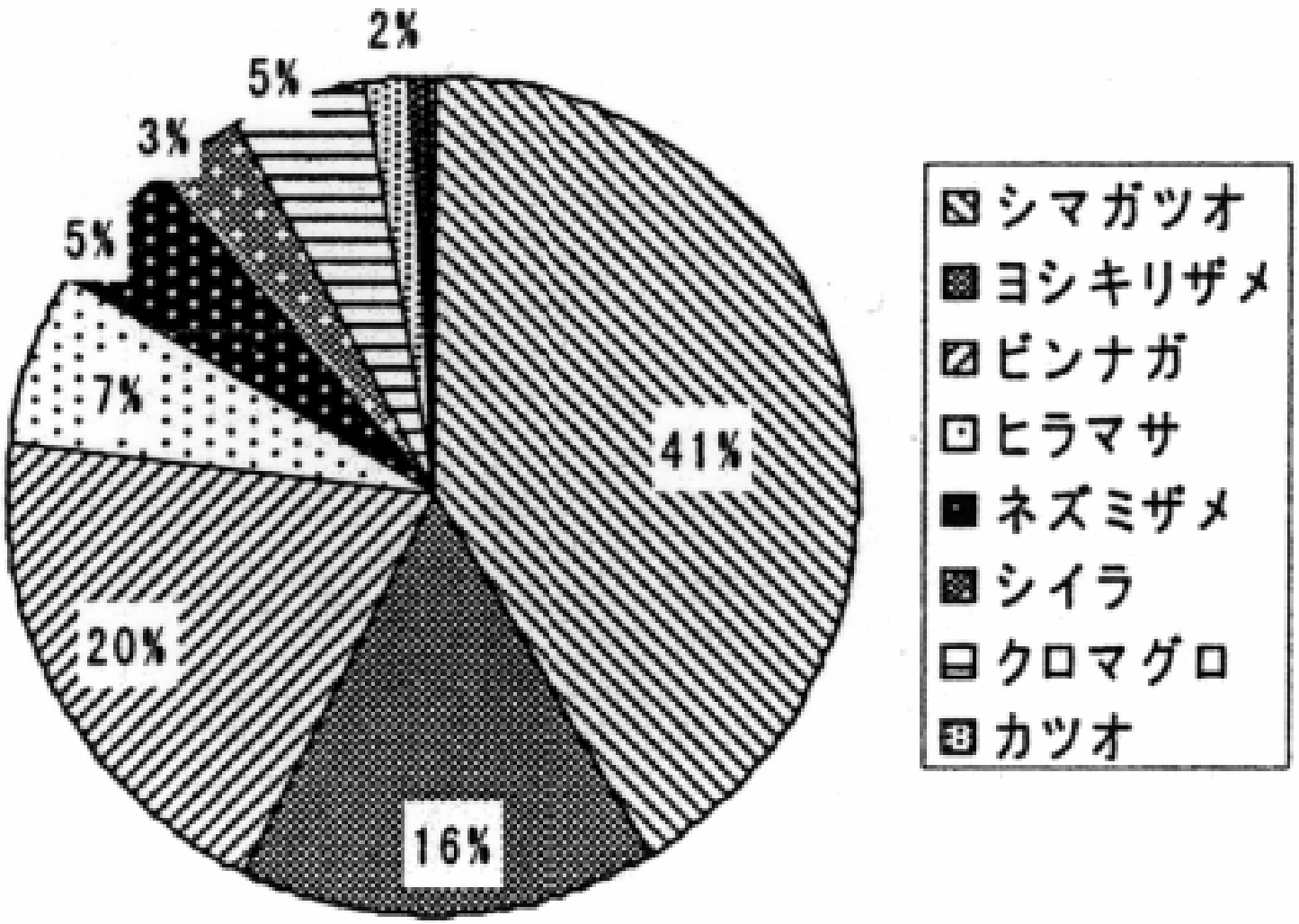
Basic Biology of Sardine and Anchovy

	Japanese sardine	Japanese ancnovy
Life span	about 7 yr	about 3 yr
Max size BL	25 cm	14 cm
Fist maturity age	1 (Low Stock) or 3 (High Stock)	1
Fist maturity BL	17 cm	6 cm
Spawning season	winter	autumn and spring
Spawning area	southern Honshu - Kyushu	northern Honshu - Kyushu (also open ocean during HS)
Prey	phytoplankton (Diatom) and zooplankton (*Calanus, Oncea, Microsetta, Corycaeus, Paracalanus,* etc.)	zooplankton (*Oncea, Microsetta, Corycaeus, Eucalanus, Paracalanus, Oithona* , etc.)

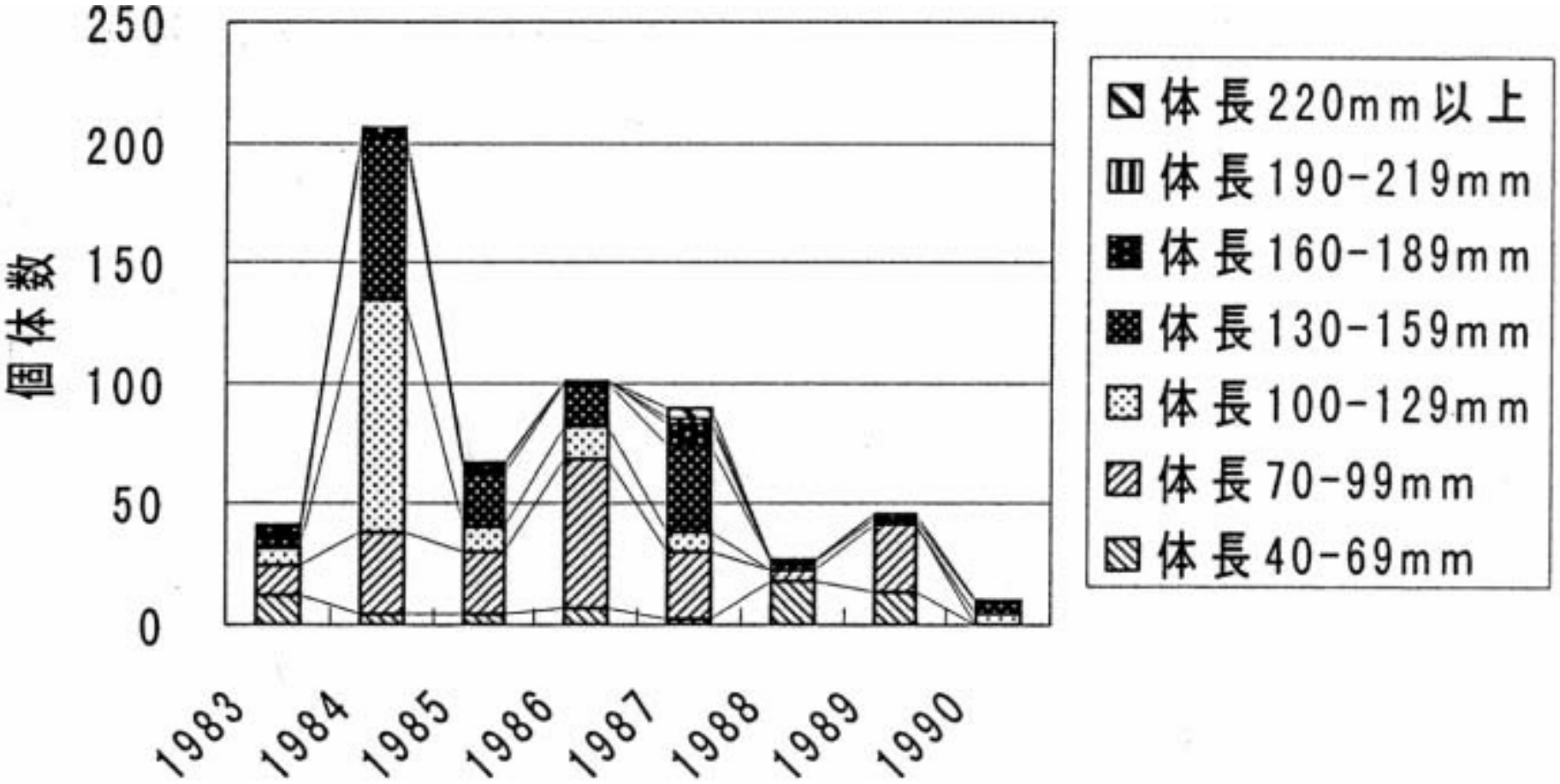
For ref.

- Only for reference

Predators of sardine during 1983-90 (Biocosmos Report)

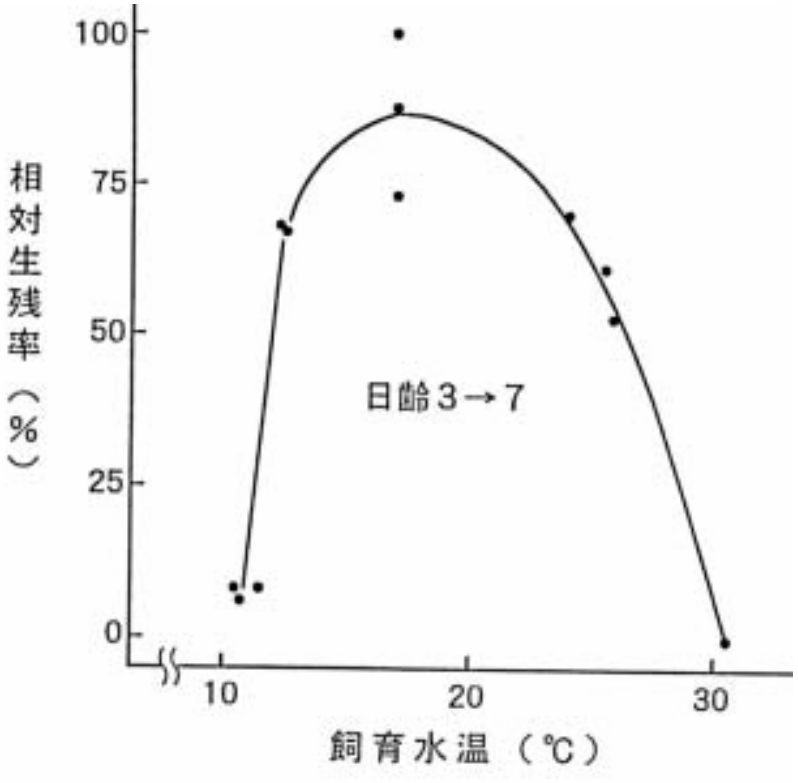


Japanese sardine consumed by *Brama japonica*, 1983-90 (Biocosmos Report)



Sardine survival and growth in tank exp.

Relative survival rate (Age 3 to 7 days)

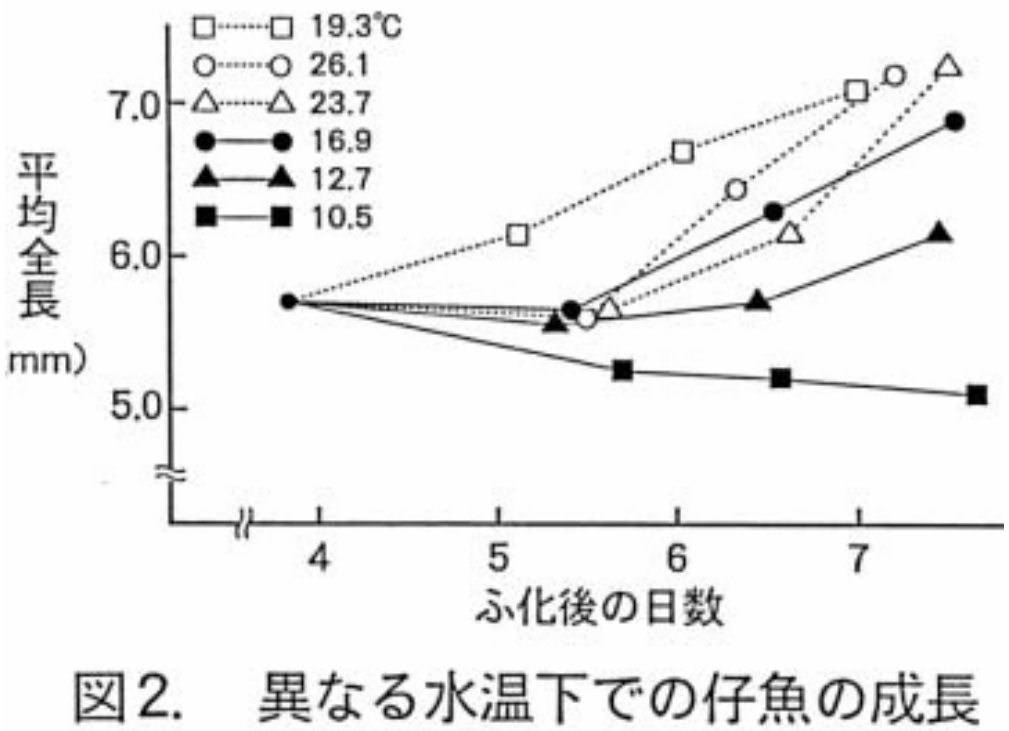


Temperature

(after Umeda 1996)

Kuroshio Spec. Vol., 19

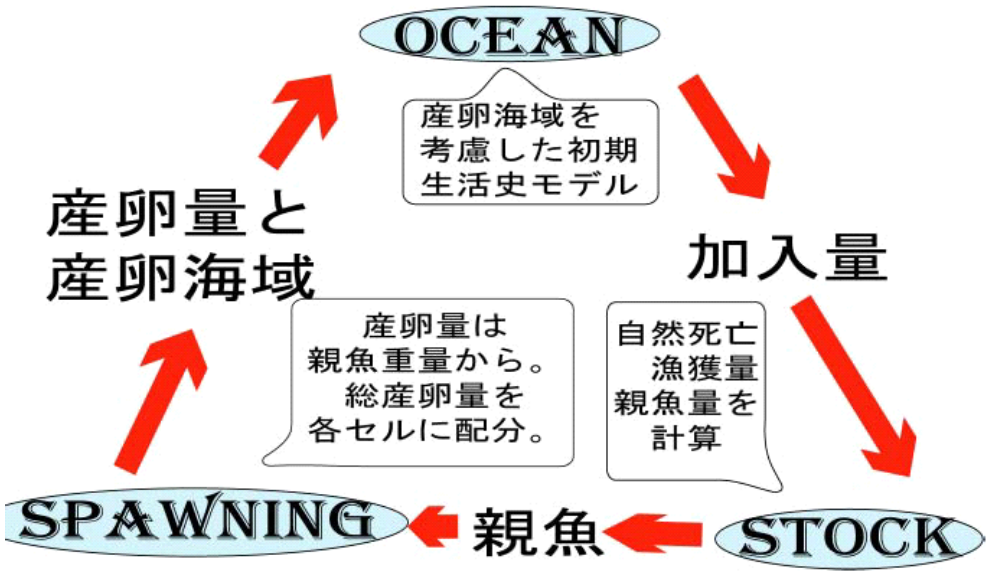
Mean total length (mm) by temp.

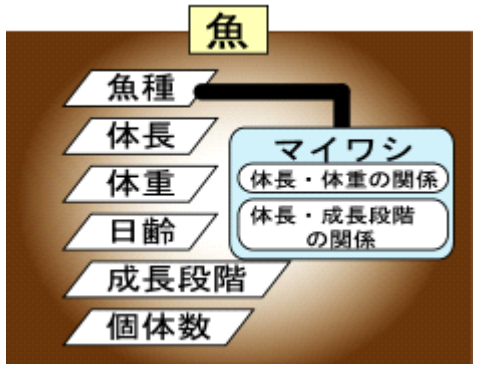


Days after hatching

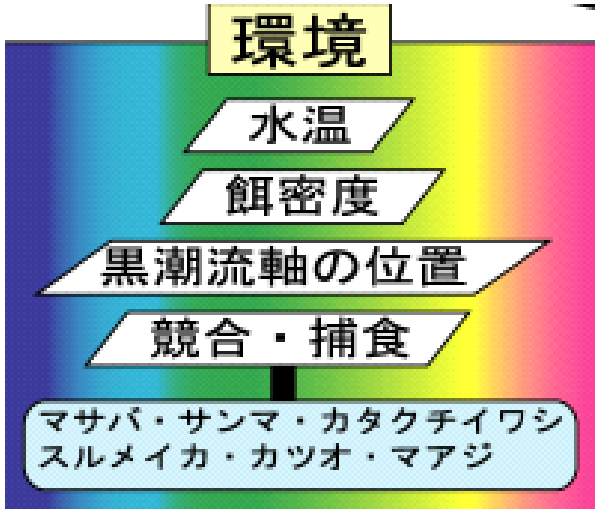
(after Umeda and Iwasaki, 2001; Biocosmos Report)

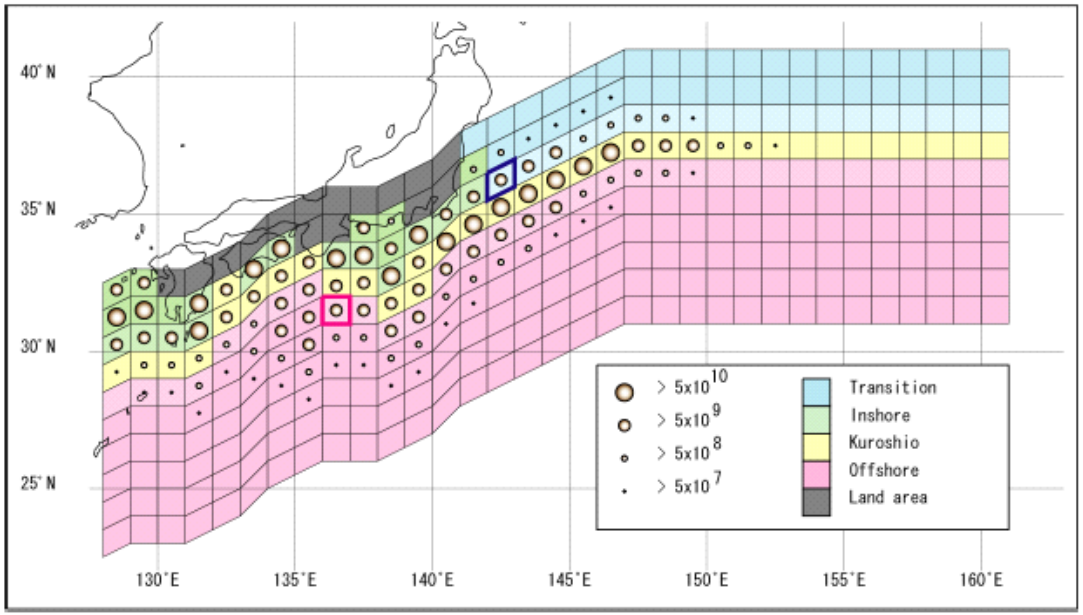
須田モデル

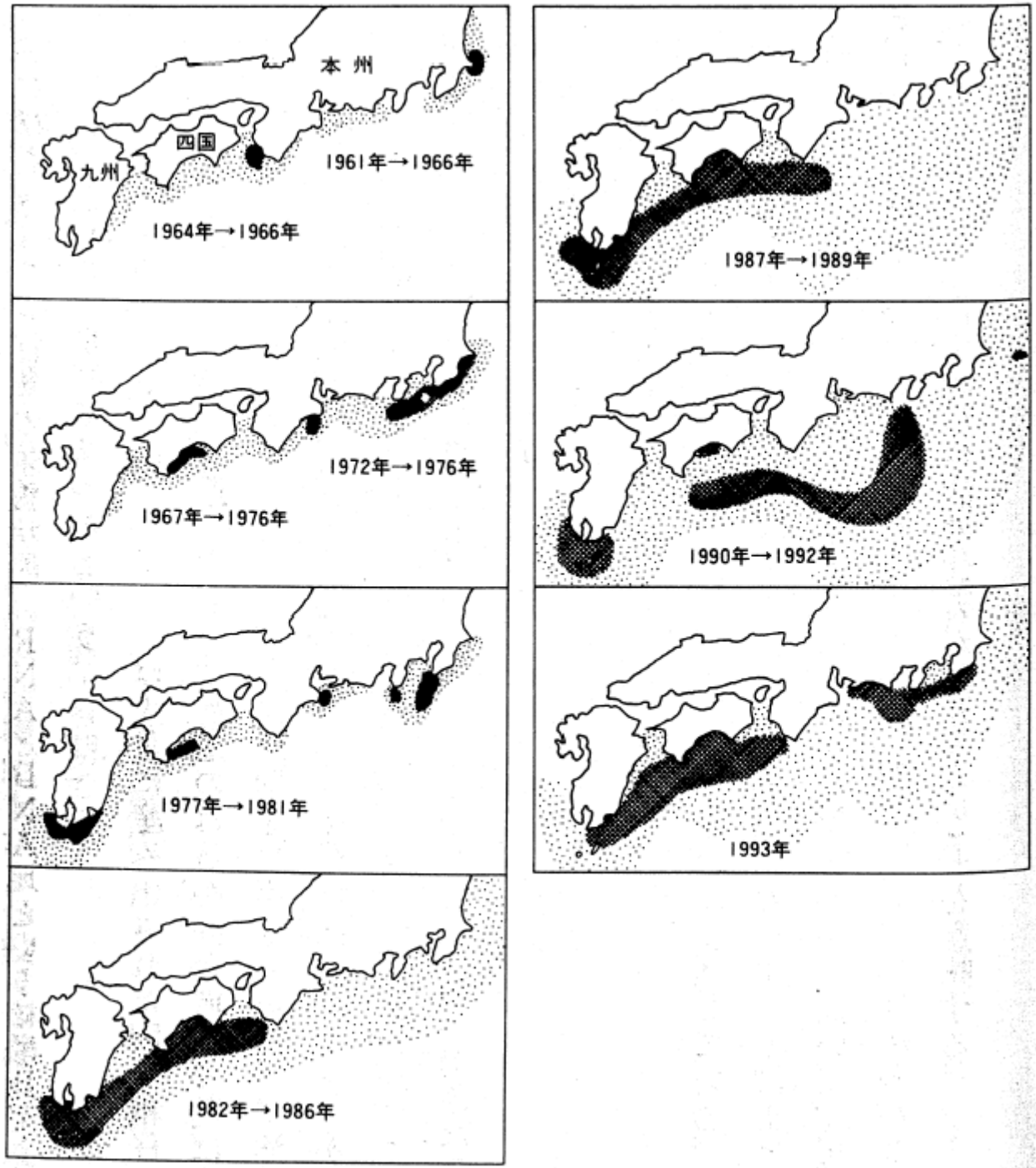




シミュレーションの例
40日目の魚の分布（1985年）



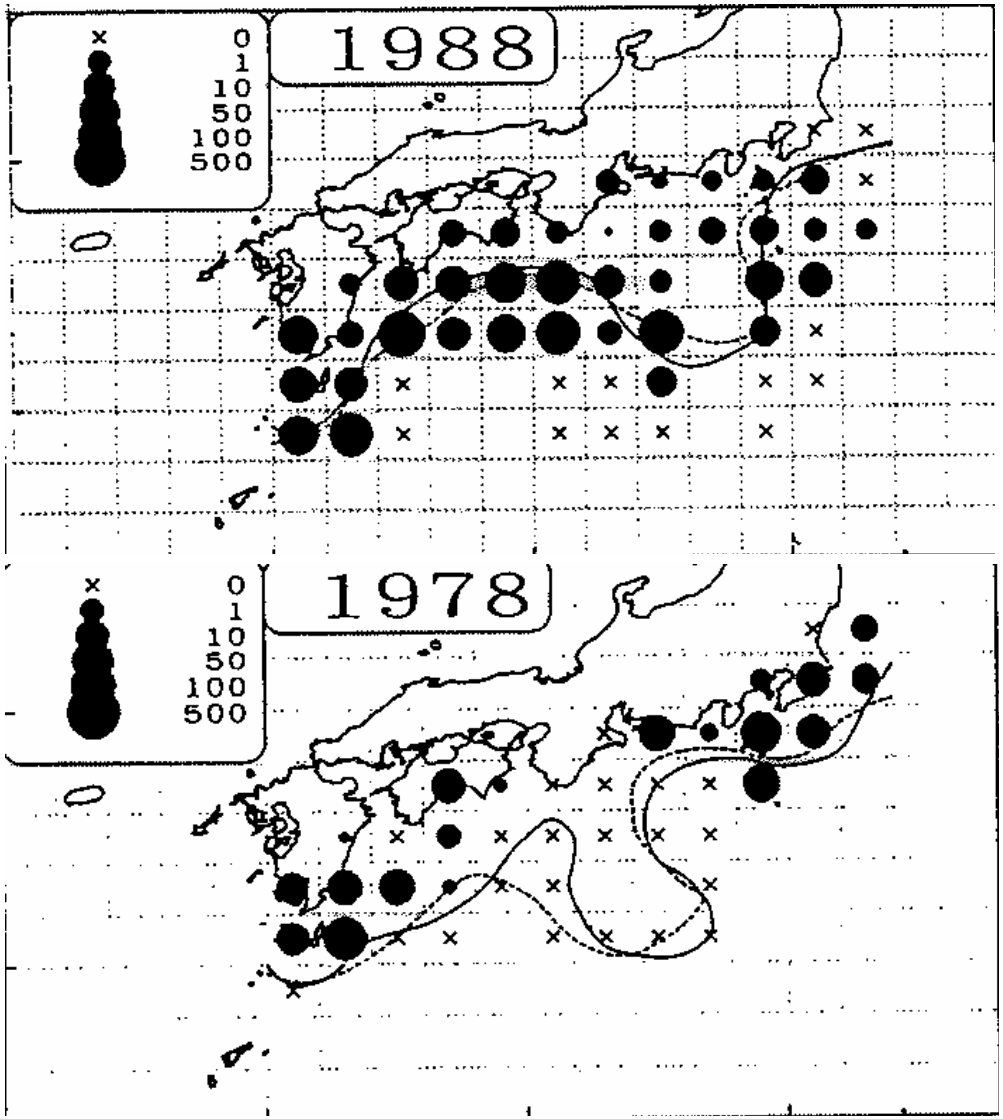




Locations of Spawning Ground 1960s-90s Estimated from Egg Census Survey

(Hiramoto, 1996)

Egg Distribution of Japanese Sardine



High stock periods:

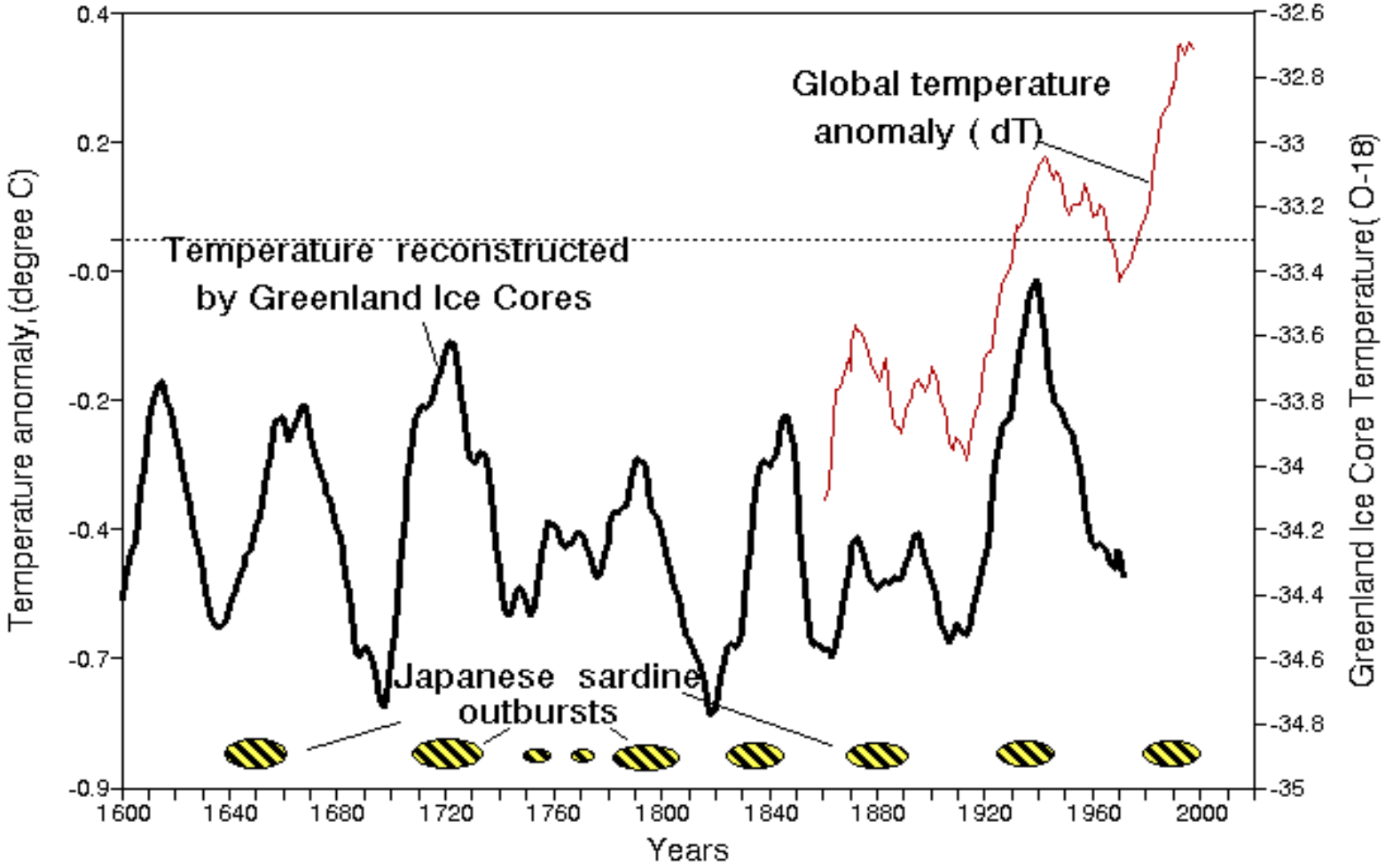
Spawning grounds extend across Kuroshio current -> -> more transport to KE

Line: Kuroshio axis

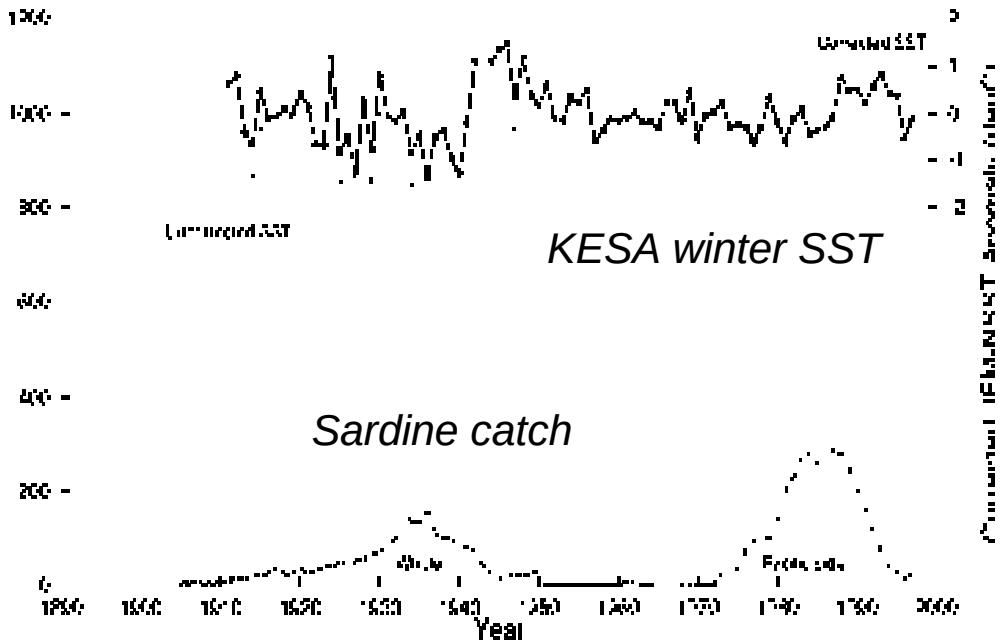
Low stock periods:

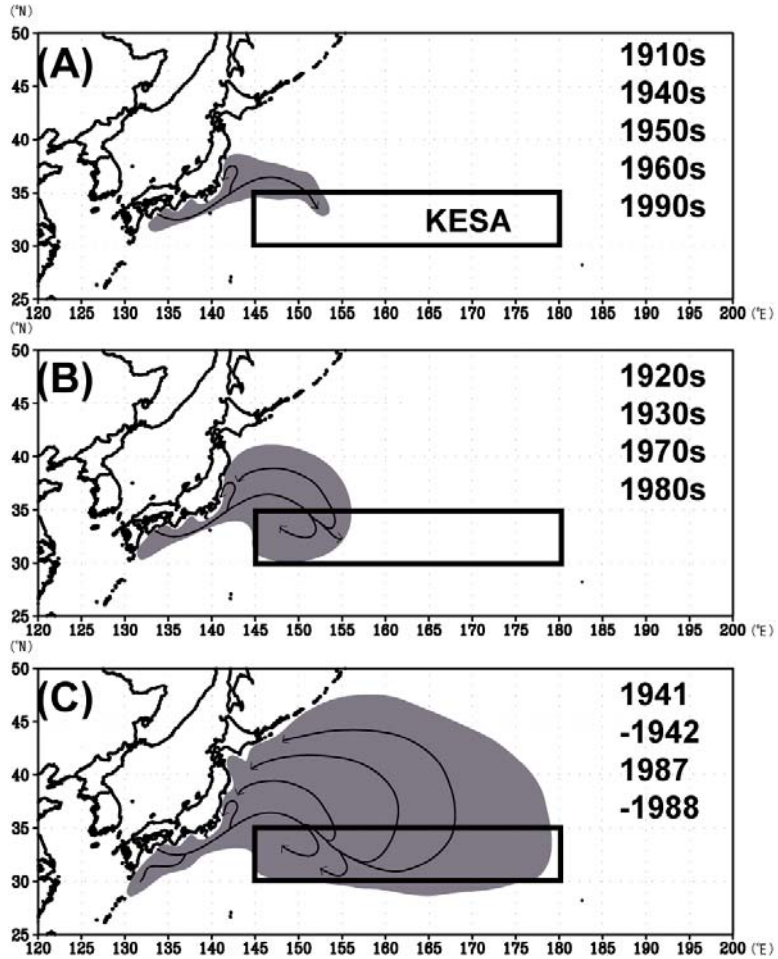
Spawning grounds confined within inshore areas

Japanese Sardine Outbursts and Global Air Temperature since the 17th Century (Klyashtorin, 2002)



KESA Winter SST and Sardine Catch and Larvae/Juveniles Distribution (Noto, 2003)

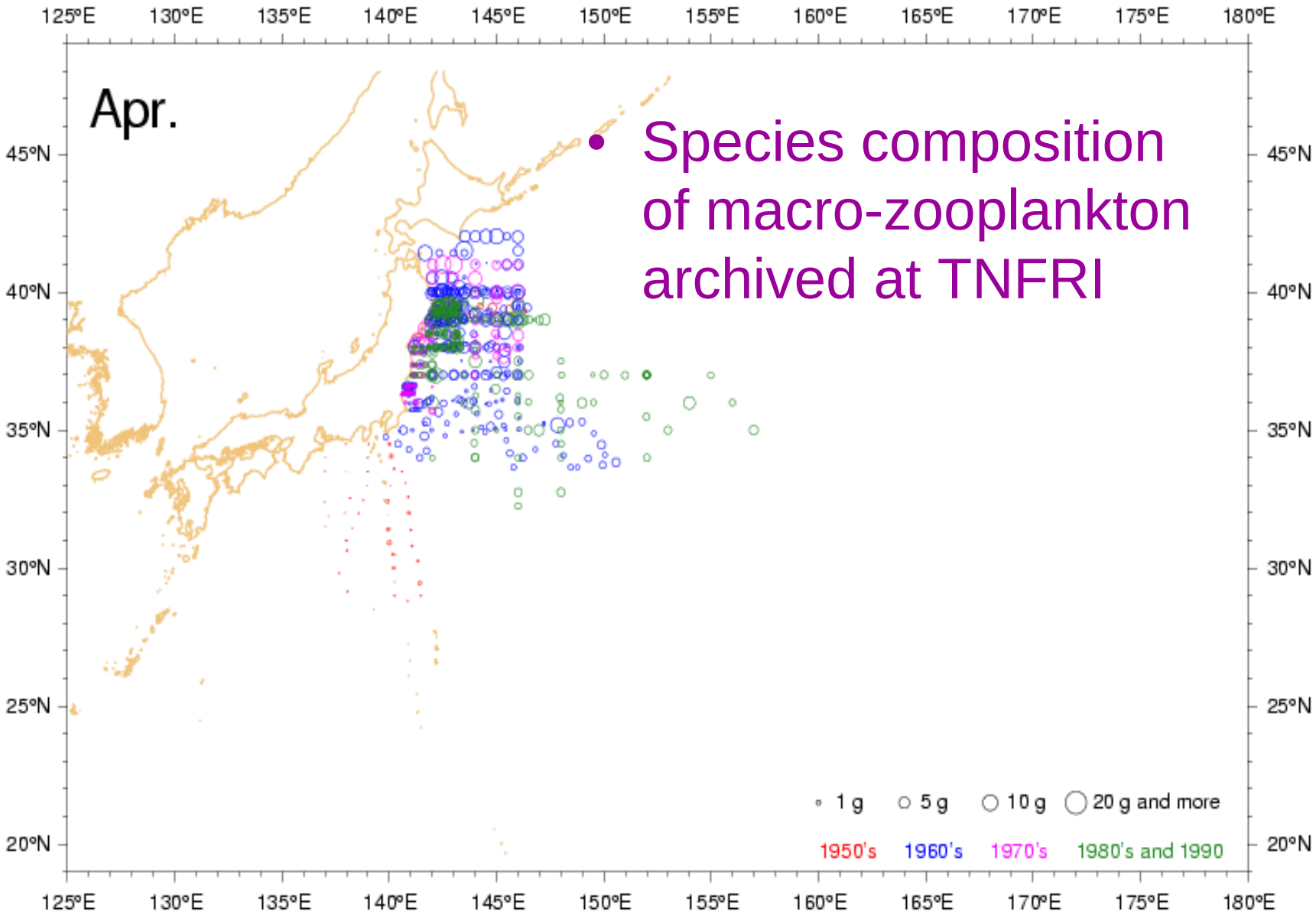




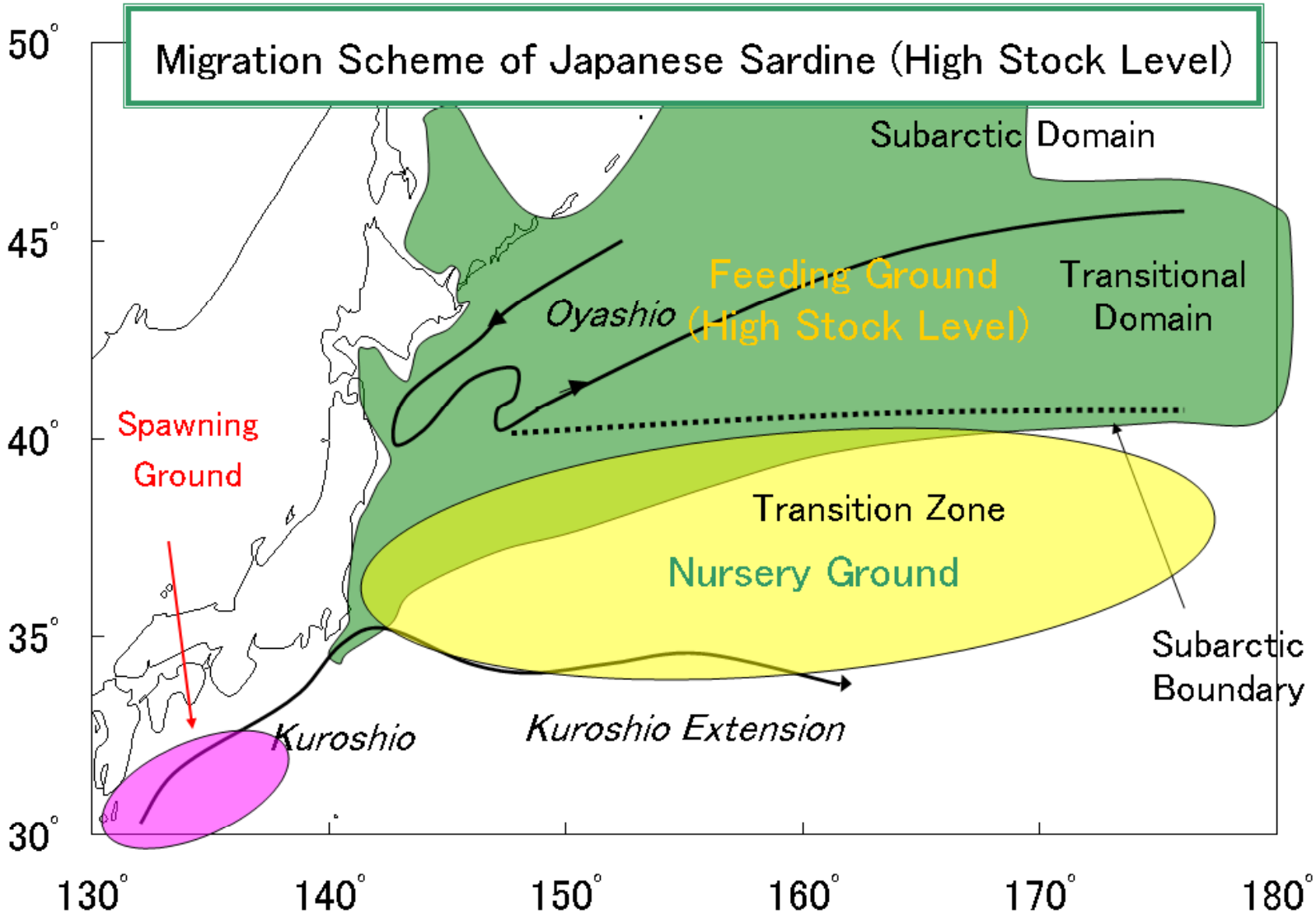
Arrows: Transportation and migration

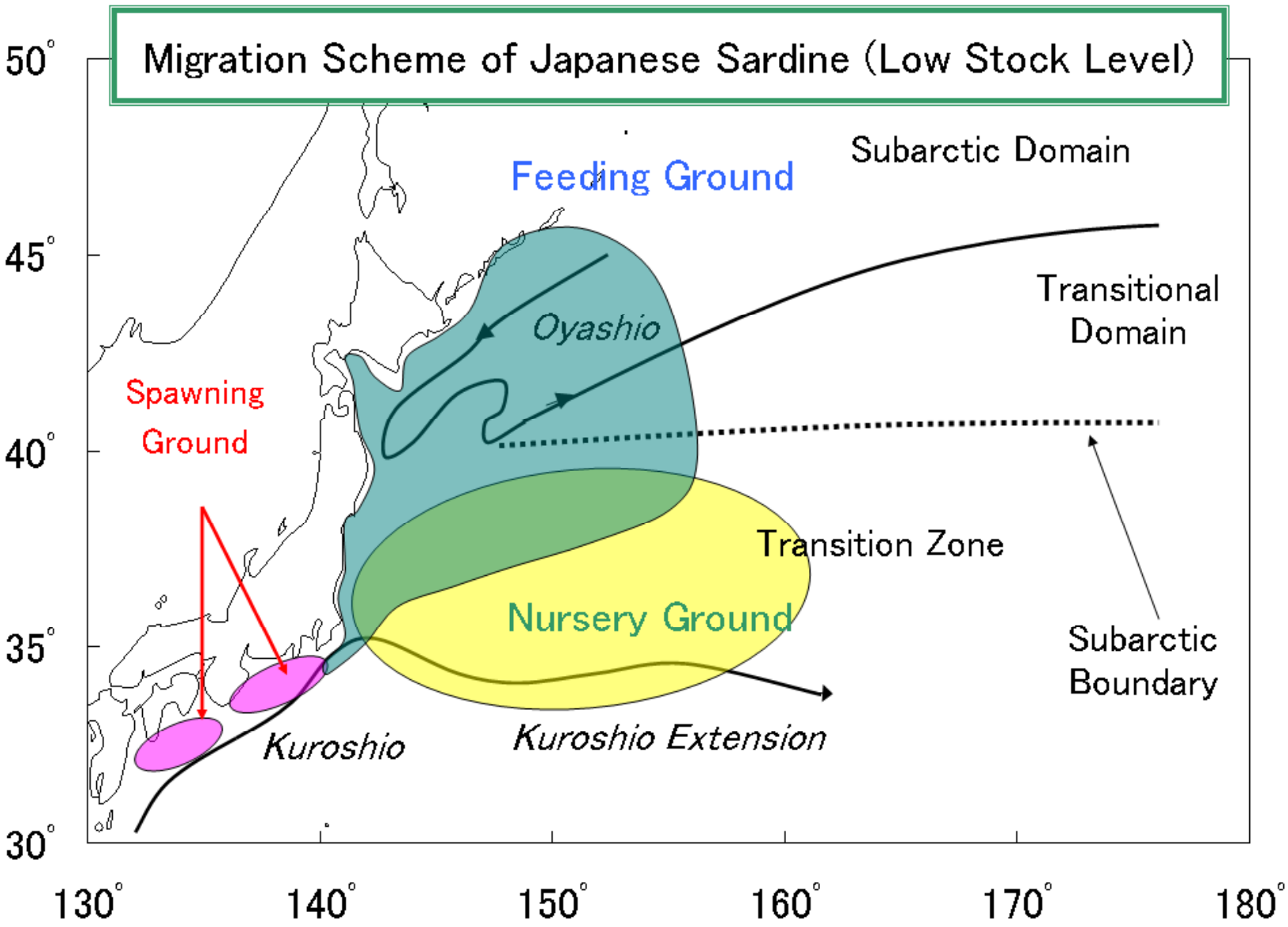
Hatched: Distribution of survivors

Odate Project – On going



- Species composition of macro-zooplankton archived at TNFRI

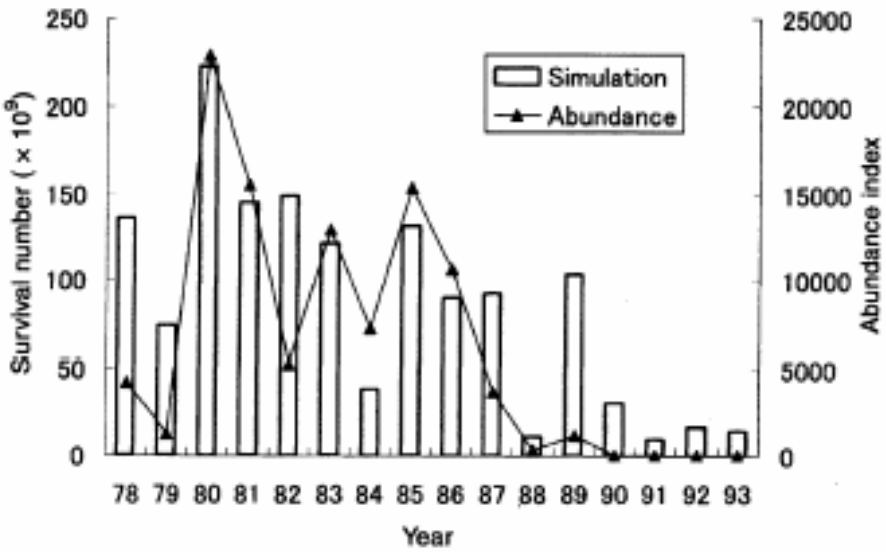

Migration Scheme of Japanese Sardine (High Stock Level)
Subarctic Domain
Feeding Ground
(High Stock Level)
Transitional
Domain
Oyashio
Spawning
Ground
Transition Zone
Nursery Ground
Subarctic
Boundary
Kuroshio
Kuroshio Extension
50°
45°
40°
35°
30°
130°
140°
150°
160°
170°
180°


Migration Scheme of Japanese Sardine (Low Stock Level)
Subarctic Domain
Feeding Ground
Transitional Domain
Oyashio
Spawning Ground
Transition Zone
Nursery Ground
Subarctic Boundary
Kuroshio
Kuroshio Extension
50°
45°
40°
35°
30°
130°
140°
150°
160°
170°
180°

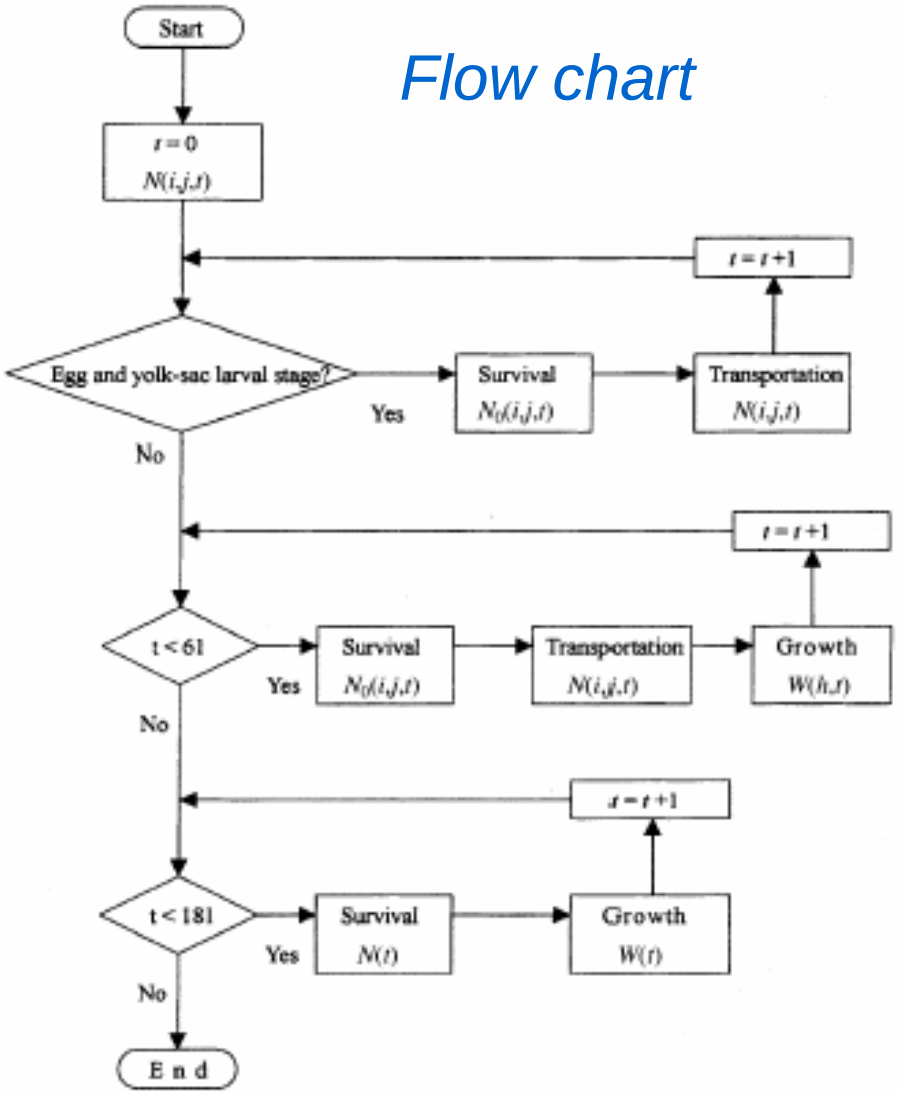
A Spatial "Individual" Based Model of Early Life

(Suda and Kishida, 2003 Fish. Oceanogr.)

Results: actual and simulated recruits



Flow chart



PDO, SOI, AO and Kuroshio