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

Scomber: chub mackerel + spotted mackerel
Distribution and migration of Japanese sardine and California sardine

Feeding Grounds High Stock Level

Spawning Ground LSL

Kuroshio

Kuroshio Extension

Subtropical Water

Transition Zone

Northern Subarctic Gyre

Western Subarctic Gyre

Subarctic Current

Alaska Current

Subarctic Domain

Alaskan Gyre

Subarctic Boundary

Spawning Ground Low SL

Spawning Ground High Stock Level
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

![Graph showing Kuroshio Transport, Kuroshio Northern Limit and Oyashio Southern Limit](image-url)
Winter SST of Kuroshio Extension South Area (KESA) and Early Mortality

Noto and Yasuda (1999, CJFAS)

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

Egg
Yolk-sac larvae
Feeding larvae
Recruit

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)

- **OYSL**: Oyashio (1st br.) Southern Limit
- **KESA**
- **LNRR** = $\ln(\text{Recruitment Residuals})$
- **Ricker curve**

### Graphs

- **Top-right graph**: Scatter plot with markers indicating positive and negative $r$ values
- **Bottom-left graph**: Scatter plot of OYSL vs. PDO
- **Bottom-right graph**: Recruitment vs. SSB (1000t) with years 77, 80, 86, and 88 marked
Extended Ricker Model

\[ \ln \text{RPS} = -0.00017 \times \text{SSB} - 1.59 \times \text{KESASST} + 30.68 \]

Graph showing the relationship between \( \ln \text{RPS} \) and years from 1950 to 2000. The graph includes observed and model predictions with an \( r^2 \) value of 0.37. The equation \( \text{RPS} \) represents 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
Prey Composition of Juvenile Small Pelagic Fishes and Myctophids (Adults & Juveniles) in May 2002

Composition by number

- Chub mackerel
- Spotted mackerel
- Sardine
- Anchovy

Neocalanus
Eucalanus
Metridia
Pleuromamma
Corycaeus
Oncaea
CALANOIDA (broken)
Other COPEPODA
Salps
Oikopleura
Oikopleura house
Gelatinous
Eggs of Invertebrates
Fish
Miscellaneous
Density-dependent Growth

[Graph showing changes in mean body weight and biomass from 1976 to 1996 for Age 0 to Age 5]
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)

**Spatial "IBM"**
Suda and Kishida (2003)

- **Input 1:** Initial stock status
- **Input 2:** Temperature, prey density and predator biomass for each area
- **Input 3:** Observed spawning area

**Spawning:** spatially allocate eggs

- Egg
- **Effect of Fishing can be also evaluated**

**Stock:**
VPA and growth incorporating environment, predation and competitions

- Recruits
- Spawning
- Stock biomass
Summary

• Reproductive success (RPS) = \( f \{ \text{SSB (density effects), SST of Kuroshio Extension, unparameterized factors (e.g., Oyashio, predators, competition with anchovy, nutrient condition of spawners)} \} \)

• Growth = \( f \{ \text{density, water temperature, prey} \} \)

• Biomass accumulation = \( f \{ \text{SSB, RPS, Growth, Survival (after recruit)} \} \)
  
  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**

<table>
<thead>
<tr>
<th></th>
<th>Japanese sardine</th>
<th>Japanese anchovy</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Life span</strong></td>
<td>about 7 yr</td>
<td>about 3 yr</td>
</tr>
<tr>
<td><strong>Max size BL</strong></td>
<td>25 cm</td>
<td>14 cm</td>
</tr>
<tr>
<td><strong>First maturity age</strong></td>
<td>1 (Low Stock) or 3 (High Stock)</td>
<td>1</td>
</tr>
<tr>
<td><strong>First maturity BL</strong></td>
<td>17 cm</td>
<td>6 cm</td>
</tr>
<tr>
<td><strong>Spawning season</strong></td>
<td>winter</td>
<td>autumn and spring</td>
</tr>
<tr>
<td><strong>Spawning area</strong></td>
<td>southern Honshu - Kyushu</td>
<td>northern Honshu - Kyushu (also open ocean during HS)</td>
</tr>
<tr>
<td><strong>Prey</strong></td>
<td>phytoplankton (<em>Diatom</em>) and zooplankton (<em>Calanus, Oncea, Microsetta, Corycaeus, Paracalanus, etc.</em>)</td>
<td>zooplankton (<em>Oncea, Microsetta, Corycaeus, Eucalanus, Paracalanus, Oithona, etc.</em>)</td>
</tr>
</tbody>
</table>
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)

Mean total length (mm) by temp.

Temperature

(after Umeda 1996)
Kuroshio Spec. Vol., 19

Days after hatching

(after Umeda and Iwasaki, 2001; Biocosmos Report)
須田モデル

環境
水温
餌密度
黒潮流軸の位置
競合・捕食

マサバ・サンマ・カタクチイワシ
スルメイカ・カツオ・マアジ

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)

KESA winter SST

Sardine catch

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)

- Spawning Ground
- Feeding Ground (High Stock Level)
- Transitional Domain
- Subarctic Domain
- Transition Zone
- Nursery Ground
- Subarctic Boundary
- Kuroshio
- Kuroshio Extension
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

PDO winter
SOI winter
AO winter

Anomaly


Transp. (SV)

KR Sverdrup transport
KR Geostrophic transport

AO negative
AO pos
AO negative
AO positive
PDO negative and La Nina dominant
PDO positive
El Nino