Stock assessment of Pacific anchovy (*Engraulis japonicus*) biomass in the Korea Strait based on Simulation-based yield-per-recruit analysis

2018.11. 2.

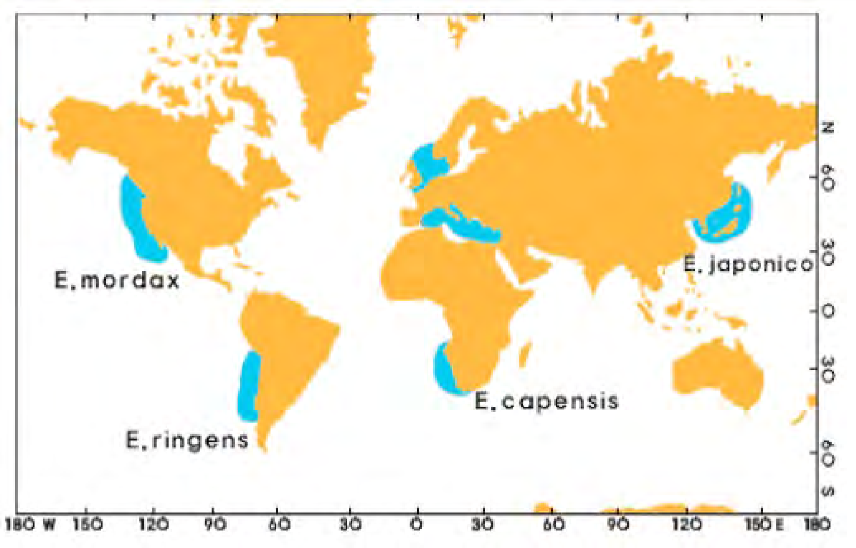
Kyunghwan Lee, Seonggil Go and Sukgeun Jung

Jeju National University

Ecology of Pacific anchovy

- **Anchovies are small pelagic species in the temperate waters around the world.**
- **Pacific anchovy *Engraulis japonica* are mainly distributed in the waters off Korea, China and Japan.**
- **Spawning period: Throughout the year (Major: May-July)**
- **Habitat depths: 0-60 m**
- **Habitat temperatures: 8–30 ℃**

Major fishing ground



Ecology of Pacific anchovy

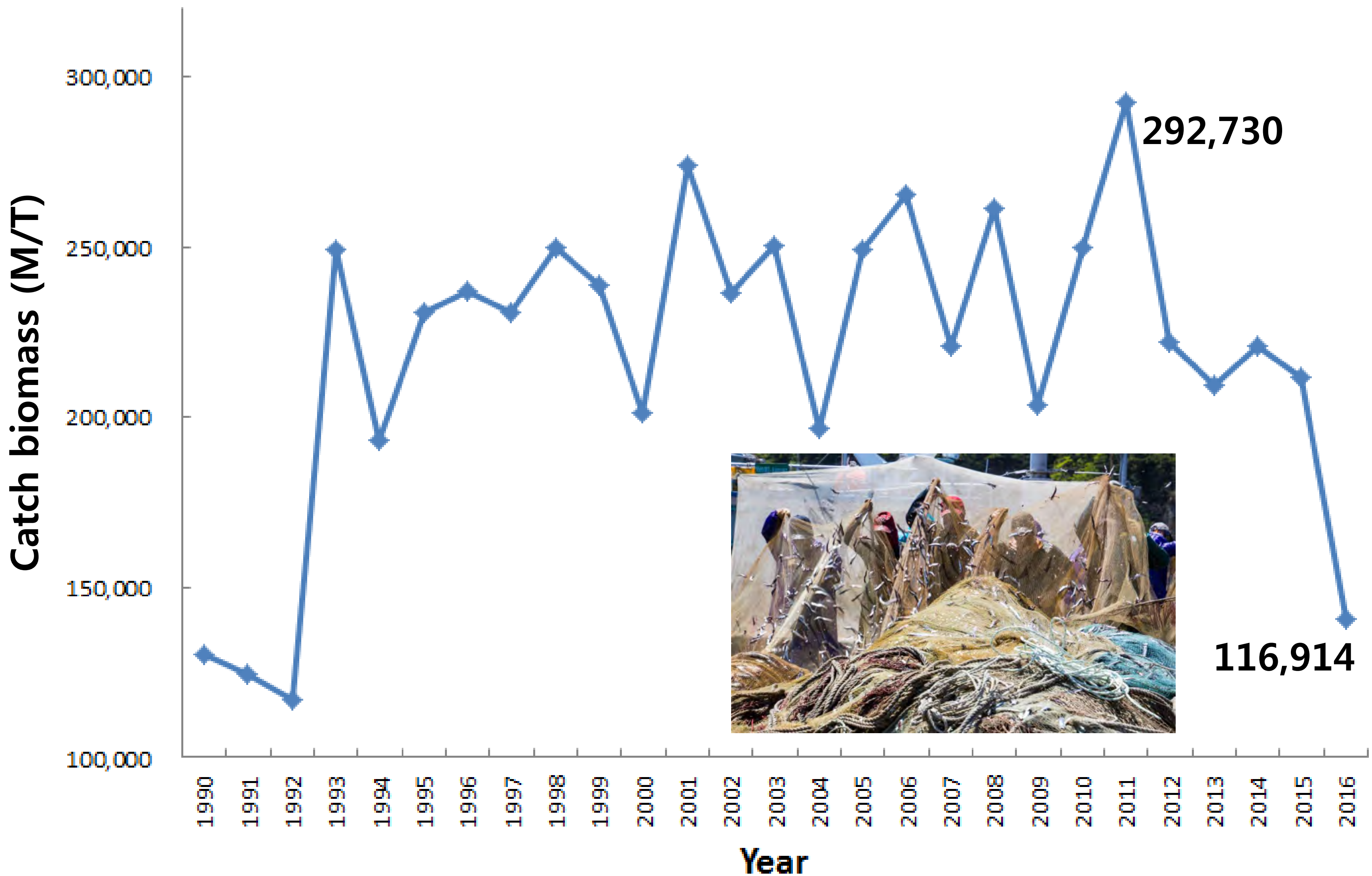
- The main characteristics
  1. Early maturity
  2. A short life span
  3. Seasonal migration

Life cycle of Pacific anchovy

	6 month	1 age	1.5 age	2 age
Total length (cm)	8.6	11.7	14.1	15
Body weight (g)	4.6	12.3	23.3	28.5

Egg 2~3 mm

Catch biomass of anchovy



(MOF, 2017)

Yield per recruit model

- Exploitation strategy for maximum yield.
  (Many small fish vs. Fewer big fish)

- Provide biological reference point (L_c, $F_{0.1}$, F_{max}) for fisheries management.
  1. Length at first capture (L_c)
  2. Fishing mortality (F)

- Classical yield per recruit analysis
  - Beverton and Holt (1957)

Yield per recruit model

- Yield per recruit model of Beverton and Holt (1957)

$$\frac{Y}{R} = F\exp\left(-M(t_c - t_r)\right)W_\infty \sum_{n=0}^{3} \frac{U_n \exp\left(-nK(t_c - t_0)\right)}{F+M+nK}$$
$$\left(1 - \exp\left(-(F + M + nK)(t_L - t_c)\right)\right)$$

F: Instantaneous fishing mortality coefficient

M: Instantaneous natural mortality coefficient

K: Growth coefficient

t_c: Age at first capture

t_r: Age at recruitment

t_L: maximum age

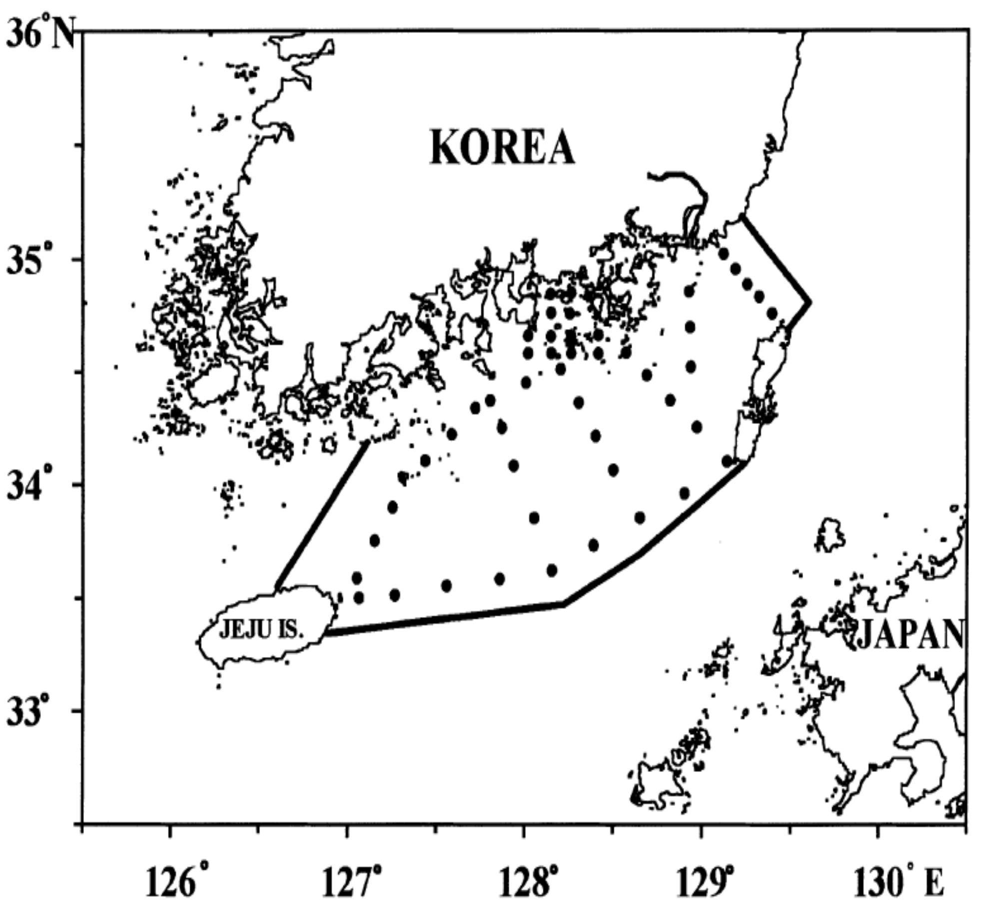
Problem

1. Anchovy is difficult to apply the Beverton-Holt model, because their life cycle is mostly shorter than 1 year and their natural mortality is greatly different with age or body size.

Objectives of study

- **Provide biological reference points.**
  1) **Fishing mortality**
  2) **Length at first capture based on an advanced simulation method that considers varying nature mortality with body size of anchovy from egg to adult stages.**

Data of Pacific anchovy in the Korea Strait



Kim and Lo (2001)

Water temperature

- Jung et al. (2008)
  - NFRDI (1996)
  - 204-207, 400 lines (10 m)

Growth & instaneous natural mortality

- Jung et al. (2008)

Hatching time

- Kim and Lo (2001)

Length-weight relation ship

- Choi and Kim (1988)

Fecundity

- Kim and Kang (1992)

Simulation based yield per recruit analysis

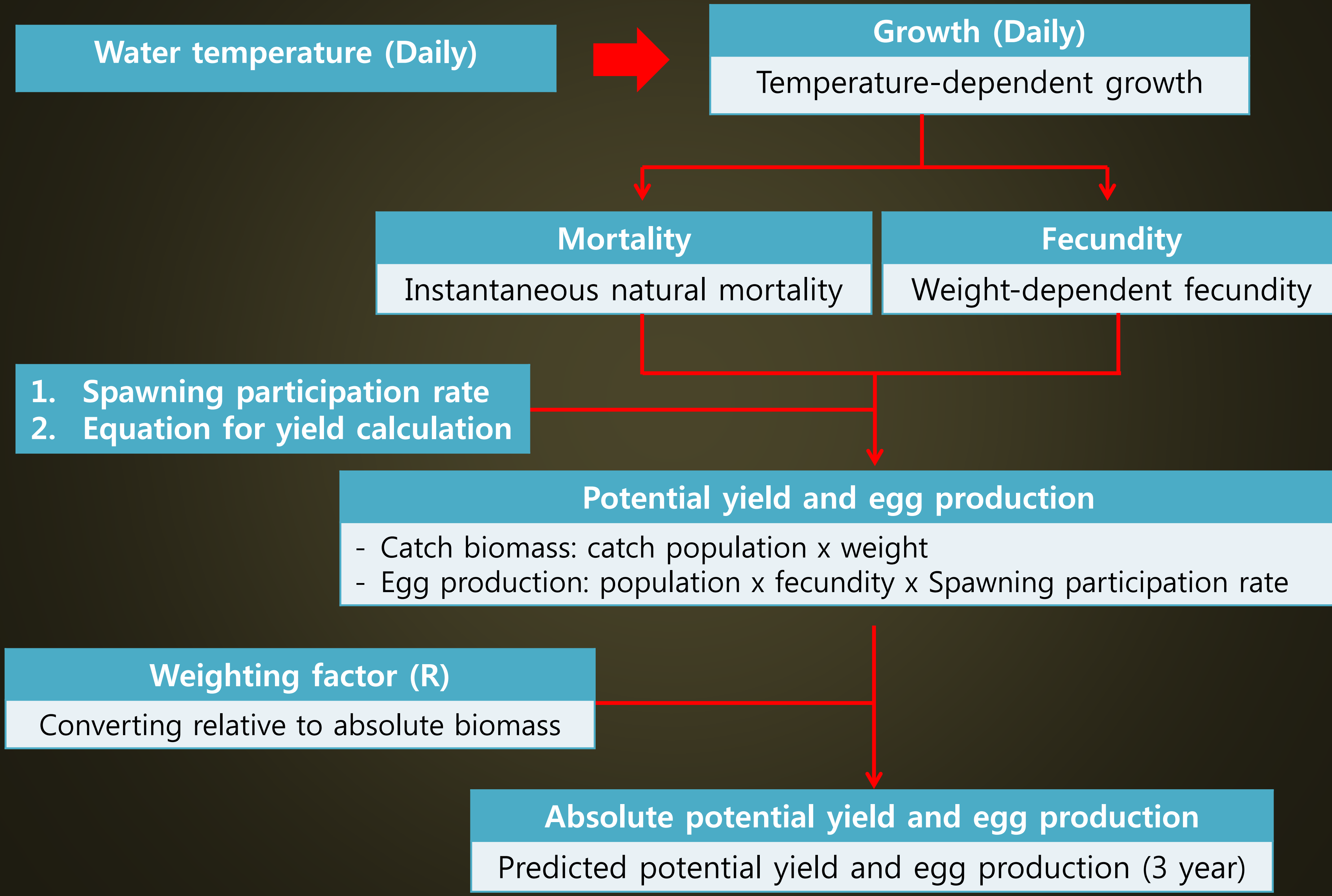
- Estimation of potential yield and egg production using developed analysis.
  - First capture length
  - Varying fishing mortality (fishing effort)

- Comparison of potential yield and egg production between two fishing conditions.
  1. The minimum length allowed to catch
     → Immature fish are protected
  2. The maximum length allowed to catch
     → Adult fish are protected

Assumption

1. Maximum age of anchovy is 2 years.
2. Growth and incubation time of eggs are function of water temperature.
3. The instantaneous rate of natural mortality is inversely proportional to body size.
4. Anchovy spawns every day and the daily egg production is constant every year.
5. The sex ratio of hatched eggs is 1:1.
6. The minimum length of spawning anchovy is 80 mm in fork length.

Flow chart


Water temperature (Daily)
Growth (Daily)
Temperature-dependent growth
Mortality
Instantaneous natural mortality
Fecundity
Weight-dependent fecundity
1. Spawning participation rate
2. Equation for yield calculation
Potential yield and egg production
- Catch biomass: catch population x weight
- Egg production: population x fecundity x Spawning participation rate
Weighting factor (R)
Converting relative to absolute biomass
Absolute potential yield and egg production
Predicted potential yield and egg production (3 year)

Initial value and growth rate

- **Initial value**
  - N_0 = 159,586
  - Estimated total number of eggs produced by an average matured female per year (Jung et al., 2008).

- **Growth rate (Jung et al., 2008)**

$$K_d = 0.00044+0.00017 \times T_d$$

* K_d is von bertalanffy growth coefficient at *d* day

* T_d is water temperature at *d* day

Instantaneous natural mortality

- Instantaneous natural mortality (Jung et al., 2008)

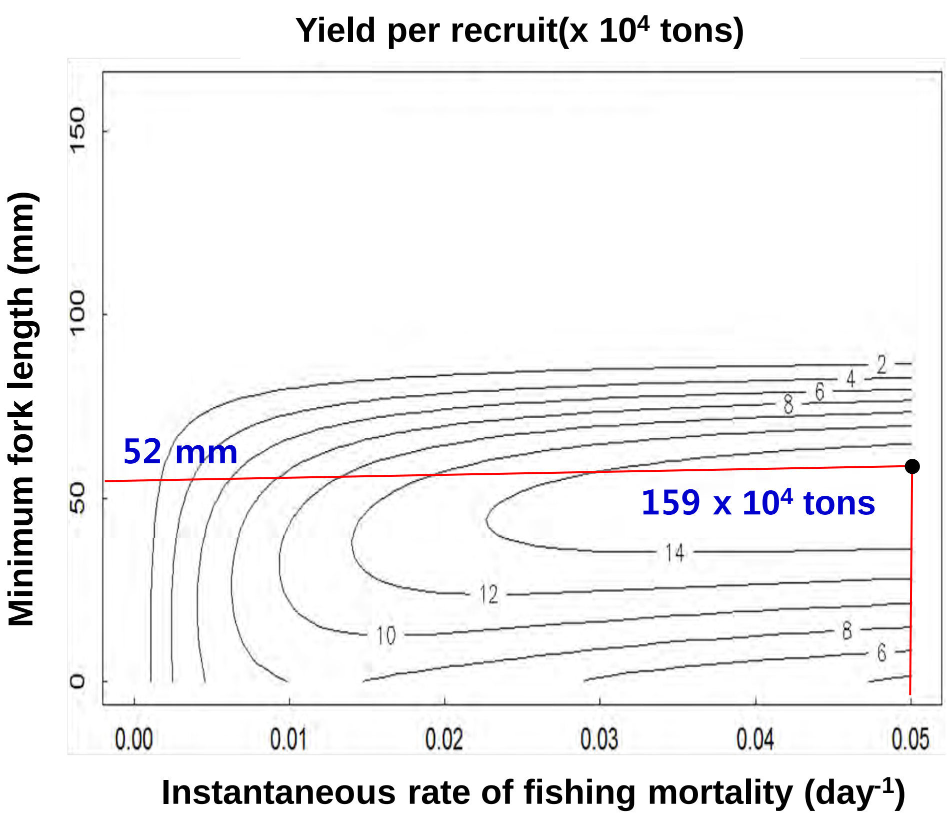
$$M = 1.24 \text{ mm day}^{-1} / L_d$$

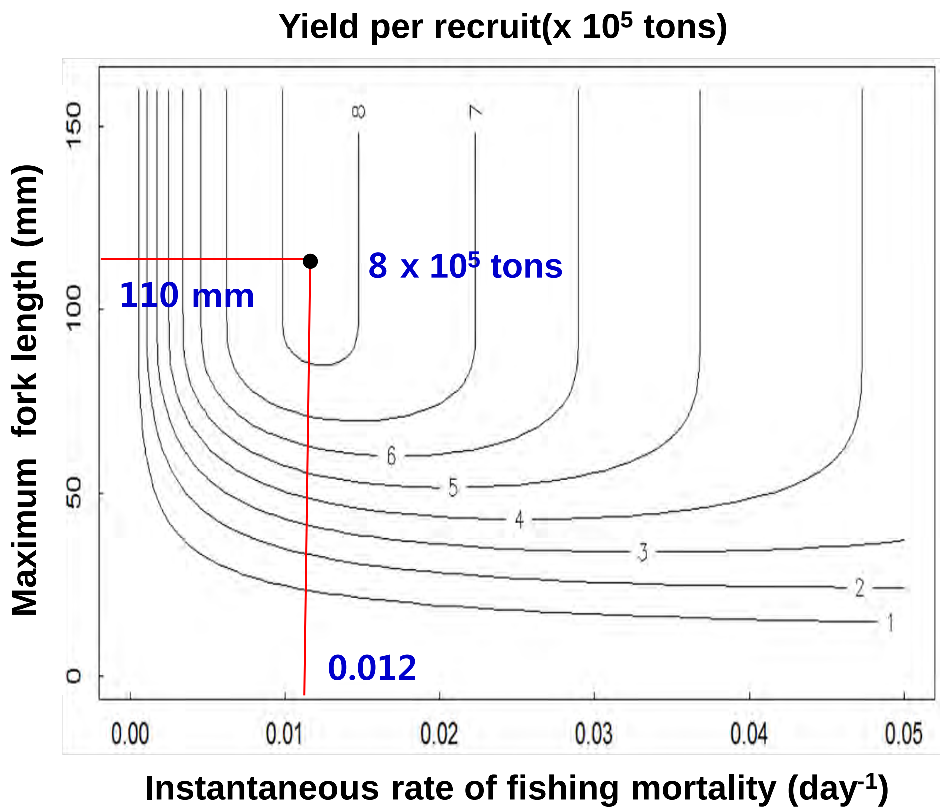
* L_d is length at d day

* M is size-dependent Instantaneous natural mortality

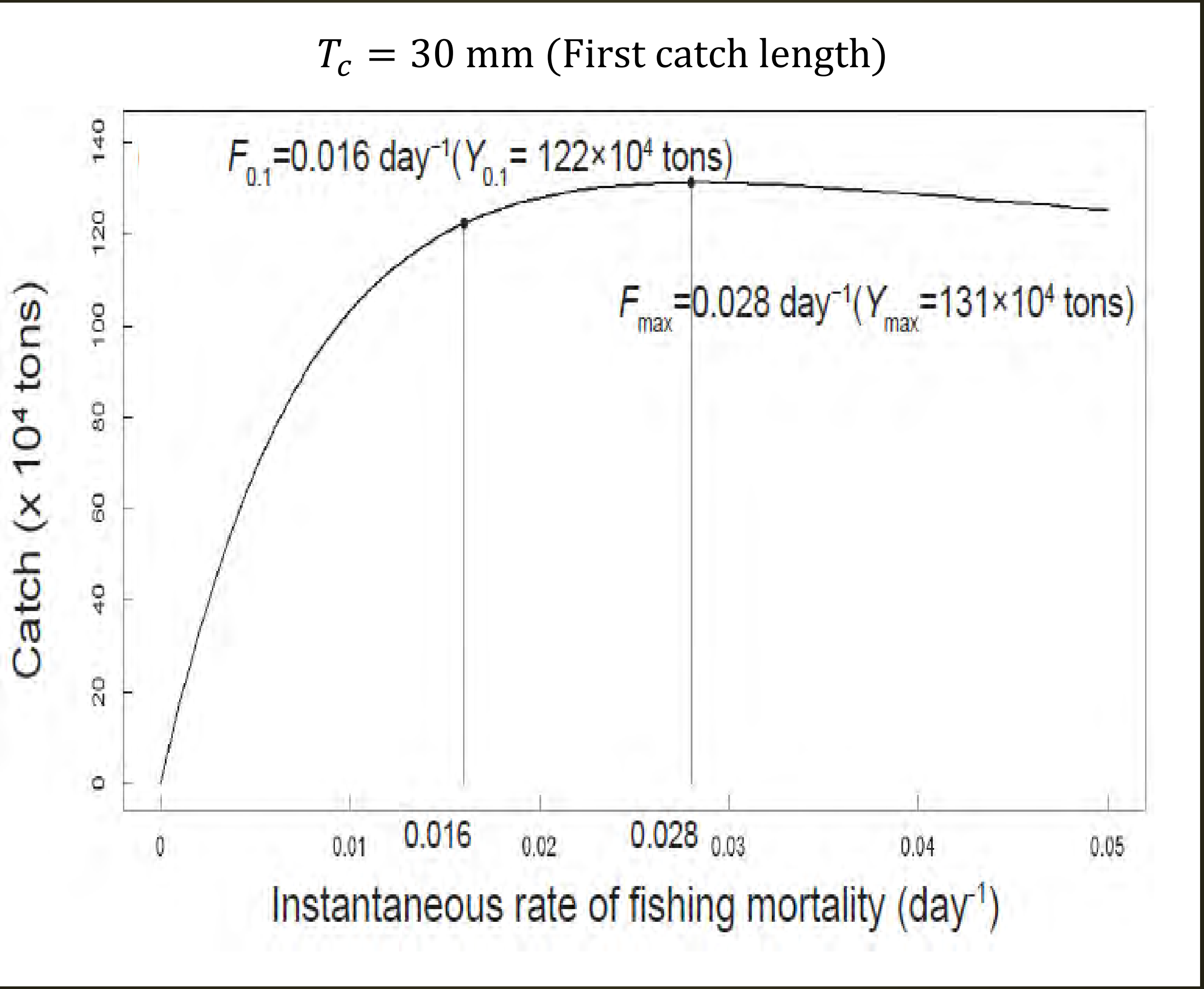
Result

Potential yield

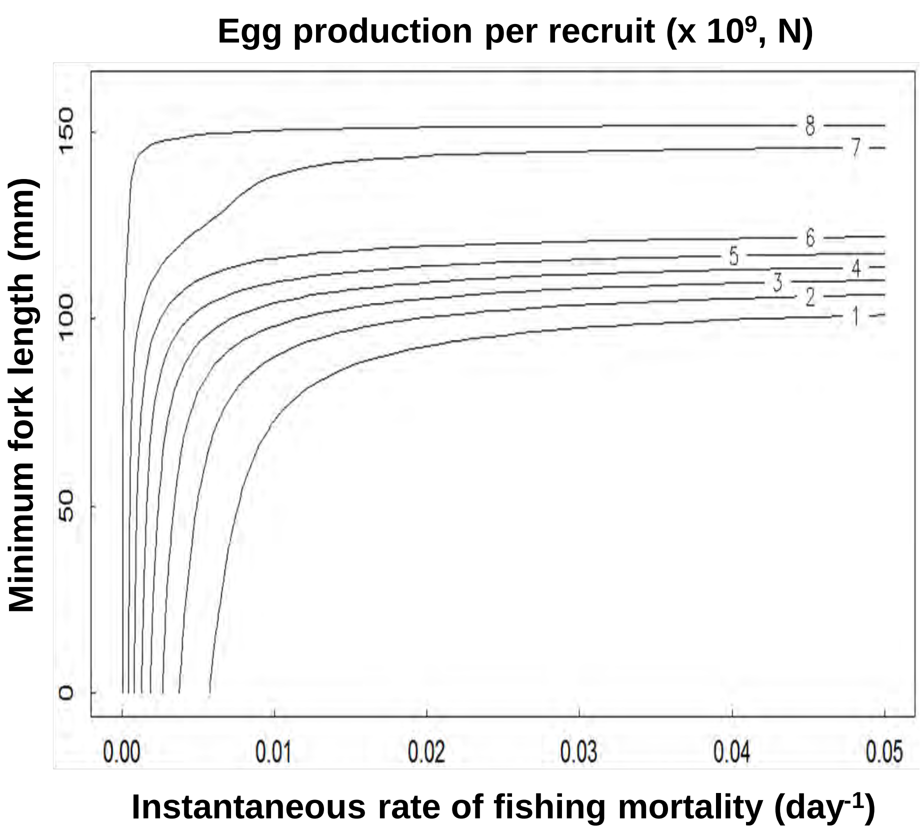


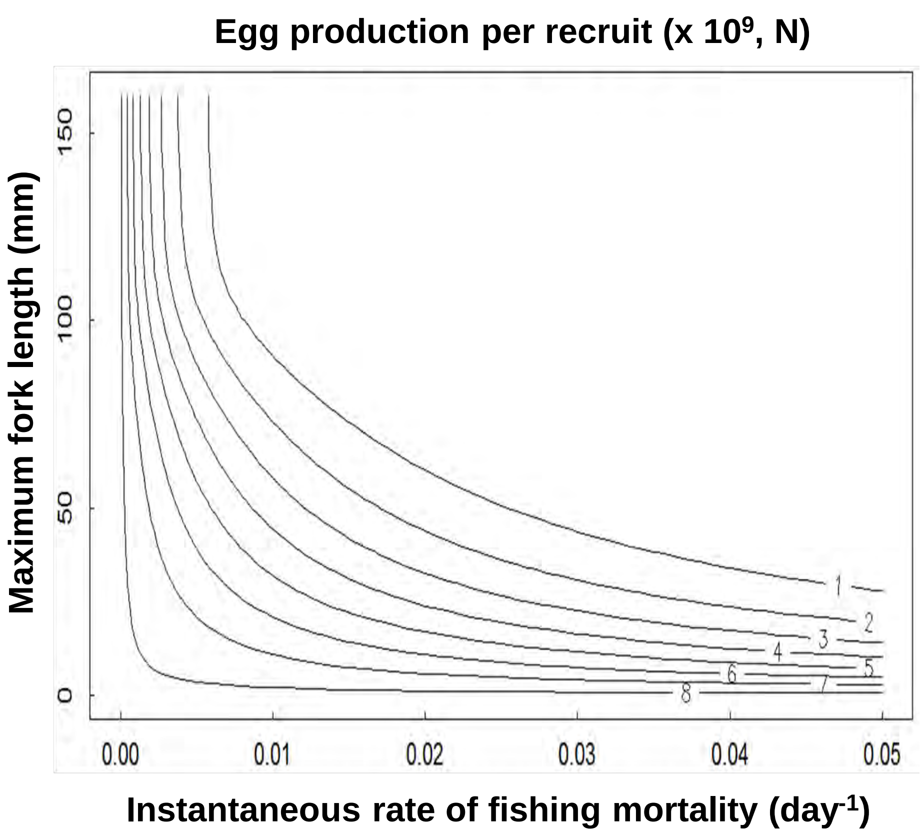


Estimated $Y_{0.1}$ and Y_{max} at L_c=30 mm



Egg production





Yield per recruit biomass

- Comparison of potential yield
  - ✓ The minimum length allowed to catch showed higher yield per recruit rate than the maximum length allowed to catch.

Maximum yield

Immature fish are protected

159 X 10^5 tons

About X 2

Mature fish are protected

81 X 10^5 tons

Yield per recruit biomass

- Biological reference point for fisheries management
  - ✓ $Y_{0.1}$ showed 1.2 million tons when $F_{0.1}$ is 0.016
  - ✓ Y_{max} showed 1.31 million tons when F_{max} is 0.028

Yield per recruit egg production

- Comparison of egg production
  - ✓ Egg production maximized at 8 billion eggs when no catch.
  - ✓ Two fishing conditions show opposite tendency.

Egg production

Immature fish are protected

Opposite

⇔

Mature fish are protected

Applying predicted model result

- The current fisheries regulation of protecting young anchovy can produce higher yield than protecting adult.

- Overfishing does not occur even if the current catch is increased.
  - Y_{max}=131 x 10^4 tons
  - Average catch from 2000 to 2010 = 22 x 10^4 tons

Future studies

- Additional studies on evaluation of yield including economic costs.
- Reflecting recent data of anchovy biological characteristics.
- The developed model can be applied to other commercially important small pelagic species.

Marine ecosystem-based analysis and decision-making support system development for marine spatial planning.

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