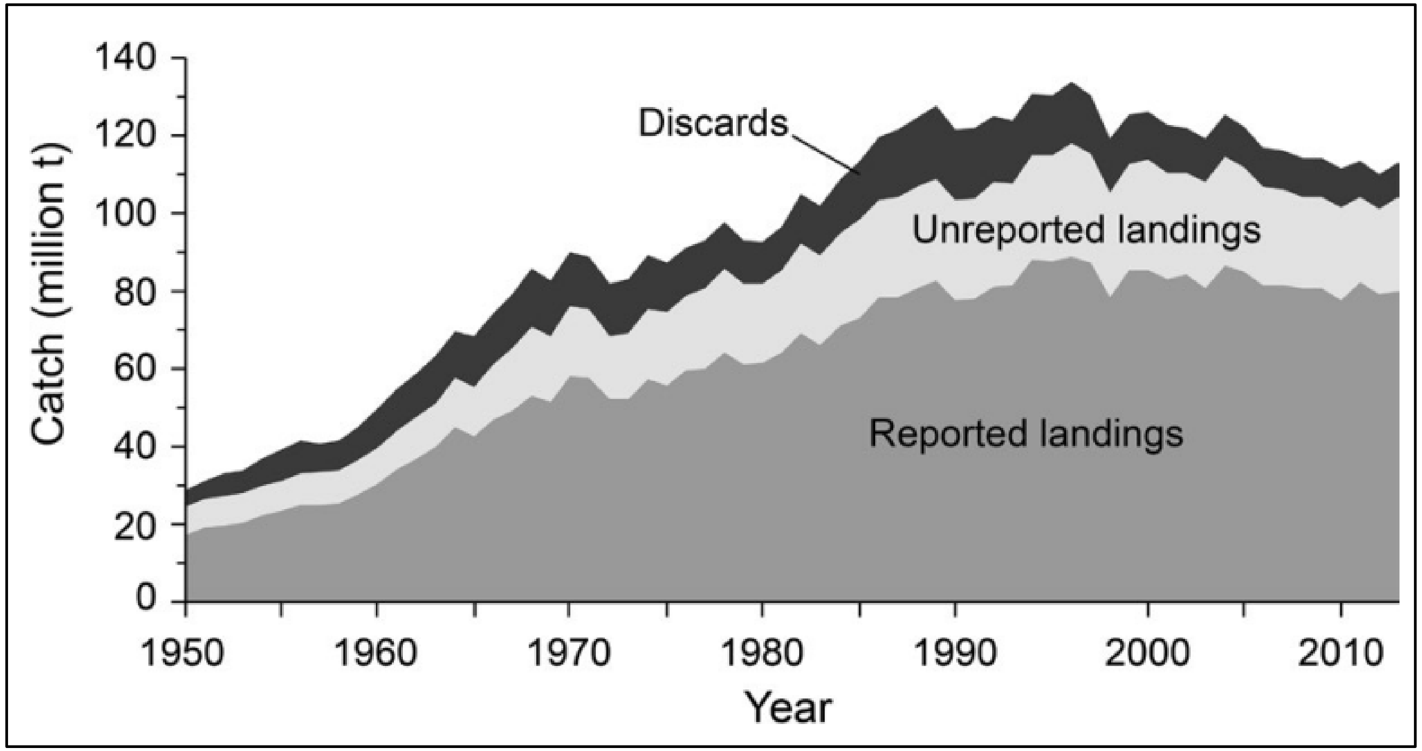
Comparative analysis of stock assessment models for planning the effective fishery resource management: Analyzing potential yield of West sea, Republic of Korea

Minje Choi, Jaebeum Hong & Dohoon Kim
Department of Marine & Fisheries Business and Economics
Pukyong National University

Contents

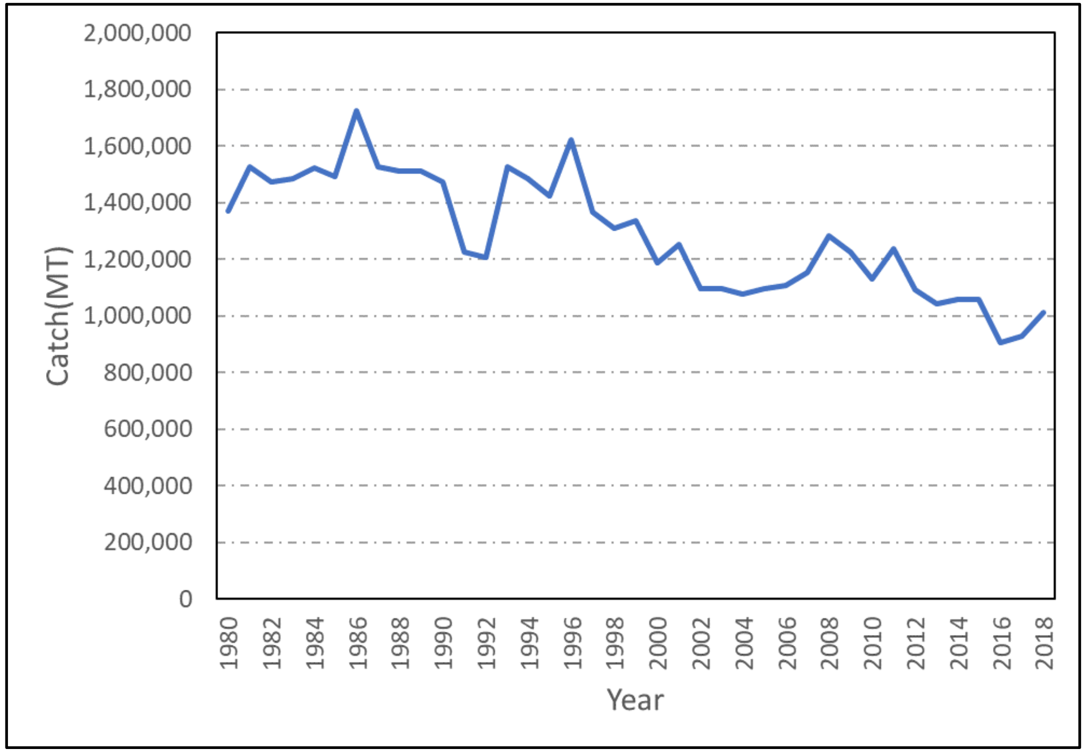
Present condition

Global



*Zeller et al. (2017)

Republic of Korea



*Statistics Korea (2019)

- **Catch of marine fisheries have been decreasing since the1990s globally.**
- **It has been decreasing since 1985 in the Republic of Korea.**

1. Introduction

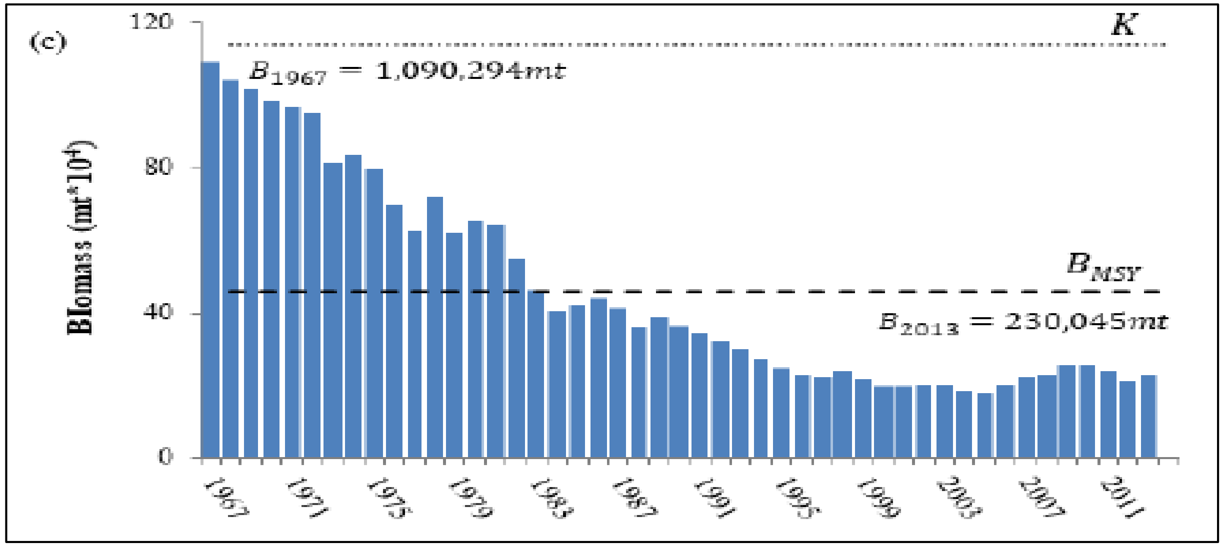
Previous study

Table A1. Annual catch, observed fishing effort, estimated gross tonnage of aquaculture and inland fishery (AIGT) and standardized GT using Catching efficiency (CE) for Korean west coast fisheries from 1967 to 2013

Year	Catch (mt)	Observed fishing effort (GT)	Estimated AIGT	Standardized GT using CE
1967	124,571	40,940	1,517	28,384
1968	132,735	43,064	1,428	31,006
1969	123,761	45,125	1,948	33,311
1970	133,947	52,770	2,491	40,078
1971	137,302	58,664	3,136	46,008
1972	151,543	67,053	2,892	55,480
1973	173,940	71,230	2,356	62,043
1974	198,532	80,563	2,506	73,696
1975	229,902	86,950	6,440	78,693
1976	232,565	92,327	3,021	91,046
1977	231,472	98,496	3,109	101,236
1978	230,820	110,345	3,260	117,959
1979	229,570	107,593	4,244	117,149
1980	226,400	110,305	4,155	124,103
1981	236,981	112,347	3,587	131,065
1982	253,628	115,430	4,626	137,645
1983	257,686	115,364	3,659	197,973
1984	245,347	120,811	3,243	215,071
1985	252,582	115,939	2,830	212,689
1986	263,568	114,530	4,422	212,354
1987	254,085	115,713	5,695	217,836
1988	228,596	116,994	6,764	225,063
1989	236,939	109,430	8,220	212,233
1990	224,207	109,834	7,112	220,355
1991	224,623	111,224	7,983	226,960
1992	213,444	107,330	5,682	225,104
1993	213,719	104,621	3,265	229,546
1994	205,543	102,962	2,967	232,431
1995	178,086	98,577	2,400	228,219
1996	156,784	97,115	2,049	230,240
1997	148,601	95,653	1,674	232,553
1998	182,141	100,627	2,597	246,457
1999	166,720	100,009	2,755	250,913
2000	161,439	96,481	3,427	245,488
2001	135,560	94,922	3,926	239,001
2002	135,781	87,540	3,902	222,976
2003	158,484	85,352	4,122	229,492
2004	137,938	81,660	3,581	224,689
2005	117,239	82,259	3,655	229,415
2006	130,871	80,189	3,267	229,347
2007	142,492	78,119	2,981	225,632
2008	129,565	64,960	3,628	184,696
2009	158,601	59,030	3,818	167,285
2010	163,582	59,204	3,366	172,153
2011	154,230	58,773	2,678	176,020
2012	127,231	59,175	2,678	180,145
2013	117,010	59,291	3,226	181,720

Table 2. Summary of the estimated results for Korean west coast fisheries by each model using gross tonnage for effort

Parameter	Fox model	CYP model	ASPIC model	Maximum entropy model
$MSY = PY(mt)$	219,146	174,232	232,700	238,088
$B_{MSY}(mt)$	-	796,311	808,500	459,762
$f_{MSY}(GT)$	123,110	142,232	138,800	161,438
$K = ECC(mt)$	-	2,164,598	1,617,000	1,140,541
$q(/GT)$	-	1.54E-06	2.07E-06	3.21E-06
$r(/year)$	-	0.219	0.476	0.835
R^2	0.896	0.899	0.933	0.953
RMSE	0.451	0.728	0.290	0.252
U	2.671	2.482	1.478	1.173



*Kim et al.(2018)

- **Process-error model(Fox and CY&P models), ASPIC model, and Maximum entropy model were conducted for assessing the potential yield of West sea.**

Goals of study

- **Estimate the fishery resources of West sea in the Republic of Korea using Observation-error model and Bayesian state-space model.**

- **Compare the models for selecting an appropriate model.**
  - **Models from the previous study: Process-error model, ASPIC model, and Maximum entropy model**
  - **Models from this study: Observation-error model and Bayesian state-space model**

- Suggest a stock assessment model which can be used for planning fishery resource management plans for West sea.

Reasons for selecting the models

- **Using age-structured models are limited due to paucity of data in the Republic of Korea.**

- **Bayesian state-space model can simultaneously consider the process error and the observation error.**

- **Stock assessments using Observation-error model and Bayesian state-space model are still limited in the Republic of Korea.**

Data

Table A1. Annual catch, observed fishing effort, estimated gross tonnage of aquaculture and inland fishery (AIGT) and standardized GT using Catching efficiency (CE) for Korean west coast fisheries from 1967 to 2013

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2013	117,010	59,291	3,226	181,720

- **Use the 'same' catch and fishing effort data from Kim et al.(2018) which were applied for assessing the potential yield of West sea, Republic of Korea.**

- **Total catch(all species) and standardized CPUE data of West sea from 1967~2013 are applied.**

- **Prior distributions for Bayesian state-space model are specified from the previous studies.**

(Kim et al., 2018; Miller and Meyer, 1999)

Stock assessment models

Surplus production model

- Models for assessing resources using only catch and catch effort data

  Biomass dynamic function : $B_{t+1} = B_t + g(B_t) - C_t$

  Relative abundance index : $I_t = qB_t$

- Be divided by how fit to fishery assessment models to the observed data

Model	Method	Assumptions
Process-error model **(Fox model, CY&P model)**	Linear Regression Analysis	Error in resource dynamics, Linear
Observation-error model	Maximum Likelihood Estimate	Error in observed data, Non-linear
Bayesian state-space model	Bayesian Inference	Both process-error and observation-error, Non-linear

▶ **The assessment of Korean fishery resources has been mainly conducted by process-error model.**

Methods

- **Bayes's theorem**

$$p(K,r,q,\sigma^2,\tau^2,P_1,\dots,P_N,I_1,\dots,I_N) = p(K)p(r)p(q)p(\sigma^2)p(\tau^2)p(P_1|\sigma^2)\times\prod_{y=1}^{N}p(P_y|P_{y-1},K,r,\sigma^2)\prod_{y=1}^{N}p(I_y|,q,\tau^2)$$

Posterior distribution — Prior distribution — Likelihood

- **Prior distribution**

Parameter	Form of prior distribution	Mean	Standard error
Intrinsic growth rate(r)	Lognormal	-1.38	0.51
Catchability coefficient(q)	Inverse-gamma	1	1
Carrying capacity (K)	Inverse-lognormal	16	0.75
Process error(σ^2)	Inverse-gamma	3.79	0.01
Observation error(τ^2)	Inverse-gamma	1.71	0.01

- Prior distributions are obtained from the previous studies (Miller and Meyer, 1999; Kim et al., 2018)

- **Gibbs Sampling**

$$simulate\ K^{(1)}\sim f\left(K\middle|r^{(0)},\cdots,\tau^{2(0)},P_1^{(0)},\cdots,P_n^{(0)},I_1^{(0)},\cdots,I_n^{(0)}\right),$$

$$simulate\ r^{(1)}\sim f\left(r\middle|K^{(1)},q^{(0)},\cdots,\tau^{2(0)},P_1^{(0)},\cdots,P_n^{(0)},I_1^{(0)},\cdots,I_n^{(0)}\right),$$

$$\vdots$$

$$simulate\ I_n^{(1)}\sim f\left(I_n\middle|K^{(1)},r^{(1)},P_1^{(1)},\cdots,P_n^{(1)},I_1^{(1)},\cdots,I_{n-1}^{(1)}\right)$$

$$\mathrm{K}\left(\theta^{(m+1)},\theta^{(m)}\right)$$

$$=\prod_{i=1}^{n}f(\theta_i^{(m+1)}|K^{(m+1)},\cdots\tau^{2(m+1)},P_1^{(m+1)},\cdots P_n^{(m+1)},I_1^{(m+1)},\cdots I_n^{(m+1)})$$

Model test

Evaluation of model precision

- RMSE(root mean square error) and R^2(coefficient of determination) using Expected and Observed CPUEs are calculated for comparison among models(Kim et al.,2018).

$$\boldsymbol{RMSE} = \sqrt{\frac{1}{n}\sum_{y}(I_y - \hat{I}_y)^2}$$

$$\boldsymbol{R^2} = 1 - \frac{\sum_y (I_y - \hat{I}_y)^2}{\sum_y (I_y - \bar{I})^2}$$

$I_y =$ Observed CPUE

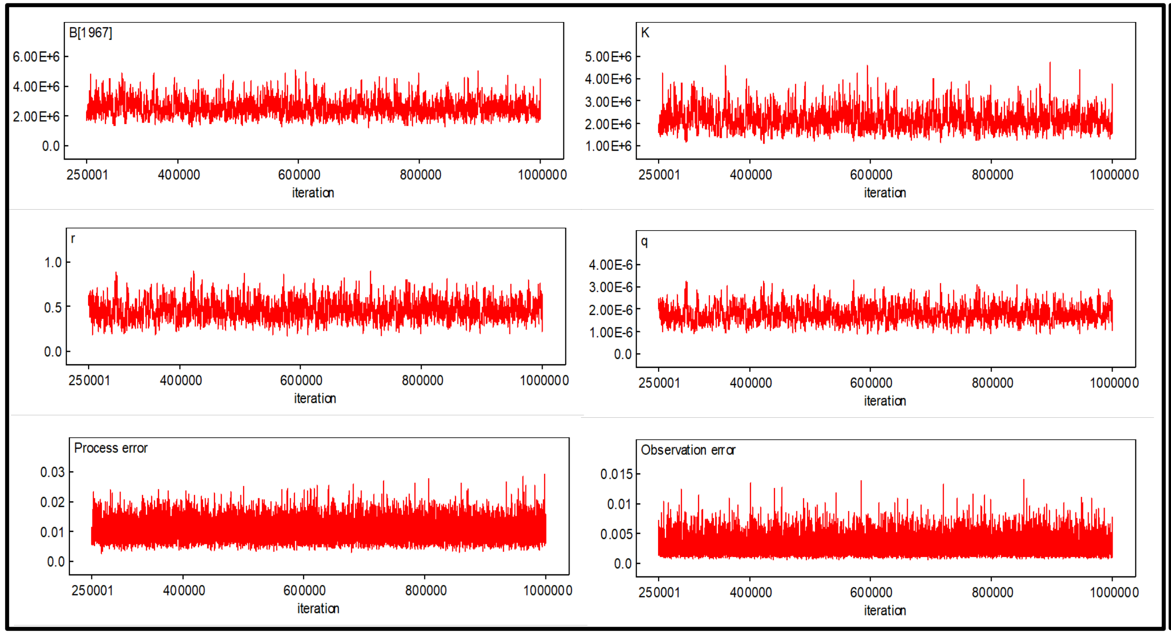
$\hat{I}_y =$ Expected CPUE

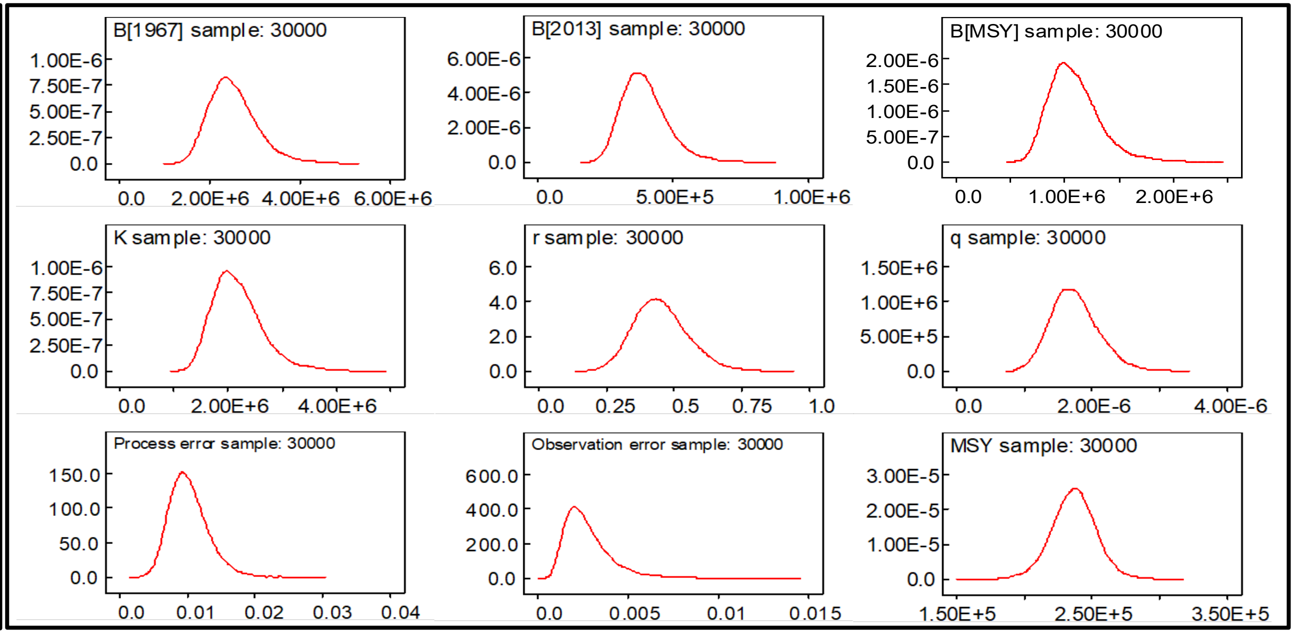
$$\bar{I}_y = \frac{1}{n}\sum_{y} I_y$$

▶ Lower RMSE and Higher R^2 indicate higher precision.

3. Results

Bayesian state-space model

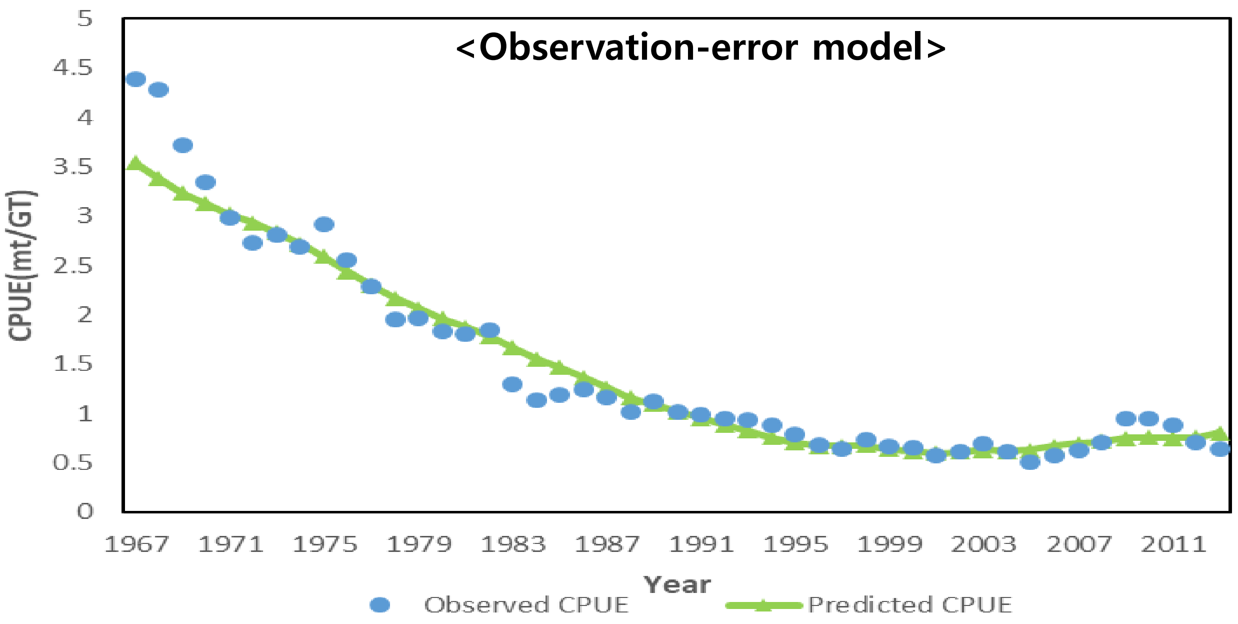


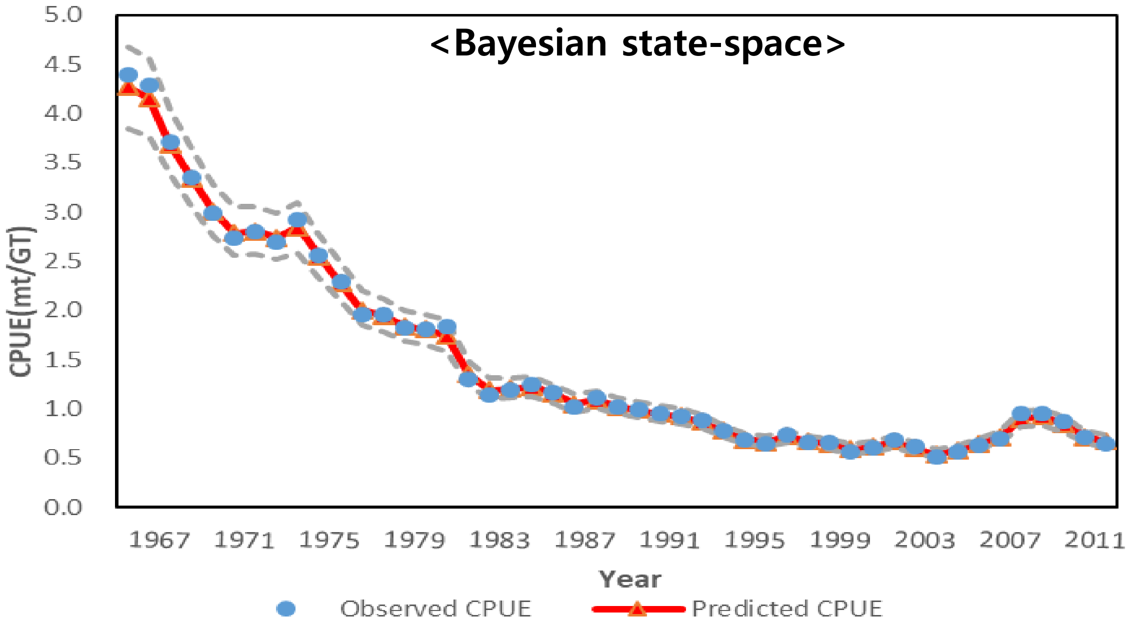


- **Use WinBUGS to estimate the Bayesian state-space model.**
- **Posterior distributions are based on 750,000 iterations after discarding the first 250,000 iterations.**
- The iterations are reduced to 30,000 by sampling every 25th value to avoid sample correlations.
- The median values are used as a representatives of the parameters of posterior distributions to reduce the influence of the outliers.

3. Results

Comparison of model results





Parameter \ Model	Fox	CY&P	ASPIC	Maximum entropy	Observation-error	Bayesian state-space
MSY (mt)	219,146	174,232	232,700	238,088	179,291	236,725
K (mt)	-	2,164,598	1,617,000	1,140,541	2,708,372	2,125,000
r	-	0.219	0.476	0.835	0.180	0.446
q	-	1.54E-06	2.07E-06	3.21E-06	1.31E-06	1.72E-06
RMSE	0.451	0.728	0.290	0.252	0.238	0.038
R^2	0.896	0.899	0.933	0.953	0.947	0.999

▶ Bayesian state-space model has the lowest RMSE and the highest R^2 values.

Further study

- **Bayesian state-space model can give the relatively reliable result among the stock assessment models.**

- **It is controversial which prior distribution for Bayesian inference can give the appropriate results(Chaloupka and Balaz, 2007; Punt and Hilborn, 1997; Thorson and Cope, 2017).**

- **Using logistic model (Schaefer) for assessing fisheries resources should be abandoned (Maunder, 2003).**

- Biomass dynamic function

  Schaefer (1954) VS Pella-Tomlinson (1969)

- Assumption of prior distribution

  Informative K vs Non-informative K

Inverse Lognormal (16,0.75)

Uniform (100,000~1,000,000,000)

Inverse-gamma (0.0001,0.0001)

- DIC(Deviance Information Criterion) $DIC = D(\bar{\theta}) + 2p_d$

$$D(\bar{\theta}) = -2logL(data|\theta), p_D = \overline{D(\theta)} - D(\theta)$$

Comparison among the different assumptions

[West sea, Republic of Korea]

DIC	Log-normal prior distribution of K	Uniform prior distribution of K	Inverse-gamma distribution of K
Schaefer	-127.191	-129.289	-132.506
Pella-Tomlinson	-127.674	**-138.685**	**-152.567**

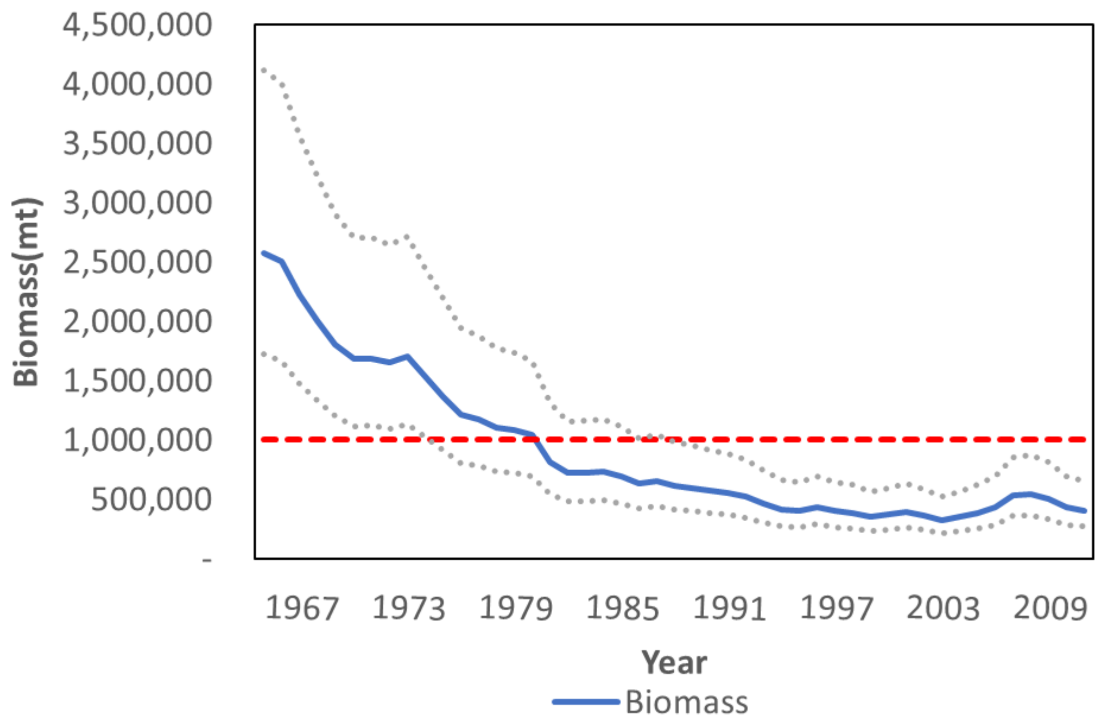
[East sea, Republic of Korea]

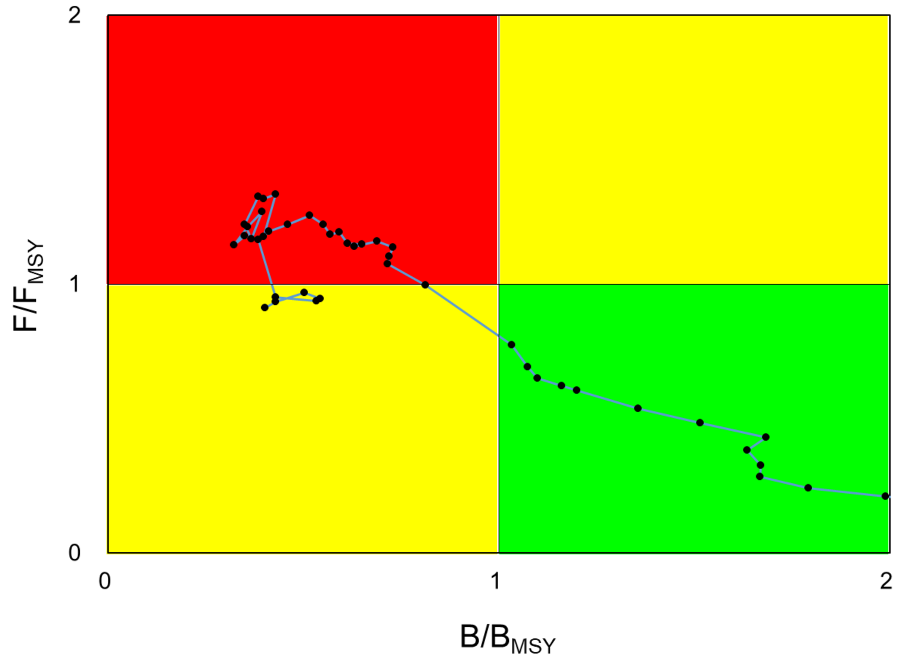
DIC	Log-normal prior distribution of K	Uniform prior distribution of K	Inverse-gamma distribution of K
Schaefer	-80.452	-88.251	-109.003
Pella-Tomlinson	-98.757	-107.027	-118.105

- **No convergence problems emerged in any of the analyses.**

▶ Assumptions of Pella-Tomlinson function and Non-informative K can give relatively reliable results.

Results





- The current biomass level of West sea is assessed to be approximately 40% of B_{MSY}.
- The recent fishing intensity is estimated to be turning to not overfishing.
- In most years, the estimated results belong to overfished and overfishing.

Discussion and conclusion

- **Bayesian state-space model is estimated to be the most reliable among the models.**

  - Process error model, ASPIC model, Maximum entropy model, Observation error model, and Bayesian state-space model

- **Assumptions of Pella-Tomlinson function and inverse-gamma distribution of K can help to get relatively reliable results of Bayesian state-space model.**

- **The recent status of West sea in Korea is analyzed to be overfished.**

  -The biomass level is estimated to be 40% of B_{MSY}.

- **Policy efforts are needed to recover the fishery resources of West sea, Korea.**

Discussion and conclusion

- **What are the benefits of using Bayesians state-space model for social & biological scientists?**

3. Biological and economic effects depending on the TAC plans

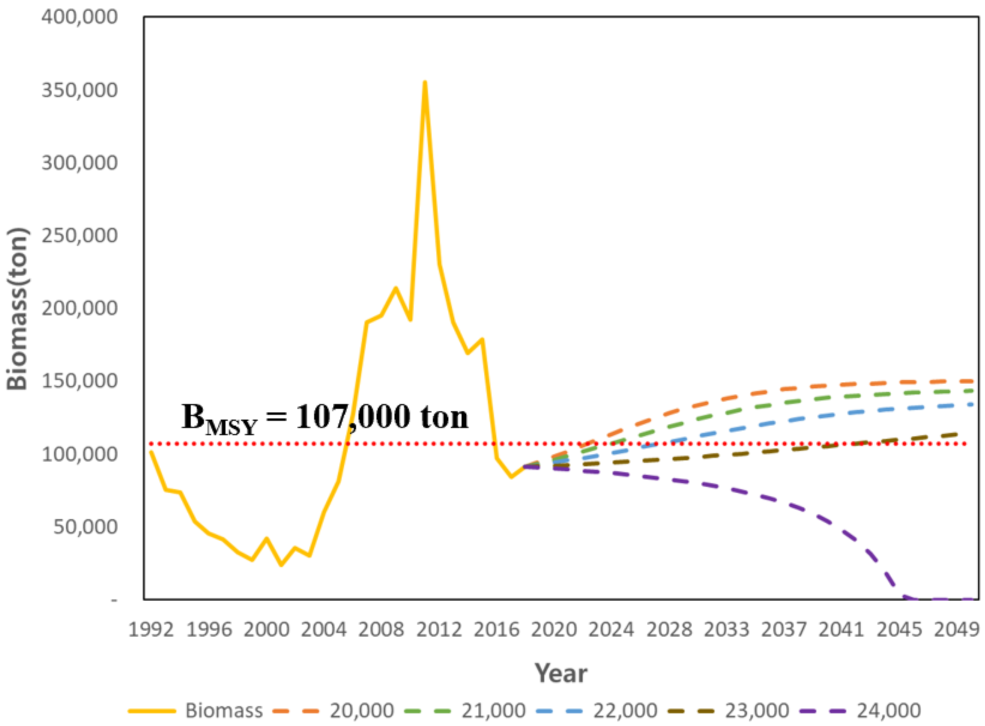


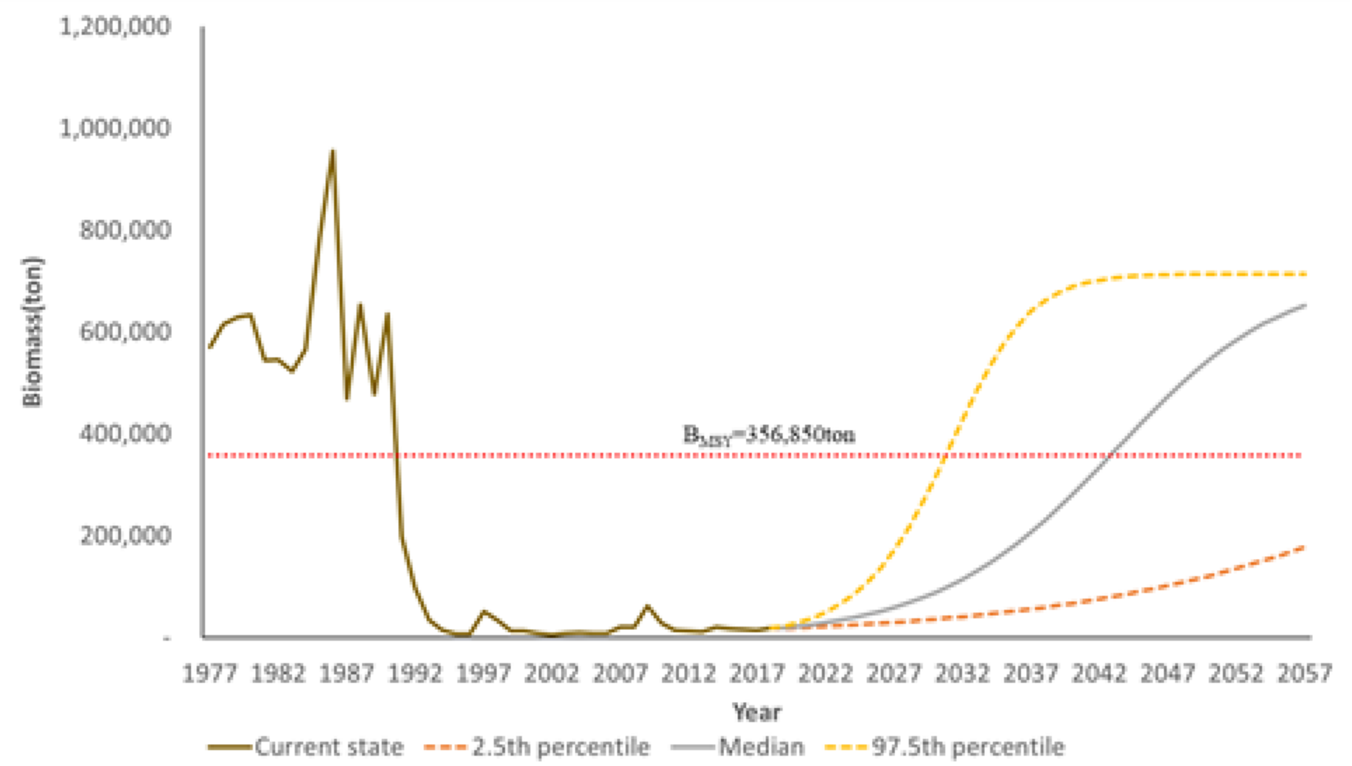
Fig. 4. Forecasting the future biomass of small yellow croaker depending on the TAC plans.

Table 2. Economic analysis of Gill net and Stow net depending on the TAC plans of small yellow croaker

TAC (ton)	Gill net (won/vessel)	Stow net (won/vessel)	Biomass (ton)
23,000	285,358	74,749	116,800
21,000	214,167	51,157	106,644
19,000	142,976	27,566	96,487
17,000	71,786	3,974	86,331
16,663	**59,794**	**0**	**84,620**
15,000	595	(19,618)	76,174
13,000	(70,596)	(52,808)	66,017

Discussion and conclusion

- **What are the benefits of using Bayesians state-space model for social & biological scientists?**



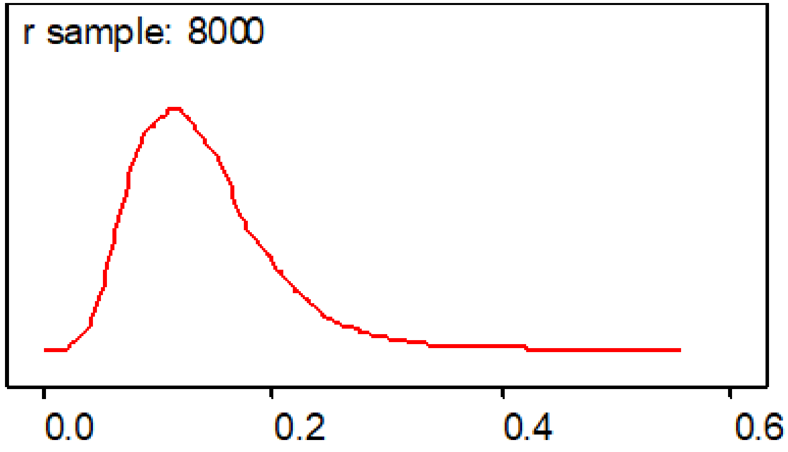


Fig. 6. Sensitivity analyses on changes of Black scraper biomass of depending on the 2.5th, 50th, and 97.5th percentile from the posterior predictive distributions of intrinsic growth rate.

THANK YOU

[cmj543@naver.com]