석사학위논문

Estimation of the potential fisheries production in the Korean waters by biomass-size-spectrum model based on satellite-derived, ocean-color data

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I. Introduction

1-1. Definition of potential fisheries production

Production is total elaboration of new tissue in a time period of interest by a species population (Chapman 1978). It includes the sum of the increased growth of all individuals alive during the period. The increased growth is the net increase or decrease in amount of tissue contained in the bodies of an individual organism. Production can be expressed as the following equation (1):

$$P = B_{t+1} - B_t + B_d \tag{1}$$

where

P is the production, during time Δt

B_t is the biomass at time t

B_{t+1} is the biomass at time $t+1$

B_d is total weight (at death) of all fish dying, during time Δt

$B_{t+1} - B_t$ is net biomass

Potential production is the sum of production by an ecosystem (Kim and Kang 1999; Ryther 1969). In this study, potential fisheries production, a part of potential production, is the sum of production of the fish and shellfish organisms which are usually positioned in the upper-trophic levels.

1-2. Past studies

1-2-1. Estimation of global potential fisheries production

The estimation of our global world potential fisheries production has been a central interest for fisheries scientists, marine biologists and other researchers of oceanography and human foods. This interest comes from two factors:

1) The estimation of total potential fish catches from the sea is critical to predict the future world food availability to man because it is presumed that the sea is not yet fully utilized and the area of the sea is more extensive compared with the land. The human population on the earth increases exponentially but the total potential fisheries production is limited, even considering the improvements of harvesting methods in the future.

2) An estimation of the global fisheries production reflects the current status of overall knowledge of marine sciences because the fish and shellfish are usually top predators in marine food chains and the underlying physical, chemical, and biological processes influence directly or indirectly on their growth and survival. Reliable estimation of potential fisheries production requires a comprehensive understanding of dynamic structure and process of marine ecosystem. Although our knowledge of the sea is imperfect and so is estimation of potential fisheries production, fisheries scientists and ecosystem ecologists have tried to estimate the global potential fisheries production, but their estimates vary greatly by a factor of 5.6.

Schaefer (1965) considered the world's oceans as a single ecosystem and its food chain with the fixed carbon efficiency conversion at 10% to estimate the potential fisheries production to be 1.08×10^9 tons. Ryther (1969) estimated the global potential fisheries production by dividing the oceans into 3 regions (open ocean, coastal zone and upwelling area) based on the mean productivity, trophic levels, and efficiency. His estimates of global potential fisheries production was 0.24×10^9 tons. Houde and Rutherford (1993) further divided the coastal region into the estuarine and continental-shelf areas to estimate the potential global catch applying Iverson’s (Iverson 1990) and Nixon's equation (Nixon 1988). Their estimates of global potential fisheries production was 1.36×10^9 tons.

Recently, climate change has been considered in estimating and projecting the global food production from the sea. Barange et al. (2010) proposed a modeling framework by dividing the scales of the available marine production models into 4 levels: population, community, ecosystem and individual. They selected biomass-size-spectrum (BSS) and individual-based models to project the change in global potential fisheries production by climate change. Free et al. (2019) used a temperature-dependent population model to evaluate changes in the habitat of fishes and invertebrates by climate change.

1-2-2. Estimation of regional scale fisheries production

Potential fisheries production has been also estimated at the regional scale. Nair et al. (1973) estimated primary production of Gulf of Mannar and west coast of India using oxygen and C^{14} techniques to estimate potential fishery resources. Jung and Houde (2005) estimated biomass size spectra of pelagic fish to describe community structure, estimate potential fisheries production, and delineate trophic relationships in Chesapeak Bay. Blanchard et al. (2009) estimated the biomass of the North Sea ecosystem using a BSS model. Pelagic predators and benthic detritivores were considered and estimated at the same time.

In Korea, Zhang et al. (2017) estimated the explosive carrying capacity of fishing targets of the East China Sea using the ecosystem modeling method (EMM) and the holistic production method (HPM). Lim et al. (2018) estimated the potential yield of East Sea using the HPM, the population production method, the fishery production method, and the EMM. Kim. et al. (2018) estimated the potential yield of a catch target of the Yellow Sea using several models among the HPM. Zhang et al. (2019) estimated maximum sustainable yield (MSY) that is 1.62×10^6 tons in the Korean waters using HPM and EMM.

1-3. Problems

Some fisheries scientists and policy makers of the Ministry of Oceans and Fisheries assume that the current fisheries capacity already exceeds the level for sustainable fisheries in the Korean waters, imposing various regulations to decrease the overall fishing effort. However, Zhang et al. (2019) reported that MSY in the Korean waters by Korean marine capture fishers is 1.62×10^6 tons, which is still greater than the recent reported annual catch of *ca.* 1×10^6 tons from Republic of Korea. Annual fisheries production in the Korean waters by both Korean and Chinese marine capture fisheries has maintained at the level of *ca.* 2.3×10^6 tons since 1974 (Fig. 1), which is greater than the reported MSY of $1.62 \text{ x } 10^6$ tons, suggesting the MSY was underestimated if including the Chinese fishing effort.

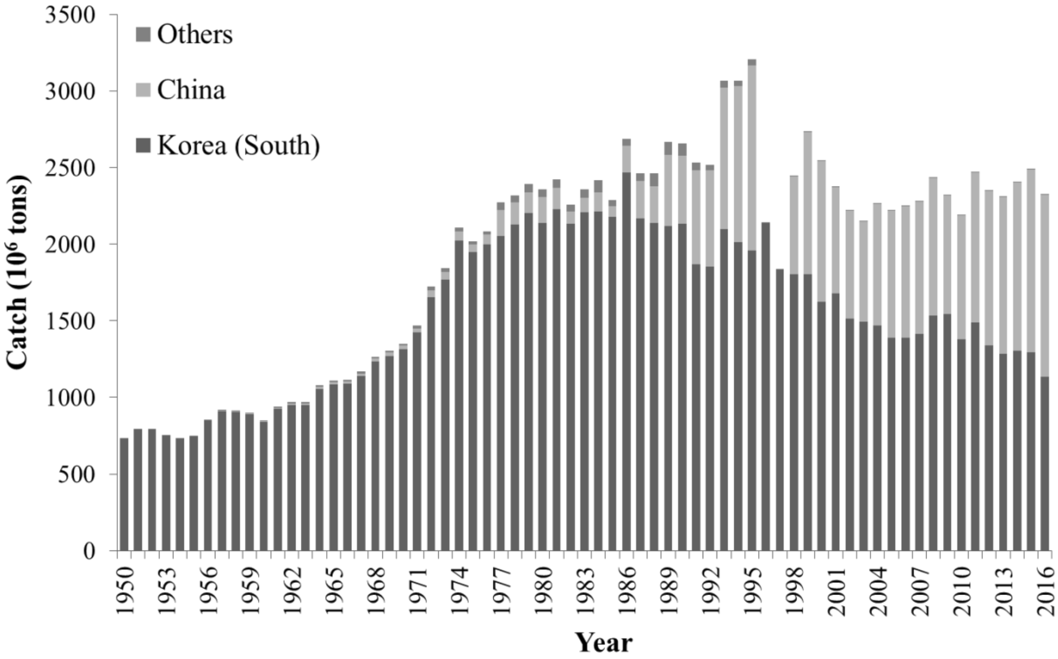


Fig. 1. Annual marine capture production from 1950 to 2016 in the Korean waters reported by Shon et al. (2014)

1-4. Objective

The objective of this study is to estimate potential fisheries production in the Korean waters based on fisheries-independent, ecosystem approaches: the Ryther's method and the BSS model. These approaches pre-empt the problems of the uncertain and unreliable fishing-effort data.

1-5. Ryther's method

Ryther (1969) divided the world ocean into 3 areas: open ocean, coastal zone and upwelling area to estimate the potential fisheries production. Mean productivity, trophic level, and transfer efficiency of each area were fixed. He estimated the global potential fisheries production to be 0.24×10^9 tons and the potential sustained yield to be 0.1×10^9 tons.

1-6. Biomass size spectrum model

1-6-1. Characteristics of marine ecosystem

The biomass structure of marine ecosystem differs from terrestrial ecosystem in which biomass decreases with increasing trophic level. Sheldon et al. (1972) measured the concentration of biological particles by the size using a Coulter counter for various seas in the world. Their results indicated that the distribution of the biomass density grouped by body-size was relatively constant, and that the total biomass is nearly the same between the lower and the upper trophic level. The total biomass by the body size at logarithmic scale of organisms in marine ecosystems was nearly constant from bacteria to whales.

1-6-2. Introduction of biomass size spectrum model

The BSS shows the distribution of biomass per unit area as a function of logarithmic body size at equal intervals (Jung and Houde 2005). Sheldon et al. (1972) developed the model by observations that biomass size spectra of aquatic pelagic communities are relatively constant along the axis of logarithmic size classes of organisms, i.e. slope equals to 0.

The BSS model has 3 assumptions. First, the abundance of fish is determined by the primary production. Second, the slope of the spectrum is determined by the trophic efficiency: a gentle slope for a higher trophic efficiency, and vice versa. Third, the human harvest of fish and shellfish in the upper trophic creatures makes the slope steep.

1-6-3. Model considering both pelagic and benthic ecosystem

Because the global fisheries production mostly occurred in shallow coastal areas where benthic-pelagic coupling processes are strong, both the benthic and pelagic components need to be considered together in estimating the regional fisheries production. Blanchard's BSS model considered benthic detritivores and pelagic predators at the same time (Blanchard et al. 2009).

II. Data and Methods

2-1. Study area

Area of estimated the Korean waters is 438,000 km^2 (Fig. 2., Shon et al. 2014) the Korean waters consist of the Yellow Sea, the East China Sea and the East Sea. The Yellow Sea, surrounded by North and South Korea and China, is a highly utilized sea which is in charge of *ca.* 0.6×10^9 population who live in coastal (Kim. et al. 2018; Zhang et al. 1993). The East China Sea is located from the south of Jeju Island to the north of Taiwan, and is composed of a region showing relatively high productivity due to the influence upwelling area and the Changjiang River flowing from China, and also composed of a poor nutritional marine environment of high temperature and high salinity Kuroshio current and Taiwan Warm Current (Chai et al. 2006; Chen et al. 2001; Chung et al. 2000; Isobe and Matsuno 2008; Son et al. 2012). The East Sea has coastal area in the west and an open sea in the east, and the depth of water rapidly deepens after 200 m and upwelling area, which has high fisheries production (Dong et al. 2017; Kim. et al. 2018; Son et al. 2012).

Fig. 2. The study areas representing the Korean Exclusive Economic Zone. The picture is redrawn from Shon et al. (2014)

2-2. Data

Geostationary Ocean Color Imager (GOCI) is payload of Communication Ocean and Meteorological Satellite. GOCI observed 8 times per day in around the Korean waters and the observation range is 2,500 km north-south and 2,500 km east-west, centering on 130 degrees east longitude and 36 degrees north latitude, which is the sea near Pohang and spatial resolution of GOCI is 500 m (Cho et al. 2010). It provided the marine environment (e.g. red tide and green algae) and fishery information (e.g. current vector and chlorophyll-a data) (Cho et al. 2010). In this study, I used the 2013 and 2014 data of the concentration of chlorophyll-a (mg m^{-3}) from GOCI data.

2-3. Methods

2-3-1. Ryther's methods

To use Ryther's method, the area of the Korean waters was divided into 3 areas: open ocean, coastal zone, and upwelling area. The total area is 438,000 km^2, the open ocean is about 183,000 km^2, the coastal zone is about 250,000 km^2, and the upwelling area is about 3,500 km^2 (Ryther 1969). The standard for dividing the sea is water depth, and it is divided based on 200 m. Other factors were applied in the same way as Ryther's method.

In addition, I used the 2013 and 2014 GOCI data to calculate the mean productivity in the Korean waters, and I estimated the potential fisheries production with the Ryther's method, applying the mean productivity in the Korean waters. To derive the mean productivity of the 3 areas, the averages of phytoplankton biomass per unit volume (mg m^{-3}) of the GOCI observation area was calculated by averaging the chlorophyll-a data at each location. And then I adjusted the averaged data for focusing on the 3 areas of the Korean waters. After multiplying the average of each area's chlorophyll-a by each location depth, the average (mg m^{-2}) was calculated and converted to the mean productivity (g C m^{-2}) with respect to each area.

2-3-2. Biomass size spectrum model

2-2-3-1. BSS model for the North Sea

In Korea, because the productivity of aquatic organisms is high in shallow waters, a BSS model that considers both pelagic and benthic ecosystems was needed. However there is insufficient data to develop the BSS model for Korea. I adopted the BSS model developed for the North Sea, which has a similar ecosystem structure to that of the Korean waters (Blanchard et al. 2009).

2-2-3-2. Estimation of phytoplankton biomass by size in the Korean waters

In order to derive the potential fisheries production, I needed biomass of lower-trophic level organisms and chose phytoplankton at organisms. In this study, to estimate the biomass of phytoplankton by size, phytoplankton was divided 3 categories: pico-phytoplankton (0.2~2 μm), nano-phytoplankton (2~20 μm), and micro-phytoplankton (20~200 μm).

However, Blanchard's model estimates the potential fisheries production from the weight of phytoplankton, so it converts the length of pico-, nano-, and micro-phytoplankton to weight using the following equations:

$W(pg\ C\ unit^{-1}) = 0.216 \cdot v^{0.939}$ (Menden-Deuer and Lessard 2000) (2)

$1\ g\ wet\ weight = 1.3\ kcal$ (Banse and Mosher 1980) (3)

$1\ g\ C = 10\ kcal$ (Jones 1984) (4)

where W is weight of organism and v is volume of organism.

As result based on preceding process, pico- was 9.72×10^{-12}~6.38×10^{-9} g $unit^{-1}$, nano- was 6.38×10^{-9}~4.18×10^{-6} g $unit^{-1}$, and micro-phytoplankton was 4.18×10^{-6}~2.75×10^{-3} g $unit^{-1}$.

For estimating phytoplankton biomass by size in the Korean waters, I used the GOCI data and a phytoplankton size-class (PSC) formula. The chlorophyll-a was divided into 3 categories by the PSC formula developed in KIOST:

$$
\begin{aligned}
C &= C_p + C_n + C_m \\
C_{pn} &= 0.9617[1 - \exp(-0.9248C)] \\
C_m &= C - C_{pn} \\
C_p &= 0.1308[1 - \exp(-5.659C)] \\
C_n &= C_{pn} - C_p
\end{aligned}
\quad (5)
$$

where

C is amount of total phytoplankton biomass (mg m^{-3})

C_{pn} is amount of pico- and nano-phytoplankton biomass (mg m^{-3})

C_p is amount of pico-phytoplankton biomass (mg m^{-3})

C_n is amount of nano-phytoplankton biomass (mg m^{-3})

C_m is amount of micro-phytoplankton biomass (mg m^{-3})

In order to obtain the phytoplankton biomass (tons) by size in the Korean waters; first the averages of phytoplankton biomass by size per unit volume (mg m^{-3}) of the GOCI observation area were calculated to averaging the each divided chlorophyll-a data at each location. Then, the averages of phytoplankton biomass by size per unit area (mg m^{-2}) of the GOCI observation area were derived from multiplying the water depth (m) and the averages of phytoplankton biomass by size per unit volume (mg m^{-3}). Finally, the averages of phytoplankton biomass by size per unit area (mg m^{-2}) was obtained by averaging the values of each location, and it multiplied by the area (km^2) of the Korean waters was the biomass (tons) of each phytoplankton size in the Korean waters.

2-2-3-3. Constructing the Biomass size spectrum in the Korean waters based on the North Sea case study

Before running the biomass size spectrum model, the biomass (g) by the phytoplankton size is converted to a $\log_2$ scale. After selecting a representative value among the values of the log scale body size, the zooplankton, small fish, medium fish, and large fish are determined by dividing by the same interval.

After designating the representative value, convert each phytoplankton to $\log_2$ scale, and then x-axis $\log_2$ (body size), and y-axis $\log_2$ (biomass), and then substitute the slope from BSS model reported by Blanchard et al. (2009), which is 0.1, for the average of phytoplankton, to estimate the values from zooplankton to large fish.

2-2-3-4. Estimation of potential fisheries production in the Korean waters by the BSS model

Multiplying fish biomass by size and the production/biomass (P/B) ratio, I estimated the production of fish organism for each size. And then the daily potential fisheries production in the Korean waters was derived from the sum of daily fish production by size. I need annual potential fisheries production so multiplied 365 days.

The P/B ratio reported by Banse and Mosher (1980) was followed:

$$P(w) = B(w) \times 10^{0.44-0.26log(w)} \tag{6}$$

where

w is size of organism (kcal)

$P(w)$ is annual production of size w

$B(w)$ is annual mean standing stock biomass of size w

III. Results

3-1. Ryther's method

The results of applying the Ryther's method to the Korean waters are listed in Table 1. The potential fisheries production is estimated to be *ca.* 2.22×10^6 tons and the potential sustained yield to be *ca.* 0.93×10^6 tons.

Also, the result of Ryther's method using the mean productivity derived by using the GOCI data was estimated to be *ca.* 5.85×10^6 tons, and the potential sustained yield were estimated to be *ca.* 2.44×10^6 tons (Fig. 3, Table 2).

Table 1. The result of potential fisheries production using the Ryther's method in the Korean waters. Mean productivity, trophic level, and efficiency are cited in Ryther (1969).

	Percentage of ocean (%)	Area (km^2)	Mean productivity (g C m^{-2} yr^{-1})	Total productivity (tons C yr^{-1})	Trophic levels	Efficiency (%)	Fish product (tons C yr^{-1})	Potential fisheries production (tons of total weight yr^{-1})
Open ocean	38.96	184,379	50	9,218,950	5	10	92	922
Coastal zone	60.30	285,401	100	28,540,100	3	15	96,323	963,228
Upwelling area	0.74	3,500	300	1,050,000	1.5	20	126,000	1,260,000
Total	100	473,280		37,759,050			222,415	2,224,150

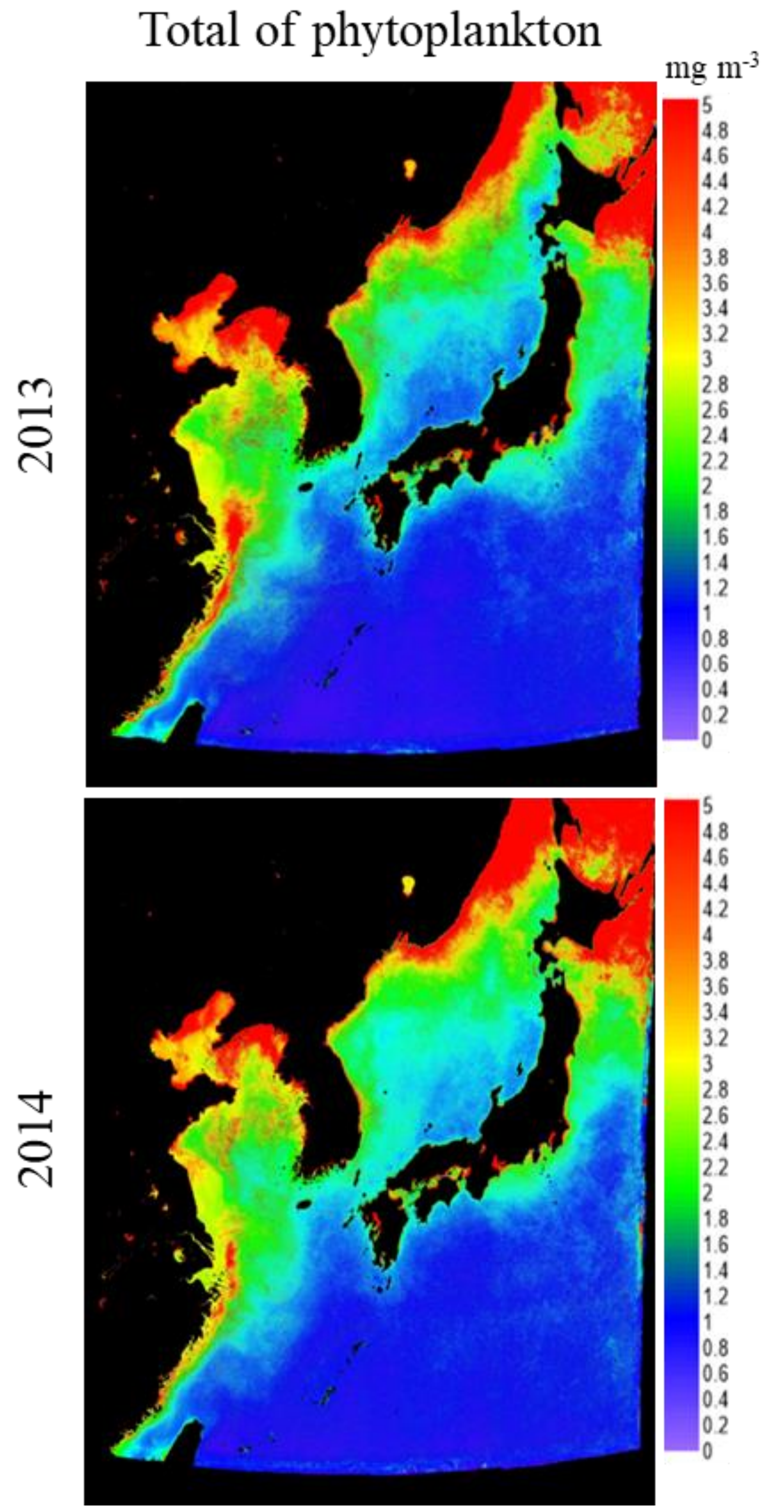


Fig. 3. The average of chlorophyll-a concentration (mg m^{-3}) from the Geostationary Ocean Color Imager data in 2013 and 2014

Table 2. The result of potential fisheries production using the Ryther's method in the Korean waters. Mean productivity is derived using the Geostationary Ocean Color Imager data (2013, 2014) and trophic level, and efficiency are cited in Ryther (1969).

	Percentage of ocean (%)	Area (km^2)	Mean productivity (g C m^{-2} yr^{-1})	Total productivity (tons C yr^{-1})	Trophic levels	Efficiency (%)	Fish product (tons C yr^{-1})	Potential fisheries production (tons of total weight yr^{-1})
Open ocean	38.64	182,879	362	66,126,303	5	10	661	6,613
Coastal zone	60.62	286,901	394	112,980,179	3	15	381,308	3,813,081
Upwelling area	0.74	3,500	484	1,693,983	1.5	20	203,278	2,032,779
Total	100	473,280		179,106,483			585,247	5,852,473

3-2. Biomass size spectrum model

The result of dividing phytoplankton using the PSC formula (5) and the GOCI chlorophyll-a data is the same as Fig. 4.

The average weight taking $\log_2$ based on phytoplankton for each size, pico-phytoplankton, nano-phytoplankton and micro-phytoplankton are ranged from -33.8 to -24.4, from -24.4 to -15.1 and from -15.1 to -5.7, respectively. In this study, representative values which are equally spaced were -30, -22 and -14, respectively. And then I determined -6, 2, 10 and 18 as zooplankton, small fish, medium fish and large fish, respectively (Fig. 5, Fig. 6).

As the results of BSS model estimation, the biomass, the P/B ratio, and the daily potential fisheries production in 2013 and 2014 are as shown in Table 3, and the annual potential fisheries production was estimated to be *ca.* 24.45×10^6 tons in 2013 and *ca.* 25.6×10^6 tons in 2014.

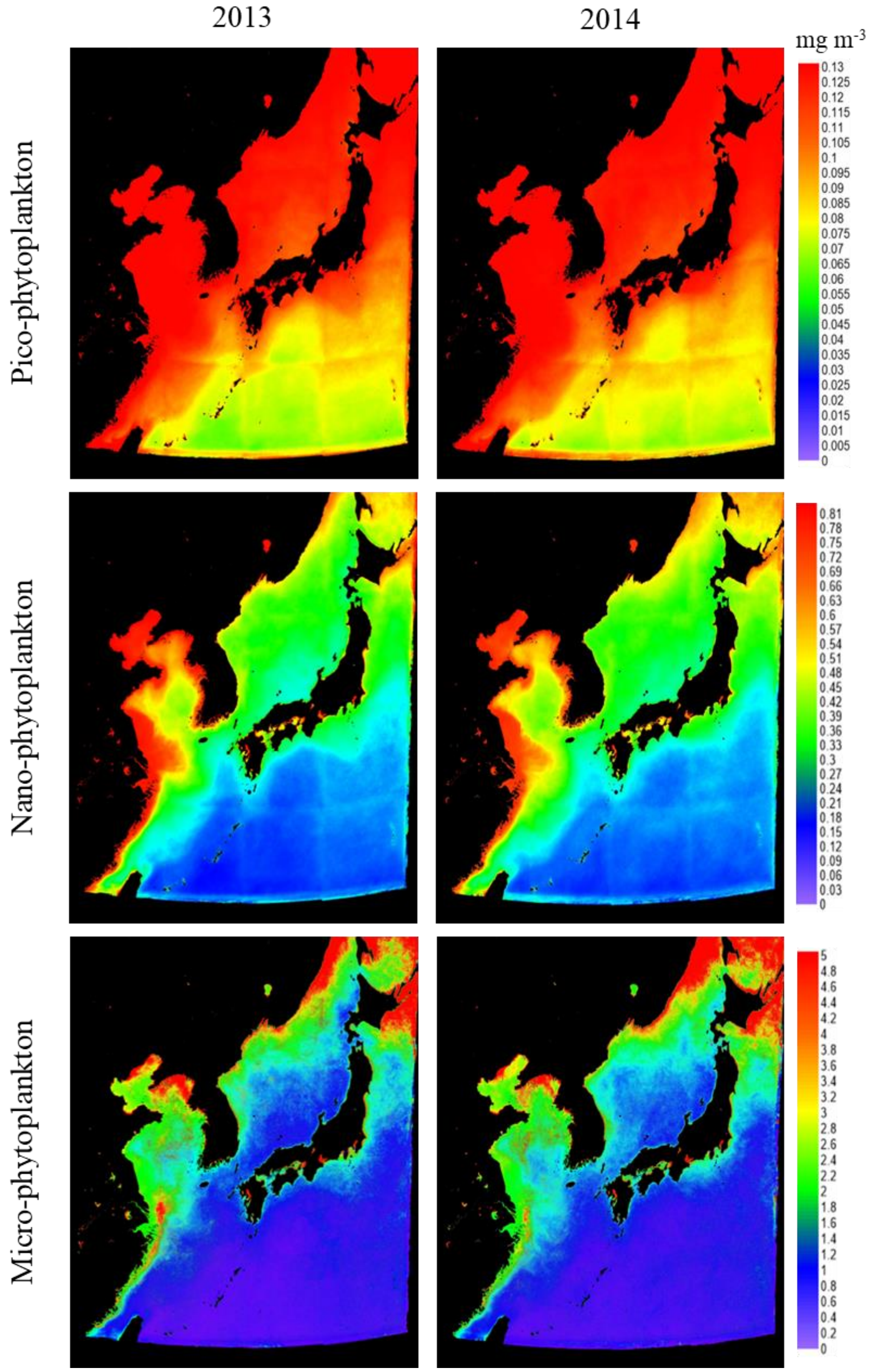


Fig. 4. The biomass (mg m^{-3}) of phytoplankton by size in 2013 and 2014 using the Geostationary Ocean Color Imager data and the phytoplankton size class formula developed by Korea Institute of Ocean Science and Technology

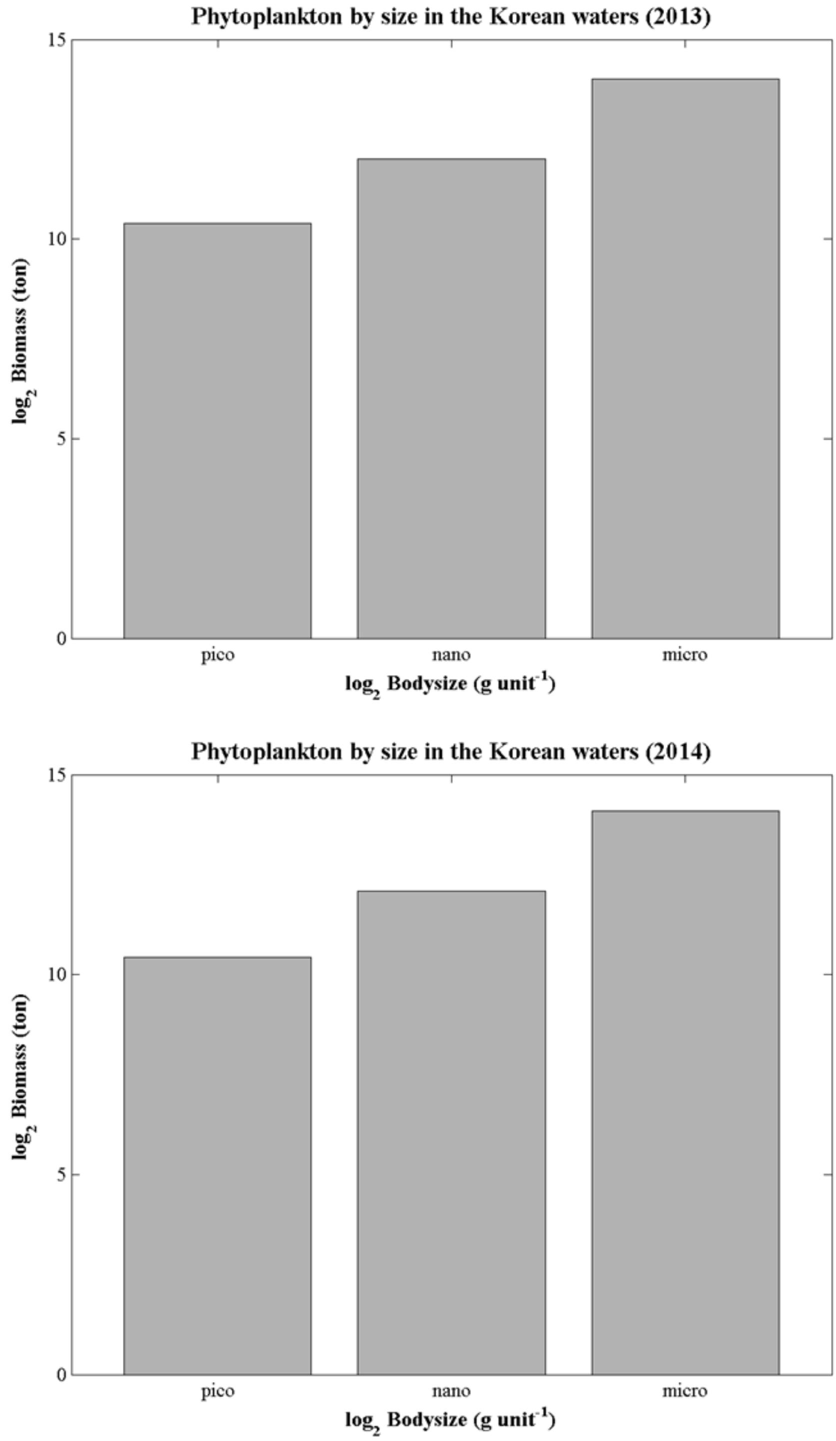
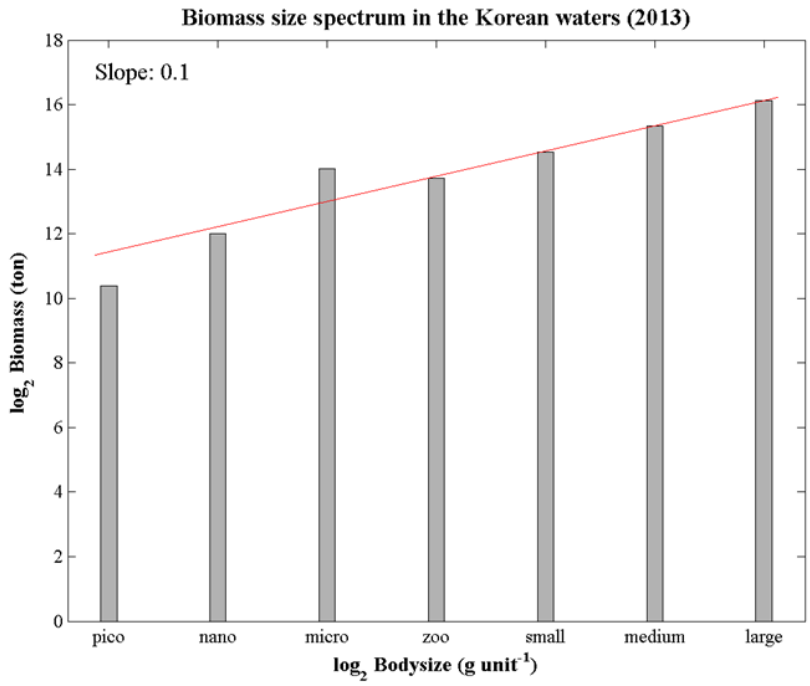


Fig. 5. The $\log_2$ biomass (tons) of phytoplankton by size in the Korean waters of 2013 and 2014 estimated by the Geostationary Ocean Color Imager data



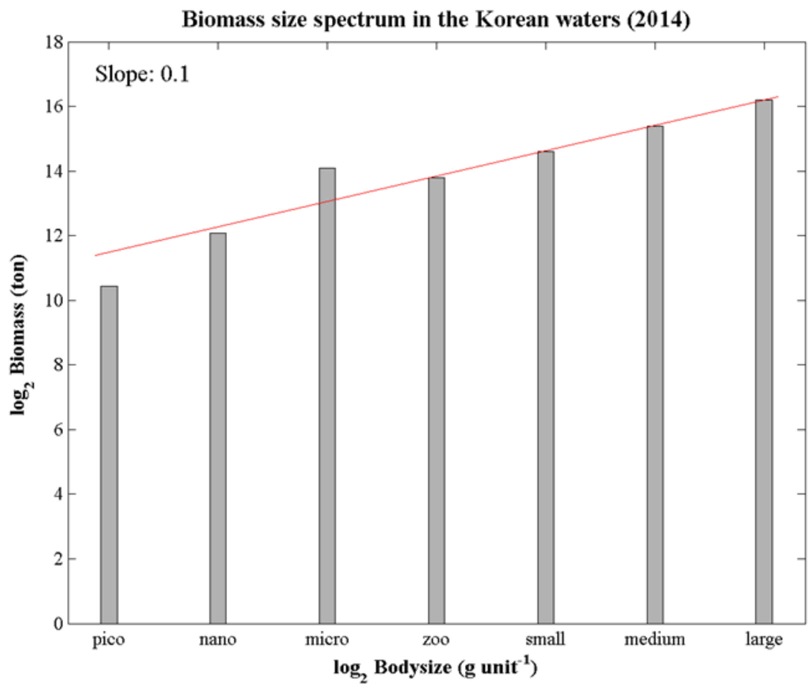


Fig. 6. The results of biomass size spectrum (BSS) in the Korean waters of 2013 and 2014. The x-axis categories mean pico-phytoplankton, nano-phytoplankton, micro-phytoplankton, zooplankton, small fish, medium fish and large fish, respectively. Pico, nano and micro are derived from the Geostationary Ocean Color Imager data, and zoo, small, medium, large are estimated by the BSS. The slope of BSS was reported by Blanchard et al. (2009)

Table 3. The result of potential fisheries production using the production/biomass ratio (P/B ratio, Banse and Mosher, 1980) in the Korean waters of 2013 and 2014.

		Small fish	Medium fish	Large fish
	Weight (g)	0.25~64	64~1.63×10^{4}	1.63×10^{4}~4.19×10^{6}
	P/B ratio	1.79	0.42	0.10
2013	Fish biomass (tons)	2.37×10^{4}	4.13×10^{4}	7.19×10^{4}
	Potential fisheries production (tons)	1.55×10^{7}	6.39×10^{6}	2.63×10^{6}
2014	Fish biomass (tons)	2.48×10^{4}	4.31×10^{4}	7.51×10^{4}
	Potential fisheries production (tons)	1.62×10^{7}	6.68×10^{6}	2.75×10^{6}

IV. Discussion

4-1. Summary and evaluation of the results

The potential fisheries production in the Korean waters estimated by the Ryther's method was *ca.* 2.22×10^6 tons and the potential sustained yield was *ca.* 0.93×10^6 tons (Table 4). The result when using the 2013 and 2014 GOCI data was *ca.* 5.85×10^6 tons of the potential fisheries production and *ca.* 2.34×10^6 tons of the potential sustained yield in the Korean waters (Table 4).

When compared to the actual catches (Fig. 1), the result of Ryther's method was estimated to be low. This is due to the tendency of Ryther's method to underestimate the potential fisheries production compared to other models (Alverson et al. 1970). In contrast, the Ryther's method using the GOCI data tended to be similar to actual catches because that used mean productivity in the Korean waters.

The potential fisheries production in the Korean waters estimated by the BSS model was *ca.* 24.55×10^6 tons in 2013 and *ca.* 25.66×10^6 tons in 2014 (Table 4). The actual catches preserved around 9% of the result of BSS model.

Because the Blanchard's model that I used was a model for the North Sea, I compared the catch per unit area of the Korean waters and the North Sea (Fig. 7). As the result of comparison, the catch per unit area of the North Sea was higher from 1950s to the 1970s, and the catches were similar until the early 2000s, and after that, the catches of the Korean water higher. In 2003~2004, which Blanchard studied, the catches of the Korean waters were higher, and this may have a difference in the slope of BSS model due to the characteristics of BSS model in which the slope changes by the catch.

Table 4. The results of Ryther's method and biomass size spectrum (BSS) model in the Korean waters

	Ryther's method		BSS model	
Data	Ryther's parameter	GOCI data	2013 GOCI data	2014 GOCI data
Biomass	-	-	0.14×10^6	0.14×10^6
Potential fisheries production	2.22×10^6	5.85×10^6	24.55×10^6	25.66×10^6
Potential sustained yield	0.93×10^6	2.44×10^6	-	-

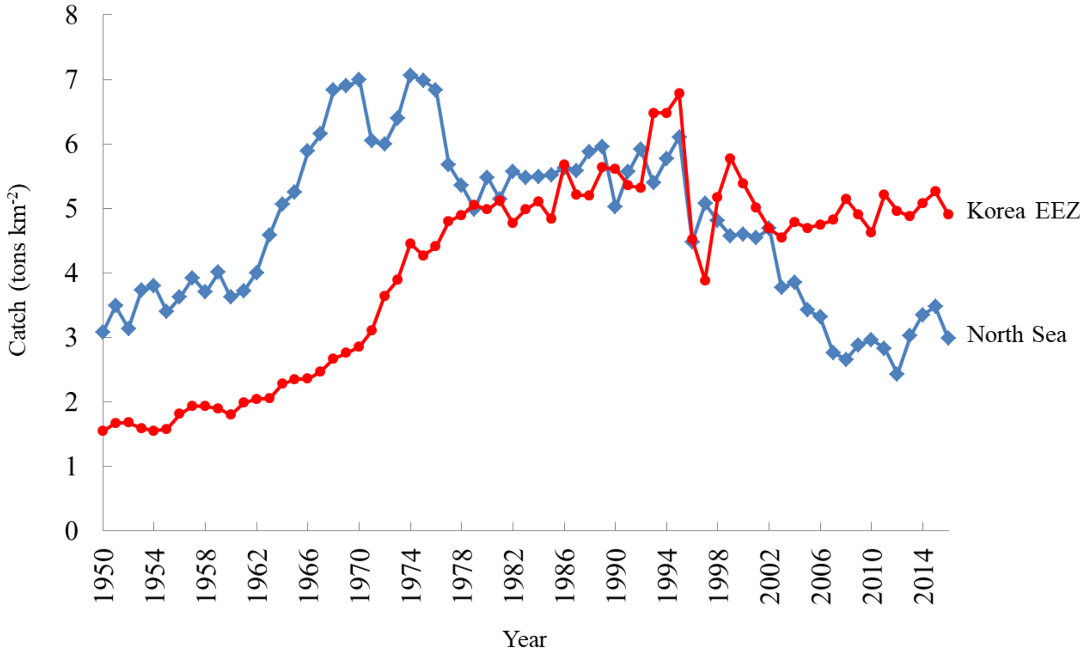


Fig. 7. The annual catches per unit area in the Korean waters (Shon et al. 2014) and the North Sea (see www.seaaroundus.org; catches in the waters of North Sea by Large Marine Ecosystems)

4-2. Comparison with the past studies in the Korean waters

The MSY of 1.62×10^6 tons reported by Zhang et al. (2019) was smaller than the actual catch because the fishing effort data of China and other countries caught in the Korean waters could not be applied. However, as a result of applying mean productivity to the Ryther's method, it came out similar to the actual catch. To use MSY in the Korean waters, fishing effort data from all countries catching the Korean waters is required. On the other hand, an ecological approach like the Ryther's method has the advantage of obtaining a potential sustained yield without this problem.

The result of Blanchard's BSS model, which is indicated as slope, was estimated by using all of the trophic levels. In this study, I do not only indicate slope but estimated the biomass of upper trophic levels by using the biomass of lower trophic levels, and the potential fisheries production in the Korean waters by using the P/B ratio (Banse and Mosher 1980).

4-3. Limitations and future studies

The Ryther's method was used trophic levels and efficiency that are not suitable for the Korean waters. Furthermore the BSS model for the North Sea was used in this study. Therefore, additional research using data appropriate for the Korean waters is needed. The Ryther's method and the BSS model can estimate the total potential fisheries production, but cannot estimate the production of a particular fish. Because of a limitation in the two models, biomass and production for specific fish species need to be estimated using the bio-physical individual based model, a Lagrange particle tracking model.

4-4. Conclusion

This study estimated the potential fisheries production in the Korean waters using the Ryther's method and the BSS using GOCI data. As the results of Ryther's method, the potential fisheries production was estimated to be *ca.* 2.22×10^6 tons and the potential sustained yield to be *ca.* 0.93×10^6 tons. As the results of BSS model, the potential fisheries production of *ca.* 24.55×10^6 tons in 2013 and *ca.* 25.66×10^6 tons in 2014 was estimated. With this study, it is possible to estimate the potential fisheries production and the potential sustained yield in the Korean waters. Furthermore, it is expected to estimate the more suitable results by developing the Korean-type Ryther’s method and BSS model.

V. Reference

Alverson DL, Longhurst A, Gulland J, Ryther JH. (1970) How much food from the sea? Science **168**(3930):503-505

Banse K, Mosher S. (1980) Adult body mass and annual production/biomass relationships of field populations. Ecol Monogr **50**(3):355-379

Barange M, Cheung WW, Merino G, Perry RI. (2010) Modelling the potential impacts of climate change and human activities on the sustainability of marine resources. Curr Opin Environ Sustain **2**(5-6):326-333

Blanchard JL, Jennings S, Law R, Castle MD, McCloghrie P, Rochet M, Benoît E. (2009) How does abundance scale with body size in coupled size-structured food webs? J Anim Ecol **78**(1):270-280

Chai C, Yu Z, Song X, Cao X. (2006) The status and characteristics of eutrophication in the Yangtze River (Changjiang) Estuary and the adjacent East China Sea, China. Hydrobiologia **563**(1):313-328

Chapman DW (1978) Production in fish populations. Blackwell Scientific Publications Oxford, pp5-25

Chen YL, Chen H, Lee W, Hung C, Wong GT, Kanda J. (2001) New production in the East China Sea, comparison between well-mixed winter and stratified summer conditions. Cont Shelf Res **21**(6-7):751-764

Cho S, Ahn Y, Ryu J, Kang G, Youn H. (2010) Development of geostationary ocean color imager (GOCI). Korean J Remote Sens **26**(2):157-165

Chung CS, Hong GH, Kim SH, Kim YI, Moon DS, Park JK, Park YC, Lee JH, Lie HJ. (2000) The origin of dissolved inorganic nutrients by Kuroshio Intermediate Water in the eastern continental shelf of the East China Sea. Korean Soc Mar Environ Eng **3**(3):13-23

Dong-Sun Kim, Ho-San Seo, Yong-Hyun Ghung. (2017) Nutrient Distribution Characteristics by Numerical Experiment around Coastal Upwelling Area in the East Sea of Korea. J Kor Soc Fish Mar Edu **29**(6):1808-1818

Free CM, Thorson JT, Pinsky ML, Oken KL, Wiedenmann J, Jensen OP. (2019) Impacts of historical warming on marine fisheries production. Science **363**(6430):979-983

Houde ED, Rutherford ES. (1993) Recent trends in estuarine fisheries: predictions of fish production and yield. Estuaries **16**(2):161-176

Isobe A, Matsuno T. (2008) Long-distance nutrient-transport process in the Changjiang river plume on the East China Sea shelf in summer. J Geophys Res **113**(C4)

Iverson RL. (1990) Control of marine fish production. Limnol Oceanogr **35**(7):1593-1604

Jones R. (1984) Some observations on energy transfer through the North Sea ans Georges Bank food webs. Rapp P-v Réun Cons int Explor Mer **183**:204-217

Jung S, Houde ED. (2005) Fish biomass size spectra in Chesapeake Bay. Estuaries **28**(2):226-240

Kim H, Seo Y, Cha HK, Kang H, Zhang C. (2018) A study on the estimation of potential yield for Korean west coast fisheries using the holistic production method (HPM). J Korean Soc Fish Ocean Technol **54**(1):38-53

Kim S, Kang S. (1999) Recent development in the concept and research direction for carrying capacity of marine ecosystem. J Korea Soc Fish Res **2:**101-110

Lim J, Seo Y, Zhang C. (2018) A comparative study on the estimation methods for the potential yield in the Korean waters of the East Sea. J Korean Soc Fish Ocean Technol **54**(2):124-137

Menden-Deuer S, Lessard EJ. (2000) Carbon to volume relationships for dinoflagellates, diatoms, and other protist plankton. Limnol Oceanogr **45**(3):569-579

Nair P, Samuel S, Joseph K, Balachandran V. (1973) Primary production and potential fishery resources in the seas around India. Proceedings of the Symposium on Living Resources of the Seas Around India. ICAR Publication, CMFRI, Cochin, India, pp 184-198

Nixon SW. (1988) Physical energy inputs and the comparative ecology of lake and marine ecosystems. Limnol Oceanogr **33**(4part2):1005-1025

Ryther JH. (1969) Photosynthesis and fish production in the sea. Science **166**(3901):72-76

Schaefer MB. (1965) The potential harvest of the sea. Trans Am Fish Soc **94**(2):123-128

Sheldon R, Prakash A, Sutcliffe Jr W. (1972) The size distribution of particles in the Ocean 1. Limnol Oceanogr **17**(3):327-340

Shon S, Harper S, Zeller D. (2014) Reconstruction of marine fisheries catches for the Republic of Korea (South Korea) from 1950-2010. Fisheries Centre working paper #2014-19, Fisheries Centre, University of British Columbia, Vancouver, 13 p

Son Y, Ryu J, Noh J, Ju S, Kim S. (2012) Climatological variability of satellite-derived sea surface temperature and chlorophyll in the south sea of Korea and East China Sea. Ocean Polar Res **34**(2):201-218

Zhang C, Seo Y, Kang H. (2017) Estimation of the exploitable carrying capacity in the Korean water of the East China Sea. J Kor Soc Fish Mar Edu **29**(2):513-525

Zhang C, Seo Y, Kang H, Lim J. (2019) Exploitable carrying capacity and potential biomass yield of sectors in the East China Sea, Yellow Sea, and East Sea/Sea of Japan large marine ecosystems. Deep Sea Res 2 Top Stud Oceanogr **163:**16-28

Zhang C, Yoo S, Sohn M. (1993) Changes in fisheries resources and future research need for the Yellow Sea ecosystem. Living marine resources of the Yellow Sea ecosystem. Bull Mar Res Ins **17:**69-83

인공위성 해색자료 기반 생체량 크기 스펙트럼 모델을 이용한 한국 해역 수산자원 잠재생산량 추정

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요 약

한국 해역에서 수산자원 잠재생산량을 추정하기 위해 생태계 접근법인 리더 방법(Ryther's method, 1969)과 생체량 크기 스펙트럼 모델을 사용하였다. 리더 방법은 바다를 외양, 내양, 용승 지역으로 나누어 각각 평균일차생산력, 영양단계, 영양전달효율을 일정한 값으로 고정하여 수산자원 잠재생산량과 최대 어획량을 추정하는 방법이며, 생체량 크기 스펙트럼 모델은 몸 크기에 따라 생체량이 비슷한 해양생태계의 특성을 이용하여 낮은 영양단계의 몸 크기 별 생체량으로 높은 영양단계의 몸 크기 별 생체량과 수산자원 잠재생산량을 추정하는 모델이다.

리더 방법을 한국 해역에 적용한 결과, 수산자원 잠재생산량은 2.22×10^6 톤, 최대 어획량은 0.93×10^6 톤으로 추정되었다. 한국 해역의 평균일차생산력을 인공위성 해색자료로 계산하여 적용한 결과, 수산자원 잠재생산량은 5.85×10^6 톤, 잠재 지속 가능한 어획량은 2.44×10^6 톤으로 실제 어획량과 비슷한 경향을 보였다. 인공위성 해색자료를 이용하여 한국 해역의 식물플랑크톤의 크기 별 생체량 평균을 계산하고 북해를 대상으로 개발된 생체량 크기 스펙트럼 모델에 적용하여 추정한 수산자원 잠재생산량은 2013 년에 24.55×10^6 톤, 2014 년에 25.66×10^6 톤으로 실제 어획량은 추정한 값의 약 9%에 해당되었다. 그러나 이 연구는 전세계를 대상으로 계산한 영양단계와 영양전달효율을 이용한 리더 방법과 북해를 대상으로 한 생체량 크기 스펙트럼 모델을 사용하였다. 따라서 한국 해역의 자료를 수집하여 한국형 모델을 만들 필요가 있다.