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〈Original Article〉

Economic benefits and management implications of reducing the harvest of juvenile mackerel in Korea

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It is essential to provide good environment for juvenile fish to grow and spawn in order to keep reproduction mechanism of fisheries resources. However, harvesting juvenile fish deprives adult fish of the opportunity to reproduce, thereby changing self-regulating renewable resources into non-renewable ones and preventing sustainable harvesting as well as reducing fishers' income. We reviewed the catch status of Korea on juvenile mackerel and analyzed how reducing the catch ratio of juvenile mackerel may affect the spawning stock and Korean fishermen's revenue. In addition, we analyzed the problem of caching juvenile mackerel in Korean fisheries and current efforts to protect and reduce the catch ratio of juvenile mackerel in Korea. Furthermore, we suggested future efforts to protect juvenile mackerel. The result of the study showed that reducing the catch ratio of juvenile mackerel from 44.4% to 30.0% would increase fishers' revenue by 60.6 billion KRW. We suggest the changing of purse seine fishery's catching methods from night operation to day operation, relocation of fishing vessels to move to other fishing grounds when fishing vessels meet high density of juvenile mackerel, and consumers' clever choice of consuming adult mackerel in order to accelerate the move toward protecting juvenile mackerel in Korea.

Keywords : Juvenile fish, Reproduction, Cconomic impact, Korean fisheries, Mackerel

Introduction

Unlike non-renewable resources such as coal, petroleum, gas, and minerals, fisheries resources are self-regulating and reproducing (Gavin and Waldman, 1999; Hilborn and Walters, 1992; Neher, 1990). Therefore, maintaining an environment in which fisheries resources can grow and reproduce is crucial. However, harvesting juvenile fish deprives adult fish of the opportunity to reproduce, thereby changing self-regulating renewable resources into non-renewable ones and thus preventing sustainable harvesting as well as reducing fishers' income.

In addition to simply deteriorating fisheries production from both a quantitative and a qualitative perspective, harvesting juvenile fish deteriorates the sustainability of certain species as well as the ecosystem to which they belong. Thus, the fisheries management approaches taken by some countries have attempted to protect juvenile fish by regulating catch size limit, harvesting season and areas,

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and fishing gears. For instance, Ireland has long protected juvenile fish under its Sea Fisheries Protection of Immature Fish Act, while Uganda has also banned the catch and sale of juvenile fish from Lake Victoria since 2003 (Ponte, 2007).

Similarly, Korea protects juvenile fish among economically important species in order to promote the continuous reproduction of fisheries resources. For example, the Fishery Resource Management Law regulates catch size limit and harvesting season in this regard. However, mackerel and hairtail, the most economically important fish in Korean coastal and offshore fisheries, are not properly protected under this regulation. In particular, almost 150,000 metric tons of mackerel are caught in Korean coastal and offshore fisheries per annum (MOF Fisheries Information Service), reducing sustainable production and endangering the stable supply of people's preferred fish.

Because mackerel is a schooling species, purse seiners, the most modernized with the largest fishing vessels, accounting for 80 percent of total landings of mackerel in Korea, seize and harvest large amounts of mackerel in one trip. Specifically, large purse seiners in Korea use light vessels to harvest schooling mackerel based on its phototactic behavior. During this type of harvesting process, a large quantity of juvenile as well as adult mackerel is caught. If this problem continues, it will be difficult to maintain sustainable growth in Korean coastal and offshore fisheries as well as in purse seine fisheries.

Mackerel, considered to be the most important commercial species in Korea, is one of the 11 target species managed by the total allowable catch (TAC) system. However, the fisheries authority has not yet identified how seriously catching juvenile mackerel will affect fish stocks and damage the fishing industry. Moreover, Korea has not carried out enough scientific research to identify the status of harvesting juvenile fish nor developed appropriate management tools based on research results. In summary, both fishers and the fisheries authority have paid insufficient attention to the need to manage juvenile fish stocks.

Against this background, this study analyzes the status of harvesting juvenile mackerel, impacts on fish stocks, and economic benefits of reducing the catch ratio of juvenile mackerel for fishers. In addition, it also evaluates Korea's current efforts to protect and reduce the catch ratio of juvenile mackerel and suggests future directions to protect young mackerel and make mackerel fishing sustainable.

Materials and Methods

Growth of juvenile mackerel

The juvenile stage lasts until a fish is fully grown, sexually mature, and interacting with other adult fish. Therefore, juvenile fish do not go through reproduction by spawning. Nevertheless, if they are as large as adult fish, they are vulnerable to fishing since they are of merchantable quality and marketable. Since all fish must go through the juvenile stage to become adult fish, catching juvenile fish excessively leads to stock depletion.

In particular, mackerel is very important in Korea as the finfish with the highest catch amount except for anchovy. Mackerel is found around the coast and offshore in most seas including the Atlantic, Indian, and Pacific Oceans, migrating into and out of temperate and tropical seas. Mackerel around Korea is mostly Scomber japonicus, and this species is divided into two subpopulations, namely the Tsushima Warm Current subpopulation and East China Sea subpopulation (Choi et al., 2004). The Tsushima Warm Current subpopulation of mackerel lives near the coastal area of the Tsushima coast during the fall and winter and migrates to the East China Sea during spring and summer. The East China Sea subpopulation, on the contrary, migrates along the West Sea of Korea during fall and winter (Choi et al., 2004; NFRDI, 2010).

Mackerel around the Korean coast and offshore shows an almost constant increase in body weight as it grows,

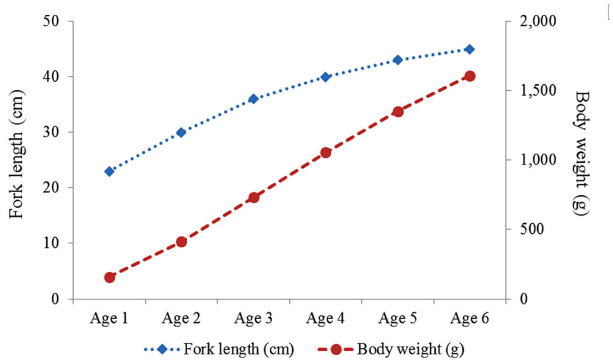

Fig. 1. Changes in length and weight by age (source: NFRDI, 2010).

whereas fork length increases at a decreasing rate as shown in Fig. 1. In the early stage of growth, this fish grows very fast, with its growth influenced by water temperature. Mackerel grows to 23 cm by one year of age and to almost 30 cm after the second year. By six years, body length can reach almost 45 cm. Mackerel matures at 2.27 years and has an average length of 28.6 cm. Body weight reaches about 160 g after one year and 413 g after two years. Its weight is about 1,600 g at six years (NFRDI, 2010).

Mackerel fisheries in Korea

Except for 1996 when the annual mackerel catch in Korea was unusually high (415,003 tons), the annual catch was around 170,000 tons in the late 1990s. However, as shown in Fig. 2, this amount decreased to 136,700 tons over the past 10 years. On average, the most recent 10-year average catch was almost 12,000 tons lower than the 20-year average catch. In terms of fishing types and gears, 126,301 tons of mackerel were harvested by large purse seiners in 2011, 91 percent of the total amount. Catches by large trawlers were second (3,180 tons, accounting for 2.3 percent of the total) followed by set-net fisheries (1.8 percent). These three fisheries accounted for 95 percent of the total catch in 2011. The remainder was accounted for by offshore gill-net fisheries, large bottom trawl fisheries, and small purse seine fisheries (Table 1).

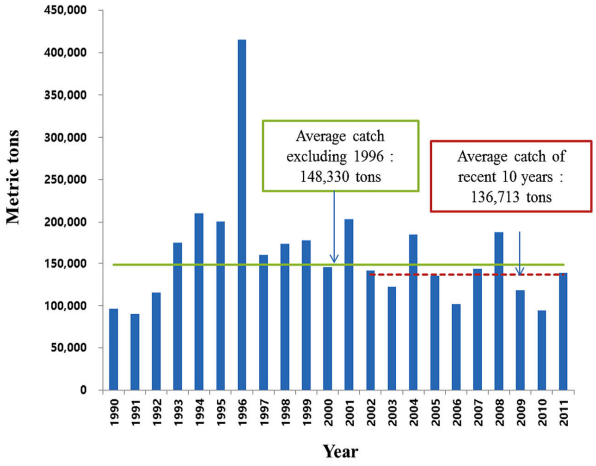

Fig. 2. Annual catch of mackerel in Korea (source: MOF, Fisheries Information Service, www.fips.go.kr).

Table 1. Mackerel catch by fishing gear

(Unit: metric tons)

Gear type	2009	2010	2011
Total	117,960	94,331	138,729
Large purse seine (percentage share)	109,459 (92.8)	87,796 (93.1)	126,301 (91.0)
Large trawl	391	124	3,180
Set net	818	3,248	2,440
Large gillnet	943	513	1,970
Large pair bottom trawl	2,227	886	1,736
Small purse seine	2,615	1,122	730
Coastal composite	423	203	631
Coastal gillnet	381	166	363
Off-shore stow net	124	66	306
Ohers	579	207	1,072

Source : MOF, Fisheries Information Service (www.fips.go.kr)

Catch of juvenile mackerel and unit price by size

Juvenile mackerel accounted for 56 percent of total mackerel landings in 1990, and this rose to almost 76 percent in 1996 before dropping below 50 percent in 2002 (Kim et al., 2012; Seo, 2012). This decrease in the juvenile/adult ratio was presumed to be because mackerel stocks shrank owing to the long-lasting excessive catch of juvenile mackerel and because of the introduction of the TAC system. However, as shown in Fig. 3, this ratio increased again in 2008 and it is currently above 50 percent. The annual catch of adult mackerel from 1990 to 2011 did not go beyond 100,000

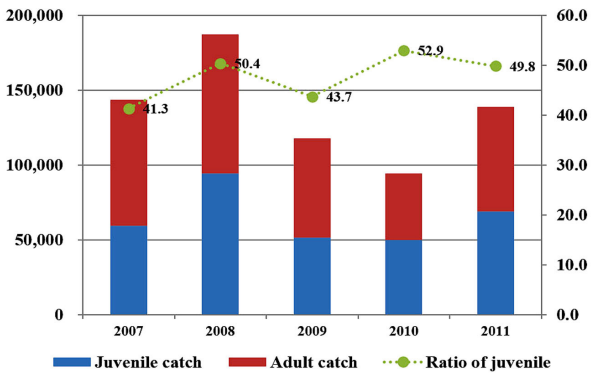

Fig. 3. Trend of catch ratio of juvenile mackerel (source: Seo, 2012).

tons. In 2011, total catch amount increased, with about 70,000 tons of adult mackerel.

As mentioned before, large purse seiners are the main fishing type for catching mackerel. Large purse seine fishery cooperatives classify landed mackerel into four categories based on size: L (large), M (medium), S (small), and SS (extra small). According to these cooperatives, the average weight of SS mackerel is less than 250 g and all SS mackerel are juvenile fish. The average weight of S mackerel is around 350 g, suggesting that most S mackerel are also juvenile fish.

There is a huge price difference by size in Korea. As seen in Table 2, the average unit price of L mackerel is 5,749 KRW/kg compared with 4,224 KRW for M mackerel, 1,531 KRW for S mackerel, and 757 KRW for SS mackerel. In addition, large purse seine fisheries are managed by the TAC system. Therefore, mackerel catches by large marine fisheries are limited. However, no regulation limits the catching of juvenile fish, leading to the excessive catch of juvenile mackerel and thus stock depletion.

Table 2. Unit price of mackerel by size

(Unit: KRW)

Size category	2009	2010	2011	average
L size	3,817	5,836	7,593	5,749
M size	2,553	4,354	5,764	4,224
S size	1,238	1,366	1,988	1,531
SS size	591	832	849	757

Source: Busan Central Fish Market (www.bcfm.co.kr)

Distribution and utilization of juvenile mackerel

The general distribution pattern of mackerel runs as follows: producers, jobbers in production areas, inland

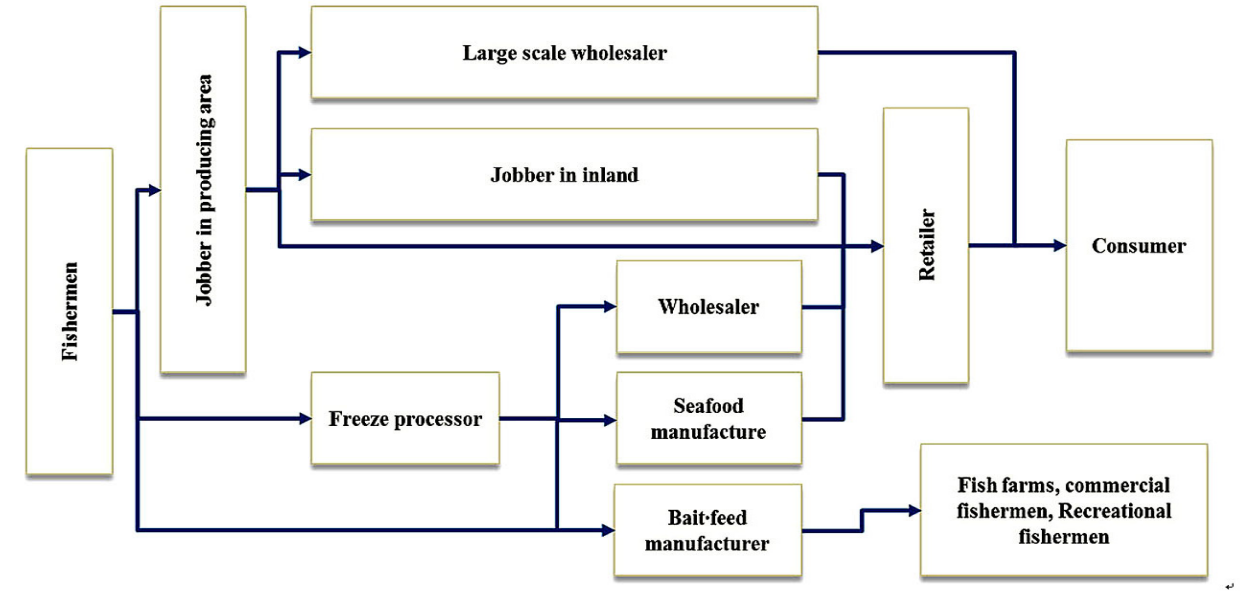

Fig. 4. Marketing distribution of mackerel in Korea.

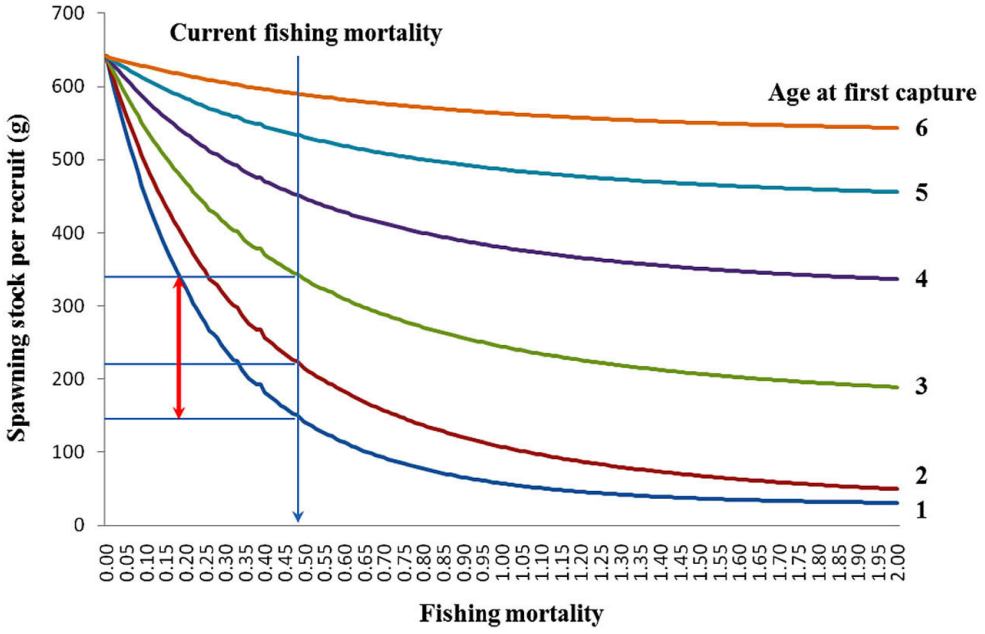

Fig. 5. Changes in spawning stock by age at first capture (source: Seo, 2012).

jobbers, large distributers, and consumers (Fig. 4). The distribution of mackerel is largely divided into frozen and fresh/chilled. Frozen mackerel goes through jobbers in production areas before being stored in refrigerated warehouses and distributed after a certain period of time to wholesalers, processors, bait makers, and fishmeal factories.

Mackerel's distribution channels differ based on size. L and M mackerel are usually sent to wholesale markets in consumption areas or processors via wholesale commission merchants in landing areas. S mackerel is exported for processing or canned in domestic processors for export or domestic consumption by wholesale commission merchants in landing areas. SS mackerel is exported to developing countries or processed as feed in the domestic market.

Impacts on mackerel stocks

According to Article 2 of the Fishery Resources Management Law, fishery resources include "aquatic animals and plants living in water that are useful for the national economy and life." According to this law, the goal of fishery resources management is to contribute to a fishery's sustainable development and increase fishers' income by managing fishery resources efficiently based on the regulations necessary for protecting, rebuilding, and enhancing them. Sustainable development can maximize fisheries' benefits because catching juvenile mackerel reduces the size of spawning stocks, which decreases total mackerel stocks. On the contrary, reducing the catch of juvenile mackerel increases spawning stock size.

According to Fig. 5, spawning stock biomass per recruit (SPR) increases as age at first capture rises with current fishing mortality kept constant. SPR at the current age at first capture is 147 g, but this increases to 221 g, almost 1.5 times greater, after increasing age at first capture to age 2. If age at first capture is raised to age 3, SPR increases to 340 g, which is almost 2.3 times greater. Therefore, by reducing the catch of juvenile mackerel by increasing age at first capture to over 2, SPR would rise.

Results

In general, juvenile fish are sold at a lower price than adult fish and are often utilized for feed instead of for food (the price of feed is much lower than that of food). As shown in Table 2, the average unit price of L mackerel was 7,593 KRW/kg in 2011 compared with only 849 KRW/kg for SS mackerel. Therefore, deferring the catch of juvenile mackerel to adult mackerel could increase the economic benefits for fishers through an increase in sales prices. Here, we quantify the potential economic benefits for fishers by reducing the catch of juvenile mackerel under the following assumptions.

First, because catch amount changes every year according to stock status and fishing capacity, we used the average catch amount of the 10 years from 2003 to 2012. In addition, the average catch ratio of the same period was used to represent the catch ratio of juvenile fish. The average mackerel catch for the past 10 years was 136,713 tons and the base catch ratio of juvenile mackerel was 44.4 percent. The catch amount of juvenile mackerel was 60,701 tons.

Second, based on the base catch amount and ratio of juvenile mackerel, we estimated the economic benefits for fishers by reducing the catch ratio of juvenile mackerel, which could lead to an increase in the probability of catching adult mackerel and thus a rise in unit price per kilogram. Because of these increased unit prices, fishers could then increase their incomes despite catching the same amount of mackerel. As shown in Table 2, according to data from the Busan central fish market, which is the largest fish wholesale market in Korea, average body weight per mackerel is 500 g, 450 g, 350 g, and below 250 g for L, M, S, and SS mackerel, respectively.

Third, we constructed a base unit price for juvenile mackerel by using a three-year average price (2009-2011) of S and SS mackerel, since the juvenile mackerel caught are typically less than 400 g. We also assumed a three-year average price of M and L mackerel as the adult mackerel price. The average prices of juvenile and adult mackerel were 1,144 KRW/kg and 4,978 KRW/kg, respectively.

Finally, in the analysis, we assumed that age at first capture would increase from age 1 to age 2. Therefore, the biomass of mackerel at age 1 (B_1) that are not caught by fishing is changed into the biomass of mackerel at age 2 (B_2) with only a natural mortality (M) as seen in equation 1(Haddon, 2001).

$$B_2 = (B_1 e^{-(M)}) \cdot \triangle w_2 \quad (1)$$

Where, $\triangle w_2$ is an increased weight of mackerel individual from age 1 to age 2 (w_2/w_1). The natural mortality of mackerel was estimated to be 0.49/year (NFRDI, 2014).

Under the assumptions above, if fishers catch adult

Table 3. Economic benefits by catch ratio changes of juvenile mackerel

Catch ratio of juvenile mackerel (%)	Catch volume of juvenile mackerel(tons)	Catch value of juvenile mackerel (million KRW)	Catch converted to adult mackerel(tons)	Catch value of adult mackerel (million KRW)	Total catch value (million KRW)	Revenue increase (million KRW)
Current level (44.4%)	60,701	69,441	0	0	69,441	0
40%	54,685	62,560	9,705	48,392	110,951	41,510
30%	41,014	46,920	31,760	158,373	205,292	135,851
20%	27,343	31,280	53,816	268,353	299,633	230,192
10%	13,671	15,640	75,872	378,334	393,974	324,533
0%	0	0	97,927	488,315	488,315	418,874

instead of juvenile mackerel, their economic benefits would change, as shown in Table 3. If the ratio of juvenile mackerel to total catch changed from the current 44.4 percent to 40 percent (i.e., 4.4 percent of the juvenile biomass is converted into the adult catch), 9,705 tons of juvenile mackerel would grow into adult mackerel, creating 41.5 billion KRW of additional revenue for fishers. If the ratio changed from 44.4 to 30 percent, fishers could earn 135.85 billion KRW of revenue additionally.

It is also worth noting that the analysis did not consider the economic benefits of reproduction because of an increase in spawning stocks owing to data unavailability. Indeed, if reproduction effects were added, the economic benefits of reducing the harvest of juvenile mackerel would be much greater than the estimated values presented above.

Discussion

More than 80 percent of mackerel is harvested by large purse seine fisheries in Korea. These fisheries operate a fleet system composed of five or six fishing vessels such as one purse seine ship (main ship), one or two light vessels, and three carrying vessels. Korean purse seine fleets use light to attract adult and juvenile mackerel. Even though these fleets meet schools of mackerel that have a high proportion of juvenile fish, they do not move to a fishing ground that has a lower proportion.

As mentioned before, juvenile mackerel in Korea is used as aquaculture feed, fishing bait, and other raw materials. In particular, most Korean marine fish farmers use small fish as feed. Until now, strong incentives for fishers to protect juvenile mackerel have not existed. In addition, the Korean government has not regulated the protection of juvenile mackerel directly until 2015 because regulating only one species in multi-species and multi-fisheries environments is challenging. Moreover, the mackerel around the Korean peninsula is also caught by Chinese and Japanese fishing vessels as well as Korean vessels since the fish migrate through these three countries. However, there has thus far been no cooperation among these countries to protect juvenile mackerel.

As the biomass of mackerel has decreased recently, the Korean government and the fishing industry have begun to set up various management plans to protect juvenile mackerel. First, because the government considers using raw fish feed to be one of the main reasons for catching juvenile fish and the stock depletion around the Korean peninsula, it is planning to ban the use of the raw fish feed by 2016 in order to protect juvenile fish including juvenile mackerel. The government has also made plans to downsize the size of purse seine fleets from five vessels to three or four in order to decrease fishing pressure on mackerel stocks. As one element of the restructuring plan, the renovation of fishing equipment is also being considered, and the government is developing fishing nets that have different mesh sizes and shapes from which juvenile fish can escape more easily.

In addition, the government has revised the regulations related to the fishing grounds large purse seiners are permitted to use. In the past, large purse seine fleets could catch near Jeju Island, which may have resulted in an increased probability of catching juvenile mackerel near the coastal area. Therefore, the government banned the catch of mackerel near Jeju Island in 2013. In addition, large purse seine fisheries voluntarily stop catching mackerel for around 40 days during spring when the proportion of juvenile mackerel increases.

In this study, we reviewed the status of catching juvenile mackerel in Korea and quantified the economic benefits of reducing its catch ratio relative to adult fish. In addition, we also examined the efforts of the government and industry to improve the current

excessive fishing of juvenile mackerel. Even though Korean fishers could increase their fishing revenue by catching adult mackerel instead of juvenile mackerel, they continue to catch juvenile fish since their catching methods are not selective, there is demand for using small mackerel, and active governmental efforts to protect juvenile mackerel are limited. Indeed, according to the analysis presented herein, reducing the catch ratio of juvenile mackerel from 44.4 to 30 percent would increase fishers' revenue by 135.85 billion KRW. Moreover, this does not include the economic benefits of reproduction, which if added would increase this estimated value further.

The government and fishing industry both recently started efforts to protect juvenile mackerel such as relocating fishing grounds, voluntarily stopping fishing in spring, downsizing the fishing fleet size, developing selective fishing gears, and banning the use of raw fish feed. In addition, the government is considering the establishment of a cooperative international management body with China and Japan. Nevertheless, in order to decrease the proportion of juvenile mackerel caught, the government and industry should consider changing from night operations to day operations, as the use of light vessels during the former attracts more juvenile mackerel. In addition, the government should consider a regulation ordering fishing vessels to move to other fishing grounds when vessels meet large schools of juvenile mackerel, as has already been adopted in Norway. Finally, consumers choosing to consume only adult mackerel could help change the industry's fishing behavior. A consumer-led campaign to reduce the consumption of juvenile mackerel would accelerate their protection in Korea.

Acknowledgement

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