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기후변화와 동해안에서의 명태 자원의 고갈

Climate Change and Depletion of Walleye Pollock Resources in the East Sea

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ABSTRACT

Objectives: Considered the "national fish" in Korea, the walleye pollock (*Gadus chalcogrammus*) has disappeared in the East Sea (Sea of Japan), a main habitat and fishing ground for the species. The reason for the disappearance is still a matter of controversy. This study was performed to investigate the long-term relationship between the walleye pollock catch and various meteorological and oceanographic factors in these waters.

Methods: Fishery data on walleye pollock and data on meteorological and marine environmental factors over the 30 years (1981-2010) were obtained from the official national database. Time series analysis and correlation and regression analyses were performed to study the relationships.

Results: Both air temperature and sea surface temperature in the East Sea rose over these 30 years, and the latter became more prominent. Salinity and dissolved oxygen showed a tendency to decrease while concentrations of nutrients such as nitrite nitrogen and nitrate nitrogen showed an increasing tendency. Sea surface temperature, air temperature, atmospheric pressure, and wind grade were negatively correlated with the catch size of walleye pollock ($p<0.05$), but salinity was positively correlated ($p<0.001$).

Conclusion: The results of this study indicate that climate change, especially ocean warming, affected the habitat of walleye pollock. The results also indicate that lower sea surface and air temperatures, milder wind grade, and higher salinity were preferred for the survival of the fish species. It is necessary to pay attention to changes of the ocean ecosystem in terms of environmental pollution as well as seawater temperature.

Keywords: climate change, walleye pollock, *Gadus chalcogrammus*, East Sea, Korea

I. Introduction

Walleye pollock (also called Alaska pollock and spelled pollack), *G. chalcogrammus* is a marine fish species of the cod family Gadidae (Cods and haddocks). The fish is widely distributed from the east coast of Korea to Central California and adjacent to the North Pacific.[1)] Walleye pollock is one of the cold-water fish species and is known to be distributed from the surface layer of the ocean to a depth exceeding 1,200 m.[1-3)] Freshly hatchlings are distributed in the surface layer, but they change their distribution depth as they grow.[3)] The main spawning ground of walleye pollock, which circulate the East Sea, is known as Wonsan bay in North Korea.[4)]

Walleye/Alaska pollock is the second most important fish in the world in terms of catch.[5,6)] Further, walleye pollock has been said to be "the largest remaining source of palatable fish" in the world.[7)]

Walleye pollock is one of the most preferred fish

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species in Korean cuisine. It is said that Koreans have been enjoying walleye pollock since the Joseon Dynasty (1392-1910).[8] Every part of the fish is used as a Korean food. It is used as fish itself, and its eggs and intestines are used as fermented food in Korea. The salted and fermented roe of walleye pollock is one of the traditionally consumed culinary ingredients. The fish is used in various forms such as fresh, frozen, dried, even frozen fillets or minced trim pieces in Korea. The young/juvenile fish of walleye pollock is enjoyed to eat as dried or nosed pollock (made by degutting young/juvenile walleye polloks and half-drying with their nose tied). The fish and fish products are used as a popular and a good side dish for the common people. They enjoy the high nutritional quality with low cost. Thus the walleye pollock has been called the "fish of the people" or "national fish" enjoyed by all the generations in Korea.[9] A song named 'walleye pollock' was even created, and have been sung by baritone singers.

Walleye pollok was the most commonly caught fish in Korea in 1940s, when more than 270,000 tons a year were caught from the East Sea. However, it has followed by continuous decreases through the 1990s, and has ended with a complete collapse of the population in the 2000s.[10,11] The annual consumption of walleye pollock in South Korea is estimated at about 260,000 tons in 2016. Nowadays, the consumption of walleye pollock in South Korea rely heavily on import from Russia, due to the almost disappearance of the fish in the East Sea.[12] The abrupt decline of walleye pollock catches in the 1990s has caused many questions. The indiscriminate overfishing of young/juvenile walleye pollock in 1970s has been indicated as the most prominent reason for this decline.[13,14] The catch of juvenile walleye pollock (called nogari in Korea) during 1975-1997 was 954 thousand tons, accounting for 68.2% of the total catch of 1.39 million tons of walleye pollock.[4]

In addition, due to environmental changes called climate regime shift, the Korean peninsula has warmed rapidly and this warming has had a major impact on marine ecosystems.[15] The reasons for the decline in walleye pollock resources sporadically suggested were various hypotheses such as overfishing of marine resources, degradation of adaptation ability of walleye pollock due to global warming, destruction of nurseries by coastal pollution, and reduction of subscription due to structural changes of marine ecosystem.[15]

However, few studies on the climate change of Korea and its effects on the catch of walleye pollock have been reported. In this study, we investigated the long-term effects of climate change on the catch of walleye pollock in South Korea. This was studied by finding the relationship between the main meteorological and the oceanographic factors of East Sea, and also annual catch size of walleye pollock over the past three decades.

II. Methods

1. Data source

1.1. Fisheries data

We used annual catch data of walleye pollock of offshore fisheries from the Fisheries Yearbooks, Agricultural and Fisheries Statistics, and Korea Statistics over the past 30 years (1981~2010).[16-18]

1.2. Meteorological and oceanographic data

We collected the oceanographic data of offshore waters of the East Sea such as sea surface (less than 10 m depth) temperature, salinity, dissolved oxygen (DO), nutrients (nitrite/nitrate nitrogen and phosphorous) from the observed data of the Serial Oceanography Investigation (Jeongseon Marine Survey) by National Fisheries Research and Development Institute (NFRDI).[19] We selected the factors that seem to influence to the habitat of walleye pollock. The nutrients such as nitrogen and phosphorous of sea water, which are regarded as the cause of eutrophication of sea were also selected. The data was extracted by the institute six times a year from 1961 to the present, observations for 25 points, 207 lines, and 14 standard

water layers. The data of wind grade, air temperature, and atmospheric pressure of the East Sea were also collected from the observed data of Jeongseon Marine Survey. The precipitation data were obtained from the annual average precipitation data of the Korea Meteorological Administration (KMA).[20]

2. Statistical analyses

Time series analysis was carried out to observe fluctuations over time/year. Correlation analysis was performed to investigate the relationship between the selected meteorological factors and oceanographic factors over the past 30 years. Regression analysis was performed to figure out the effect of the oceanographic and meteorological factors on the catch size of walleye pollock. For the data analysis and statistical processing, Excel and SPSS were used.

III. Results

1. Variations of annual catch of walleye pollock

The catch of walleye pollock in South Korea, which started to increase in the early 1970s, reached more than 160,000 tons in 1981, marking the highest peak of pollock fishing. In the coastal waters of the Korean peninsula, the main habitat of walleye pollock is the northern part of the East Sea, and the catch of walleye pollock was about half of fish catch of North Korea.[21] Also in South Korea's East Sea fisheries, it had a pivotal position until the mid-1980s. But it dropped to less than 10,000 tons in the mid-1990s and it is not even counted in recent years (Fig. 1). In fact, nogari, the baby and juvenile walleye pollock, has been caught zero since 1998, and adult walleye pollock recorded zero catch in 2008. The price of walleye pollock continued to skyrocket, reaching 3,840.2% in 2010 compared to 1980 (Fig. 2).

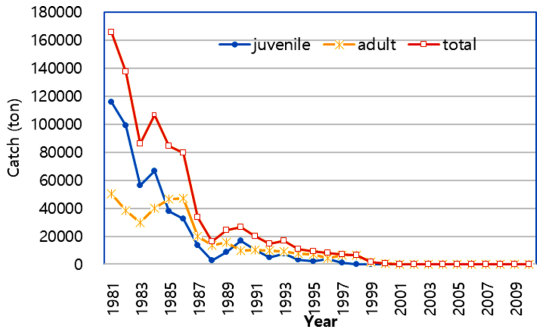

Fig 1. Changes in the catches of walleye pollack in offshore fisheries of Korea during the past three decades (*Source of data*: Statistics Korea, Ministry of Oceans and Fisheries).

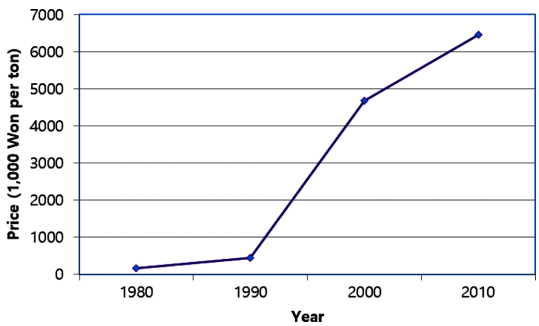

Fig. 2. The price of walleye pollock at every ten year in South Korea (*Source of data*: Ministry of Oceans and Fisheries).

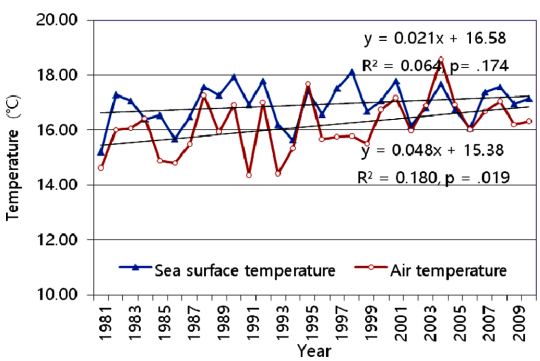

Fig. 3. Changes in the sea surface temperature and air temperature of East Sea during the past three decades.

2. Yearly variations of meteorological and oceanographic factors

The changes of the sea surface temperature and air temperature of the East Sea over the past 30 years have shown in Fig. 3. Over the past 30 years, the sea surface temperature of the East Sea has ranged from 15.18 to 18.08 degrees Celsius (°C) (mean 16.91±

Table 1. Results of correlation analysis between the meteorological and oceanographic factors

Factors	Sea surface temperature	Salinity	DO	Phosphate phosphorus	Nitrite nitrogen	Nitrate nitrogen	Wind grade	Atmos-pheric pressure	Air temperature	Precipitation
Sea surface temperature	1	-.469**	-0.311	0.052	0.131	-0.172	-0.206	0.143	.646**	-0.035
Salinity		1	0.135	-0.061	-0.246	0.471	0.062	-0.247	-0.295	-0.107
DO			1	0.113	-0.214	-.548*	0.223	-.084	-0.326	0.008
Phosphate phosphorus				1	-0.301	0.126	-0.088	-0.038	-0.136	-0.052
Nitrite nitrogen					1	0.052	-0.001	0.044	0.006	-0.032
Nitrate nitrogen						1	-0.143	-0.010	0.013	0.108
Wind grade							1	-0.201	-0.274	0.194
Atmospheric pressure								1	0.308	0.302
Air temperature									1	-0.061
Precipitation										1

*p<0.05, **p<0.01

0.13°C), while the air temperature has varied from 14.34 to 18.57°C (mean 16.13±0.18°C). In 1981, the sea surface temperature of the East Sea was 15.18°C and air temperature was 14.59°C, but it was 17.14°C and 16.29°C in 2010, respectively. In 2010, the air temperature increased by 1.70°C (p<0.001) and sea surface temperature increased by 1.96°C, respectively, compared to 1981.

During the period, the salinity of the surface water in the East Sea tended to decrease gradually although it was slight change (p=0.020). The concentration of DO showed a tendency to decrease (p=0.001), although the annual variation was not large. The concentration of nutrients, phosphate phosphorus (p=0.006) and nitrate nitrogen (p<0.001) increased. Nitrite nitrogen concentration also increased with no significance. The atmospheric pressure increased (p<0.001) but there was no significant change in the wind grade and precipitation although precipitation increased overall (figures not shown).

2. The relationships of meteorological and oceanographic factors

The results of correlation analysis between the meteorological factors and oceanographic factors are as shown in Table 1. There was positive correlation between air temperature and sea surface temperature (p<0.01). However, negative correlation between sea surface temperature and salinity, and between the concentrations of DO and nitrate nitrogen (p<0.05) were observed. Precipitation tended to increase overall and showed negative correlation with several oceanographic factors, but not significant.

3. Effects of meteorological and oceanographic factors on the catch of walleye pollock

The results of the regression analysis to examine the relationships between meteorological factors and the catch size of walleye pollock are shown in Fig. 4. Air temperature, atmospheric pressure, and wind grade were negatively correlated with walleye pollock catch (p<0.001). The overlaid line in the figure indicates the long-term linear trend fit by regression. The standardized coefficients (beta) of the effect of sea surface temperature and air temperature on the walleye pollock were found to be 0.114 and 0.122, respectively, in the regression line. As a result, it was shown that the air temperature influenced the catch of pollock a little more than the sea surface temperature.

Fig. 5 illustrates the results of our regression analyses

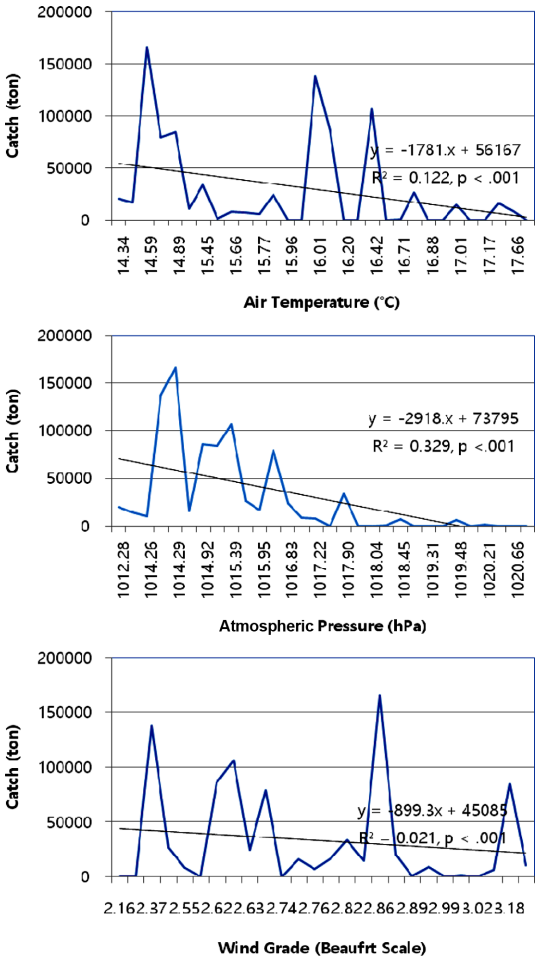

Fig. 4. Results of regression analysis between the catch of walleye pollock and the meteorological factors of East Sea.

on the relationships between the oceanographic factors and the catch size of walleye pollock. All factors except DO among oceanographic factors affected the catch of walleye pollock. Sea surface temperature, nitrite nitrogen and nitrate nitrogen showed negative correlation with the catch of walleye pollock ($p<0.01$). Salinity ($p<0.001$) and phosphate phosphorus ($p= 0.002$) showed positive correlation with walleye pollock catch. In the addition, the beta of phosphate phosphorus, nitrite nitrogen, and nitrate nitrogen on the walleye pollock catches were 0.142, 0.147, and 0.062, respectively, from the regression line.

IV. Discussions

According to the statistics of the Ministry of Maritime Affairs and Fisheries, walleye pollck is the number one fish consumed by Koreans from 2012 to 2016. It is one of the most consumed fish in South Korea, although the walleye pollock has almost disappeared in the East Sea. As a result, the consumption of walleye pollock in South Korea now depends on imports. Since 2014, the government has been transferring the aquaculture technology to the private sector through the "Restoring the Walleye Pollock Project".

Scientists has concerned about climate change in Korean peninsula and point out that the burden of mortality due to higher temperatures.[21] However, there are few scientific papers on climate change and food safety in Korea.[22] In this study, we investigated whether or not walleye pollock disappeared in the East Sea in relation to climate change. As in the global trend, both air temperature and seawater temperature tend to increase on the Korean peninsula. Ten years ago, the Ministry of Maritime Affairs and Fisheries announced that water temperature (sea surface temperature) of the East Sea has risen by 1.3°C and the 50 m layer in depth increased by 0.1°C over the past 40 years (1968~2007).[23,24] In this study, we have found that sea surface temperature and air temperature of the East Sea increased by 1.96 and 1.70°C, respectively, from 1981 to 2010. Further, during the same 30 years, the average rise of sea surface temperature in South Korea's overall coastal area (East Sea, South Sea, and West Sea) was 0.47°C and average rise of air temperature was 1.24°C. This strongly suggests that the sea surface temperature rise around Korean peninsula is the fastest in the East Sea.

When the influence of air temperature and sea surface temperature to the catch size of walleye pollck was compared, the effect of air temperature was a little greater than that of sea surface temperature. The reason for this is supported by the report of several previous researchers. Although rise in air temperature

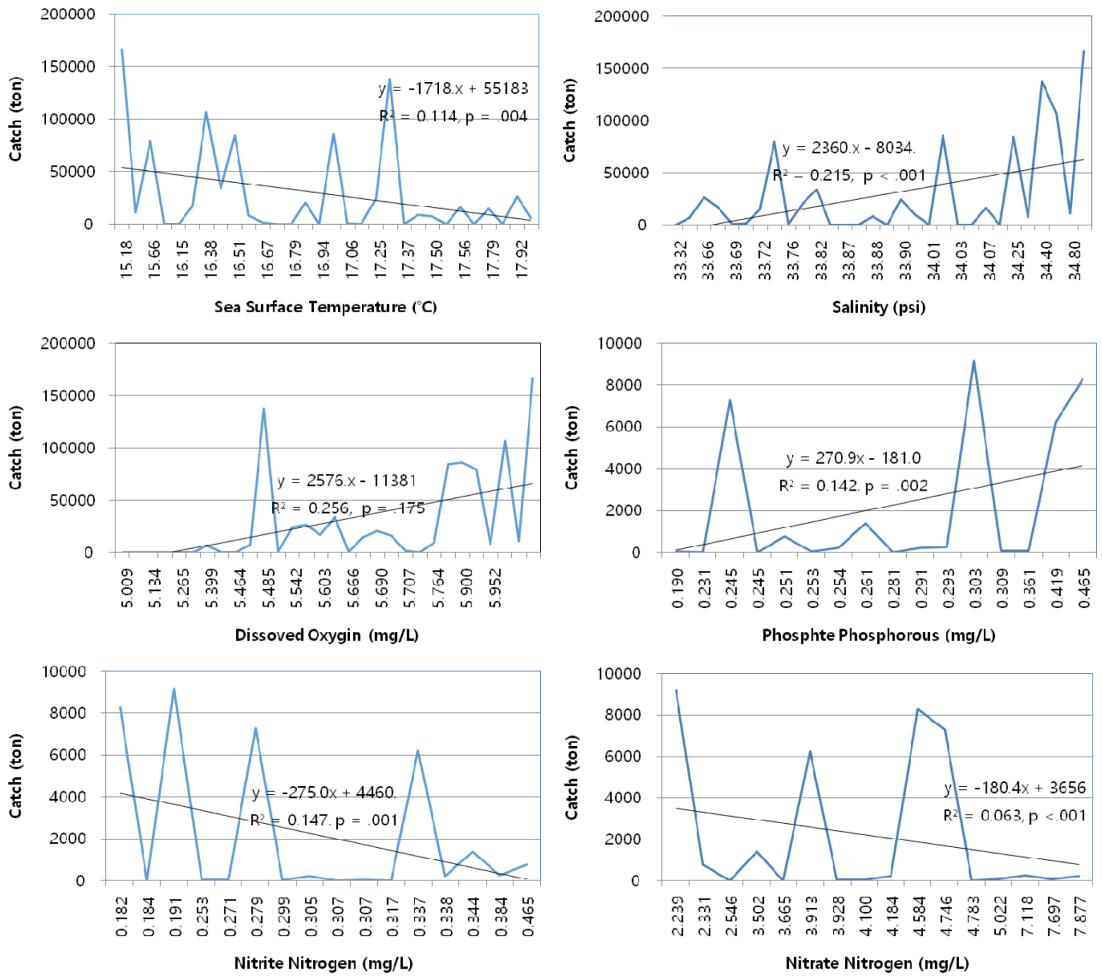

Fig. 5. Results of regression analysis between the catch of walleye pollock and the oceanographic factors of East Sea

and in sea water temperature occurred in parallel, the rise in sea surface temperature occurs a few days after the air temperature rise. Due to this time lapse phenomenon, the effect of air temperature on seawater temperature is larger than that of sea surface temperature.[25-27] The Jungsun Marine Survey does not include the data of precipitation. Although we used the annual average precipitation data of KMA, it was assumed that there would be a relationship between precipitation and marine factors such as salinity, dissolved oxygen, and nutrient concentration, but no significant correlation was found. This is explained in the report of Suh et al.[25] According to their report, precipitation affects ocean factors of the following year rather than the factors of the year.

As a result, the annual catch of walleye pollock decreased with the increases of air temperature, concentration of nitrite and nitrate nitrogen, as well as sea surface temperature. On the other hand, the catches increased as salinity and phosphorous phosphate increased. We have already seen that there was a significant correlation between air temperature and sea surface temperature, and between sea surface temperature and salinity in the correlation analysis. Therefore, the rise in air temperature caused rise in sea surface temperature, which ultimately appeared to

have adversely affected the habitat and nursery of cold-water fisheries such as walleye pollock. In addition, as the salinity decreases with the change of sea surface temperature and precipitation, it can be suspected that it negatively affected the catch of walleye pollock. Although the concentrations of the nutrients which are eutrophication materials of sea water and also used as water pollution index, have proven significant correlations with the variability of walleye pollock catches, it is difficult to explain the rationale at this point. The reason for the difficulty is that these factors have been measured since the mid-1990s, when walleye pollock almost disappeared in the East Sea. In other point of view, we need to pay special attention to the fact that both the concentrations of nitrite nitrogen and nitrate nitrogen have increased in the East Sea. This indicates that the seawater has been continuously contaminated.

The South Korean government has banned fishing for walleye pollock less than 27 cm in size since 2012. Now the walleye pollock population in the coastal waters of South Korea has been almost extinct, although the fishing is controlled and fishing of juvenile walleye pollock is prohibited by government. Therefore, it can be carefully mentioned that one of the reason of the disappearance of pollock in the East Sea is the result of climate change and warming of seawater.

From the results of this study, we can conclude that the temperature rising of the East Sea is accelerating as the years go by. This continuous rise in water temperature may affect marine life. We should be also aware that the East Sea, which was the cleanest of the three sides of Korean Sea, will be becoming more and more polluted. Therefore, in the future, the marine environment of East Sea will be expected to change continuously with global warming, and attention should be paid not only to changes in ocean temperature but also to changes in marine ecosystems according to environmental pollution. These ultimately suggests that there is a possibility of impacts on humans also, and should not be overlooked.

It has been reported by several previous studies that walleye pollock is a fish species with a habit of ontogenetic vertical migration and that early life stage of walleye pollock is sensitive to changes in the habitat.[28-30] In this study, there is a limitation that the temperatures at all water layers of the sea have not been considered. We explored the disappearance of walleye pollock in relation only with the sea surface temperature in the East Sea. Nevertheless, we could find significant influence of climate factors. The impact of climate change will be more apparent if further studies are carried out to identify the impacts of marine factors on separate water layers.

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