water

MDPI

Article

Changes in Climate Factors and Catches of Fisheries in the Republic of Korea over the Three Decades

Jong-Gyu Kim [1,*] and Jeong-Gyoo Kim [2]

[1] Major in Public Health, Faculty of Food and Health Sciences, College of Natural Sciences, Keimyung University, 1095 Dalgubeol-daero, Dalseo-gu, Daegu 42601, Republic of Korea
[2] Department of Liberal Arts, Hongik University, Sejong 30016, Republic of Korea; jgkim@hongik.ac.kr
* Correspondence: jgkim@kmu.ac.kr

Abstract: We investigated the changes of main climate factors and their relationships with the catches of offshore fisheries of the Republic of Korea over the past 30 years (1981 to 2010), using a trend analysis and Pearson's correlation analysis. This study focused on seven fish species that have been preferred in Korean cuisine for centuries. Not only the air temperature, but also the sea surface temperature (SST) on the coast of Korea has risen ($p < 0.05$) in the period. The rise in SST over 30 years is significantly correlated with the rise in temperature ($p < 0.01$), but not with precipitation. Over the past 30 years, catches of anchovies and squid have increased significantly, while Alaska/walleye pollock has become almost extinct ($p < 0.01$). The analysis of this study indicates that cold water fish species have decreased or disappeared in Korean fisheries and have been replaced by warm water fish species. Our findings suggest that the fish species caught in Korean offshore fisheries have changed due to climate change, especially global warming. These results also suggest that there may be a threat to the food security of Koreans, so it is necessary to take measures to protect this food resource.

Keywords: climate factors; air temperature; SST; catches in offshore fisheries; Republic of Korea

Citation: Kim, J.-G.; Kim, J.-G. Changes in Climate Factors and Catches of Fisheries in the Republic of Korea over the Three Decades. *Water* **2023**, *15*, 1952. https://doi.org/10.3390/w15101952

Academic Editors: Moshe Gophen and José Luis Sánchez-Lizaso

Received: 23 April 2023
Revised: 14 May 2023
Accepted: 18 May 2023
Published: 21 May 2023

1. Introduction

Concerns about the global food crisis are spreading as uncertainties in food production increase due to the extreme weather events of this century. According to the report of the United Nations [1], "climate change is already impacting the food security", which is placed atop the several purposes of the report. The report includes fisheries in its items to raise awareness. In the fisheries industry, the factors of supply and demand instability have increased due to the decrease of fishery resources. The causes of instability are known to be climate change, increased volatility of marine resources, overfishing, and increase in consumption of fishery products in countries. Global cooperation is now desperately needed to protect food resources, even in the fisheries field.

According to the Report of the Intergovernmental Panel on Climate Change (IPCC), climate change affects the marine environment by causing an increase in sea water temperature, sea level rise, and ocean acidification [2]. It is expected to have a significant impact on the marine ecosystem and fisheries resources. The IPCC also studied the impact of climate change on food security and food production systems [3].

Korea (the South) is a peninsular country, so the fisheries industry is well developed and fishery products have been produced in abundance. It has been predicted that sea temperature and sea level of Korean peninsula rise due to global warming, Korean fishery will become very vulnerable [4]. Although Korea does not have a very high dependency on fishery products as food materials, the consumption of fishery products has been greatly increasing in the 2000s. This may be due to the increase in health concerns regarding well-being and quality of life, and an increase in income. In 2010, the consumption of onfishery products amounted to 51.3 kg per person per year, which displays a remarkable increase from 33.2 kg in 1981 [5,6].

Climate change may accelerate the reduction of most fishery resources in the coastal area of Korea, and it will change the production of major fish species. This could cause a reduction in the number of fishermen and weaken the supply of marine products. In fact, the imports of fishery products are increasing in South Korea in recent years [7,8].

The effects of climate change on the Korean peninsula are emerging clearly not only in supply/consumption of agricultural products but also in fishery products. For example, the range of habitat of zooplankton is increasing in the coasts around the Korean peninsula [9–11], and cold-water fish species are gradually disappearing in their main fishing ground [12,13]. In addition, large jellyfishes are increasing in the east coast and the south coast, that were not previously there [14,15]. These phenomena indicate that there are changes in fishery resources and ecosystems along the coast of Korean peninsula, which will directly affect the supply of fishery products. However, quantitative research has not been much yet carried out that examine the relationship between fishery production and marine data according to climate change.

Therefore, this study investigates the impact of changes in major climate factors on the trends in fishery production in the Republic of Korea over the past 30 years. The objectives of this study are to: investigate the long-term change of air temperature and water temperature of Korean coastal sea and the relationship between them, investigate the changes of catches in offshore fisheries of major fish species which have been popular with Koreans, and analyze the relationships between catches of major fish species and air temperature and water temperature.

2. Materials and Methods

2.1. Study Area and Subject

Korean peninsula is located at 37° N, 127° 30′ E. Republic of Korea (sometimes called South Korea) is on the southern half of the Korean Peninsula which is surrounded by three sides of sea: to the east is the East Sea (known in Japan as Sea of Japan), to the south is the South Sea (Korean Strait, KS), and to the west is the West Sea (Yellow Sea). We investigated the climate-related phenomena of seas surrounding South Korean territory (Figure 1). The fishery production was investigated for seven major fish species preferred by Koreans among the aquatic products caught in this area.

2.2. Data Source

We first obtained data from Statistics Korea (SK) that originated from the Ministry of Agriculture, Food and Rural Affairs (MAFRA) of Korea [16,17]. For fishery production of offshore fisheries, we collected annual fishing data from the past 30 years from Fisheries Yearbooks, Fisheries Trends and Fisheries Policy, 2012; Agricultural and Fisheries Statistics [18–20]. Among the fishery products of the data, we explored the changes in production for fish species preferred in Korean cuisine such as largehead hairtail, Alaska/walleye pollock, yellow croaker, chub mackerel, Pacific saury, anchovy, and squid.

In order to investigate the climate changes, we collected data of air temperature and the temperature of offshore waters of Korea from the observed data of the Serial Oceanography Investigation by the National Institute of Fisheries Science of Korea [18]. We obtained precipitation data for the same period from the Korea Meteorological Administration (KMA) [19].

Then we extracted the oceanographic data created by Korea Oceanographic Data Center (KODC), an organization under the National Fisheries Research & Development Institute (NFRDI). The observations of the oceanographic data were recorded six times a year from 1961 to the present, and include 25 points, 207 lines, and 14 standard water layers. The observed points are shown in Figure 1. The data is divided into East Sea, South Sea, West Sea, and East China Sea.

Figure 1. Location of the serial oceanographic observation stations. *Source of data:* NIFS of Korea; KODC.

For the purpose of this study, we also used data on average annual seawater temperature and ambient air temperature (dry bulb temperature) in the East Sea, South Sea, and West Sea. Seawater temperature was observed by extracting sea surface temperature data of less than 10 m depth. Temperature units are expressed in degrees Celsius (°C).

2.3. Statistical Analyses

We quantified long-term trends (1981~2010) in sea surface temperature, air temperature, and precipitation, using a trend analysis. We performed Pearson's correlation analysis to find relationships between climate factors and major fish production (catch size).

For data analysis and statistical processing, we used Excel (Microsoft Corporation, Redmond, WA, USA) and SPSS for Windows 22.0 (IBM Corporation, Armonk, NY, USA) [20]. There was no incomplete data in our sources for the years, and we did not need a data cleaning processing with SPSS. The statistical significance level was set to $p < 0.05$.

3. Results

3.1. Changes in Sea Surface Temperature, Air Temperature, and Precipitation

According to the data observed over the past 30 years, the average sea surface temperature (SST) of the coast of Korea (SST) has risen by 0.98 °C and 1.10 °C in 2010 compared to 1981 ($p < 0.05$) (Figure 2). In addition, the variation of SST was similar to that of air temperature. There was a fluctuation in the annual average precipitation over the past 30 years. Precipitation was the smallest at 895 mm in 1988 and the largest at 1861 mm in 2003, however, we could not find any significant trend.

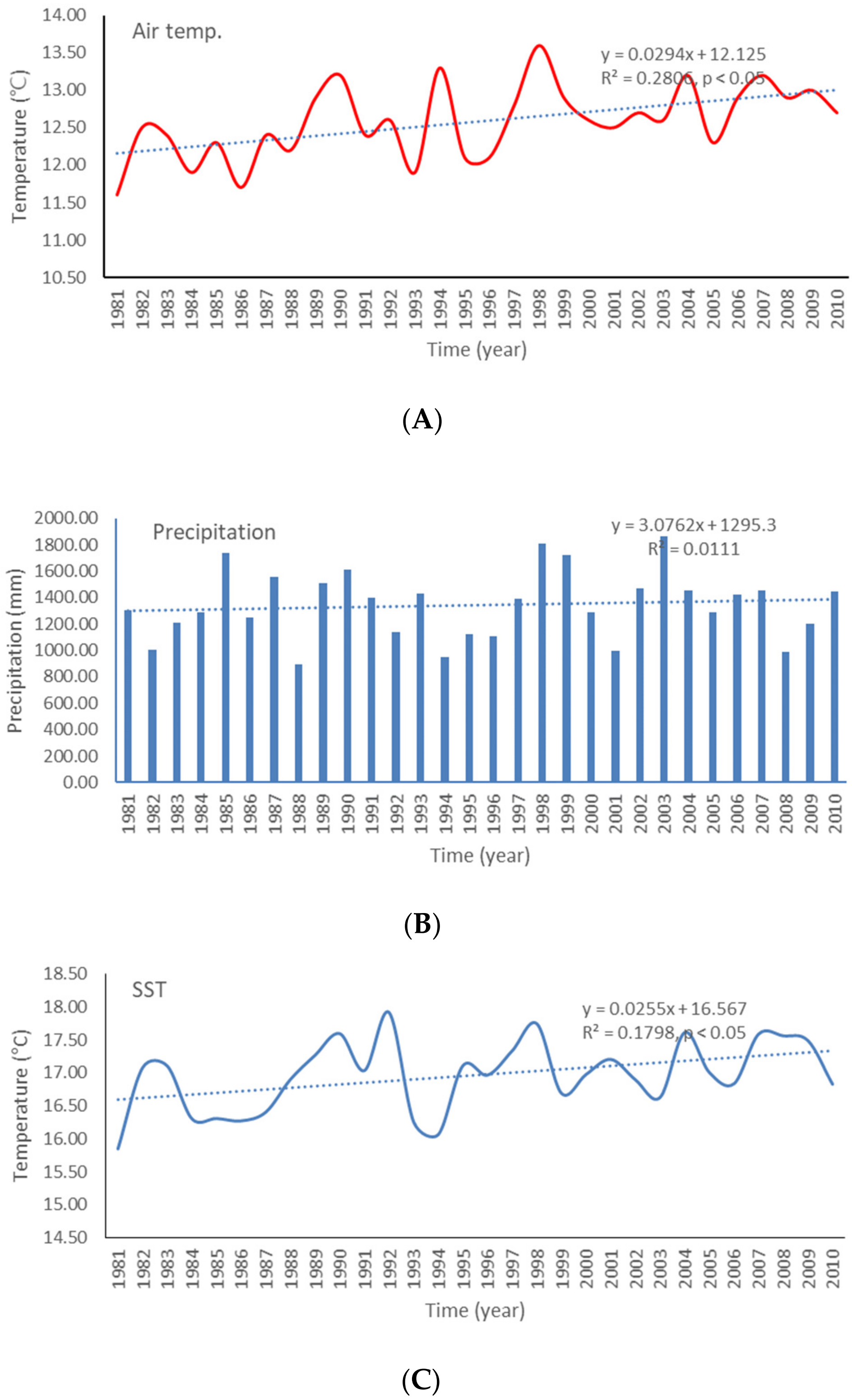
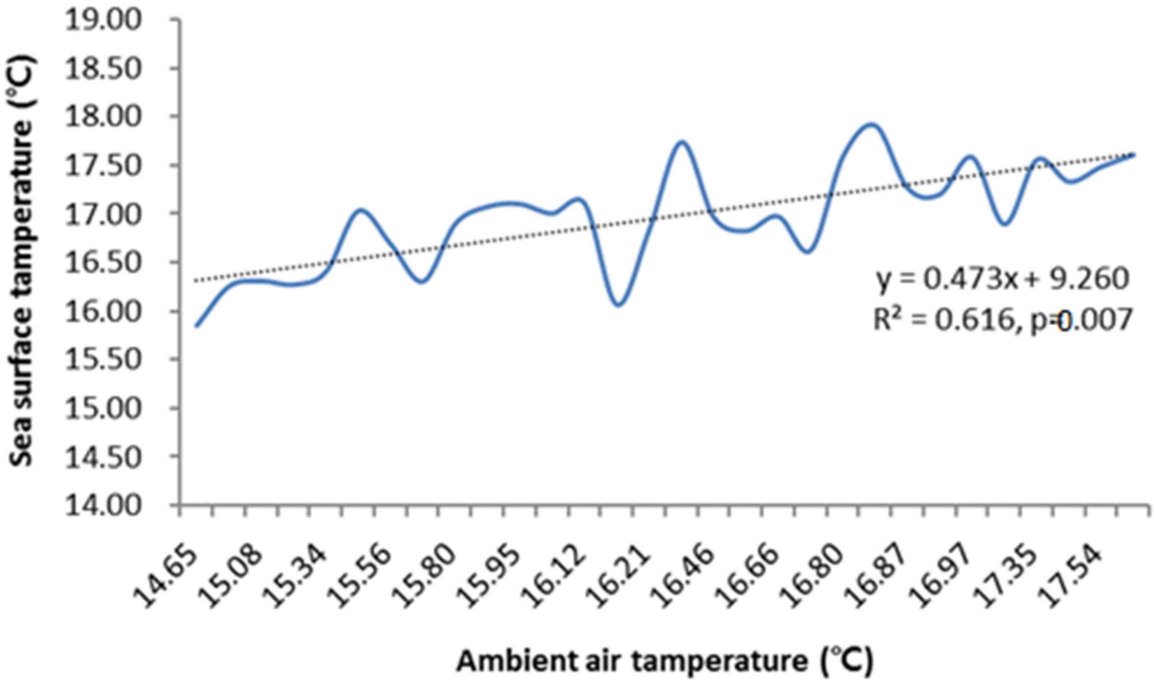
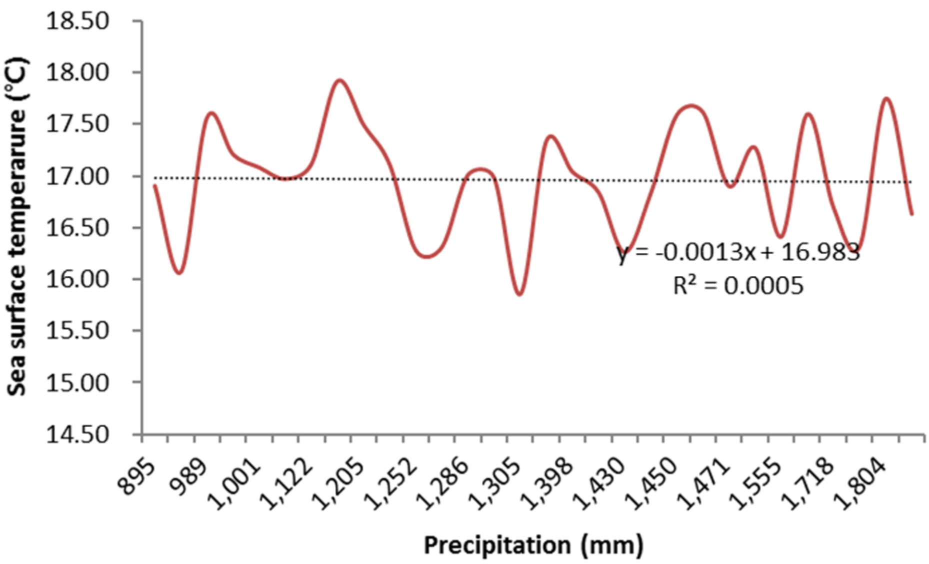


Figure 2. Changes in the average annual air temperature (**A**), precipitation (**B**), and sea surface temperature (**C**) of the Republic of Korea during the past 30 years. *Source of data*: NIFS of Korea; KODC, and KMA.

Figure 3 shows the relationship between SST and air temperature and/or precipitation on the Korean coast from the data observed over the past 30 years. The higher the temperature, the higher the SST. Furthermore, there is a significant correlation between sea surface temperature (SST) and air temperature (AT) ($p < 0.01$). There is a tendency that SST slightly decreased as the amount of precipitation increased. However, these two factors do not show any significant relationship.



(A)



(B)

Figure 3. The relationship between the sea surface temperature (SST) and air temperature (**A**)/precipitation (**B**).

3.2. Variation of Fishery Catches

Over the past 30 years, Korea's fishery catches have varied year to year. They gradually increased from 1.52 million tons in 1981 to 1.73 million tons in 1986. This was followed by a decrease then an increase in production. In 2010, 1.13 million tons were harvested, a decrease of 25.8% from 1981.

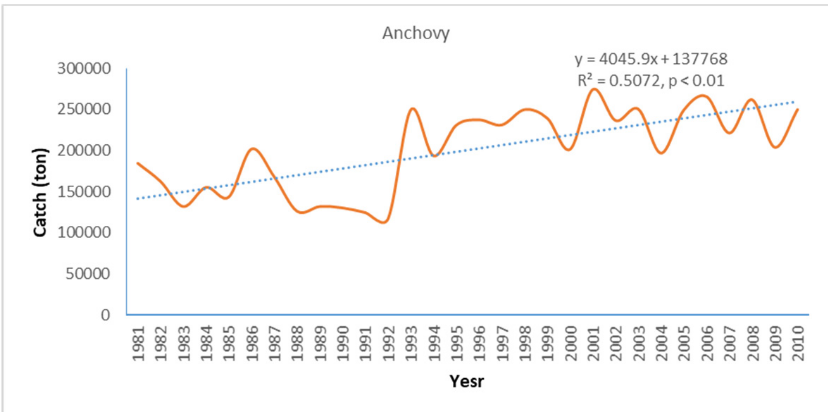
Fish species mainly caught in the offshore fisheries have also changed. In 1981, fish species with the largest catch in the offshore fisheries were of: anchovy, Alaska/walleye pollock, largehead hairtail, and chub mackerel. Their catches in the year were 184,351 t, 165,837 t, 147,677 t, and 108,082 t, respectively. The catch of the other three fish species (squid, small yellow croaker, and Pacific saury) was less than 50,000 t each in the year.

However, in 2000, the catches of three kinds of species, squid, anchovy, and chub mackerel have accounted for more than 50% [8]. In 2010 the catches in descending order were of: anchovy, squid, and chub mackerel. The catch of anchovy was more than 200,000 tons (249,636 t), squid more than 150,000 tons (159,130 t), and mackerel almost 100,000 tons (99,534 t) (Figure 4).

The catch of Pacific saury decreased from 10,844 t in 1981 to 5302 t in 1990, then temporarily increased to 19,883 t in 2000, but decreased again to 2564 t in 2010. From this, there was no significant variations during the study period. In the case of small yellow croaker, the catch was about 30,000 tons (34,477 t) in 1981, and it increased or decreased year by year, and it was restored to more than 30,000 tons again in 2010. Mackerel has been the only fish species still caught much in the last 30 years.

3.3. Relationship between Fishery Production and Climate Factors

Table 1 shows the results of Pearson's correlation analysis of the relationships between catch sizes of major fish species and climate factors (Table 1). The catches of largehead hairtail and pollock show a significant negative correlation with air/sea surface temperature ($p < 0.01$), but anchovy, squid ($p < 0.01$), and chub mackerel ($p < 0.05$) show a positive correlation SST ($p < 0.01$). The catch of the small yellow croaker shows a significant negative correlation with precipitation ($p < 0.01$).



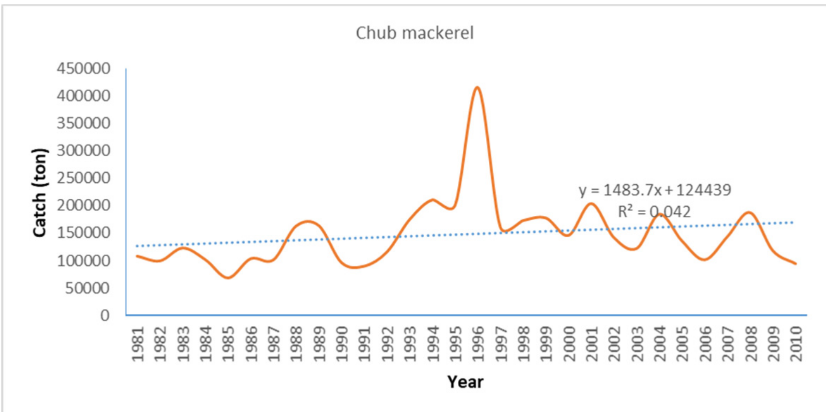


Figure 4. *Cont.*

Figure 4. *Cont.*

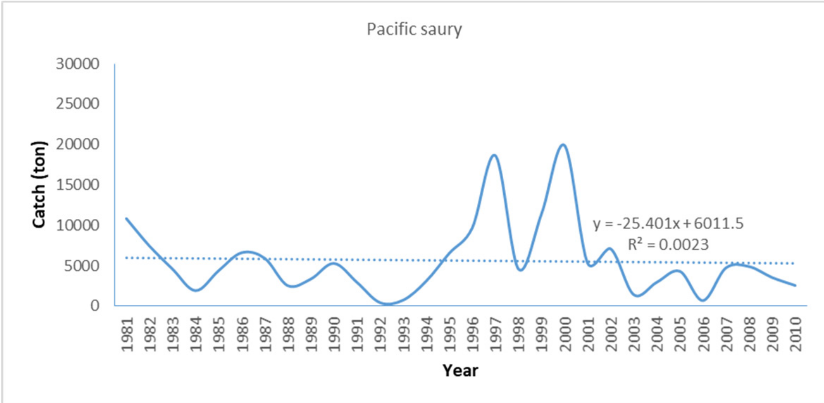


Figure 4. Changes in the catches of major fish species in the offshore fisheries of Korea from 1981~2010.

Table 1. Results of Pearson's correlation analysis between the air/sea surface temperature and catch size of fish species in the Republic of Korea.

Factors	Large Head Hairtail	Chub Mackerel	Anchovy	Walleye Pollack	Small Yellow Croaker	Squid	Pacific Saury	Pptn.	Sea Surface Temp.	Air Temp.
Largehead hairtail	1	−0.6731 ***	−0.9544 ***	0.9728 ***	0.1787	−0.9741 ***	−0.6044 **	−0.4175	−0.8597 ***	−0.9226 ***
Chub mackerel	−0.6731 ***	1	0.6267 **	−0.7364 ***	0.1958	0.7939 ***	0.7778 ***	−0.0537	0.5309 *	0.4952 *
Anchovy	−0.9544 ***	0.6267 **	1	−0.6771 *	−0.1222	0.9033 *	0.4534 *	0.4872 *	0.7770 ***	0.9298 ***
Walleye pollack	0.9728 ***	−0.7364 ***	−0.6771 *	1	−0.3421	−0.8442 *	−0.1653	−0.2742	−0.8509 ***	−0.8604 ***
Small yellow croaker	0.1787	0.1958	−0.1222	−0.3421	1	0.1311	−0.3952 *	−0.7501 ***	−0.0684	−0.3582
Squid	−0.9741 ***	0.7939 ***	0.9033 *	0.8442 *	0.1311	1	0.4331 *	0.3631	0.8089 ***	0.8811 ***
Pacific saury	−0.6044 **	0.7778 ***	0.4534 *	−0.1653	−0.3952 *	0.4331 *	1	0.3511	0.3880	0.5119 *
Pptn.	−0.4175	−0.0537	0.2872	−0.2742	−0.7501 ***	0.3631	0.3511	1	0.3486	0.4522 *
Sea surface temp.	−0.8597 ***	0.5309 *	0.7770 ***	−0.8509 ***	−0.0684	0.8089 ***	0.3880	0.3486	1	0.8946 ***
Air temp.	−0.9226 ***	0.4952 *	0.9298 ***	−0.8604 ***	−0.3582	0.8811 ***	0.1699	0.4522 *	0.8946 ***	1

Notes: *: $p < 0.05$, **: $p < 0.01$, ***: $p < 0.001$.

4. Discussion

Over the past 30 years (1981~2010), air temperature and SST of offshore waters of the Korean coastal area have both increased in terms of annual average values. From the results of this study, we found that the SST of Korean seas has a significant positive correlation with air temperature, which indicates that climate change, especially warming, affects both land and oceans. Our findings are supported by a report that there was a relationship between monthly air temperature and sea surface temperature at nine points in the East, South, and West Seas of Korea [21].

This study showed that the SST of Korean seas increased by almost 1 °C over the past 30 years. This is about twice the increase in the global average for the past 40 years for SST. Furthermore, the SST of Korean seas has continued to rise every decade over the past 30 years. Another study reported that the SST in Korean sea increased linearly by approximately 1.0 °C from 1968 to 2005 [22]. Our findings of this study along with that report [22] suggest that the local warming trend may be the highest in the Pacific region.

As a result of examining the relationship between catches of major fish species and climate factors, catches of largehead hairtail and pollock showed significant negative correlations with air temperature/SST ($p < 0.01$), and catches of anchovy, squid, and chub mackerel showed positive correlations ($p < 0.05$). In other words, warm-water fish species, such as anchovy and squid, increased and cold-water fish species, such as pollock and Pacific saury, decreased in the offshore fisheries of Korea. This correlation analysis suggests that the catches of cold-water fish species decrease as the seawater temperature rises, and warm-water fish take their place. Meanwhile, the catch of largehead hairtail, a warm-water fish species, also decreased, so there may have been other influences besides the climatic factor.

In fact, the catches of several fish species in the offshore fisheries have been drastically reduced in the East Sea compared with about 30 years ago. Catches of a typical cold-water fish, Alaska/walleye pollock (myeong-tae in Korean) sharply decreased due to rising coastal water temperature, as well as irresponsible over-fishing of young/juvenile fish in the 1980s. The annual catch of the fish, which is the most popular fish in Korean cuisine, was more than 160,000 tons in 1980, but dropped to less than 10,000 tons in 1990, and again dropped to less than 1000 tons in 2000. In addition, the annual catch of pollock in 2004 was less than 100 tons, but it is not even counted (it was shown as zero) in statistics in 2008 [22,23]. Recently, pollock is reported to have almost disappeared in coastal sea of Korea since it was only about one ton in a year [6,24]. The distribution of young fish tends to shift northward with the rising sea surface temperatures. For the reason why water temperature has risen in the East Sea, it has been said that the Kuroshio warm-water current is strong in the East Sea in summer time, but the cold-water is not generated [4]. Several scientists explain the rapid rise in temperature in the East Sea as an example of climate change in the North Pacific [25], but it is still not very clear.

On the other hand, squid, a warm-water fish, fills the fishing grounds where pollock has disappeared. In 2010, the catch of squid was more than 160,000 tons, which has increased more than four times over the past 30 years. In the case of squid, there were higher catches in the East Sea, the main spawning and fishing ground, and also caught in the West Sea due to changes in the pathway and habitat according to the rise of sea water temperature [10,26]. Anchovy, also a warm-water species, is continuously increasing in catches [23]. There were relationships between the growth rate of fish during early life stages and sea temperature, and the shifts between the warm anchovy regime and the cool sardine regime in the western North Pacific was reported [27,28]. Due to the rise in water temperature, the catch of chub mackerel, which is a typical warm-water fish species living in the temperature range of 15 to 19 °C, has increased remarkably from the mid-1990s, and there was a big catch of mackerel in the 2000s. The fishing grounds of chub mackerel have also been extended to the coastal area of the East Sea and West Sea. Meanwhile, there is a report that catches of the fish are decreasing again as the proportion of small fish (less than 350 g) has recently increased [6,29].

Until 1991, largehead hairtail was widely distributed and caught in the west and south coastal waters. However, it turns out in this study that catch size of the fish was considerably reduced compared to 30 years ago. As an explanation for this, it was reported that the reduction of fishing grounds in the western coastal waters caused this fish group to migrate southward to the southern coast and Jeju-do coast, and that the catches were decreasing as the amount of resources decreased [23,29].

The catch of the small yellow croaker was negatively correlated with precipitation. When the precipitation increases, the salinity of seawater seems to decrease. In the survival test of juvenile of small yellow croaker according to the salinity, the survival rate by salinity was higher as the salinity was lower. In another study, juvenile of large yellow croaker showed the possibility of cultivation at low salinity [30,31]. These reports suggest that young yellow croaker is tolerant to low salinity, and support our finding.

In addition to climate (water temperature) changes, catch size can vary due to complex factors such as fishing vessels and/or fishing gear, overfishing, and illegal fishing of neighboring countries. However, as pointed out in this section, climatic factors, especially temperature rise, have a large effect on some fish species. We can predict that if the water temperature rises as the current trend is continued, cold-water fish species will gradually decrease in the coastal waters of Korea and the proportion of warm-water and subtropical fish species will increase [29]. The warmer sea has changed the most caught fish in Korea; it is no longer Alaska/walleye pollock [24].

Recently the FAO warned that global warming is gradually exhausting fish stocks, but the consumption of aquatic products is soaring, leading to a rise in fishery product prices, or fishflation (fisheries plus inflation) [1,32]. Although the government of the Republic of Korea is trying to guide and encourage the aquaculture industry [33,34], they should respond more aggressively so as not to lose more fishery resources. We expect that the results of this study would provide important information to cope with fishflation that South Korea may be encountering in the near future. Further, the safety of the fishery products and its relation to fish migration should be monitored more frequently. There are many concerns about the food issue caused by warming of the Korean Peninsula, but there are not enough scientific data on safety of fishery product. We think that food security should be explored together with food safety. Further studies on the effect of warming and contamination of sea water and safety of fishery products should be done more and in detail.

5. Conclusions

Over the past 30 years (1981~2010), both the annual average values of air temperature and SST of the Korean coastal area have increased. The SST has a significant positive correlation with air temperature, which indicates that warming affects both land and oceans. The increased SST also appeared to affect the catches of fish species preferred in Korean cuisine. The catches of cold-water species, such as Alaska/walleye pollock, were negatively correlated with SST, indicating that climate change, especially ocean warming, could affect the price inflation of fisheries and aquatic products. These results suggest that warming will apparently be a threat to the fisheries and fish supply sustainability in Korea.

Author Contributions: J.-G.K. (Jong-Gyu Kim) conceived and designed the study. Both authors searched for data sources and J.-G.K. (Jeong-Gyoo Kim) edited the data. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Acknowledgments: The authors express the deepest appreciation to Joong-Soon Kim, of Industrial Engineering at Keimyung University, who advised for this study and helped us to complete the paper.

Conflicts of Interest: The authors declare no conflict of interest.

References

1. FAO of the United Nations. *Climate Change and Food Security: Risks and Response*; FAO: Rome, Italy, 2015.
2. Bindoff, N.L.; Willebrand, J.; Artale, V.; Cazenave, A.; Gregory, J.; Gulev, S.; Hanawa, K.; Le Quéré, C.; Levitus, S.; Nojiri, Y.; et al. Observations: Oceanic Climate Change and Sea Level. In *Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change*; Solomon, S., Qin, D., Manning, M., Chen, Z., Marquis, M., Averyt, K.B., Tignor, M., Miller, H.L., Eds.; Cambridge University Press: Cambridge, UK; New York, NY, USA, 2007.
3. Intergovernmental Panel on Climate. (IPCC) Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. In *Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change*; Field, C.B., Ed.; Cambridge University Press: Cambridge, UK; New York, NY, USA, 2014; p. 485.
4. Lee, J.W.; Jeon, D.S. Climate change and its impact on marine ecosystem. *Nat. Conserv.* **2005**, *132*, 1–8.
5. Korea Fisheries Association (KFA). *Korean Fisheries Yearbook 2006*; KFA: Seoul, Republic of Korea, 2006.
6. Korea Fisheries Association (KFA). *Korean Fisheries Yearbooks 2011*; KFA: Seoul, Republic of Korea, 2011.
7. Kang, Y.S.; Jung, S.; Zuenko, Y.; Choi, I.; Dolganova, N.T. Regional differences in response of mesozooplankton to long-term oceanographic changes (regime shifts) in the northeastern Asian marginal seas. *Prog. Oceanogr.* **2012**, *97-100*, 120–134. [CrossRef]
8. Korea Fisheries Association. *Korean Fisheries Yearbook: Fisheries Trends and Fisheries Policy*; KFA: Seoul, Republic of Korea, 2012; p. 219.
9. Kang, Y.S.; Kim, J.Y.; Kim, H.G.; Park, J.H. Long-term changes in zooplankton and its relationship with squid, Todarodes pacificus, catch in Japan/East Sea. *Fish Oceanogr.* **2002**, *11*, 337–346. [CrossRef]
10. Kim, S.; Zhang, C.-I.; Kim, J.-Y.; Oh, J.-H.; Kang, S.; Lee, J.B. Climate variability and its effects on major fisheries in Korea. *Ocean Sci. J.* **2007**, *42*, 179–192. [CrossRef]
11. Rebstock, G.A.; Kang, Y.S. A comparison of three marine ecosystems surrounding the Korean peninsula: Responses to climate change. *Prog. Oceanogr.* **2003**, *59*, 357–379. [CrossRef]

12. Jung, S. Spatial variability in long-term changes of climate and oceanographic conditions in Korea. *J. Environ. Biol.* **2008**, *29*, 519–529. [PubMed]
13. Uye, S. Blooms of the giant jellyfish Nemopilema nomurai: A threat to the fisheries sustainability of the East Asian Marginal Seas. *Plankton Benthos Res.* **2008**, *3*, 125–131. [CrossRef]
14. Dong, Z.; Liu, D.; Keesing, J.K. Jellyfish blooms in China: Dominant species, causes and consequences. *Mar. Pollut. Bull.* **2010**, *60*, 954–963. [CrossRef] [PubMed]
15. Yoon, W.D.; Yang, J.Y.; Shim, M.B.; Kang, H.K. Physical processes influencing the occurrence of the giant jellyfish Nemopilema nomurai (Scyphozoa: Rhizostomeae) around Jeju Island, Korea. *J. Plankton Res.* **2008**, *30*, 251–260. [CrossRef]
16. Ministry of Agriculture Food and Rural Affairs (MAFRA) of Korea. *Consumptions of Republic Fishery Products of Koreans 1981–1997*; MAFRA: Sejong, Republic of Korea, 1998.
17. Statistics Korea (SK). *Cconsumptions of Fishery Products of Koreans 1999–2010*; SK: Daejeon, Republic of Korea, 2016.
18. National Institute of Fisheries Science (NIFS)/Korea Oceanographic Data Center (KODC). Year Data of 1981~2010 Jeongseon Marine Survey Data. 2016. Available online: http://www.nifs.go.kr/kodc/soo_list.kodc (accessed on 26 April 2017).
19. Korea Meteorological Administration (KMA). *Climate Perspectives on the Korean Peninsula*; KMA: Seoul, Republic of Korea, 2012; p. 66.
20. *IBM SPSS Statistics 24*, version: 24.0; IBM Corporation: Chicago, IL, USA, 2021.
21. Jang, L.H.; Kang, Y.Q.; Suh, Y.S. Relationship between sea surface temperature and air temperature variation depend on time scale at coastal stations in Korea. *J. Korean Environ. Sci. Soc.* **2000**, *9*, 303–309.
22. Korea Marine Institute (KMI). *KMI Weekly Report*; KMI: Busan, Republic of Korea, 2017; Volume 25, pp. 1–15.
23. Ministry of Oceans and Fisheries (MOF) of Korea. *Statistical Yearbook of Maritime Affairs & Fisheries*; MOF: Sejong, Republic of Korea, 2013.
24. Kim, J.G.; Kim, J.S. Climate change and depletion of walleye pollock resources in the East Sea. *J. Environ. Health Sci.* **2018**, *44*, 259–266.
25. Perry, R.I.; McKinnell, S.M. (Eds.) *Marine ecosystems of the North Pacific PICES Special Publication*; PICES: Sidney, BC, Canada, 2004; Volume 1, p. 80.
26. Kim, J.G.; Kim, J.S. Climate change and expansion of squid catches in Korea. *J. Environ. Health Sci.* **2017**, *43*, 516–524.
27. Kim, J.Y.; Kim, S.; Choi, Y.M.; Lee, J.B. Evidence of density dependent effects on population variation of Japanese sardine (Sardinops melanosticta) off Korea. *Fish Oceanogr.* **2006**, *15*, 345–349. [CrossRef]
28. Takasuka, A.; Oozeki, Y.; Aoki, I. Optimal growth temperature hypothesis: Why do anchovy flourish and sardine collapse or vice versa under the same ocean regime? *Can. J. Fish. Aquat. Sci.* **2007**, *64*, 768–776. [CrossRef]
29. Anonymous. Changes in Catches of Major Fish Species due to Climate (Water Temperature) Changes. *Statistics Korea Press Release*, 25 June 2018.
30. Korean Intellectual Property Office. Method for Breeding of Family Sciaenidae. 2011. Available online: https://patents.google.com/patent/KR101021068B1/ko (accessed on 22 August 2022).
31. Wang, Y.; Li, W.; Li, L.; Zhang, W.; Lu, W. Effects of salinity on the physiological responses of the large yellow croaker Pseudosciaena crocea under indoor culture conditions. *Aquac. Res.* **2016**, *47*, 3410–3420. [CrossRef]
32. Cho, J.H.; Nam, J.O. Creative approaches for future aquaculture in Korea. *Ocean Future* **2013**, *41*, 5–8.
33. Jeong, I.J.; Lee, S.H. Korea's effective approach to adapting climate change in the fisheries sector. In *The Economics of Adapting Fisheries to Climate Change*; OECD: Paris, France, 2011; pp. 367–376.
34. Kim, J.G.; Kim, J.S. Impact of climate change on food safety: A mini review. *J. Environ. Health Sci.* **2016**, *42*, 465–477. [CrossRef]