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Influence of Spawning and Nursery Ground Environmental Changes on Walleye Pollock Catches Along the Eastern Coasts of Korea and Japan After the Late-1980s Climate Regime Shift

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Abstract: The eastern coasts of Korea (ECK) and Japan (ECJ) are located at the southernmost limit of walleye pollock distribution in the Northwest Pacific. Following the climate regime shift (CRS) in the late 1980s, pollock catches in these regions have declined sharply, with different trends emerging. This study examined the relationship between environmental factors, such as sea surface temperature (SST) and habitat suitability, and changes in pollock catches from the late 1980s to 2022. From the late 1980s to the late 1990s, El Niño and positive Pacific decadal oscillation (PDO) phases dominated, increasing SST in the ECK and ECJ habitats and rapidly decreasing catches. Although spawning grounds (SGs) have maintained high habitat suitability, nursery ground (NG) suitability has declined. From the late 1990s to 2022, La Niña and negative PDO phases prevailed, with SST continuing to rise along the ECK, further reducing catches. SG suitability remained high, but NG suitability declined. Along the ECJ, SST decreased after the late-1990s CRS, stabilizing catches. After the mid-2010s, the SST increased along the ECJ, reducing pollock catches, although SG suitability remained high. This study elucidates SST changes during early life stages and their effects on pollock catch, habitat, and resources in future marine environments.

Keywords: walleye pollock; early life stage; climate regime shift; habitat suitability

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1. Introduction

Walleye pollock (*Gadus chalcogrammus*) is a semi-demersal, cold-water fish species and is an important commercial fish [1]. Pollock are distributed across the North Pacific, from Korea to the northwestern coast of the United States [2,3]; Korea and Japan in the Northwest Pacific are considered the southernmost limit of pollock habitat [2–8]. In the Northwest Pacific, the main countries that catch pollock are Korea, Japan, and Russia, and from the late 1980s to the early 1990s, pollock catches decreased across all three countries. Since the 2000s, pollock catches have tended to increase in Russia, whereas Japan has remained consistent in its pollock catches. However, in Korea, pollock catches have continuously declined, and there are currently almost no catches [1,6,9–11]. Although Korea and Japan are both on the southernmost limit of pollock habitat in the Northwest Pacific Ocean, they exhibit different trends in pollock catch fluctuations.

Pollock begin their life in the surface layer, and as they grow, they gradually move to deeper waters [7,12–14]. During the early life stages (eggs and larvae), they live as ichthyoplankton and are therefore highly sensitive to environmental changes, such as sea surface temperature (SST) and current distribution [15–18]. Growth and survival during early life can substantially influence the recruitment of pollock populations [14,18,19]. For example, during early life stages, unlike juveniles and adults, they have little ability to

behaviorally regulate their body temperature and have limited mobility, making them more susceptible to environmental changes. This can lead to higher mortality rates if they fail to adapt [20].

The main spawning season for pollock along the eastern coast of Korea (ECK) is from December to March of the following year, with primary spawning grounds (SGs) and nursery grounds (NGs) in East Korea Bay and the coastal waters of Goseong, respectively (Figure 1) [6,7,9,13]. Primary SGs and NGs for pollock in Japan differ by population [14,21]. The main SGs and NGs for pollock along the eastern coast of Japan (ECJ) are known to be in Funka Bay and the Tohoku coastal waters, respectively (Figure 1) [8,10,22,23], with the main spawning season occurring from December to March of the following year [24].

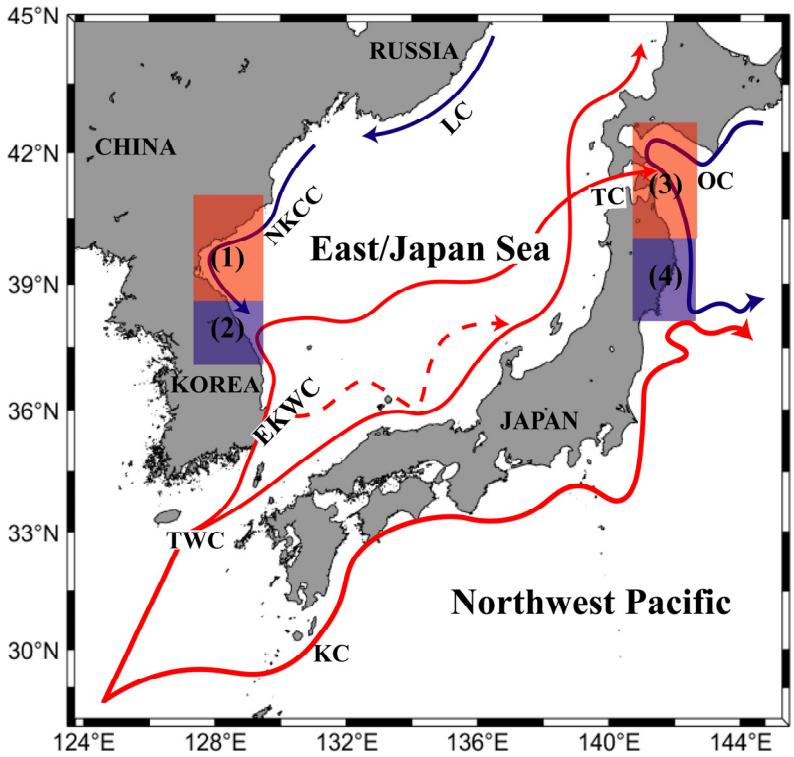


Figure 1. Schematic map of the major pollock spawning (red-colored boxes) and nursery grounds (blue-colored boxes) and ocean currents along the eastern coast of Korea (ECK) and the eastern coast of Japan (ECJ). (**1**) represents the major spawning ground in East Korea Bay on the ECK, (**2**) is the nursery ground along the Goseong coast on the ECK, (**3**) is the major spawning ground in Funka Bay on the ECJ, and (**4**) is the nursery ground along the Tohoku coast on the ECJ. Warm currents (red allows): EKWC—East Korea Warm Current; TWC—Tsushima Warm Current; KC—Kuroshio Current; TC—Tsugaru Warm Current. Cold currents (blue allows): NKCC—North Korea Cold Current; OC—Oyashio Current.

The pollock NG environments along the ECK and the ECJ share the common characteristic of warm and cold currents meeting to form a front (Figure 1). On the ECK, a subpolar front forms, where the high-temperature, high-salinity East Korea Warm Current meets the low-temperature, low-salinity North Korea Cold Current originating from the Liman Current [25,26]. On the ECJ, a polar front forms when the Kuroshio Current meets the Oyashio Current [27,28]. Changes in volume transport of the Kuroshio Current, which originates from the equatorial current system, can affect the SG and NG environments in the two regions differently [29,30]. Variations in the Kuroshio Current volume are known to be highly correlated with Pacific decadal oscillation (PDO), El Niño-southern oscillation (ENSO), and other phenomena [29–37]. During El Niño (La Niña) periods or when the PDO is in a negative (positive) phase, the Kuroshio Current volume transport tends to

weaken (strengthen) [38–41]. When the Kuroshio Current strengthens, the current volume transported to the ECJ increases, which can substantially impact the variability of biological resources [42]. Conversely, when the warm current volume transported to the ECK weakens, it can potentially alter the coastal water mass structure [30,43–45] and affect trends in the fish community index [46,47].

Previous studies on changes in pollock catches in Korea and Japan have focused on overfishing, climate change, and changes in current distribution. In Korea, juvenile pollock overfishing in SGs continued to increase until the early 1980s. After the climate regime shift (CRS) in the late 1980s, pollock stock rapidly declined [6,13]. Following the CRS in the late 1980s, the surface water temperature in pollock SGs increased, leading to a reduction in the potential spawning area [6,48]. Concurrently, the distribution of eggs and larvae shifted towards the open sea due to currents [49]. In Japan, following the CRS in the late 1980s, an increase in warm current volume transport through the Tsugaru Strait affected fluctuations in the pollock catch [8].

Additionally, variations in the Oyashio Current, influenced by the strength of the northwesterly winds, impact the abundance of pollock resources and the transport of pollock eggs, potentially affecting the recruitment of biological resources [35,50]. The surface water temperature in pollock SGs can act as a key factor in regulating the timing and growth of larvae and juvenile pollock [51]. Whereas previous studies have explained the fluctuation in pollock fishing grounds in each region (ECK and ECJ), a comparative analysis of pollock catch fluctuations between the two regions following the late-1980s CRS, and a clear explanation of the causes, needs to be carried out.

The current study aimed to identify the causes of pollock catch fluctuations along the ECK and the ECJ after the late-1980s CRS from the perspective of the early life stages of pollock. It was hypothesized that changes in the marine environments of the ECK and the ECJ impact pollock habitats (SGs and NGs) differently. To explain this, the long-term changes in the marine environment of pollock habitats and changes in pollock catch along the ECK and the ECJ before and after the CRS were analyzed. Secondly, the suitability of the pollock habitats along the ECK and the ECJ was examined. Finally, the relationship between the environmental conditions of the pollock habitats and catch fluctuations in the two regions was discussed.

2. Materials and Methods

2.1. Study Area and Summary of Abbreviations

The main pollock habitats along the ECK and the ECJ were determined based on the findings of previous studies [6–8,13,21,22,50]. The pollock habitats in the two regions were set within areas with depths of less than 500 m. Along the ECK, the primary SGs and NGs were designated as East Korea Bay (38.5°–41° N) and the Goseong coast (37°–38.5° N), respectively. Along the ECJ, the primary SGs and NGs were designated as Funka Bay (40°–42.8° N) and the Tohoku coast (38°–40° N), respectively (Figure 1). The abbreviations used in this paper are summarized in Table 1 as follows.

Table 1. Summary of abbreviations in this article.

Abbreviation	Full Name	Abbreviation	Full Name
ECK	Eastern coast of Korea	RS	Regime shift
ECJ	Eastern coast of Japan	SG	Spawning ground
CRS	Climate regime shift	NG	Nursery ground
SST	Sea surface temperature	HSI	Habitat suitability index
PDO	Pacific decadal oscillation	SOI	Southern oscillation index

2.2. Sea Surface Temperature and Climatic Factors

Sea surface temperature (SST) is a key environmental factor influencing the early life stages of pollock. SST was analyzed using data from 1982 to 2022 from the Operational

Sea Surface Temperature and Sea Ice Analysis (OSTIA) [52]. The SST during the main spawning season of pollock (January to March) was averaged to analyze the SST in SGs and NGs in both regions (ECK and ECJ). Additionally, climatic factors closely related to North Pacific SST variations, such as ENSO and PDO, provided by the National Centers for Environmental Information (NCEI), were considered, and the indices for January to March from 1982 to 2022 were averaged. The southern oscillation index (SOI) is an index representing the ENSO phenomenon. During El Niño (La Niña) periods, the SOI tends to have a negative (positive) phase [53–55], which is associated with a relative weakening (strengthening) of the Kuroshio Current volume transport [38–41]. When the PDO index (PDOI) is in a negative (positive) phase, relatively cool (warm) SSTs tend to appear along the North American coast, whereas relatively warm (cool) SSTs tend to appear in the Northwest Pacific [32,40].

2.3. Habitat Suitability and Catch Data for Pollock

The habitat suitability index (*HSI*) [56,57] was calculated using pollock hatch rate values based on the water temperature [7,58–61]. To explain the relationship between hatch rate and water temperature, a Gaussian model and a Cauchy (Lorentzian) model, both nonlinear functions, were compared. The Gaussian model, which showed a high variance correlation (R^2) with hatch rate changes (ANOVA; $F_{[19,31]} = 12.896$, $p < 0.01$), was used to calculate the HSI for pollock along the ECK and the ECJ (Figure 2):

$$HSI = 0.8265 \times \exp\left(-0.5 \times \left(\frac{T - 4.1315}{6.626}\right)^2\right) \quad (1)$$

where T represents the water temperature.

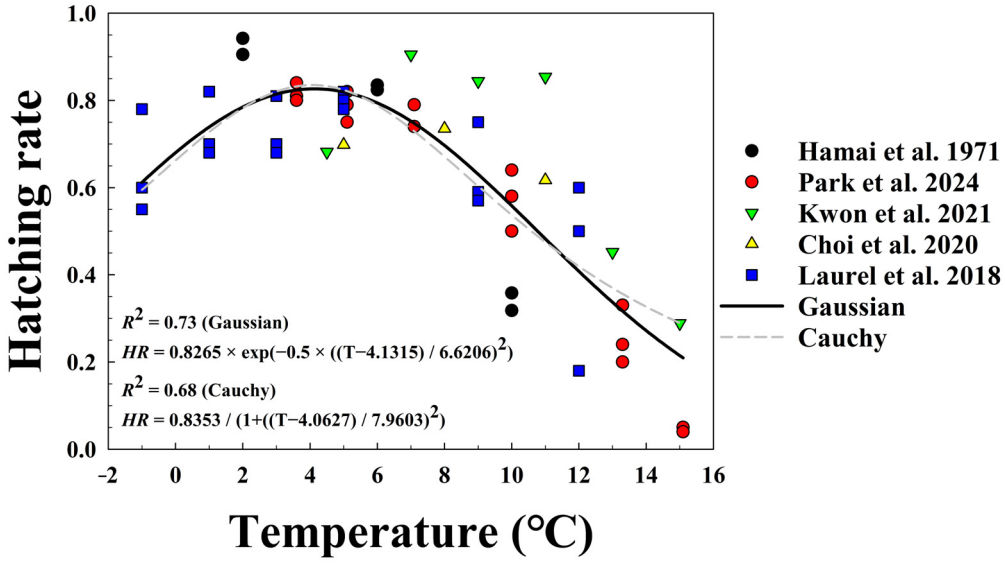


Figure 2. Changes in pollock hatching rates with temperature variation [7,58–61]. The black and dashed lines represent the results of the Gaussian and Cauchy models, respectively.

In the current study, a water temperature of 9 °C, at which the hatch rate during the early life stages of the pollock decreased to approximately 60%, was determined as the threshold temperature that negatively affected these stages (Figure 2).

Pollock catch data for the ECK and the ECJ from 1970 to 2020 were obtained from annual total fishery production statistics. Pollock catch data for the ECK were provided by the Korean Statistical Information Service (https://kosis.kr/index/index.do (accessed on 1 May 2024)), whereas the pollock catch data for the ECJ were obtained from the Ministry of Agriculture, Forestry, and Fisheries (http://www.maff.go.jp/j/tokei/kouhyou/kaimen_

gyosei/index.html (accessed on 1 May 2024)) and represent the total catch in the Tohoku region, comprising the combined catch of the Miyagi, Iwate, and Fukushima prefectures.

3. Results

3.1. Time Series Changes in the Pollock Catch

From 1982 to 2000, two regime shifts (RSs) in pollock catch occurred on the ECK and the ECJ (first RS: 1987–1990; second RS: 1998–1999). Along the ECK, the first RS occurred in 1987, and the catch gradually decreased until 1997 (Figure 3). The second RS occurred in 1998; since then, the catch has continued to decline, with almost no catch in recent years. Along the ECJ, the first RS occurred in 1990, and the catch remained steady until 1998. Despite the second RS in 1999, unlike the ECK, pollock catches along the ECJ have remained relatively stable to the present day.

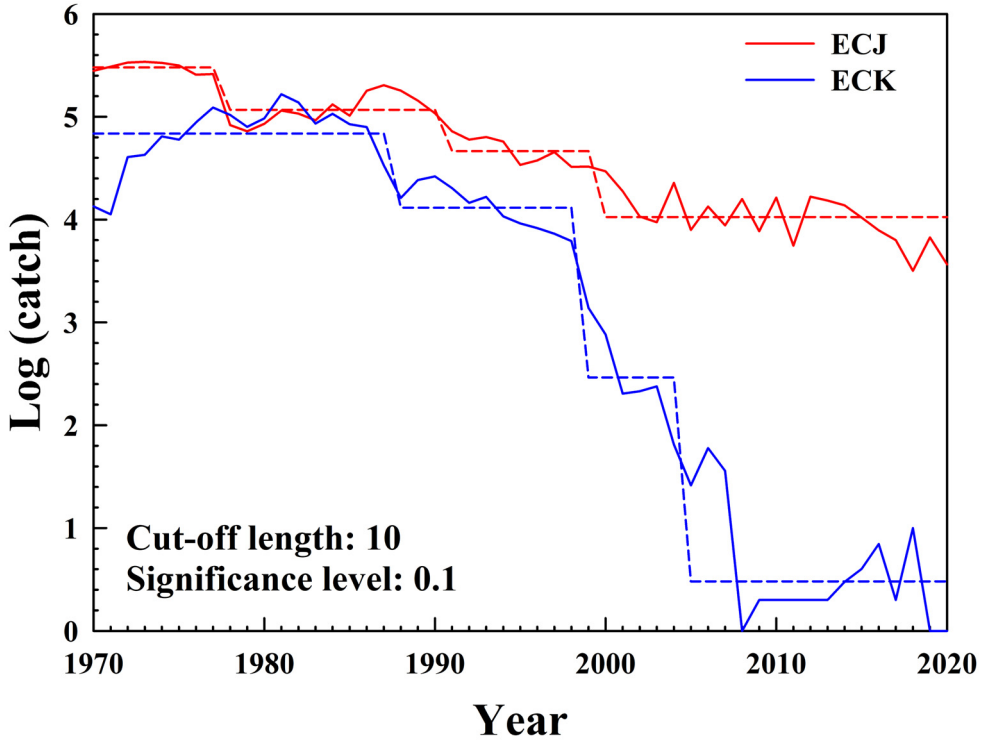


Figure 3. Time series change in pollock catch from 1970 to 2020 along the eastern coast of Korea (ECK) and the eastern coast of Japan (ECJ). The solid line represents the pollock catch rate, and the dashed line represents the step changes estimated by the sequential *t*-test analysis of regime shifts.

3.2. Environmental Changes in the Pollock Habitats along the ECK and the ECJ

The period from the 1980s to the 1990s was characterized by the predominance of El Niño and PDO-negative phases in the pollock habitats of the ECK and the ECJ; since the 2000s, La Niña and PDO-positive phases have been predominant in both regions (Figure 4).

The SST in the pollock habitats of both regions showed periods of common increases and opposite trends at different times (Figure 4). Specifically, in the 1980s, the SST in pollock habitats in both regions exhibited a positive correlation, whereas in the 1990s, the SST in NGs showed a negative correlation (Table 2). Along the ECK, SSTs above 9 °C began to appear in the NGs of pollock starting in 1987, with temperatures above 10 °C persisting from the late 1990s (Figure 4). Along the ECJ, SSTs above 9 °C began to appear in the NGs of pollock starting in 1989, with temperatures remaining approximately 9 °C throughout the 1990s (Figure 4). From 1998 to the 2000s, the SST in the NGs of the ECK increased, whereas the SST in the NGs of the ECJ decreased (Figure 4). Since 2010, the SST in the pollock habitats of both regions have been positively correlated (Figure 4; Table 2). The SST

in the SGs of the ECK remained lower than that of the ECJ until the late 2010s (3–5 °C), but since the 2020s, the SST in the pollock SGs of the ECJ has become lower (Figure 4).

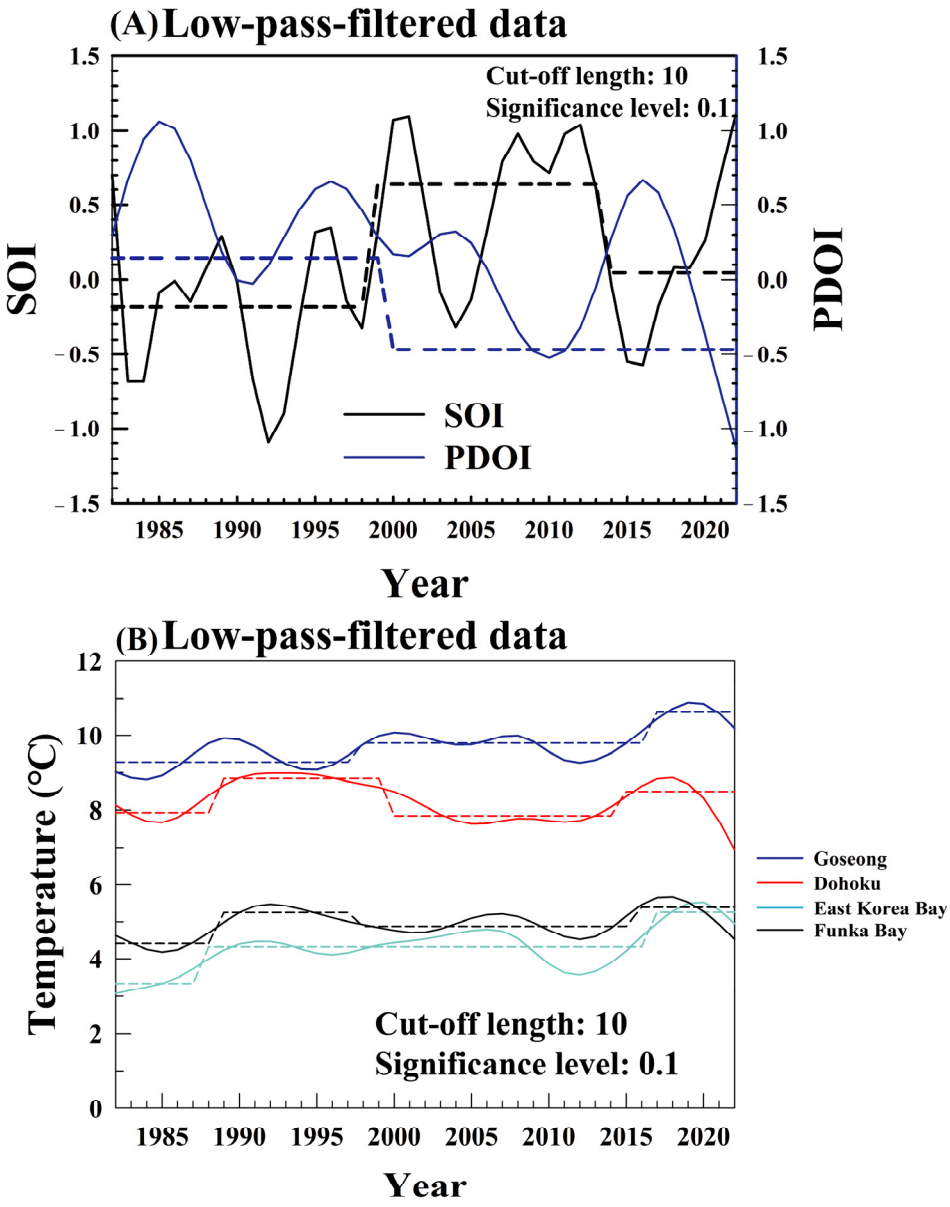


Figure 4. Time series changes in the southern oscillation index (SOI) and Pacific decadal oscillation index (PDOI) (**A**) and sea surface temperature (**B**) of pollock spawning and nursery grounds in two regions (ECK and ECJ) from 1982 to 2022. The dashed lines in both subfigures represent the step changes estimated using a sequential *t*-test analysis of regime shifts.

Table 2. Correlation coefficients of sea surface temperatures in the spawning and nursery grounds along the eastern coasts of Korea (ECK) and Japan (ECJ) during specific periods.

	Spawning Ground (ECK and ECJ)	Nursery Ground (ECK and ECJ)
1980s (1982–1990)	0.80 *	0.90 **
1990s (1991–2000)	0.21	−0.81 **
2000s (2001–2010)	0.52	0.56
2010s (2011–2020)	0.89 **	0.84 **

Note(s): * $p < 0.05$; ** $p < 0.01$.

When spatially comparing the pollock habitat environments during periods of RS in the pollock catch along the ECK and the ECJ (Figure 5), the 9 °C isotherm in the NGs of both regions moved northward during the first RS. Moreover, the habitat during the second RS showed different patterns between the two regions. Along the ECK, the 9 °C isotherm in pollock NGs moved even further north compared to the first RS. However, along the ECJ, the position of the 9 °C isotherm in the pollock NGs did not change substantially from its position during the first RS. The SG environments in both regions showed a temperature range of 3–6 °C throughout all periods. The SST in the SGs of the ECK appears to have increased more during the second RS than during the first RS, whereas the SST in the SGs of the ECJ, in contrast, appears to have decreased.

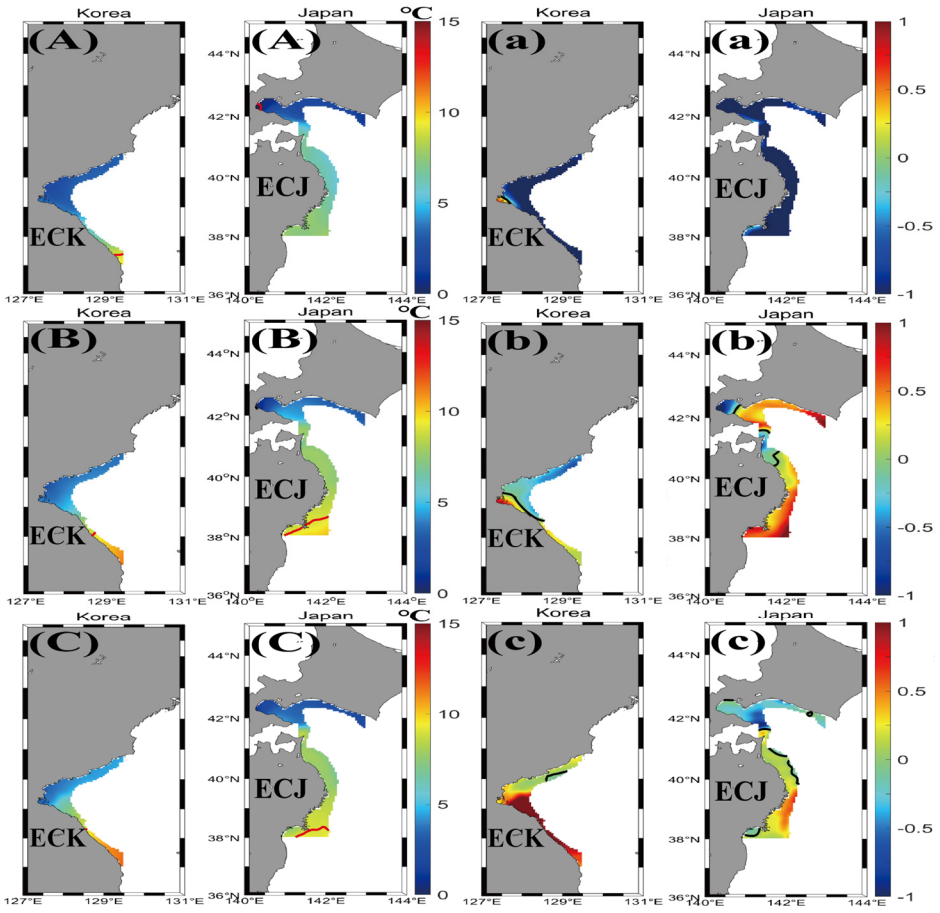


Figure 5. Spatial distribution of average sea surface temperatures (**A**–**C**) and temperature anomalies (**a**–**c**) in the pollock spawning and nursery grounds along the eastern coasts of Korea (ECK) and Japan (ECJ). (**A**,**a**) represent the relatively low sea surface temperatures in 1984. (**B**,**b**) represent the first regime shift in the pollock catch from 1987 to 1990. (**C**,**c**) represent the second regime shift in the pollock catch from 1998 to 1999. The red solid lines in (**A**–**C**) indicate the 9 °C isotherm; black solid lines in (**a**–**c**) indicate 0 °C.

3.3. Habitat Suitability Index (HIS) of Pollock along the ECK and the ECJ

The HSI for pollock NGs in both regions showed variability from 0.5 to 0.7, whereas the HSI for pollock SGs varied from 0.8 to 0.82 (Figure 6). The HSI for NGs along the ECK began to decrease in the mid-1980s, dropping to <0.6 by the early 1990s. In contrast, the HSI for NGs along the ECJ also decreased during the same period but remained in the low 0.6 range throughout the 1990s (Figure 6; Table 3). From the late 1990s to the early 2010s, the HSI for NGs in the two regions exhibited opposite trends. Along the ECK, the HSI dropped to approximately 0.5 and remained low, whereas along the ECJ, the HSI increased

to approximately 0.6 and then stabilized (Figure 6). After the 2010s, the HSI for NGs began to decline in both regions. The HSI along the ECK fell further to <0.5, whereas it remained at the 1990s level along the ECJ (Figure 6; Table 3).

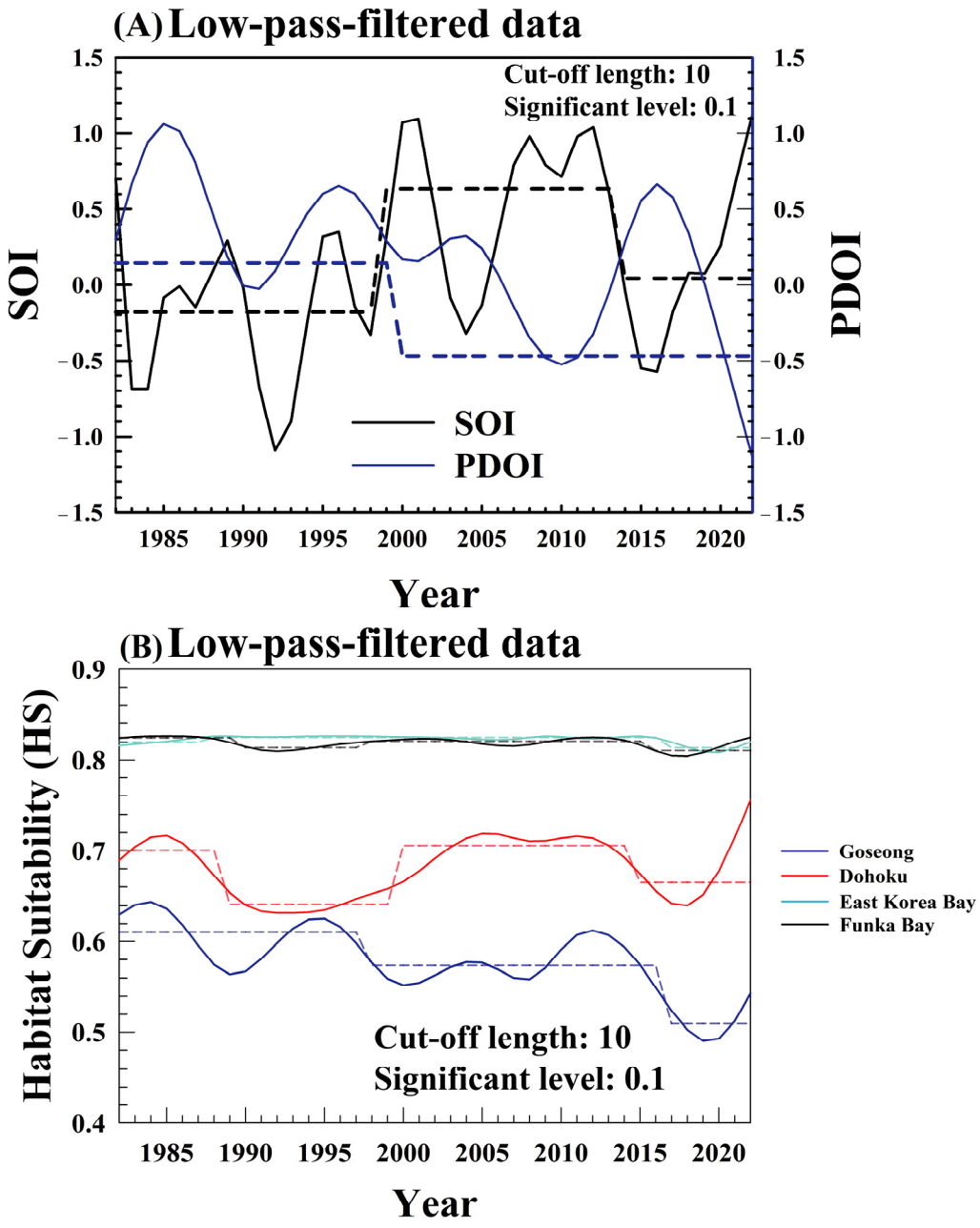


Figure 6. Time series changes in the southern oscillation index (SOI) and Pacific decadal oscillation index (PDOI) (**A**) and habitat suitability index (**B**) of pollock spawning and nursery grounds along the eastern coasts of Korea (ECK) and Japan (ECJ) from 1982 to 2022. The dashed lines in both subfigures represent the step changes estimated using a sequential *t*-test analysis of regime shifts.

When examining the spatial HSI in both regions, the SG environment consistently had a relatively high HSI throughout all periods (Figure 7). Relative to 1984, during the first RS, the HSI 0.6 line in the NGs of both regions gradually moved northward. During the second RS, the HSI 0.6 line in the ECK NGs continued to move northward and remained stable, whereas in the ECJ NGs, the HSI showed a relative increase (Figure 7).

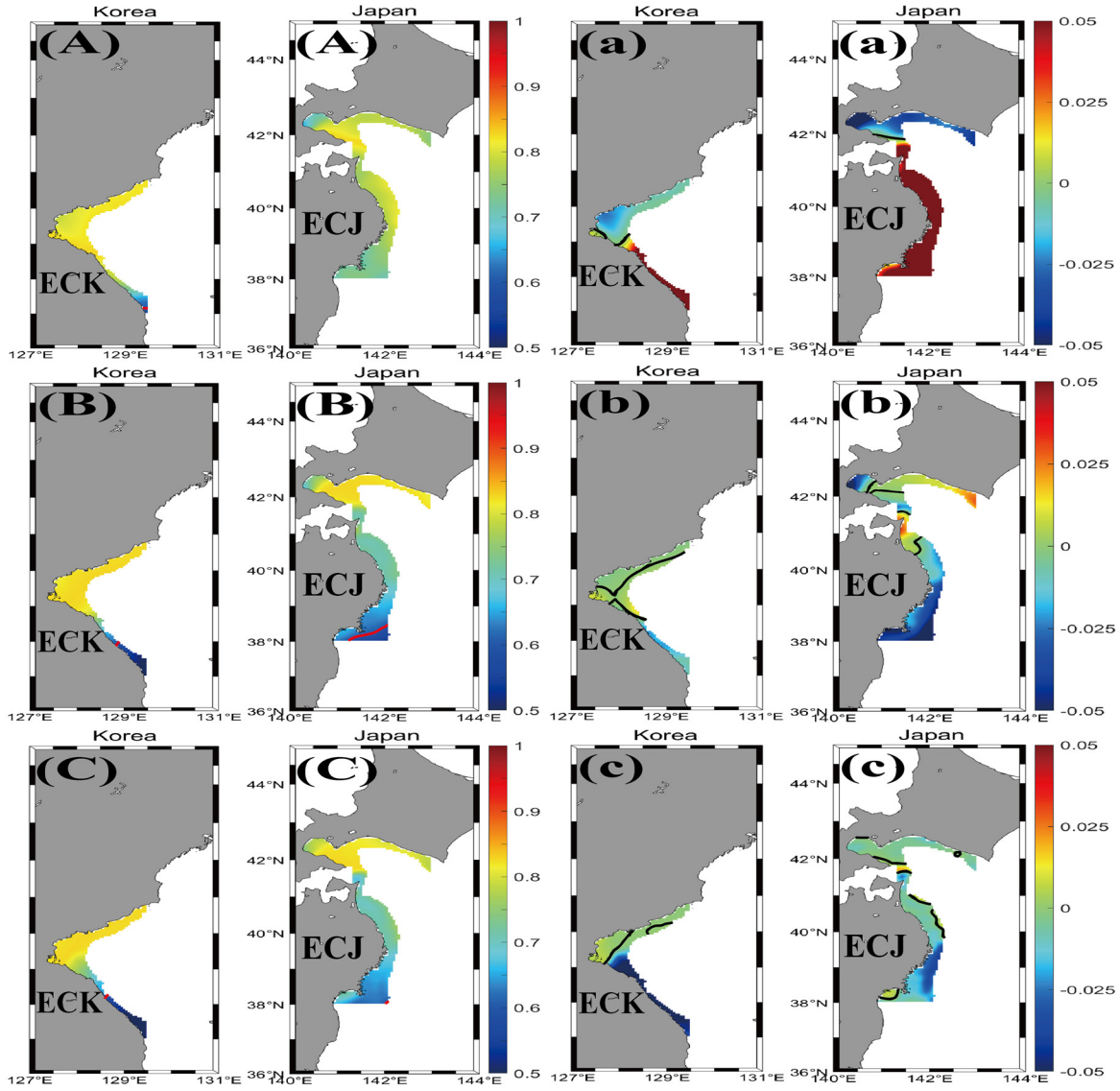


Figure 7. Spatial distribution of the average habitat suitability index (**A**–**C**) and habitat suitability index anomalies (**a**–**c**) in pollock spawning and nursery grounds on the eastern coasts of Korea (ECK) and Japan (ECJ). (**A**,**a**) represent the relatively high habitat suitability index in 1984, (**B**,**b**) represent the first regime shift in pollock catch from 1987 to 1990, and (**C**,**c**) represent the second regime shift in pollock catch from 1998 to 1999. The red solid lines in (**A**–**C**) indicate a 0.6 habitat suitability index, whereas the black solid lines in (**a**–**c**) indicate zero.

Table 3. Correlation coefficients of habitat suitability indices in spawning and nursery grounds on the eastern coasts of Korea (ECK) and Japan (ECJ) during specific periods.

	Spawning Grounds (ECK and ECJ)	**Nursery Grounds (ECK and ECJ)**
1980s (1982–1990)	−0.54	0.90 **
1990s (1991–2000)	0.35	−0.81 **
2000s (2001–2010)	0.66 *	0.56
2010s (2011–2020)	0.56	0.84 **

Note(s): * $p < 0.05$; ** $p < 0.01$.

4. Discussion

The Kuroshio Current is an environmental factor that commonly affects the SST in the pollock habitats of the ECK and the ECJ [29,30,35]. When the volume transport of the Kuroshio Current increases (decreases), the amount of warm water transported to the ECK (ECJ) tends to decrease (increase) [30,41,62,63]. Additionally, when the PDO is in a positive (negative) phase, the East Asian winter monsoon tends to be weak (strong), and the increase (decrease) in sea level and pressure gradient in the western Pacific can strengthen (weaken) the Kuroshio Current volume transport [35,64,65]. During La Niña (El Niño) periods, the strengthening (weakening) of the trade winds tends to enhance (reduce) the Kuroshio Current volume transport [38–41]. These changes in the current volume transport can affect the delivery of warm water to pollock habitats and influence the transport of eggs and larvae to SGs and NGs [6,49].

Pollock are a cold-water species that hatch and grow in surface layers during early life stages and gradually move to deeper waters as they mature [6,7,66–68]. Prolonged exposure to high-temperature environments during these early stages can negatively affect hatching and post-hatching survival [7,61,69]. For example, fish eggs that develop at temperatures outside the optimal range may have an increased likelihood of abnormal hatching [7,70,71], and larvae that do not quickly begin feeding after yolk absorption may have a reduced survival period [7,72,73]. The proportion of eggs and larvae transported to SGs and NGs can influence their recruitment into the pollock population [74], and the distribution of water masses can affect the distribution of larvae and juveniles [75]. In the current study, the first period of catch RS along the ECK and the ECJ (1987–1990) coincided with the CRS of the late 1980s. Until the second period of catch RS (1998–1999), the environment was dominated by El Niño- and PDO-positive phases. From 1982 to the mid-1990s, SST increased rapidly owing to global warming [76,77], and the East Asian winter monsoon weakened [49,64,76].

In the case of the ECK, the pollock catch declined sharply from the first to the second period of catch RS. During this time, it is believed that the pollock habitat environment experienced a strong influence of warm currents towards the coast, leading to an increase in SST [41,49,62–64,76]. From the CRS in the late 1980s to the early 1990s, changes in warm current volume transport during the early life stages of pollock led to the formation of SGs farther north than usual [49]. Consequently, the potential spawning area in these grounds decreased, which likely affected the recruitment of pollock resources [6]. In the present study, although the water temperature in the pollock SGs increased, the HSI remained conducive to the survival of eggs and larvae. However, in NGs, the persistent high-temperature environment likely affected the survival rate of pollock eggs and larvae, contributing to fluctuations in pollock catch. Spies et al. reported that pollock larvae, even those with sufficient food, die after a certain period of growth in environments above 12 °C [78]. Similarly, if the high-temperature environment in the NGs persists, pollock larvae are expected to die without growing, even under favorable feeding conditions.

In the case of the ECJ, pollock catches, including adult and age-0 fish, sharply declined from the first to the second period of catch RS [8]. During this time, the pollock habitat along the ECJ experienced an increase in SST owing to the weakening of the Oyashio Current and the strengthening of warm currents [8,35]. Pollock recruitment along the ECJ did not show marked changes in the average recruitment of age-2 fish in the 1990s compared to the 1980s [8], which is attributed to the formation of pollock NGs along the Doto coast, located north of the Tohoku coast [8,50,79]. Within the optimal range, an increase in water temperature can enhance hatching and growth rates during the early life stages [7,50,61]. It is believed that the pollock SGs on the ECJ provided a favorable environment for hatching and post-hatching survival during the early life stages, resulting in relatively little change in average recruitment [8,50,79].

The second period of catch RS on the ECK and the ECJ (1998–1999) coincided with the CRS of the late 1990s, and La Niña and negative PDO phases were predominant until the 2020s. The period from the 2000s to the mid-2010s is known as the global sur-

face warming slowdown [76,80,81], during which the influence of the seasonal monsoon strengthened [49,64,76].

In the case of the ECK, pollock catches have further declined since the second period of catch RS, and by the mid-2010s, almost no catch had been recorded (Figure 3). During this time, the pollock habitat along the ECK experienced an increase in SST in the NGs to over 10 °C due to the strengthening of the East Korea Warm Current [62] and the cumulative effects of global warming [76,77,80]. Consequently, the HSI in the NGs likely decreased further. The frequency of marine heat waves (MHWs) has increased along the ECK since 2004, likely contributing to further increases in SST in the pollock habitat [77].

In the case of the ECJ, unlike the ECK, pollock catches remained stable from the second period of catch RS until the mid-2010s (Figure 3). During this time, the pollock habitat along the ECJ experienced a decrease in SST in its NGs to below 8 °C due to the strengthening of the Oyashio Current [35,82] and changes in the Kuroshio Current distribution [41,83]. Consequently, HSI was likely to have increased. The pollock habitat along the ECJ can be influenced by various environmental changes, depending on the position of the Aleutian Low, strength of the seasonal monsoon, and Tsugaru Warm Current volume transport [35,82]. When the center of the Aleutian Low shifts northward, the Kuroshio Current strengthens, with its axis forming further north, leading to higher-than-average SST and sea surface pressure along the ECJ [83–85]. According to Kohyama et al., when the Boundary Current Synchronization (BCS), calculated using the Model for Interdisciplinary Research on Climate (MIROC6)-subhires model, is positive, the SST increases on the northern ECJ, whereas when it is negative, the SST increases on the southern ECJ [86]. During this period, BCS exhibited a negative trend, which could have contributed to the higher HSI for pollock along the ECJ.

Since the late 2010s, SST in pollock habitats along the ECK and the ECJ have risen again, leading to a decrease in HSI, temporarily resembling climate conditions during the first RS period. The SST in the pollock NGs along the ECK increased to approximately 11 °C (Figure 4), and pollock remained mostly unharvested (Figure 3). In contrast, the NGs along the ECJ maintained an SST of 8–9 °C (Figure 4), with a gradual decline in pollock catches (Figure 3). The continued negative impact on pollock habitat along the ECK is likely due to the combined effects of changes in the seasonal monsoon and global warming. The pollock habitat along the ECK has experienced an increase in the frequency and intensity of marine heat waves (MHWs) and an increase in the average winter SST due to global warming [77,87]. In 2019, the pollock habitat along the ECK experienced a prolonged MHW lasting over 200 days [77], and the intensity of MHWs has gradually increased since 2010 [77]. A similar warming trend was observed in Alaska during the same period, where the MHW known as "The Blob" from 2014 to 2016, caused by global warming, negatively affected the spawning habitats of Pacific cod in Alaska, impacting cod resources [56,57]. If the current trend of global warming continues, it is expected that by the late 2020s, the SST will have risen more than 2 °C compared to pre-industrial levels [88], which could lead to spatiotemporal changes in the distribution of future pollock habitats.

The current study analyzed the impact of changes in the marine environment on HSI and pollock catch during the early life stages of pollock in the southernmost regions of their range. This elucidates future changes in pollock habitats and resource levels in response to marine environmental changes.

5. Conclusions

This study analyzed the characteristics of environmental changes in habitat and pollock catch fluctuations along the ECK and the ECJ, which are the southernmost limit of pollock habitat in the Northwest Pacific. During the study period, SST in the pollock habitats of both regions tended to increase; however, the impacts on SGs and NGs varied. These differences are considered one of the main causes of pollock catch fluctuations in the two regions.

Following the CRS in the late 1980s and until the late 1990s, El Niño- and PDO-positive phases were predominant. In the ECK pollock habitat, persistently high temperatures in NGs, driven by global warming and changes in the strength of the seasonal monsoon, negatively affected pollock recruitment. Additionally, in the pollock NGs of the ECJ, the strengthening of the Kuroshio Current and weakening of the Oyashio Current led to a sharp decline in HSI, which persisted over a long period, likely contributing to the decline in pollock catches.

Since the CRS of the late 1990s, La Niña- and PDO-negative phases have been predominant. Anomalous phenomena caused by global warming, such as marine heat waves, changes in warm current distribution, and variations in the strength of the seasonal monsoon, have increased the volume transport of the East Korea Warm Current to the ECK, further reducing the HSI for pollock. Consequently, pollock are now believed to be rarely harvested. However, in the NGs of the ECJ, weakening of the Kuroshio Current and strengthening of the Oyashio Current restored the HSI for pollock to early-1980s levels, likely contributing to the maintenance of pollock catches at a certain level.

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