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Acknowledgements

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FISHING *VS*. CLIMATE CHANGE: AN EXAMPLE OF FILEFISH (*Thamnaconus modestus*) IN THE NORTHERN EAST CHINA SEA

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Key words: East China Sea, filefish, climate change, fish assemblages.

ABSTRACT

The main cause of annual fluctuations in catch and species composition of fisheries is usually uncertain, but a prevailing view has been that fishing effects are more critical than environmental variability. Filefish is a good anecdote: many Korean fisheries scientists have attributed the sudden collapse of Korean filefish fisheries in the early 1990s to overfishing, especially by trawl fisheries in the northern East China Sea (NECS). However, interdisciplinary researches have revealed that climate-driven, multi-decadal variability in oceanic conditions impacts both fish and fisheries around the world. To test the two alternative hypotheses (i.e., fishing and climate) as the major cause of the sudden decline of filefish, we compared fisheries data of filefish from the adjacent countries of the NECS and analyzed oceanographic conditions in relation to changes in species composition of fish assemblages in the NECS. Results suggested that the basin-wide, 1989 regime shift in the North Pacific and the subsequent shrinkage of habitat range to the southwest were the major cause of the sudden decline of filefish catch in the NECS. Locally, shifts in water temperature and currents were identified in the NECS for the early 1990s, but further physiology-oriented researches are required to understand the detailed mechanism of climate-change effects on filefish stocks in the marginal seas of East Asia.

I. INTRODUCTION

1. Fishing *vs*. Climate Change

Since the 1950s, annual catch by marine capture fisheries of Korea had gradually increased to 1.4×10^6 metric tons in the mid-1980s, probably by improvement of fishing technology and capitalization. However, thereafter the annual catch level seemed to reach an equilibrium level at ca. 1.0×10^6 metric tons, causing concern over possible overfishing. Consequently, in the late 1990s, Korean government began to impose the total allowable catch (TAC) for major commercial species [35, 61] to manage and preserve fish stocks. However, despite relatively stable status of the total annual catch, catches of individual species have fluctuated greatly with decadal cyclic patterns and strong autocorrelations [11, 26].

The main cause of greater annual fluctuations in catch of individual species is uncertain, but a prevailing view is that fishing effort and technical factors have been more critical than environmental factors [35, 53, 61]. During the late 20th century, stock assessment for fisheries management was mostly based on surplus production and stock-recruitment models, which usually assume and treat climate and environmental fluctuations as a long-term constant with white noise [12]. Under this deterministic paradigm, especially in Schaefer's maximum sustainable yield, it was probably inevitable that fisheries scientists and managers were prone to attributing the major cause of declining fish catch trend to fishing efforts [44].

However, recent multidisciplinary researches suggest that climate variability has been the major force in fluctuating fish population [3, 31, 59]. Evidences of warming sea waters at global scale [17] and at local scale in Korean sea waters [19, 20, 24, 26] suggest that the assumption of the long-term equilibrium of environmental factors is inadequate in stock assessment for fisheries management.

2. Introduction to Filefish in the ECS

Filefish or black scraper (*Thamnaconus modestus*) has been popular among Koreans since the 1980s when they developed the process technique of drying and making into a sweet and salty jerky called *jwipo*, which is then roasted before eating. It distributes in the Northwest Pacific, ranging from Hokkaido, the East Sea and the Korea Strait to the East and South China Seas (Fig. 1(a)) [1, 2, 4, 8, 28, 34]. Most filefish in Korea were harvested in the NECS and the southern East

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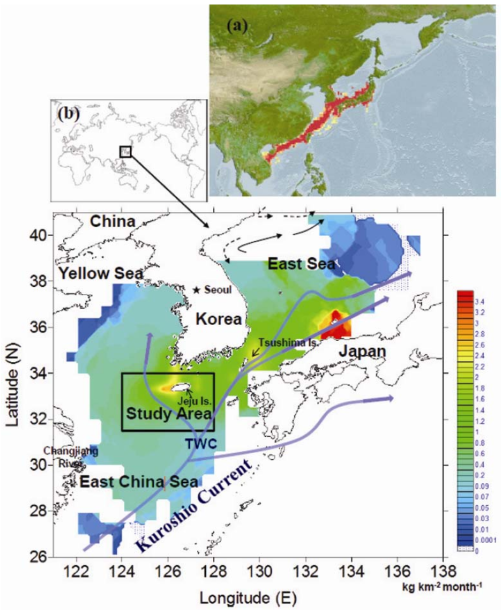

Fig. 1. **(a) Distribution map of filefish compiled by fishbase.org, (b) the study area (31°30′-34°N and 124°-128°E), and its nearby major currents (arrows), and mean biomass (color contour, kg km^{-2} month^{-1}) of filefish (*Thamnaconus modestus*) captured and reported by Korean fishers from 1981 to 2010. TWC: Tsushima Warm Current.**

Sea (Fig. 1(b)). Its catch by Korean fishers was once exceeded 300×10^3 tons [37]. However, Korean filefish fisheries were nearly collapsed in the early 1990s, and remained below 3×10^3 tons from 1999 to 2010 [9], puzzling Korean fisheries scientists over the cause of the sudden and consistent decline of the stock. Most Korean fisheries scientists and managers instantaneously cited overfishing as the major cause of the sudden decline in the filefish stock in Korean waters, especially in the NECS. However, there have been few quantitative researches to test and verify the overfishing hypothesis as a major cause of the decline of filefish stock. Recent studies suggest that basin-wide climate variability and regime shift has been a major mechanism explaining fluctuating catches of major fisheries species in Korean sea waters [10, 11, 16, 24, 26, 55, 62, 63].

3. Objective and Hypothesis

To determine whether overfishing or climatic regime shift in the North Pacific was the major cause of the sudden decline of the filefish stock in the NECS, we summarized and analyzed 1) annual changes in filefish catch from China, Taiwan and Korea based on Food and Agriculture Organization (FAO) statistics, 2) trends of filefish stocks in the neighboring seas of the NECS based on published papers, 3) oceanographic changes in the NECS and its adjacent seas (1968-2010), and 4) compositional changes in fishery catches in the NECS (1981-2010). We interpreted the results to test the two contrasting (but not necessarily mutually exclusive) hypotheses: fishing *vs*. climate.

II. MATERIALS AND METHODS

1. Study Area

We selected the study area of the NECS between 31°30′-34°N and 124°-128°E for analyzing fisheries and oceanographic data (Fig. 1(b)). The zonal line of 31°30′ is the southern limit of the long-term bimonthly oceanographic observation program operated by Korea Oceanographic Data Center (KODC) [29], and also is near the northern boundary of the China and Japan's joint fishing zone. The zonal line of 34°N is the boundary between the Yellow and the East China Sea. The meridional line of 124° is the western limit of the KODC observation program, and also is near the western limit of most of fisheries activity by Korean fishing vessels. The meridional line of 128°E is the eastern limit of drag-net fishing by Korean vessels of not less than 50 tons, regulated by the Korea-Japan fisheries agreement signed in 1965 [21, 58]. Thus, technically Korean trawl vessels could not catch fishes in the sea water east of the 128°E line after 1965. The average water depth of the study area is 85 m and the maximum depth is 187 m. From 1968 to 2010, the water temperature in the study area ranged from 0.01° to 31.48°C, averaged 16.12°C.

The Tsushima Warm Current (TWC), a branch of the Kuroshio Current, enters the NECS and flows northeastward to enter the Korea Strait and the southern portion of the East Sea (Fig. 1(b)) [32]. The Korea Straight Bottom Cold Water (KSBCW), originated from the deeper East Sea, enters the Korea Strait [6, 18, 27, 41]. In winter, another branch intrudes into the Yellow Sea through the Yellow Sea Warm Current [33]. The North Korea Cold Current, a branch of the Primorye Current, flows south along the Korean coast [50].

2. Fish

As long-term fisheries-independent data were not available, we utilized two sources of commercial fisheries data from the study area of the NECS from 1981 to 2010, provided by the Ministry of Ocean and Fisheries (MOF) and National Fisheries Research & Development Institute (NFRDI). The MOF has compiled and publish annual and monthly catch statistics of marine capture fisheries by Korean fishing vessels since 1971 [36-39, 42]. NFRDI provided spatially-explicit catch data obtained from the partially-selected fishing vessels from 1981 to 2010. The variables of the NFRDI data include 1) catch (kg), 2) species or common name of fish, 3) fishery type, 4) date of fishing, 5) fishing location (latitude and longitude at an interval of 30 min. degree). Based on the fishing location information, we could select the data records for the study area. Because lack of reliable fishing effort data, the absolute biomass or catch per unit effort could not be estimated based on the NFRDI data, but biomass composition by taxonomic groups could be estimated for the study area. We supposed that relative biomass compositions in fisheries catch are less biased than catches of individual species for the purpose of evaluating annual changes in fish assemblage structure, and that the uncertainty and lack of information on fishing effort would not significantly bias the relative biomass composition of fisheries target species. As data for chub mackerel (*Scomber japonicas*) and sardine (*Sardinops sagax*) were not available for 1981 and 1982, we selected the data from 1983-2010 for summarizing and further analyses on changes in fish assemblage structure.

To determine whether fishing or climate change played a major role in fluctuations of filefish, and to examine whether there was any regional difference or synchrony, we retrieved the database of marine capture fisheries statistics by country, covering the period of 1972-2010, compiled by the FAO of the United Nations [9]. We included the time-series data of China, Taiwan and Korea, but excluded the data of Japan where filefish has not been a major target species for commercial fisheries. As there were some confusions or errors in the identification of filefish species, we included all of Monacanthidae species, because *Thamnaconus modestus* has been the dominant species among all of the filefishes in the western North Pacific, and was once erroneously reported to FAO as threadsail fifish (*Stephan cirrhifer*),

In addition, we searched published papers related with the trend of filefish populations in the western North Pacific to synthesize and evaluate the fishing *vs*. climate hypothesis as the cause of their decline in the NECS.

3. Environment

To evaluate the influence of oceanographic conditions on filefish populations and fish assemblages in the waters of the NECS (31°30′-34°N and 124°-128°E), we utilized available long-term ocean monitoring data covering the period of 1968 to 2010, although the fish data covered only for 1981-2010. Depth-specific oceanographic variables (temperature and salinity) have been measured in every two months for the water columns at 175 fixed stations along 22 oceanographic lines in Korean sea waters since 1961 by the NFRDI, and KODC publish the data to the public [29]. The stations are located in areas deeper than 20-m depth, in which research vessels can safely maneuver. Most of data have been collected at the 7 standard water depths of 0, 10, 20, 30, 50, 75, and 100 m. To infer any change in the currents in the NECS, we calculated water density based on temperature, salinity and depth [57].

To minimize biases due to yearly differences in observation stations, anisotropic (both latitudinal and longitudinal) linear variogram functions without ‘nugget’ effect [7], were used in estimating the mean values of hydrographic variables for the study area by interpolation of values for unsampled 10×10 nautical-mile. The variogram functions were derived by applying proc variogram of SAS version 9, and the grid data files were generated by proc krige2d to produce distribution maps and derive the mean values for the study area [49].

To examine possible influences of the TWC and the KSBCW, monthly volume transports were estimated for 1968 to 2010 based the methods of Na *et al*. [41]. An index was made for the KSBCW volume transport, and higher value denotes higher volume transport, and *vice versa*.

4. Canonical Correspondence Analysis

To summarize annual changes in fish assemblage structure of the NECS, annual taxonomic compositions in catch weight by major fishery types (surrounding net, otter and pair trawls, Danish seine and stow net) for the 10 species/taxa from 1983 to 2010 were graphically summarized by correspondence analysis (CA) [14-16]. The CA was performed in SAS (proc corresp) (SAS 1989). We correlated the two major dimensions extracted by CA on species composition of fish catch from the NECS with depth-specific hydrographic conditions in the NECS and the monthly and yearly volume transports of TWC and KSBCW by applying canonical correspondence analysis (CCA) [54].

5. STARS

A sequential t-test analysis of regime shifts (STARS) [46, 47] was applied to detect step changes in the time series of depth-specific oceanographic variables in the NECS and volume transports of TWC and KSBCW. STARS uses a *t*-test analysis to determine whether sequential observations in a time series represent statistically significant departures from mean values observed during the preceding period of a predetermined duration. Periods of regime shift are determined by the cut-off length for proposed regimes (L), and the means for the regime shifts are adjusted by the Huber weight parameter (H), which defines the range of departure from the observed mean beyond which observations are considered as outliers. As oceanographic conditions in the NECS showed 3-6 year oscillation patterns, we set L = 5. Although the average value for each regime is not critical in this study, we set H = 1, following Rodionov [47].

III. RESULTS

1. Filefish

FAO statistics from 1972 to 2010 showed that Korean filefish (Monacanthidae) catch was once reached 328×10^3 tons in 1986, but dramatically declined after 1991 (Fig. 2(a)). Annual catch of filefish in China from 1977 to 2010 had been relatively stationary compared with Korean filefish catch, ranging from 96×10^3 tons in 1993 to 427×10^3 tons in 1986 (Fig. 2(b)). Both Korean and Chinese filefish catch peaked in 1986. Chinese filefish catch did decrease after 1992, but the degree of decrease was not so much dramatic compared with Korean filefish catch. After recording the lowest catch in 1993, Chinese annual filefish catch ranged from $122\text{-}211 \times 10^3$ tons from 1994 to 2010. Taiwanese catch of filefish (Fig. 2(c)), which seems compiled firstly in 1989, was negligible compared with Chinese and Korean catch, but once exceeded Korean catch from 2002 to 2006, peaking at 4.5×10^3 tons in 2005.

Annual catch by the partially-selected Korean fishing vessels in the NECS for the same period accounted for 2-62% of the entire Korean filefish catch, averaged 32% (Fig. 3). It

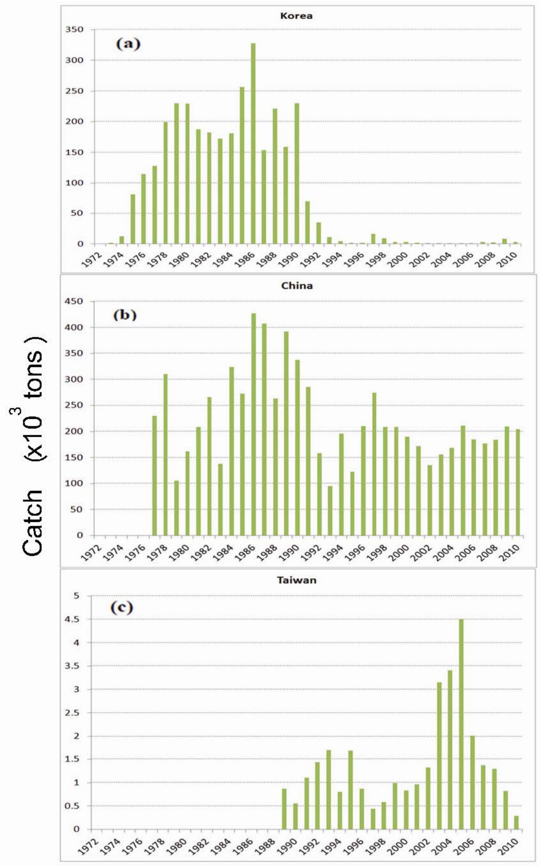

Fig. 2. Annual catch of filefish (Monacanthidae) of (a) Korea, (b) China, and (c) Taiwan from 1972 to 2010, compiled and published by the Food and Agriculture Organization of the United Nations.

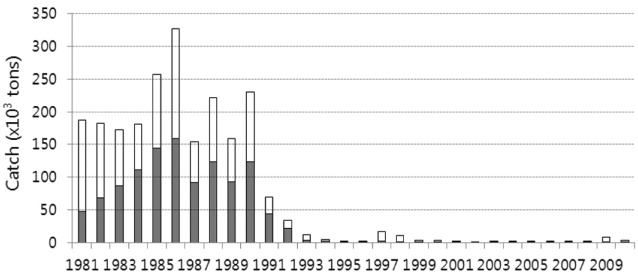

Fig. 3. Proportion of the filefish catch reported by the selected fishing vessels in the study area of the northern East China Sea (31°30′-34°N and 124°-128°E) to the total Korean filefish production from 1981 to 2010.

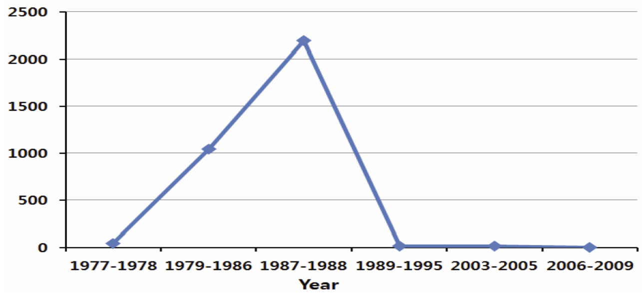

Fig. 4. Changes in abundance density (individuals km^{-2}) of filefish (*Thamnaconus modestus*) in Tokyo Bay, Japan from 1977 to 2009. Data was provided by K. Kodama [28].

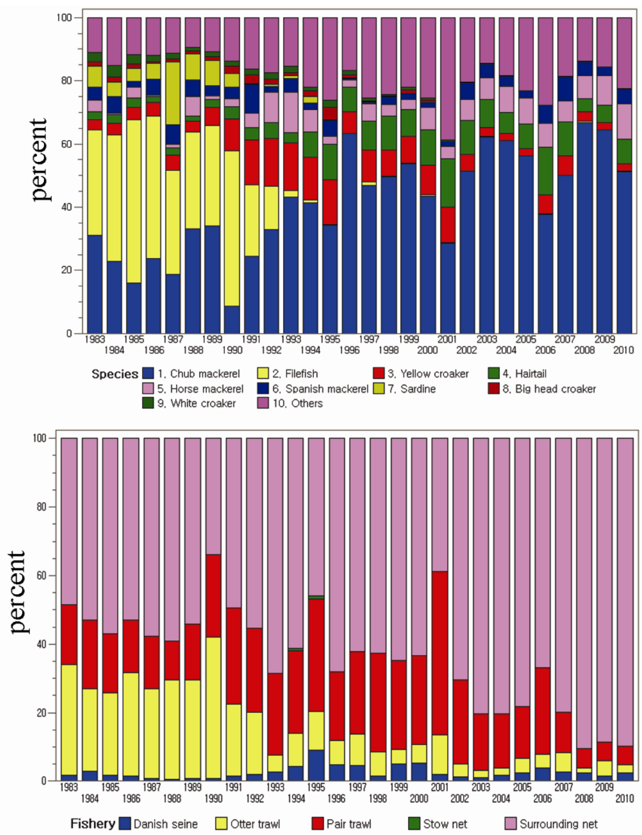

Fig. 5. Annual changes of biomass composition of fishery catch from the northern East China (31°30′-34°N and 124°-128°E) from 1983 to 2010, (a) by species, and (b) by fishery type.

showed a similar trend as the total Korean catch: it peaked at 160×10^3 tons in 1986 and had remained $< 0.7 \times 10^3$ tons since 1998.

There were few published papers on fluctuations of filefish stocks. Although Japanese filefish catch has not been compiled in the FAO statistics, Kodamo *et al*. [28] reported changes in abundance-based density of filefish in Tokyo Bay, Japan, from 1979 to 2009 [Fig. 4]. Like the Korean filefish catch, filefish abundance in Tokyo Bay peaked at 233.7 kg km^{-2} in 1987-1988, but thereafter dramatically decreased in 1989-1995 to nearly zero.

2. Canonical Correspondence Analysis

To evaluate overall changes in the structure of fish community surrounding filefish, we summarized relative biomass composition of commercial fish catch from the NECS from 1983 to 2010 (Fig. 5). The dominant species was filefish from 1983 to 1990, but was changed to chub mackerel thereafter (Fig. 5(a)). The dominant fishery type was surrounding net

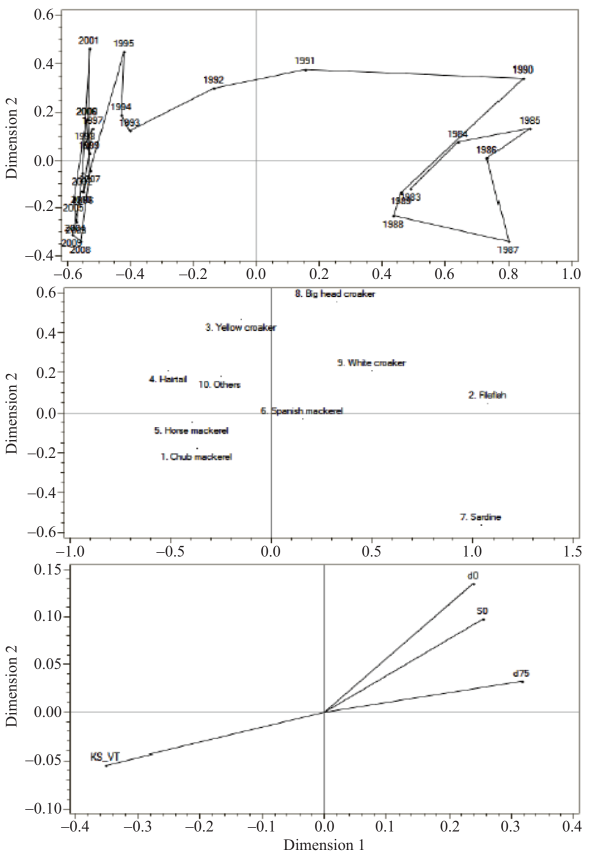

Fig. 6. **Canonical correspondence analysis on fish species composition in biomass with respect to environmental variables in the northern East China Sea (31°30′-34°N and 124°-128°E). The environmental variables were depth-specific oceanographic variables in the northern East China Sea (water temperature, salinity and sea water density at 0-100 m depth) and the volume transports by the Tsushima warm current and by the Korea Strait bottom cold water S and d denote salinity and sea water density, respectively, and the suffix number denotes water depth (m); KS_VT is an index of the annual volume transport by the Korea Strait Cold Bottom Water. (a) ordination of the years from 1983 to 2010, (b) ordination of the ten taxonomic groups of fish catch, (c) ordination of environmental variables that were significantly correlated with the dimension 1 or 2 at the 1% significance level. The three panels can be overlapped to be a triplot to interpret graphically.**

for the entire period (Fig. 5(b)). In overall, contribution by otter trawl fisheries to the total annual catch had gradually decreased from 1981 to 2010; whereas the proportion of catch by surrounding-net fisheries had steadily increased.

CCA of biomass compositions in commercial catch of the ten taxonomic groups by year revealed that the compositions varied annually and the fish community structure dramatically shifted in 1990-1993 in the NECS (Fig. 6). The first dimension (x-axis) explained 72% of the total inertia (variance in taxonomic composition) and the second dimension (y-axis) explained 11%. The ordinations of the years from 1983 to 2010 generally showed a step-by-step shift, but the distance of the shift varied and was greater for 1990-1993 (Fig. 6(a)), which corresponded to the period of the sudden collapse of filefish fisheries. The entire period could be broadly divided in two segments, 1983-1990 and 1991-2010.

Ordination of the taxonomic groups by CCA (Fig. 6(b)) showed that the three mackerels (chub, horse (*Trachurus japonicas*) and Spanish mackerel (*Scomberomorus niphonius*)) were similar in their annual changes, and also the three croakers (yellow (*Pseudosciaena polyactis*), white (*Argyrosomus argentatus*) and bighead croaker (*Collichthys niveatus*)). Filefish and sardine were distinctive, positioned to the opposite site of the mackerel group and hairtail (*Trichiurus lepturus*). Spanish mackerel positioned close to the origin. Overlapping Fig. 6(a) with 6(b) confirmed the overall trend indicated in Fig. 5(a): filefish and sardine were dominant in the earlier years from 1983 to 1990; whereas hairtail, mackerels and croakers were more dominant in the later years from 1991 to 2010.

Fig. 6(c) shows the selected environmental factors that were significantly correlated with the two dimensions of CCA at the 1% significance level. The annual volume transport of the KSBCW (KS_VT), salinity at surface (S0) and water density at surface and 75-m depth (d0 and d75) in the NECS were significantly correlated with the first dimension of CCA. Among these, KS_VT was most closely correlated with the first dimension, and generally negatively correlated with S0, d0 and d75, as indicated in the graphics.

Although annually-averaged water temperatures and salinities in the NECS mostly did not show significant correlation with the two dimensions, December water temperature at 0-50 m depths and February salinity at 10-30 m depths did show significant correlations ($p < 0.01$). December water temperatures at 0-75 m depths in the NECS shifted to higher values in 1988-1990 and in 2002-2003 (Fig. 8, only graphics for 50-m depth is shown). Between 1988 and 1990, December water temperature in the NECS increased by ca. 2°C at 0-50 m depths. February salinities at 0-75 m depths in the NECS shifted to lower values in 1997-1998 (graphics are not shown).

3. Annual Changes of Oceanographic Conditions in the Northern East China Sea

Annual changes of the environmental factors that were significantly correlated with the two dimensions of CCA, and their shifts detected by STARS for the period of 1968-2010 are shown in Fig. 7. KS_VT (Fig. 7(a)) showed a shift to higher values in 1992-1993, which lagged behind the 1990-1993 shift indicated in CCA (Fig. 6(a)) by 2 years. Sea surface salinity and water density together showed a shift to lower values in 1997-1998 (Fig. 7(b) and (c)). Sea water at 75-m depth showed fluctuating trend in its density, and became heavier in 1984-1989, and then lighter in 1990-2010. The sudden decrease of water density at 75-m depth was not detected in relation to the 1990-1993 shift in CCA (Fig. 6(a)). KS_VT was significantly negatively correlated with sea surface salinity and water density at sea surface ($p < 0.01$), but not with water density at 75 m ($p = 0.29$).

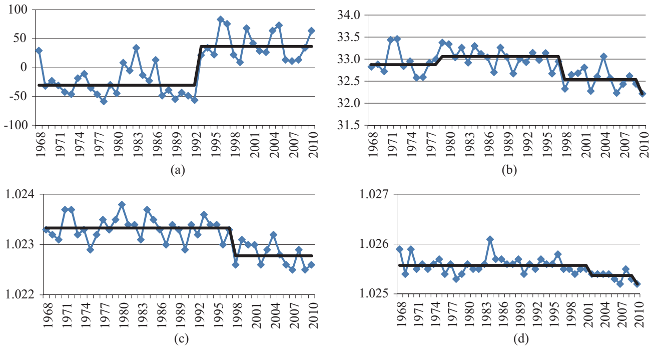

Fig. 7. Annual changes of the environmental factors that were significantly correlated with the two dimensions of correspondence analysis (Fig. 6). (a) Annual index of the Korea Strait Bottom Cold Water, estimated by temperature section along the Busan-Moji line in the Korea Strait from 1968 to 2010 (Na *et al*. 2010), (b) Sea surface salinity, (c) Sea water density (g cm^{-3}) at surface and (d) 75-m depth in the northern East China Sea Sea (31°30′-34°N and 124°-128°E), The step changes detected by STARS were overlaid with the solid bold line.

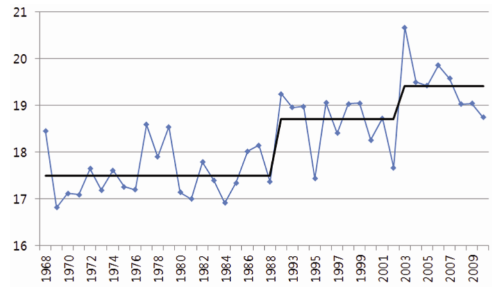

Fig. 8. Annual changes of December water temperature (°C) at 50-m depth in the northern East China Sea Sea (31°30′-34°N and 124°-128°E). The step changes detected by STARS were overlaid with the solid bold line. The data points for 1989, 1991 and 1992 are omitted, because no observation was made.

IV. DISCUSSION

1. Fishing *vs*. Climate Change Hypotheses

Comparisons of annual changes in filefish catch or abundance among Korea, Japan and China suggested that climate-driven oceanographic changes, rather than fishing, was the major cause of the sudden decline of the filefish stock started in 1991. While Korean filefish catch dramatically decreased after 1991 (Fig. 2(a)), Chinese filefish catch maintained a similar level of the pre-1990 catch. If overfishing was the major cause, then the same trend of filefish fishery collapse should have been observed in China after 1991, but this was not the case. Past data on body size composition of the filefish stock just before the 1991 collapse would corroborate this, but it was difficult to obtain. On the other hand, in Tokyo Bay, Japan, the sudden declining trend of filefish stock was observed after 1989 (Fig. 4), which was nearly the same trend observed in Korea. As filefish has not been a target species of Japanese commercial fisheries, the overfishing hypothesis was ruled out, suggesting that the same environmental changes might have triggered the decline of both Korean and Japanese filefish stocks. As it is certain that filefish stocks in the Chinese waters maintained the pre-1991 level, but were greatly declined in the Korean waters and the waters off Tokyo after 1991, the habitat range of filefish stocks seems to have been shrunken southwest to the southern East China Sea and the South China Sea, drastically decreasing filefish stocks in the East Sea, the NECS and the coastal waters of the Pacific side of Japan (Fig. 1(a)).

2. Mechanisms of Climate Change Effects on Filefish

Annual changes in species biomass composition of fish catch (Fig. 5) and CCA results (Fig. 6) suggest that the fish assemblage in the NECS was dramatically shifted from filefish-dominated to mackerel-dominated one in 1990-1993. It is uncertain what caused the sudden change in fish assemblage and filefish stock in the NECS, but the present study suggests that climate-driven changes in oceanographic conditions and currents were a major cause. From 1981 to 2010, two basin-wide regime shifts were proposed to have occurred in 1989 and 1998 in the North Pacific [13, 40]. The two regime shifts were also suggested in the marginal seas of East Asia [5, 22, 23, 25, 30, 45, 51, 55, 56, 60, 62, 63]. Thus, the period of sudden decline of filefish in the NECS corresponds to the 1989 regime shift, suggesting that the climate-driven regime shift in the North Pacific at basin-scale caused regional changes in oceanographic conditions and currents in the NECS, and subsequently the recruitment and habitat range of filefish, possibly by changes in prey or predator species of filefish.

However, STARS failed to detect a shift around 1989 with respect to annually-averaged water temperature or salinity at 0-100 m depth in the NECS (graphics are not shown), bud did detect a shift in the volume transport of the (Figs. 7(a)). The water density at 75-m depth peaked in 1984, and thereafter had steadily decreased until 1990 to be shifted to a lower level until 2010. As the KSBCW is less-saline and cold water, transported from the deeper waters of the East Sea to the Korea Strait [41], oceanographic changes in the East Sea were also related with the decline of the filefish in the East Sea and the NECS. The intensified KSBCW after 1993 might have lowered salinity in the Korea Strait and the NECS, which was confirmed by its significantly negative correlations with salinity and water density at sea surface of the NECS.

On the other hand the sudden shift to warmer waters in December at 0-50 m depths in 1988-1990 (Fig. 8) preceded the sudden decline of filefish stock and the dramatic shift in fish assemblage in 1990-1993. This suggests that the increased winter temperatures after 1989 might have favored mackerels while impeding filefish in the NECS, but requires further research to validate.

As the same declining trend of filefish was observed in the Pacific side of Japan (Tokyo Bay), basin-wide climatic changes in the western North Pacific may be the ultimate cause of the habitat contraction of filefish. Locally, oceanographic changes in the East Sea and the KSBCW might have played a role in the 1990-1993 shift in fish assemblage structure in the NECS. Or, the basin-wide climate change might have directly influenced on oceanographic conditions in the NECS, as suggested in changes in December water temperatures (Fig. 8).

V. CONCLUSION

Although the present study suggested the basin-wide climatic regime shift in the North Pacific and subsequent changes in oceanographic conditions were the major factor explaining the sudden decline of filefish in the NECS, it is still possible that intensive fishing activity, especially by Korean trawlers in the waters west of the 128°E line, could have aggravated the declining trend of filefish catch [48]. More regional comparative studies are required to validate and evaluate the two hypotheses on the cause of filefish decline in the early 1990s.

An understanding of mechanisms on the 1990-1993 shift from filefish to mackerel-dominated fish assemblages in the NECS requires detailed information on physiology and recruitment processes in relation to climate change [43], as exemplified in the recent works of Taksuka *et al*. [51, 52]. We hope the present paper will encourage physiology-oriented studies for understanding effects of climate change on fisheries and its implications to fisheries management in the western North Pacific.

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